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SENSITIVITY ANALYSIS OF A TERRAMECHANICS MODEL OF TRACK-TERRAIN INTERACTION WITH RESPECT TO VEHICLE DESIGN PARAMETERS

ABSTRACT: This paper presents a sensitivity analysis of a terramechanics model of track-terrain interaction based on shear stress theory. The aim of the study is to identify the design parameters of a tracked vehicle that have the greatest influence on the generation of contact forces, traction performance, and vehicle stability. The effects of variations in vehicle mass, center of gravity height, moment of inertia and distance between the centerlines of the tracks on the distribution of contact forces within the contact zone are investigated. The model was implemented in the MATLAB/Simulink environment and applied to the BVP M80A tracked vehicle. Numerical simulations were performed for the turning manoeuvre, while the influence of individual parameters on the model outputs was quantified. The obtained results indicate that certain design parameters have a dominant effect on traction performance, contact force distribution, and vehicle stability. The presented sensitivity analysis enables the identification of key parameters for the optimization of tracked vehicle design and provides a basis for the further development of efficient terramechanics models intended for simulation and mobility enhancement of vehicles operating on deformable terrain.

KEYWORDS: terramechanics, tracked vehicle, sensitivity analysis, contact forces

ANALIZA OSETLJIVOSTI TERAMEHANIČKOG MODELA INTERAKCIJE GUSENICE I PODLOGE NA PROMENU KONSTRUKCIONIH PARAMETARA VOZILA

REZIME: U radu je predstavljena analiza osetljivosti teramehaničkog modela interakcije gusenice i deformabilne podloge zasnovanog na teoriji smicajnih napona. Cilj istraživanja je identifikacija konstrukcionih parametara guseničnog vozila koji imaju najveći uticaj na generisanje kontaktnih sila, vučne karakteristike i stabilnost kretanja.

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Analizirani su efekti promena mase, visine težišta, momenta inercije, širine traga, dužine kontakta gusenice i podloge i širine gusenice vozila na raspodelu kontaktnih sila u kontaktnoj zoni. Model je implementiran u MATLAB/Simulink okruženju i primenjen na gusenično vozilo BVP M80A. Numeričke simulacije sprovedene su za različite režime kretanja, uključujući pravolinijsko kretanje i skretanje, pri čemu je izvršena kvantifikacija uticaja pojedinačnih parametara na izlazne veličine modela. Dobijeni rezultati pokazuju da određeni konstrukcioni parametri imaju dominantan uticaj na vučne performanse, raspodelu kontaktnih sila i stabilnost kretanja vozila, dok promene ostalih parametara izazivaju znatno manje promene odziva modela. Predstavljena analiza omogućava identifikaciju ključnih parametara za optimizaciju konstrukcije guseničnih vozila i predstavlja osnovu za dalji razvoj efikasnijih teramehaničkih modela namenjenih simulaciji i unapređenju mobilnosti vozila na deformabilnim podlogama.

KLJUČNE REČI: teramehanika, gusenično vozilo, analiza osetljivosti, kontaktne sile

INTRODUCTION

Tracked vehicle steering is governed by the complex interaction between the vehicle and the terrain, with the resulting response depending on both the vehicle characteristics and the parameters used to describe the track-terrain interaction. Variations in parameters such as vehicle mass, yaw moment of inertia, centre-of-gravity height and track spacing can affect the distribution of contact forces and consequently the vehicle trajectory, turning radius, and dynamic response (Chakravarthy & Sharma, 2024; Drakulic et al., 2025; Garber & Wong, 1981a, 1981c). Therefore, understanding the influence of individual model parameters is essential for assessing the reliability and robustness of numerical predictions.

In (Drakulic et al., 2025), a numerical model of track-terrain interaction during steering of a high-speed tracked vehicle was developed and experimentally validated using measurements obtained from a BVP M80A vehicle. The model demonstrated good agreement with the experimental results and provided a reliable basis for further numerical investigations. However, experimental validation performed for a nominal set of parameters does not indicate how sensitive the predicted outputs are to variations in individual model parameters.

The mathematical description of track-terrain interaction requires the coupling of the vehicle equations of motion with a formulation describing the generation and distribution of stresses within the contact region. In terramechanics-based approaches, the normal and shear stresses developed between the track and deformable terrain are related to the mechanical properties of the terrain, track geometry, normal loading, and shear displacement. Integration of these stresses over the track-terrain contact area provides the longitudinal and lateral forces acting on the vehicle, which subsequently determine its translational and rotational motion (Chen et al., 2025; Du et al., 2018; Garber & Wong, 1981b).

The resulting mathematical model represents a coupled system in which changes in vehicle and geometric parameters can influence both the contact force distribution and the overall vehicle response. Parameters such as vehicle mass and yaw moment of inertia directly affect the equations of motion, while track spacing and centre-of-gravity height influence the geometric and force relationships within the model (Dimauro et al., 2024; Lv et al., 2023). Consequently, variations in these parameters may produce different levels of change in the calculated forces and kinematic characteristics, even when the same steering manoeuvre and terrain conditions are maintained.

For numerical analysis, the mathematical formulation is implemented in MATLAB/Simulink, where the individual relationships describing vehicle motion, track kinematics, and track-terrain interaction are represented by interconnected computational blocks. This implementation enables the model parameters to be systematically varied while maintaining the same initial conditions and operating scenario. The resulting model outputs can therefore be directly compared for different parameter values, providing a consistent framework for evaluating the influence of individual parameters on the simulated vehicle response.

The aim of this study is to investigate the influence of selected model parameters on the output results of the experimentally validated numerical model. The effects of variations in vehicle mass, yaw moment of inertia, centre-of-gravity height and track spacing are analyzed with respect to the main dynamic outputs of the vehicle. The obtained results are used to identify the parameters with the greatest influence on the model response and to assess their relative importance for accurate simulation of tracked vehicle steering.

SIMULATION MODEL

Considering the wide range of methods available for modelling track-terrain interaction, different terramechanical approaches have been developed to describe the behaviour of deformable terrain (Chakravarthy & Sharma, 2024; Garber & Wong, 1981b; Jia et al., 2023). In the present study, the Janosi-Hanamoto semi-empirical formulation is used to characterize the shear response of the terrain. This approach provides a suitable compromise between the

representation of the essential physical mechanisms, numerical robustness, and computational requirements, making it appropriate for integration into a vehicle-level simulation model. The selected formulation has also been employed within the modelling framework considered in this study and experimentally evaluated for the BVP M80 infantry fighting vehicle (Drakulic et al. 2025).

Within the Janosi-Hanamoto formulation, the key coupling variable between vehicle kinematics and soil response is the shear displacement, which arises due to the relative motion between the track and the deformable soil (Meywerk et al., 2016). This quantity governs the development of shear stress within the contact patch and provides a direct link between slip conditions and traction generation. The shear stress is described by the exponential relationship:

$$\tau = (c + \sigma tan\phi)\left(1 - e^{-\frac{j}{K}}\right) \quad (1)$$

where c is the soil cohesion, σ is the normal stress, φ is the internal friction angle, j is the shear displacement, and K is the shear deformation modulus.

The mathematical formulation of the model is based on the terramechanics approach, in which the interaction between the vehicle tracks and deformable terrain is described through the distribution of normal and shear stresses within the track-terrain contact region. The shear stress distribution is determined according to the vehicle kinematics, loading conditions, and mechanical properties of the terrain. The resulting longitudinal and lateral contact forces acting on the left and right tracks are obtained by integrating the corresponding stress components over the contact area (Dimauro et al. 2024; Tota et al. 2021). The detailed procedure for the development and formulation of the mathematical model is presented in (Drakulic et al. 2025). In the present study, the established mathematical formulation is implemented in MATLAB/Simulink and subsequently used to investigate the influence of selected model parameters on the calculated vehicle response (Figure 1).

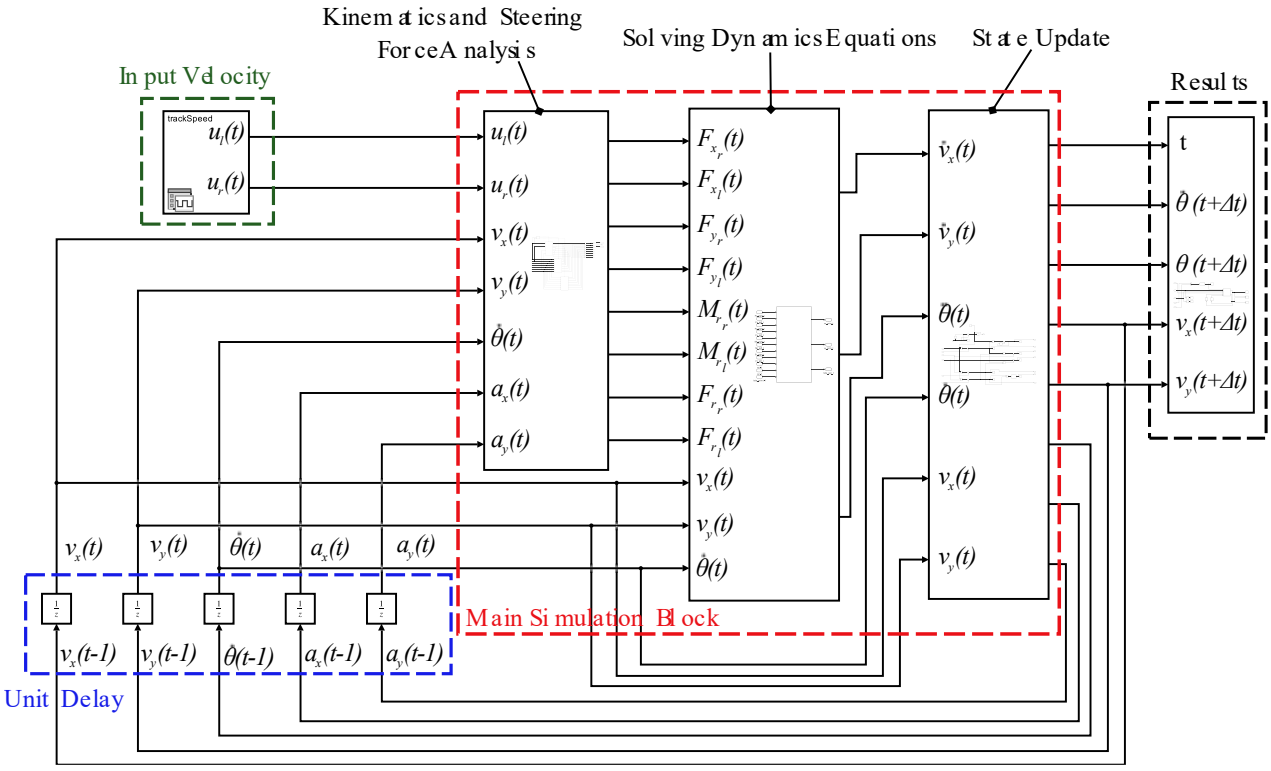


Figure 1 Simulation model (Drakulic et al. 2025)

The implemented simulation model consists of several interconnected functional blocks that describe the vehicle motion, track kinematics, and track-terrain interaction. The vehicle motion module provides the kinematic quantities required for the calculation of the local slip and shear displacement within the track-terrain contact region. These quantities are combined with the terrain and vehicle parameters to determine the stress distribution and the resulting longitudinal and lateral contact forces for the left and right tracks. The calculated forces are then introduced into the vehicle dynamics equations, forming a coupled computational structure in which the track-terrain interaction directly affects the simulated vehicle motion.

For the purposes of the present analysis, the model is evaluated under a predefined steering manoeuvre and fixed terrain conditions, while selected vehicle and model parameters are varied individually. The investigated parameters include vehicle mass, yaw moment of inertia, centre-of-gravity position and track spacing. For each parameter, a range of values around the nominal configuration is considered, while the remaining parameters and simulation

conditions are kept unchanged. The resulting changes in the model outputs are subsequently analysed in terms of longitudinal and lateral track forces and steering resistance torques. This approach enables the relative influence of each parameter on the simulated vehicle behaviour to be evaluated systematically.

SENSITIVITY ANALYSIS OF THE MODEL

Sensitivity analysis is performed to evaluate how variations in selected vehicle parameters affect the response of the developed simulation model. The analysis is focused on the response of the model outputs to changes in individual input parameters, rather than on the absolute influence of the vehicle parameters themselves. The terrain parameters are kept constant throughout the analysis, using the values defined for the selected terrain condition (Table 1). This ensures that the observed changes in the simulation results can be attributed exclusively to variations in the investigated vehicle parameters.

Table 1 Terrain Parameters for Wet grassy

Parameter	Value	Unit
c	15	kPa
φ	25	^{0}
K	0.05	m

Four vehicle parameters are selected for the simulation model sensitivity analysis: vehicle mass m, yaw moment of inertia of the tracked vehicle about the z - axis - Iz, distance between the centerlines of the tracks on both sides - B, and centre-of-gravity height - h (Table 2). These parameters are selected because changes in their values affect different parts of the mathematical model. Vehicle mass modifies the loading conditions and consequently the forces developed at the track-terrain interface. The yaw moment of inertia affects the rotational response of the vehicle, while track spacing directly influences the moment generated by the forces acting on the two tracks. The centre-of-gravity height affects the distribution of normal loads and the dynamic response of the vehicle during steering.

Table 2 Vehicle Parameters

Parameter	Value	Unit
m	*13 850*	kg
Iz	*42 086*	kgm²
B	*2.526*	m
h	*1.139*	m

For each investigated parameter, its nominal value is systematically varied within a predefined range, while all other model parameters and simulation conditions are maintained at their nominal values (Drakulic et al., 2025). The response of the model is calculated for each parameter value and compared with the response obtained for the nominal configuration. In this way, the sensitivity of the model to each individual parameter can be evaluated independently. The same steering manoeuvre, initial conditions, terrain characteristics, and track velocity conditions are used in all simulations to ensure consistency between the investigated cases.

The sensitivity of the model is evaluated by analysing changes in the principal output variables, including the longitudinal and lateral track-terrain contact forces and steering resistance torques. The magnitude and nature of the changes in these outputs are examined as a function of the corresponding variation in each input parameter. This allows the response of the model to parameter perturbations to be identified and provides an indication of whether a particular output is weakly or strongly sensitive to the investigated parameter.

The results of the sensitivity analysis are used to compare the relative response of the model to variations in the four selected parameters. Attention is given to the parameters that produce the largest changes in the calculated output quantities, as these parameters have the greatest effect on the numerical prediction of vehicle behaviour. The analysis therefore provides a quantitative basis for assessing the robustness of the model and for identifying the vehicle parameters that require particular attention during model parameterisation and further experimental characterisation. In the considered steering manoeuvre, the left track represents the outer track, whereas the right track represents the inner track, therefore, the subscripts l and r denote the left and right tracks, respectively.

Sensitivity of the model to vehicle mass

To assess the sensitivity of the developed simulation model to variations in vehicle mass, a series of simulations was performed in which the nominal vehicle mass was varied within a predefined range (±25% and ±50% relative to the nominal value), while all other vehicle, steering, and terramechanical parameters were kept constant. This approach allows the effect of vehicle mass to be evaluated independently and provides a direct assessment of the response of the model to changes in this parameter. The results of the performed simulations are presented in Figure 2.

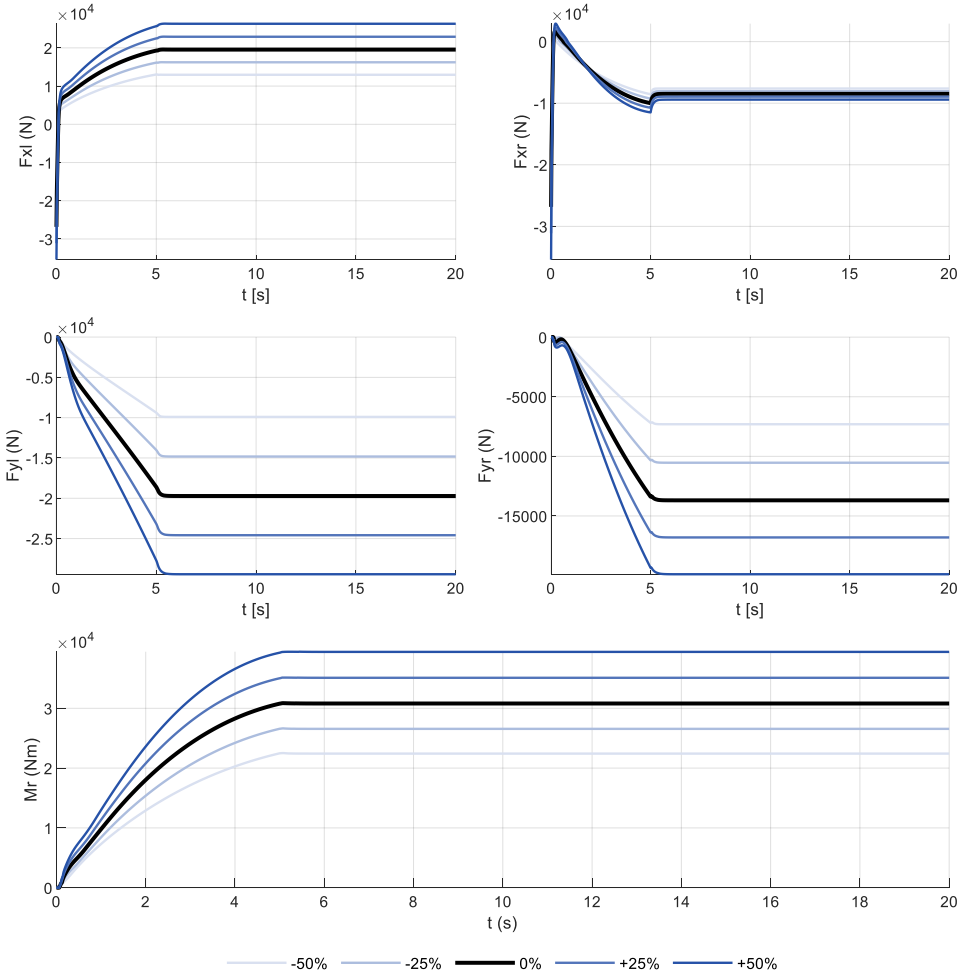


Figure 2 Influence of vehicle mass on model response during steering manoeuvre

The variation in vehicle mass has a pronounced effect on the track-terrain contact forces in both the longitudinal and lateral directions (Fx and Fy force). As the vehicle mass increases, the normal load acting on the tracks increases, which directly affects the distribution of contact stresses and the resulting interaction forces. Consequently, an increase in mass leads to higher longitudinal forces on both tracks. This behaviour is associated with the increased loading of the track-terrain interface and the higher forces required to maintain the prescribed vehicle motion during the steering manoeuvre. Within the investigated range, the steady-state longitudinal force on the outer track (Fxl) decreases to approximately 13 kN at -50% mass to approximately 26 kN at +50% mass, relative to a nominal value of approximately 19.5 kN — a change of roughly -35%/+25%.

An increase in vehicle mass also results in a noticeable change in the lateral contact forces. The absolute values of the lateral forces increase with increasing mass, which can be attributed to the greater dynamic loading of the vehicle during the steering manoeuvre. At the same time, a clear difference between the lateral forces generated by the inner and outer tracks can be observed. This asymmetry results from the different kinematic and loading conditions of the two tracks during steering and reflects their different contributions to the lateral and rotational response of the vehicle. The inner-track lateral force (Fyr) ranges from approximately -10 kN to -30 kN relative to a nominal value of approximately -19.5 kN, while the outer-track lateral force (Fyl) ranges from approximately -7 kN to -19.5 kN relative to a nominal value of approximately -14 kN — indicating a proportionally larger relative sensitivity for the outer track.

A particularly pronounced dependence on vehicle mass is observed for the steering resistance moment. As the vehicle mass increases, the normal loading of the tracks and the corresponding interaction forces with the terrain also increase. Consequently, greater resistance to the change in vehicle heading is generated, resulting in an increase in the steering resistance moment. This indicates that vehicle mass affects not only the magnitude of the individual track-terrain forces but also the overall resistance associated with the steering manoeuvre. The steering resistance moment (Mr) increases from approximately 22 kNm at -50% mass to approximately 39 kNm at +50% mass relative to a nominal value of approximately 31 kNm, corresponding to the largest relative variation (approximately ±25%) among the analyzed output quantities.

The obtained results demonstrate that the simulation model exhibits a pronounced sensitivity to vehicle mass, with the most significant effects observed in the track-terrain contact forces and steering resistance moment. The systematic increase in these quantities with increasing vehicle mass is consistent with the physical behaviour

expected from the increased normal loading of the tracks. The results therefore confirm the importance of accurately defining vehicle mass in the model, particularly when the model is used for predicting track-terrain interaction forces and steering behaviour under different vehicle configurations.

Sensitivity of the model to yaw moment of inertia

The influence of the yaw moment of inertia on the simulated vehicle response was examined by varying this parameter within a range of ±25% and ±50% relative to its nominal value, while the remaining vehicle, steering, and terramechanical parameters were held fixed at their nominal settings. Isolating the yaw moment of inertia in this manner makes it possible to distinguish its effect on the model response from that of the other investigated parameters. The corresponding results are shown in Figure 3.

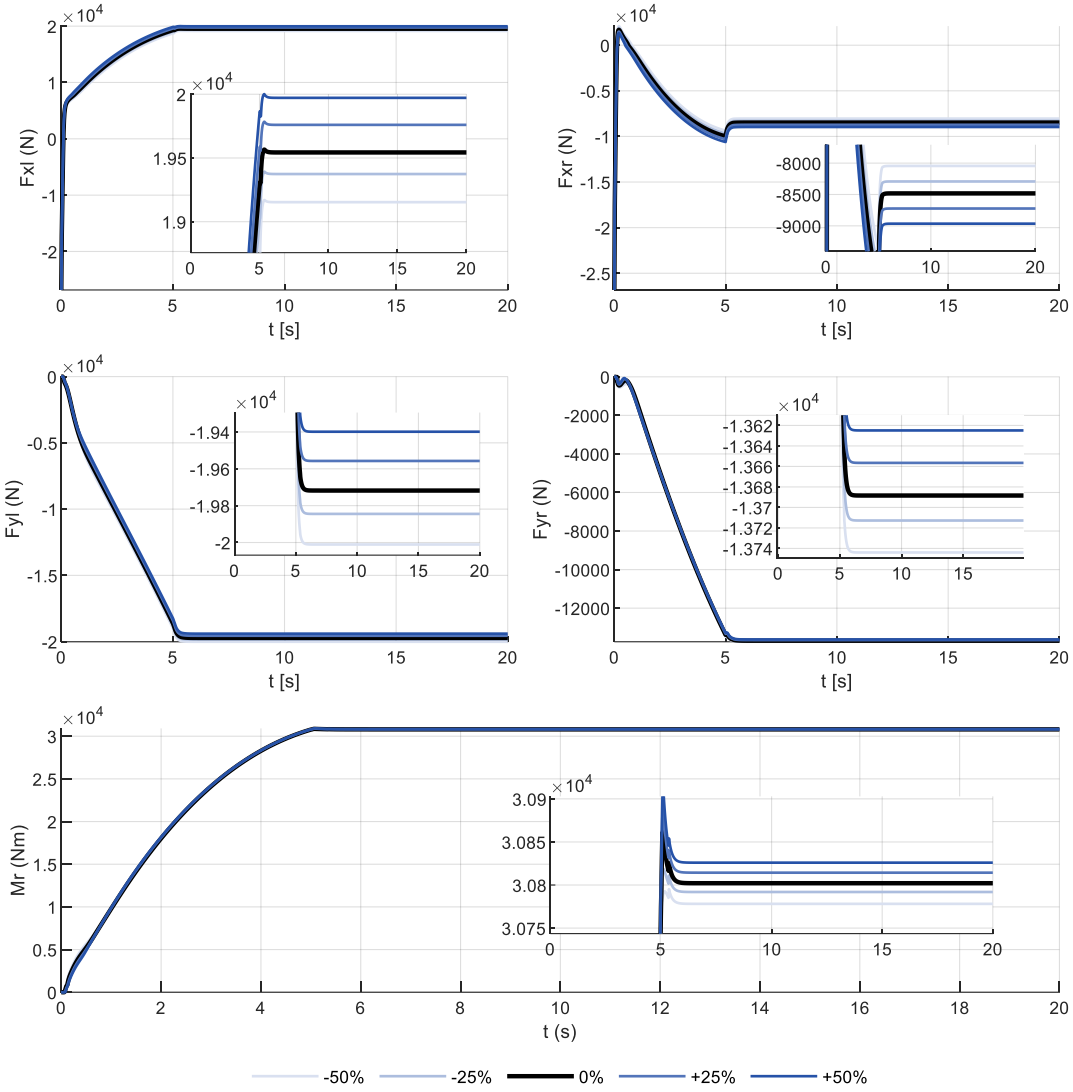


Figure 3 Influence of yaw moment of inertia on model response during steering manoeuvre

The analysis of the track-terrain contact forces shows that variations in the yaw moment of inertia have a negligible influence on the longitudinal and lateral forces in the steady-state steering regime. The force responses corresponding to different values of the parameter practically coincide once the transient phase has ended. The steady-state spread across the full ±50% range remains within a few percent of the nominal value for all four force components — approximately 1.9 to 2.0 kN for Fxl, -8.0 to -9.0 kN for Fxr, and -19.4 to -19.8 kN for Fyl, while Fyr shows the tightest band of all, varying only between approximately -13.64 kN and -13.74 kN. This behaviour is expected because the yaw moment of inertia does not directly affect the normal loading of the tracks or the quasi-static distribution of contact stresses. Its influence is primarily related to the dynamic response of the vehicle during changes in angular motion.

The effect of the yaw moment of inertia is therefore mainly observed during the initial phase of the manoeuvre. Higher values of the yaw moment of inertia result in a slower development of the vehicle rotational response, which is reflected in a slightly slower increase in the lateral contact forces and steering resistance moment. As the vehicle approaches the steady-state condition, these differences gradually disappear and the corresponding output values

converge. This is particularly visible in the steering resistance moment, where the response briefly overshoots to approximately 30.85 kNm for lower values of Iz before settling to a steady-state value within roughly 0.3% of the nominal 30.8 kNm - confirming that the parameter's effect is confined almost entirely to the transient phase of the manoeuvre. The results indicate that the model has low sensitivity to the yaw moment of inertia with respect to steady-state contact forces, while its influence becomes more relevant when analysing the transient steering response.

Sensitivity of the model to distance between the centerlines of the tracks on both sides

Unlike the previously discussed parameters, track spacing was examined over a narrower interval of ±10% and ±20% relative to its nominal value, since larger deviations would no longer correspond to realistic design variations of the vehicle undercarriage. All other vehicle, steering, and terramechanical parameters were kept fixed at their nominal settings throughout this analysis, and the corresponding results are shown in Figure 4.

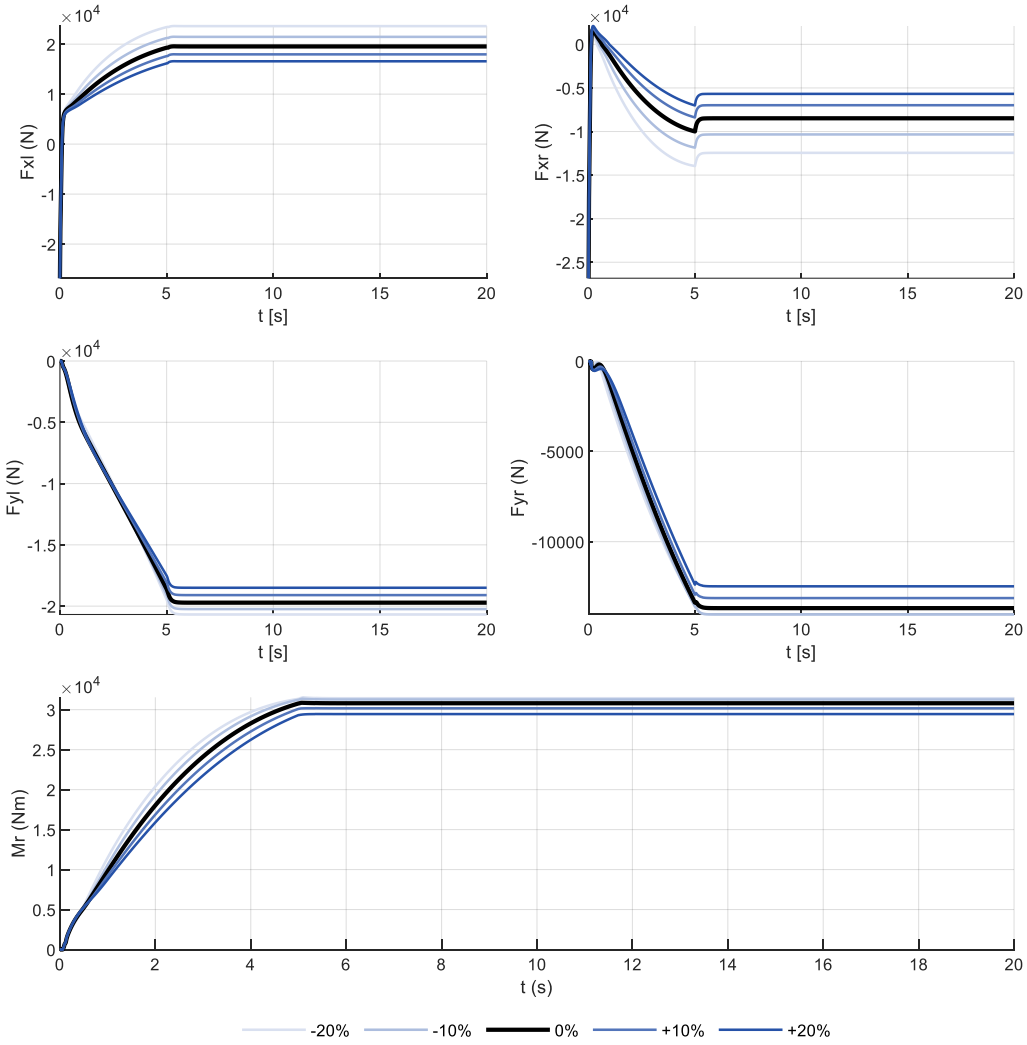


Figure 4 Influence of track spacing on model response during steering manoeuvre

Even within this comparatively narrow interval, track spacing clearly redistributes the contact forces between the two tracks. The steady-state longitudinal force on one track shifts from roughly 17.5 kN at -20% to roughly 23 kN at +20% relative to a nominal value of approximately 19.5 kN (Fxl), while the opposite track shows the largest relative shift among all five monitored outputs, moving from approximately -6 kN to -12 kN around a nominal value of -8 kN (Fxr). The lateral forces move in the opposite sense: Fyl stays confined to a narrow band of roughly -18 to -20 kN, whereas Fyr spans a wider interval of approximately -12 kN to -14kN around a nominal value near -13 kN. This redistribution reflects the altered steering geometry - a wider track spacing changes the effective radius at which the driving forces act, reducing the lateral slip needed to complete the prescribed turning manoeuvre.

The steering resistance moment is comparatively insensitive to this parameter by comparison, staying within roughly 29 - 31 kNm of the nominal 30.5 kNm across the full ±20% interval - a narrower relative band than either of the lateral forces. Beyond the contact forces shown in Figure 4, track spacing also affects the turning radius and the lateral velocity/acceleration components: a larger spacing widens the turning radius and lowers the lateral velocity, whereas

the longitudinal and total vehicle speed remain governed almost entirely by the prescribed track velocities and are only marginally affected by this parameter.

Taken together, these results place track spacing among the parameters worth prioritizing during vehicle parameterisation - not because of its effect on the steering moment, which is modest, but because of how strongly it redistributes load and lateral force between the two tracks, with direct consequences for turning geometry.

Sensitivity of the model to centre-of-gravity height

Of the four parameters considered in this study, centre-of-gravity height proved to have the most limited influence on the model outputs. Simulations were performed for values of this parameter varied by ±25% and ±50% relative to its nominal setting, with all other vehicle, steering, and terramechanical parameters held constant; the corresponding results are shown in Figure 5.

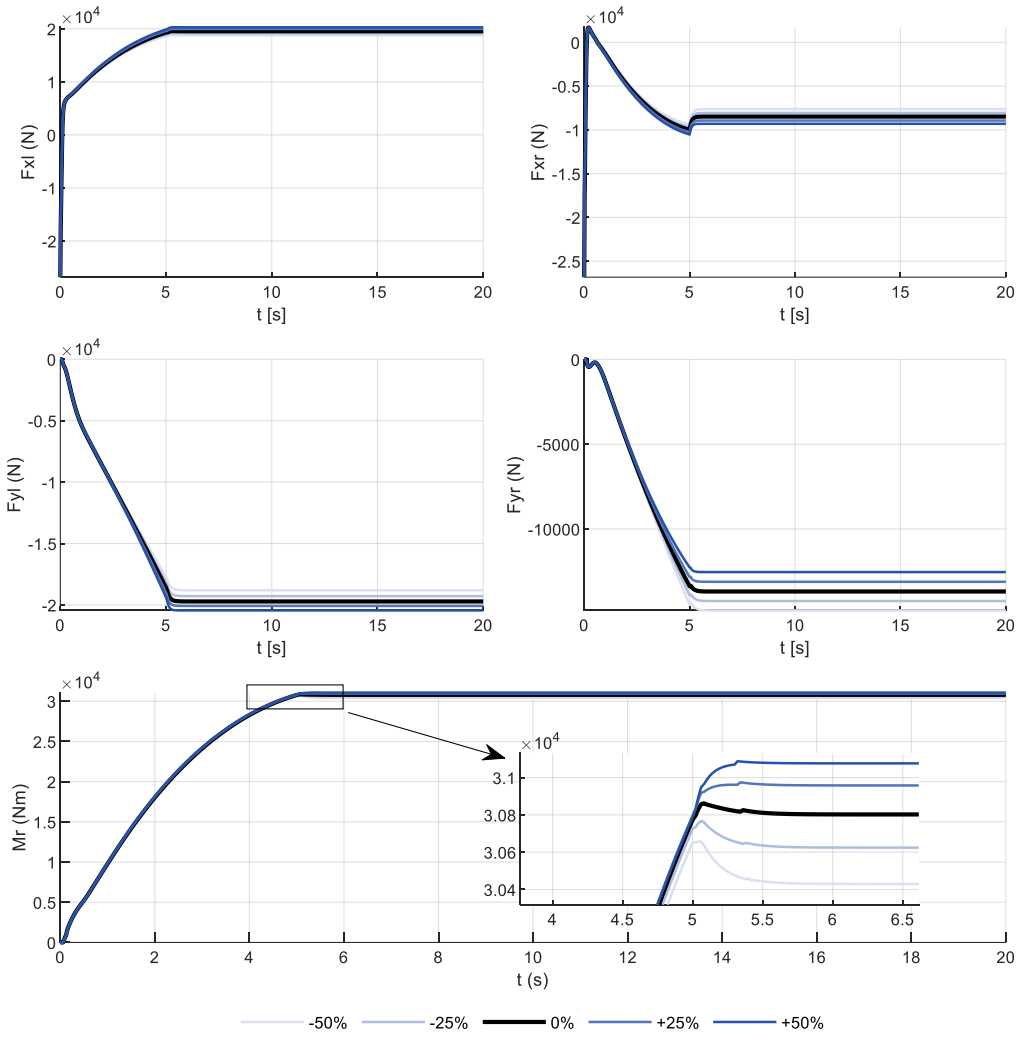


Figure 5 Influence of centre-of-gravity height on model response during steering manoeuvre

The longitudinal forces are scarcely affected by this parameter, with Fxl remaining within roughly 0.1 kN of its nominal 19 kN value and Fxr similarly staying close to its nominal value of approximately -8 kN across the entire investigated range. This behaviour is consistent with the fact that the total normal reaction at the track-terrain interface is governed primarily by vehicle weight, whereas variations in centre-of-gravity height do not directly alter its overall magnitude. The influence of this parameter is instead associated with the dynamic load transfer occurring during the steering manoeuvre, which may modify the distribution of normal loads and consequently affect the resulting contact forces. The lateral forces respond somewhat more visibly to this parameter, particularly on the outer track: Fyl stays confined to a tight band around -19 kN, while Fyr ranges from approximately -12 kN to -14.5 kN around a nominal value near -13.5 kN, representing the largest relative variation among the monitored outputs for this parameter, although the change remains modest in absolute terms.

The steering resistance moment follows the same pattern of limited responsiveness: the steady-state value shifts by no more than approximately 0.5 - 1 kNm around its nominal 30.8 kNm across the full ±50% interval, with the visible

differences in Figure 5 concentrated in a brief overshoot just after the transient phase rather than in the settled response. Taking the four investigated parameters together, centre-of-gravity height contributes the smallest overall variation to the model outputs, suggesting that within the range considered here, it can be assigned lower priority than vehicle mass or track spacing when calibrating the model for a new vehicle configuration.

CONCLUSIONS

This study investigated the sensitivity of a terramechanics-based numerical model of a tracked vehicle to variations in vehicle mass, yaw moment of inertia, track spacing, and centre-of-gravity height. The model was implemented in MATLAB/Simulink, while the terrain, steering conditions, and all non-investigated parameters were kept constant, allowing the individual influence of each selected parameter on the track-terrain interaction and vehicle response to be evaluated in isolation.

The analysis demonstrates that the sensitivity of the investigated terramechanics model is strongly dependent on the physical mechanism through which individual vehicle parameters affect the coupled vehicle-terrain system. Parameters influencing the normal loading conditions and steering geometry, particularly vehicle mass and track spacing, produce the most pronounced changes in the calculated interaction forces. Conversely, parameters primarily associated with the transient vehicle dynamics, such as the yaw moment of inertia, have only a limited influence on the steady-state force predictions.

Vehicle mass and track spacing emerged as the two parameters governing the largest share of the model's response, though through different mechanisms. Across the ±50% mass range, the steering resistance moment varied from approximately 22 to 39 kNm around a nominal value of 31 kNm, while the lateral force on the inner track ranged from approximately -10 to -30 kN - the largest relative spread of any monitored output. Track spacing, investigated over a narrower ±20% interval, produced a comparable redistribution of forces between the two tracks: the outer-track longitudinal force shifted from approximately -6 to -12 kN around a nominal -8 kN, while the steering resistance moment remained comparatively stable, within roughly 29-31 kNm of its nominal 30.5 kNm. Vehicle mass therefore primarily scales the overall force and moment levels, whereas track spacing reshapes how those forces are distributed between the inner and outer tracks.

By contrast, the yaw moment of inertia had almost no bearing on the steady-state outputs: Fxl remained within approximately 19 - 20 kN, Fxr within -8.0 to -9.0 kN, and Fyl within -19.4 to -19.8 kN across the full ±50% range, while Fyr showed the tightest band of all, varying only between approximately -13.64 kN and -13.74 kN. Its effect was instead confined to the transient phase of the manoeuvre, where the steering resistance moment briefly overshot to approximately 30.85 kNm before settling within roughly 0.3% of the nominal 30.8 kNm, and higher values of the parameter delayed the development of the rotational response. Centre-of-gravity height behaved similarly to a lesser degree: the longitudinal forces were essentially unaffected (Fxl within 0.1 kN of its nominal 19 kN, Fxr close to its nominal -8 kN), while the outer-track lateral force showed the most visible response of the four monitored quantities for this parameter, spreading from approximately -12 to -14.5 kN around a nominal -13.5 kN, and the steering resistance moment shifted by no more than approximately 0.5 - 1 kNm around its nominal 30.8 kNm.

These findings should be interpreted within the scope of the adopted one-at-a-time approach, a single terrain condition, and a single steering manoeuvre, potential interaction effects between parameters, as well as the influence of alternative terrain and manoeuvre conditions, were not addressed and remain open for further investigation. Within these limits, the results suggest that vehicle mass and track spacing warrant the greatest care during model parameterisation and experimental characterisation, whereas the yaw moment of inertia and centre-of-gravity height can be defined with comparatively less precision without substantially compromising the accuracy of the predicted steady-state track-terrain interaction.

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NOMENCLATURE

- τ - shear stress
- σ - normal stress
- φ - internal friction angle

c - soil cohesion
j - shear displacement
K - shear deformation modulus
m - vehicle mass
Iz - yaw moment of inertia of the tracked vehicle about the z-axis
B - distance between the centerlines of the tracks (track spacing)
h - centre-of-gravity height
Fx - total longitudinal force (both tracks)
Fy - total lateral force (both tracks)
Fxl - longitudinal force on the outer (left) track
Fxr - longitudinal force on the inner (right) track
Fyl - lateral force on the outer (left) track
Fyr - lateral force on the inner (right) track
Fr_l - resultant contact force – left track
Fr_r - resultant contact force – right track
Mr - total steering resistance moment
t - time
Δt - time step
u_l - left track (input) velocity
u_r - right track (input) velocity
v_x - longitudinal velocity of the vehicle
v_y - lateral velocity of the vehicle
$\dot{v}_x$ - rate of change of longitudinal velocity
$\dot{v}_y$ - rate of change of lateral velocity
a_x - longitudinal acceleration
a_y - lateral acceleration
$\dot{\theta}$ - yaw rate
$\ddot{\theta}$ - yaw angular acceleration

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