DEVELOPING A TRUCK ROLLOVER RISK CALCULATOR FOR SOUTH AFRICA

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ABSTRACT

The Static Rollover Threshold (SRT) is an important metric for characterising a heavy vehicle's inherent stability and risk of rollover. Current methods of assessing SRT include a tilt-table test and multi-body dynamics simulation which can be costly, time-consuming and often require significant technical expertise or technical vehicle data not normally accessible to the public. Simplified calculation methods exist, but a remaining challenge exists to reduce the required level of user expertise and input data to make the assessment useable by, for example, fleet insurers who would have an interest in SRT information. In this paper we investigate the use of simplified calculations prescribed by the New Zealand Land Transport Rule (NZLTR) and UNECE 111 as the basis for the development of a user-friendly SRT calculator. The calculation results were validated against a multi-body dynamics model using TruckSIM for the case of a rigid truck for a range of vehicle suspension and mass properties. The NZLTR and 'interpolated' UNECE 111 methods resulted in the smallest errors compared with TruckSIM, averaging 6-7% in absolute error over the 16 scenarios assessed. Maximum errors occurred when the ratio between drive axle and steer axle roll stiffness was at its highest (at a ratio of 4.7:1). The UNECE 111 method was then used as the basis for a Python-based SRT calculator tool. The tool demonstrates how pre-loaded technical vehicle data and logic can be used to minimise the required user expertise and hence make SRT calculation feasible by non-technical users in the fleet insurance industry in South Africa.

Keywords: Static rollover threshold; Heavy goods vehicles; Truck rollover; UNECE 111; New Zealand Land Transport Rule (NZLTR).

1. BACKGROUND

The Static Rollover Threshold (SRT) is an important metric for characterising a heavy vehicle's inherent stability and risk of rollover. It forms the basis for several Performance-Based Standards (PBS) frameworks for the regulation of heavy vehicle safety throughout the world, including in Australia (National Transport Commission, 2008) and South Africa (Nordengen *et al.*, 2018). The SRT is the maximum steady-state lateral acceleration a vehicle can experience before rollover occurs, usually defined by the lift-off of all wheels on one side of the vehicle (Winkler and Ervin, 1999). For a vehicle to be considered safe, a universally accepted minimum SRT is 0.35g (where g is the acceleration due to gravity). This value comes from empirical data gathered from road accidents which indicate that a sharp increase in accidents involving rollover occur when a vehicle's SRT is lower than 0.35*g*, as shown in Figure 1 (Mueller, de Pont and Baas, 1999).

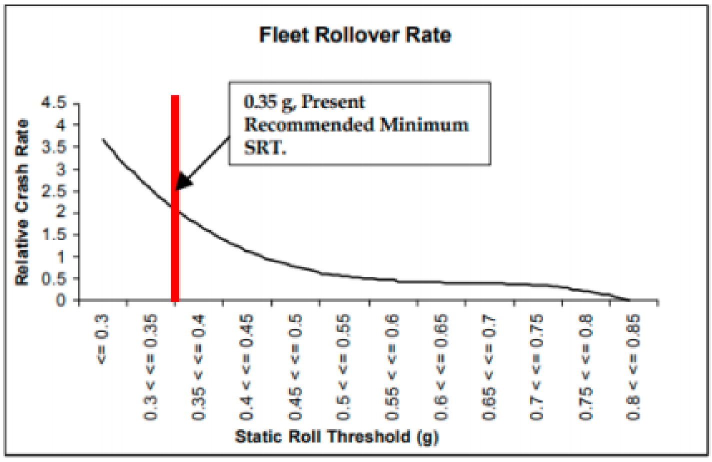


Figure 1: Relative Crash Rate vs SRT (Mueller, de Pont & Baas, 1999)

Current methods of assessing a vehicle's SRT include a physical tilt-table test (if the actual vehicle already exists) and multi-body dynamics (MBD) simulation. These can be costly, time-consuming, or require an engineering professional to perform, and MBD simulations typically require extensive technical vehicle data not usually accessible to the public. Simplified calculation methods exist, such as the New Zealand-developed SRT Calculator (Latto, 2001) (TERNZ, 2016) but these still require a level of technical data input that is usually restricted to technical professionals familiar with at least basic heavy vehicle dynamics principles. Furthermore, generic data used in such tools is generally specific to the country in question and its typical vehicle designs which have been shaped by that country's own regulations and conventions.

There is therefore a need to develop a South African-specific SRT calculator which would be useable by non-specialist professionals such as fleet insurers, fleet financers or accident investigators. Such a tool would make use of underlying technical vehicle data specific to South Africa that has been carefully prepared in relation to typical South African heavy vehicle designs and conventions. Ultimately, this would allow users to describe a vehicle to be assessed through simple word-based descriptors instead of specifying the input data directly, and the underlying database would choose the required technical data based on the user's choices.

In this paper we investigate the use of simplified calculations prescribed by the New Zealand Land Transport Rule (NZLTR) (New Zealand Ministry of Transport, 2016) and UNECE 111 (UNECE, 2000) as the basis for the development of a user-friendly South African SRT calculator. The calculation results were benchmarked against a detailed MBD model using TruckSIM (Mechanical Simulation Corporation, 2019) for the case of a rigid truck for a range of vehicle suspension and mass properties. A user-friendly interface and underlying logic were also developed.

2. LITERATURE REVIEW

2.1 The Tilt-Table Test Multi-Body Dynamic Simulation

The most common physical method of assessing the SRT of a heavy vehicle is the tilt-table test. In such a test a truck is placed on a flat platform, secured by means of chains, and the plate is then slowly mechanically tilted until the wheels of one side of the truck lose contact with the platform. The angle of the platform at this point may then be used to calculate the SRT with the following equation (Sweatman and Mai, 1984):

$$\tan(\alpha) = \frac{a}{g} \tag{1}$$

where α = the roll angle at lift-off (degrees), a = effective lateral acceleration (m/s^2) and g = acceleration due to gravity (m/s^2).

A tilt angle of 19° would indicate an SRT of 0.35*g*. This method is time-consuming to prepare and costly, and, of course, requires the availability of a full-scale vehicle. A less costly alternative is to use multi-body dynamics (MBD) simulation software such as TruckSim. This has the added benefit of being able to assess a theoretical or concept design before the vehicle has been manufactured. Equations are performed on a user-generated vehicle model and calculated at various time steps for an accurate model of the vehicle's performance.

Despite the elimination of the need for a physical test, the MBD approach requires costly software license fees and the requirement of expertise to model the vehicle and interpret the results. Additionally, the need for detailed technical vehicle specifications can result in added time, costs and challenges.

2.2 The UNECE 111 Method

In Europe, a legally acceptable alternative to the tilt table test is the use of UNECE SRT calculation (UNECE, 2000). The calculations adopt a two degree of freedom system (based on the roll angle of the axle with respect to the ground, and that of the sprung mass with respect to the roll centre of the axle), and are derived from static equilibrium considerations (Tomar, 2015). The UNECE method resolves the total roll stiffness of each set of axles about the ground plane, which allows each axle contribution to be combined about a common point. The effective roll stiffness per axle group about the ground, K_{sg}, is calculated as follows:

$$K_{sg} = K_s \left(\frac{h_s}{h_s - h_{rc}}\right)^2 \left(1 - \frac{m_s g h_{rc}(h_s - h_{rc})}{K_s h_s}\right) \tag{2}$$

where K_s = axle roll stiffness about the roll centre (Nm/rad), h_s = sprung mass centre of gravity height above ground (m), h_{rc} = roll centre height above ground (m), g = acceleration due to gravity (m/s^2) and m_s = sprung mass (kg).

K_{res}, the resolved combination of the axle suspension stiffness and the tyre stiffness about the ground (Nm/rad), is then calculated as follows:

$$\frac{1}{K_{res}} = \frac{1}{K_{sg}} + \frac{1}{K_{al}} \tag{3}$$

where K_{al} = tyre roll stiffness about ground (Nm/rad).

The maximum lateral acceleration for complete wheel lift-off, a_{yT} (i.e., no wheels on one side of the vehicle are in contact with the ground), and the maximum acceleration able to be withstood by the stiffest axle, a_{yS}, may be calculated using the following formulae (Tomar, 2015):

$$a_{yT} = \frac{m_T g^2 l_{tT}}{2(m_T g h_{cg} + \frac{\left((m_T - m_{uT}) g h_s\right)^2}{K_{resT} - m_T g h_s})} \tag{4}$$

$$s_f = \frac{K_{res} S}{K_{resT}} \tag{5}$$

$$a_{yS} = \frac{m_s T g^2 l_{tS}}{2(s_f m_T g h_{cg} + \frac{\left(s_f (m_T - m_{uT}) g h_s\right)^2}{K_{resT} - s_f m_T g h_s})} \tag{6}$$

where m_T = total combination mass (kg), $l_{tT=}$ average wheelbase (m), h_{cg} = total combination centre of gravity height (m), m_{uT} = total combination unsprung mass (m), K_{resT} = total combination resolved roll stiffness (Nm/rad), m_{sT} = total load on the stiffest axle (kg), K_{resS} = resolved roll stiffness of stiffest axle (Nm/rad), l_{tS} = wheelbase of stiffest axle (m) and s_f = ratio of the highest axle roll stiffness to the total resolved stiffness of the combination.

The SRT is then found by interpolating between total wheel lift-off and lift-off of the stiffest axle as follows:

$$SRT = a_{yT} - \frac{(a_{yT} - a_{yS}) m_s}{m_T} \tag{7}$$

The UNECE 111 method does not take any suspension lash effects into account, and it considers the fifth wheel as having infinite stiffness, resulting in an anticipated overestimation of the realistic case. A major advantage of the UNECE111 system is that it can be calculated using only axle total roll stiffness, eliminating the need for other information such as auxiliary or vertical stiffness if the total stiffness is known (Tomar, 2015).

2.3 The New Zealand Land Transport Rule and TERNZ SRT Calculator

In New Zealand, it is legally permissible to use the TERNZ Online SRT Calculator (TERNZ, 2016) to validate the stability of a vehicle in accordance with the NZLTR (New Zealand Ministry of Transport, 2016). The user selects vehicle properties from a predefined set of inputs and conditions, which are then calculated according to calculations described in the NZLTR (New Zealand Ministry of Transport, 2002). The Calculator goes some way towards achieving the objectives mentioned earlier, but does require additional external calculations in some instances, as well as a certain level of technical expertise on the part of the user. There are also some uncertainties in how the tractor unit is modelled when assessing semi-trailer and full trailer arrangements. Furthermore, the provided generic user input data is specific to the vehicles and conventions of New Zealand and Australia and may not necessarily be applicable to the South African context.

The NZLTR calculates the SRT according to a similar two-degree of freedom model to UNECE 111 as shown in Figure 2 (New Zealand Ministry of Transport, 2002). The SRT can be summarized as:

$$SRT = \frac{T}{2H} - \phi_T \tag{8}$$

where T = wheelbase (m), H = combination centre of gravity, and ϕ_T = total roll angle about point R (rads).

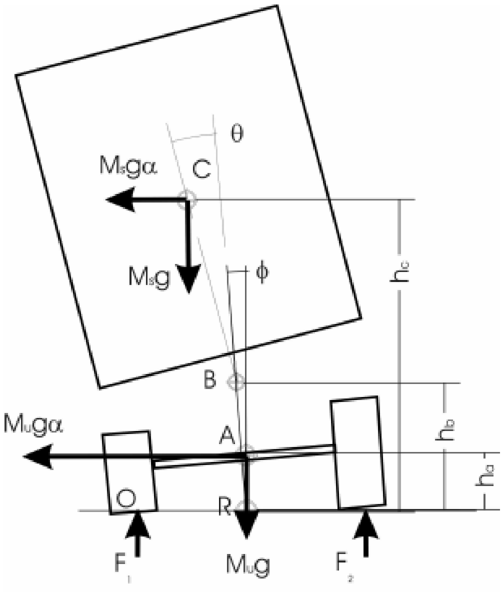


Figure 2: Free Body Diagram of a Truck Undergoing Rollover (Gosche, 2002)

The calculation of Φ_T is based on the following formula

$$\phi_T = \phi + \frac{M_s(\theta+\zeta)}{MH} \tag{9}$$

where ϕ_T = total roll angle about point R (rad), ϕ = axle roll angle (rad), θ = body roll angle relative to axle (rad) , ζ = roll angle due to lash (rad) and M = total combination mass (kg).

The equilibrium equation is then given as:

$$K_R MH\theta + K_{aux} MH\zeta - M_s g(h_c - h_b)(M_s h_b + M_u h_a)(\theta + \zeta) = \frac{K_t T^2}{2} M_s(h_c - h_b)\phi \tag{10}$$

where K_R = total axle roll stiffness (Nm/rad), K_{aux} = axle auxiliary roll stiffness (Nm/rad), M_s = sprung mass (kg), h_c = sprung mass centre of gravity from ground (kg), M_u = unsprung mass (kg), h_b = axle roll centre from ground (m), h_a = unsprung mass centre of gravity from ground (m), K_T = tyre vertical stiffness (N/m).

The NZLTR derivation accommodates three potential cases, with Case 2 involving the calculation of three scenarios, and their potential sequences. Case 1 assumes no lash occurs, and that rollover occurs at wheel lift-off ($\Phi = Mg/k_tT$). Case 2 outlines three possible scenarios where rollover occurs in the spring unloading cycle: (1) when one spring is unloaded before lash occurs ($\zeta = 0$ and $\theta = M_sg/k_vt_s$), (2) when lash is completed at wheel lift-off (ζ=0 and $\Phi = Mg/k_tT$), and (3) at a point during lash between wheel lift-off and spring unloading. The SRT is calculated by considering each scenario at each axle as lateral acceleration increases. The scenario that yields the highest SRT value will be considered the critical scenario.

The equations for the vehicle state are then adjusted to calculate which scenario occurs next. The process is repeated until wheel lift-off occurs and the SRT is calculated. Case 3 is used when there is a significant difference between axle group roll stiffnesses and makes use of various weighting and load distribution factors and lift-off conditions to assess individual axle groups. Through a series of simultaneous equations, various SRT values are calculated and checked for validity before a selection is made. In reality there may be a large difference in the roll stiffness properties of the front and rear axles in a single vehicle unit (such as between the steer axle, and drive axles of a rigid truck). The variation in front/rear "roll-couples" for a rigid truck is typically 1:4 (Winkler and Ervin, 1999).

The NZLTR makes provision for lash to be included in the calculation of the SRT, in the form of the ζ term. However, in the South African PBS pilot project, lash is typically assumed to be zero in MBD simulations for the sake of consistency between assessments, and so it was decided to assume zero lash for this study (Case 1 of the NZLTR). For the sake of simplicity, auxiliary roll stiffness was also assumed to be zero, although it is noted that typical suspension systems with no auxiliary roll stiffnesses, such as steel springs, will typically have lash.

If lash is completely ignored, rollover is assumed to occur at tyre lift-off. The resulting conditions needed to calculate the SRT are therefore:

$$\phi = \frac{Mg}{k_t T} \tag{11}$$

$$\zeta = 0 \tag{12}$$

Unlike the UNECE 111 Method, non-additive axle parameters such as roll centre and sprung mass are calculated as weighted averages instead of absorbed into resolved stiffnesses about the ground plane (in Case 1) (Benade *et al.*, 2016). No calculation of the load on the stiffest axle is required as the SRT can be calculated directly without any interpolation, eliminating the need for geometric parameters such as hitch and axle positions. However, three separate equations are required before SRT selection can take place (New Zealand Ministry of Transport, 2002).

2.4 Other Studies

The wide-ranging safety and economic applications of having a cost-effective and user-friendly SRT calculator have prompted other investigations into manual calculation methods. Benade et al. investigated the viability of replacing MBD methods with equations prescribed by the NZLTR (Benade *et al.*, 2016). Data collected from original equipment manufacturers (OEMS) were used as inputs for simulations using MBD methods, and as inputs for the NZLTR and other simplified methods. The study concluded that the various NZLTR calculations were the most accurate compared to MBD methods, with average absolute errors for trucks of 4.8%, and a maximum of 6%. A practical challenge that arose during the investigation was the difficulty of obtaining accurate data from OEMs. Machine learning and statistical methods were recommended as avenues for further study.

Another proposed SRT calculation method is the Roll Compliant Vehicle (RCV) model, which takes into account the fifth wheel coupling and lateral movement due to tyre compliance. While providing a more accurate model of the vehicle's behaviour, it increases calculation complexity significantly, as new adjustment factors for stiffnesses, geometric parameters for fifth wheel and lateral shift calculations, scenarios and interpolations need to be considered. In a comparative study of tilt table tests, UNECE and the RCV method, the RCV method, was found to be the most accurate. The UNECE 111 data tended to overestimate the SRT and produced errors of -3.3 to -11.68% (Tomar, 2015).

3. OBJECTIVES

In this work we set out to:

- Compare the NZLTR and UNECE 111 SRT calculation methods against an equivalent multi-body dynamics model for a rigid truck over a range of vehicle parameters to determine suitability for use in a new SRT calculator.
- Capture the calculations in a user-friendly Graphical User Interface (GUI) to demonstrate the future potential of a South African SRT calculator tool.

4. METHODOLOGY

The UNECE 111 equations were captured in Excel, while the TERNZ SRT Calculator was used for the calculation of the more complex NZLTR equations. TruckSIM 2019.1 was used to develop the MBD model to be used as the benchmark against which UNECE 111 and NZLTR results would be validated. A representative set of vehicle parameters for a simple rigid truck were determined, along with 15 variants of the model in which critical suspension and inertial parameters were varied, giving 16 cases in total.

Three variants of calculating SRT using the UNECE 111 method were included. First, the main ‘interpolated’ method was used according to equation 7. Then, a method based purely on drive axle lift-off (equations 4-6) was considered. Finally, a ‘lumped’ approach was also considered, wherein axle track width was assumed to be a mass weighted average of front and rear axles, and a single total roll stiffness comprising the sum of front and rear axles was used.

The vehicle parameters used in the case study are summarised in Tables 1 and 2. Two steer axle variations were considered with varying roll centre and unsprung mass centre of gravity heights as shown in Table 1. Remaining variations are detailed in Table 2. These included the drive axle suspension spring stiffness (varying from 400 to 2000 kN/m per spring) and the sprung mass and associated centre of gravity height (15428 kg at 2.097 m, 15428 kg at 1.480 m, and 9996 kg at 1.490 m). Cases 13-16 represented a 3-axle variation of the rigid truck (with two drive axles), with a sprung mass of 23578 kg, sprung mass centre of gravity height of 1.983 m, and a wheelbase of 5.865 m. The 3-axle truck was then subjected to a drive axle spring stiffness variation of 400 to 2000 kN/m per spring. Steer and drive axle suspension track widths were kept constant at 890 mm and 1000 mm respectively. Lash was assumed to be zero in line with current South African PBS practise and due to the incompatibility of the UNECE method with lash.

Table 1: Steer axle parameters used in the case study

	Track width	Unsprung mass	Suspension stiffness per side	Tyre stiffness per side	Unsprung mass height	Roll center height from floor	Auxilliary stiffness
Unit	**(m)**	**(kg)**	**(kN/m)**	**(kN/m)**	**(m)**	**(m)**	**(kNm/rad)**
Case 1-12	1.95	422	275	987	0.501	0.449	99.98
Case 13-16	1.95	422	275	987	0.515	0.462	99.98

Table 2: Drive axle and inertial vehicle parameters used in the case study

	Track width	Unsprung mass	Suspension stiffness per side	Tyre stiffness per side	Unsprung mass height	Roll center height from floor	Auxilliary stiffness	Sprung mass longitudinal CoG	Wheelbase	Sprung mass height	Sprung mass
Unit	**(m)**	**(kg)**	**(kN/m)**	**(kN/m)**	**(m)**	**(m)**	**(kNm/rad)**	**(m)**	**(m)**	**(m)**	**(kg)**
Case 1	1.863	850	400	1974	0.518	0.739	0	2.654	5	2.097	15428
Case 2	1.863	850	800	1974	0.518	0.739	0	2.654	5	2.097	15428
Case 3	1.863	850	1200	1974	0.518	0.739	0	2.654	5	2.097	15428
Case 4	1.863	850	2000	1974	0.518	0.739	0	2.654	5	2.097	15428
Case 5	1.863	850	400	1974	0.518	0.739	0	2.654	5	1.480	15428
Case 6	1.863	850	800	1974	0.518	0.739	0	2.654	5	1.480	15428
Case 7	1.863	850	1200	1974	0.518	0.739	0	2.654	5	1.480	15428
Case 8	1.863	850	2000	1974	0.518	0.739	0	2.654	5	1.480	15428
Case 9	1.863	850	400	1974	0.518	0.739	0	2.654	5	1.490	9996
Case 10	1.863	850	800	1974	0.518	0.739	0	2.654	5	1.490	9996
Case 11	1.863	850	1200	1974	0.518	0.739	0	2.654	5	1.490	9996
Case 12	1.863	850	2000	1974	0.518	0.739	0	2.654	5	1.490	9996
Case 13	1.863	1700	800	3948	0.524	0.739	0	4.054	5.865	1.983	23578
Case 14	1.863	1700	1600	3948	0.524	0.739	0	4.054	5.865	1.983	23578
Case 15	1.863	1700	2400	3948	0.524	0.739	0	4.054	5.865	1.983	23578
Case 16	1.863	1700	4000	3948	0.524	0.739	0	4.054	5.865	1.983	23578

The vehicle parameters were selected from representative vehicle data available in TruckSim and obtained from previous heavy vehicle dynamic assessments conducted at the CSIR. When specifying the values in TruckSim, suspension settling under load was taken into consideration to achieve the final parameters specified in Tables 1 and 2.

For the TruckSIM model, SRT was obtained using the built-in tilt-table simulation with a data sampling frequency of 2000 Hz and a tilt rate of 0.1 degrees per second. An example of the output from one of the TruckSim simulations is shown in Figure 3, indicating the reduction of vertical wheel loads on one side of the truck as a function of effective lateral acceleration (see equation 1). As is typical, the stiffer drive axles are first to lift off the ground (the first at ~0.32g and the second at ~0.34g) followed by the steer axle at ~0.35g. The drive axle and all-axle lift-off points from the TruckSIM simulations were recorded for each case.

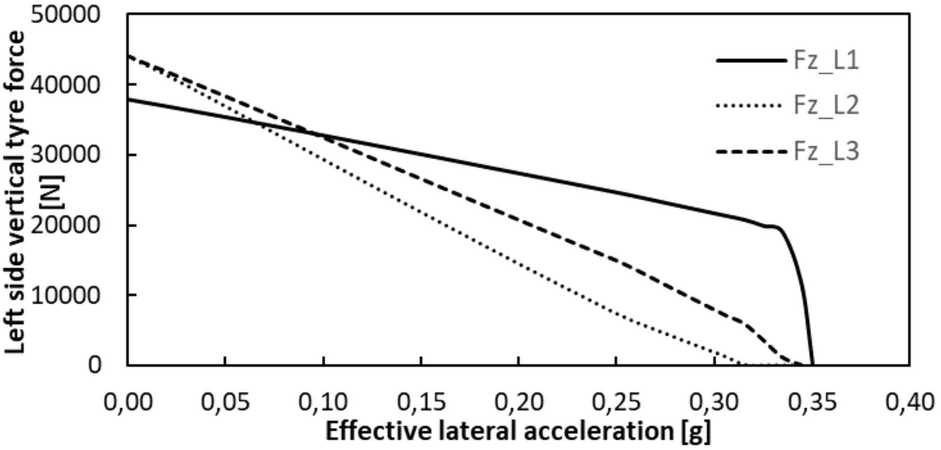


Figure 3: Tilt table test output from TruckSim for a validation case

5. RESULTS

The SRT results for all 16 cases and each of the calculation methods are summarized in Figure 4. The resultant errors between the simplified methods and the TruckSIM results are summarised in Table 3. The TruckSIM drive and all-axle results are very similar except in cases 10-12 where the sprung mass was reduced from 15 to 10 tonnes. The NZLTR and UNECE 111 Interpolated methods give the most comparable results to TruckSIM overall with average absolute errors of 6-7%. However, the NZLTR method gives the lowest maximum error of the two, at 8% versus 14%. The highest errors in both methods occur in case 4 where the drive axle roll stiffness is at its highest compared to that of the steer axle, at a ratio of 4.7:1. An underestimated SRT is preferable from a safety perspective, and in these 16 cases the UNECE interpolated method overestimates SRT less often than the NZLTR. The UNECE lumped method gave the least comparable results overall with errors of up to 44% (also for case 4) and an average absolute error of 21%.

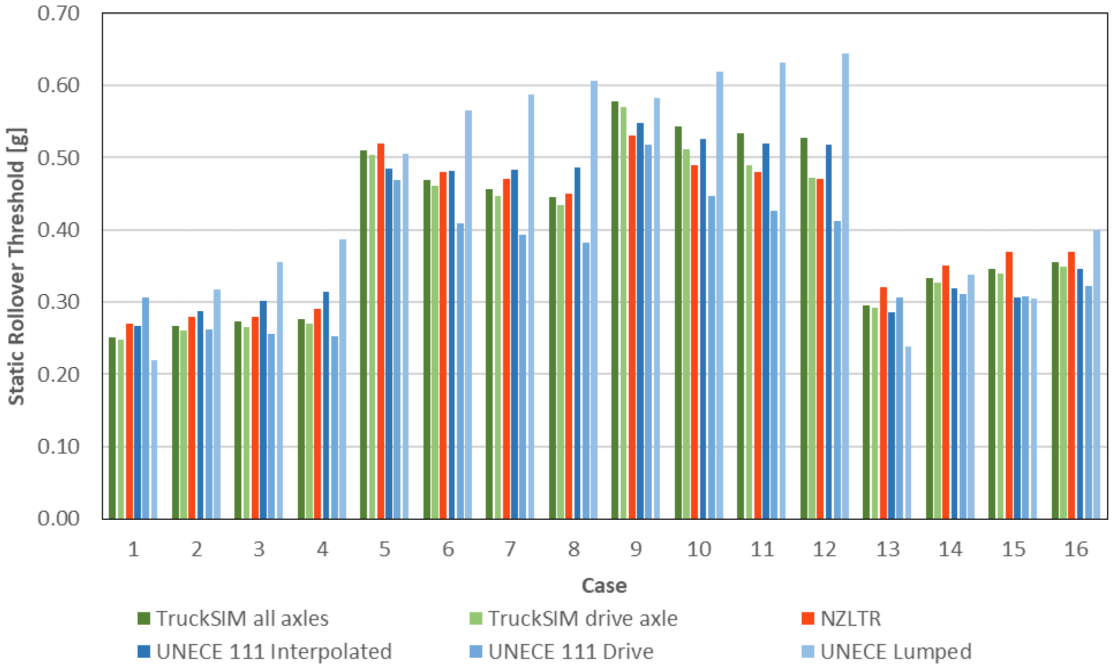


Figure 4: Calculated SRT results for all calculation methods

Table 3: SRT calculation errors with respect to TruckSim (all axles)

Case:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Ave.	Ave. abs.
SRT (g):																		
TruckSIM all axles	0.25	0.27	0.27	0.28	0.51	0.47	0.46	0.44	0.58	0.54	0.53	0.53	0.30	0.33	0.35	0.36	-	-
TruckSIM drive axle	0.25	0.26	0.27	0.27	0.50	0.46	0.45	0.43	0.57	0.51	0.49	0.47	0.29	0.33	0.34	0.35	-	-
NZLTR	0.27	0.28	0.28	0.29	0.52	0.48	0.47	0.45	0.53	0.49	0.48	0.47	0.32	0.35	0.37	0.37	-	-
UNECE interpolated	0.27	0.29	0.30	0.31	0.49	0.48	0.48	0.49	0.55	0.53	0.52	0.52	0.29	0.32	0.31	0.35	-	-
UNECE drive axle	0.31	0.26	0.26	0.25	0.47	0.41	0.39	0.38	0.52	0.45	0.43	0.41	0.31	0.31	0.31	0.32	-	-
UNECE lumped	0.22	0.32	0.36	0.39	0.51	0.57	0.59	0.61	0.58	0.62	0.63	0.64	0.24	0.34	0.30	0.40	-	-
Errors w.r.t TruckSIM all axles:																		
NZLTR	7%	5%	3%	5%	2%	2%	3%	1%	-8%	-10%	-10%	-11%	8%	5%	7%	4%	**1%**	**6%**
UNECE interpolated	6%	8%	11%	14%	-5%	2%	6%	9%	-5%	-3%	-3%	-2%	-4%	-4%	-11%	-3%	**1%**	**6%**
UNECE drive axle	24%	1%	-4%	-6%	-7%	-11%	-12%	-12%	-9%	-12%	-13%	-13%	4%	-5%	-9%	-8%	**-6%**	**9%**
UNECE lumped	-13%	19%	30%	40%	-1%	20%	29%	36%	1%	14%	18%	22%	-20%	2%	-12%	12%	**12%**	**18%**
Errors w.r.t TruckSIM drive axle:																		
NZLTR	9%	7%	5%	8%	3%	4%	5%	3%	-7%	-4%	-2%	0%	9%	7%	9%	6%	**4%**	**6%**
UNECE interpolated	7%	10%	13%	17%	-4%	4%	8%	12%	-4%	3%	6%	10%	-3%	-2%	-10%	-1%	**4%**	**7%**
UNECE drive axle	24%	1%	-4%	-6%	-7%	-11%	-12%	-12%	-9%	-12%	-13%	-13%	4%	-5%	-9%	-8%	**-6%**	**9%**
UNECE lumped	-12%	22%	34%	44%	0%	23%	32%	39%	2%	21%	29%	37%	-19%	4%	-10%	14%	**16%**	**21%**

Given the high errors in case 4, the data were studied further for insights into the effect of drive axle roll stiffness on the SRT calculation errors. First, we consider the cases where only the drive axle roll stiffness was varied while the steer axle roll stiffness remained constant at 208 895 Nm/rad (cases 1 to 4). The results are given in Figure 5. The errors tend to increase as the drive axle roll stiffness increases further away from the steer axle roll stiffness, but this trend appears to flatten at higher values suggesting a limiting effect imposed by the drive axle contribution. The UNECE drive axle and UNECE lumped methods give quite noticeably different values and trends especially at lower values of drive axle roll stiffness.

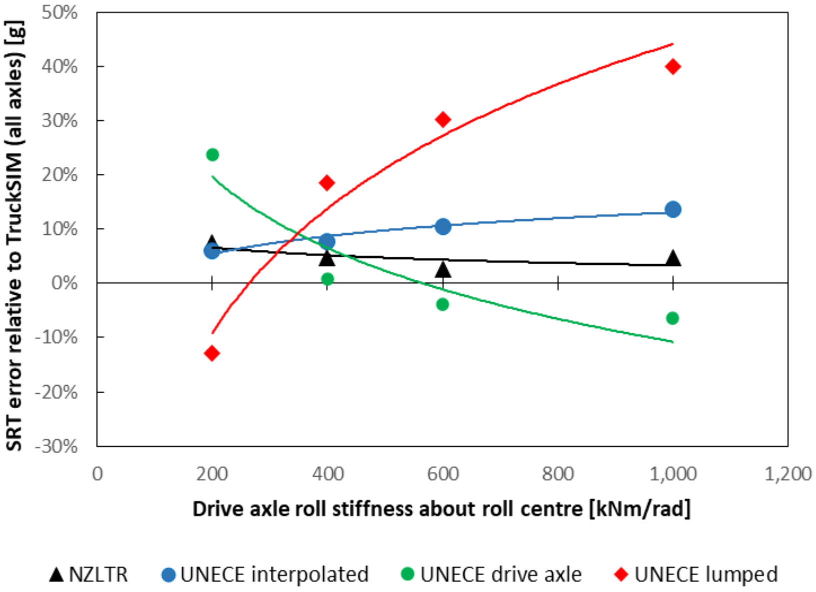


Figure 5: SRT calculation errors as a function of drive axle roll stiffness (cases 1-4)

Figure 6 demonstrates the variation of error with sprung mass centre of gravity height (cases 1 and 5). As the sprung mass centre of gravity height increases, the absolute value of the error increases for all methods. However, the UNECE 111 interpolated and NZLTR methods both give the lowest errors overall, and also exhibit much lower sensitivity to variations in the centre of gravity height than the other methods.

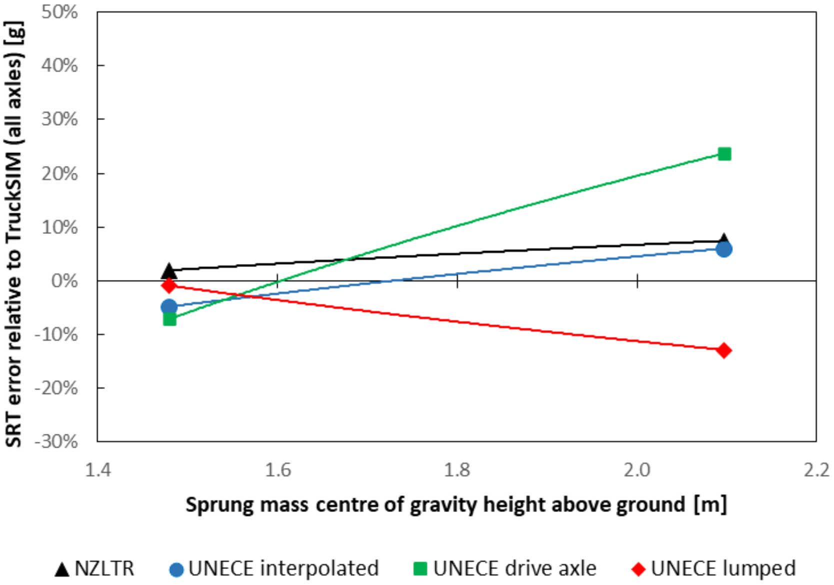


Figure 6: SRT calculation errors as a function of sprung mass COG height (cases 1 & 5)

Overall, both NZLTR and UNECE interpolated methods performed best with comparable overall average errors in this set of cases. However, the NZLTR appeared to be more robust to changes in parameters and gave lower maximum errors, while the UNECE 111 interpolated method tended to underestimate SRT more often than the NZLTR method which is preferable from a safety perspective. The UNECE 111 methods are also simpler to implement. The UNECE 111 interpolated method was adopted in the proof-of-concept SRT calculator for South Africa.

6. GRAPHICAL USER INTERFACE

The Graphical User Interface (GUI) for the South African SRT Calculator was developed to help users calculate the SRT of a heavy vehicle in a quick and user-friendly way using the UNECE 111 Interpolated method as the basis for calculation. The welcome page provides the user an option of two methods of calculating SRT: a ‘generic’ method, and a manual method. The assisted generic method requires minimal technical data inputs which will be useful to users who may not have the required technical data for using the manual method.

In the generic method, the user if first presented with a choice of common vehicle combinations to select (see Figure 7). This selection will help the tool to select a subset of vehicle input data appropriate to the selected vehicle. In the next step, the user is given the option of specifying additional vehicle characteristics (see Figure 8), which allows for a more accurate selection of input data from the underlying database. If the user does not have this additional information, the most suitable generic values are used. The “vehicle type” option includes options for timber trucks, car-carriers, tankers, flatbed, and tautliners.

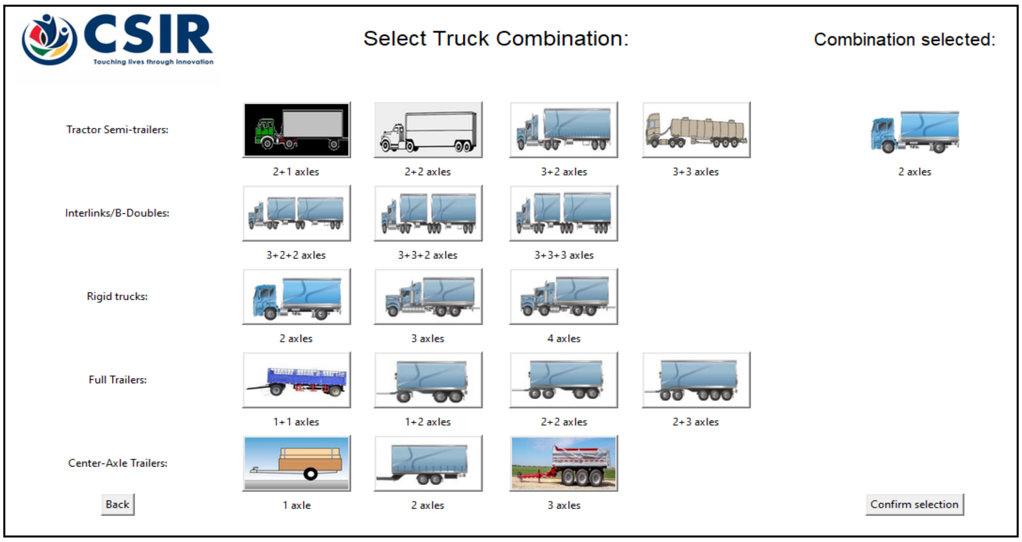
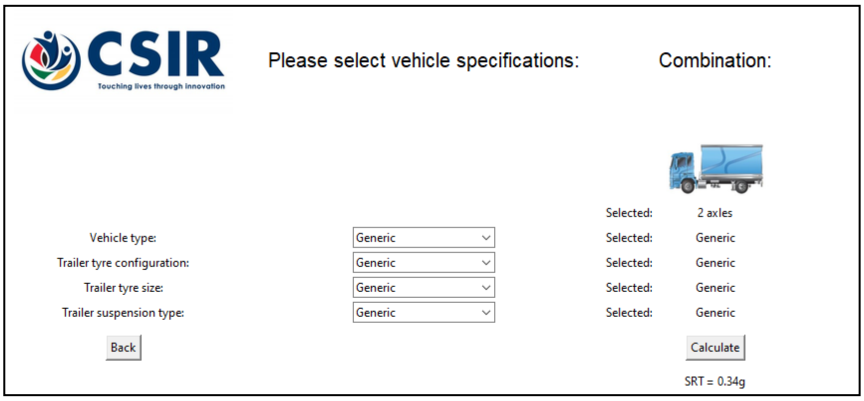


Figure 7: Generic method GUI: Vehicle combination selection

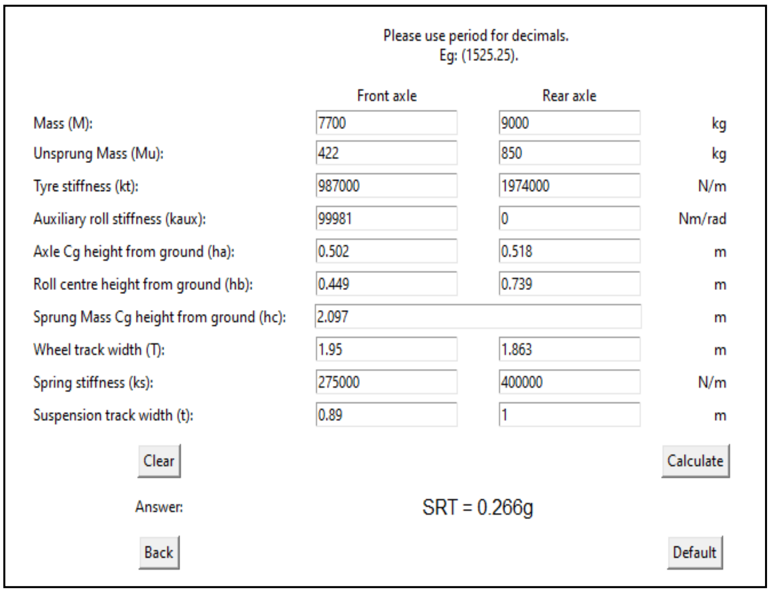


Selected: 2 axles
Vehicle type: Generic — Selected: Generic
Trailer tyre configuration: Generic — Selected: Generic
Trailer tyre size: Generic — Selected: Generic
Trailer suspension type: Generic — Selected: Generic

SRT = 0.34g

Figure 8: Generic method GUI: Additional parameter selection

The manual method (see Figure 9) allows the user to directly insert the required technical input values required by the underlying equations if these are available, more in line with the approach of the TERNZ SRT Calculator. This is intended for more technical users who are more likely to have the data available, which can offer a more accurate SRT value for the selected combination. Default values are displayed that may help the user when inputting the data. Once the user has entered all required values the user can click the "Calculate" button and the SRT value will be generated as indicated.



Please use period for decimals.
Eg: (1525.25).

	Front axle	Rear axle	
Mass (M):	7700	9000	kg
Unsprung Mass (Mu):	422	850	kg
Tyre stiffness (kt):	987000	1974000	N/m
Auxiliary roll stiffness (kaux):	99981	0	Nm/rad
Axle Cg height from ground (ha):	0.502	0.518	m
Roll centre height from ground (hb):	0.449	0.739	m
Sprung Mass Cg height from ground (hc):	2.097		m
Wheel track width (T):	1.95	1.863	m
Spring stiffness (ks):	275000	400000	N/m
Suspension track width (t):	0.89	1	m

Answer: SRT = 0.266g

Figure 9: Manual method GUI

7. CONCLUSIONS AND RECOMMENDATIONS

For the purposes of developing a simplified truck rollover risk calculator, the UNECE 111 "interpolated" SRT calculation method was found to give a good balance of accuracy and simplicity. This method was then used as the basis for a simplified truck rollover risk calculator, which has been developed as a simple GUI-based software tool. The tool makes use of underlying technical data specific to South Africa and insights compiled by vehicle dynamics specialists, which assists non-technical users to use the tool effectively when this data is not explicitly available to them.

The tool is intended for use by fleet insurers, fleet financers, transport operators, truck and trailer OEMs, accident investigators and possibly transport consignors and consignees. The tool can be used to assess vehicle rollover risk (coupled with a route risk assessment), can assist those considering a PBS vehicle design and comparing design concepts, or can be used by trailer manufacturers who may want to improve the stability of standard heavy vehicle combinations.

8. ACKNOWLEDGEMENTS

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