GEOTRACK: AN EFFICIENT SIMULATION TOOL FOR THE ANALYSIS OF HEAVY VEHICLE MANOEUVRABILITY

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ABSTRACT

The road space utilised by a heavy goods vehicle during low-speed manoeuvring has direct safety and operational implications. This is especially true for vehicles which are longer/wider than usual, such as abnormal loads vehicles. The same applies to vehicles that are required to meet certain performance-based manoeuvrability criteria, such as those participating in the South African “Smart Truck” programme. For both abnormal loads vehicles and many “Smart Trucks”, route approval is required which is often restricted due to concerns over manoeuvrability at particular challenging road sections. GeoTrack is a simulation tool which is able to efficiently analyse the manoeuvrability of any vehicle combination performing any turning manoeuvre. The tool has been tailored for both general user-defined analyses based on satellite images of the road section of interest, as well as for the requirements of the Smart Truck programme. Despite requiring only basic vehicle dimensional data, the tool captures >95% of the performance of competing software packages which are expensive and highly time intensive. In this paper we will give an overview of the tool and its capabilities, discuss how it has aided ongoing industry and research projects, and present a novel validation study conducted on a full-scale heavy goods vehicle.

Key words: Heavy goods vehicles; Manoeuvrability; Performance-based standards; Swept path; Tail swing; Frontal swing; Off-tracking

1 INTRODUCTION

1.1 Background

GeoTrack is a software tool which simulates the low-speed turning behaviour of heavy goods vehicles (HGVs), especially those with one or more trailers. HGVs in excess of legal dimensions have to operate under permit, and these permits are subject to route clearance by provincial road authorities. A critical factor in assessing route suitability for an over-size HGV is the low-speed manoeuvrability, particularly at intersections and access points. This has become increasingly relevant with the Performance-Based Standards (PBS or “Smart Trucks”) demonstration project which has been spear-headed by the CSIR since 2003 (Nordengen, Kienhöfer, & de Saxe, 2014). The PBS project is a framework for assessing and regulating over-size and/or over-mass HGVs. In the PBS scheme, vehicle manoeuvrability is usually assessed via simulation, and acceptable performance limits must be met such as “low-speed swept path”, “frontal swing” and “tail swing”.

The GeoTrack tool is able to assess manoeuvrability for both the PBS scheme (which specifies fixed manoeuvres and performance criteria), and also for the general case of a given road intersection geometry obtained from Google Maps. A complete assessment only requires basic vehicle dimensions which are available at an early design stage, and results are computed in seconds. This makes it ideal for vehicle design optimisation as many different configurations can be assessed quickly. For the general road geometry case, an interface is included to define a path overlaid on a Google Maps image. Existing methods for performing such an assessment include time-consuming and expensive multi-body dynamic simulation tools. GeoTrack is easy-to-use, efficient, flexible, and has the required PBS standards built in.

The tool has already proven especially useful for the PBS scheme, and has been used to save clients money and time at the initial design stages of PBS vehicles. It will have further impact on reducing the man-hour load on assessing and implementing PBS vehicles on South African roads. It has also been used in a number of recent research studies, including: (de Saxe, Kienhöfer, & Nordengen, 2012), (Benade, Berman, Kienhöfer, & Nordengen, 2016), (Benade, Berman, Kienhöfer, & Nordengen, 2015), (Benade, 2016), (Berman, Benade, & Rosman, 2015), (Berman, Benade, Rosman, & Nordengen, 2016).

1.2 Aim of paper

This paper aims to introduce the GeoTrack tool to the transport research and regulation communities in South Africa, and to demonstrate its usefulness and accuracy.

1.3 Scope of paper

The paper includes a brief background to the PBS pilot project in South Africa, followed by an overview of low-speed manoeuvrability evaluation manoeuvres and performance metrics. A review of existing approaches to low-speed manoeuvrability simulation is then provided, which leads into the motivation for developing the current tool. Next, a high-level overview of the tool is presented, showing how it has been implemented and how it can be applied to both the PBS and generalised assessment scenarios. The results of a validation exercise are then presented, followed by conclusions.

The scope of the paper has been intentionally kept high-level, excluding mathematical details of the model and excluding an extensive description and analysis of the validation exercises. A more detailed treatment will be presented in a forthcoming paper, but some additional details may be found in (de Saxe, 2012).

2 LOW-SPEED TURNING PERFORMANCE OF HGVS

2.1 Low speed turning and performance metrics

The South African PBS pilot project (Nordengen *et al.*, 2014) has adopted its performance standards from the well-regarded Australian PBS scheme (National Transport Commission, 2008). These performance standards include low-speed manoeuvrability, high-speed dynamic, and infrastructure impact performance metrics. The low-speed manoeuvrability metrics include:

1. Low-Speed Swept Path (LSSP),
2. Tail Swing (TS),
3. Frontal Swing (FS),
4. Difference of Maxima (DoM), and
5. Maximum of Difference (MoD).

These are assessed simultaneously via a prescribed low-speed 90° turn of radius 12.5 m. The path must be followed with respect to the outermost tyre wall on the steer axle, within a tolerance of no more than 50 mm, and the manoeuvre should be conducted at a speed of no more than 5 km/h. An illustration of the manoeuvre and metrics is given in Figure 1.

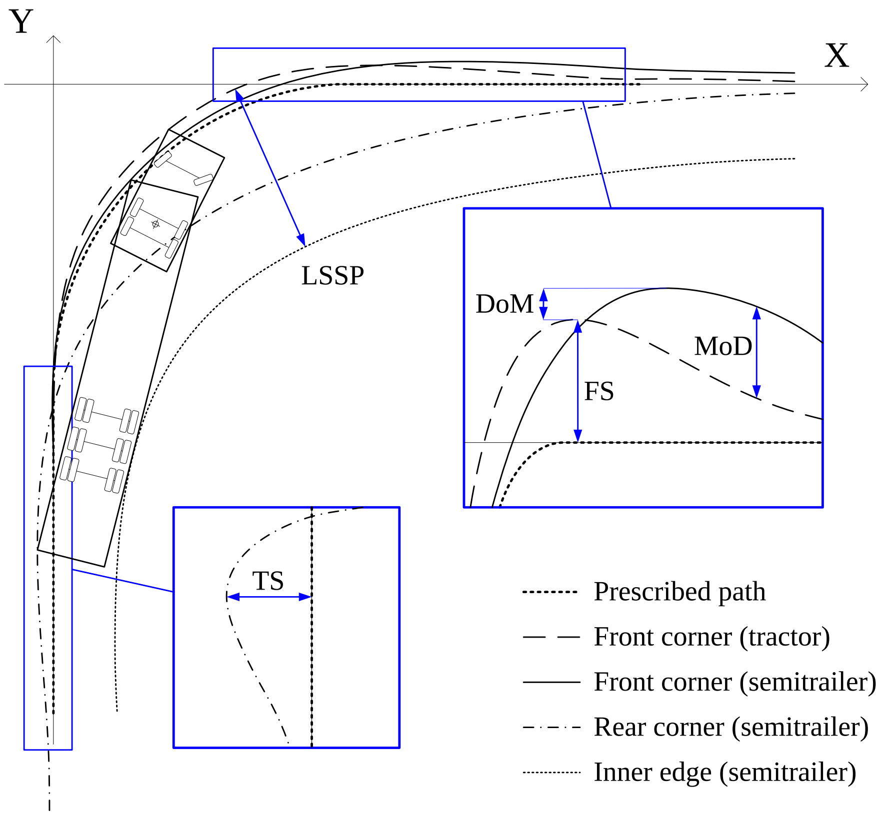


Figure 1: Illustration of the low-speed manoeuvrability standards (de Saxe, 2012)

The various trajectories indicated in Figure 1 must be tracked during the manoeuvre, as these are used to calculate the required performance metrics. LSSP is a measure of the maximum road space utilised by the vehicle during a turn, which gives an indication of how well the vehicle can navigate an intersection without impeding into other lanes and/or the pavement. This is measured laterally between the outmost trajectory (usually the front outer corner of the truck or tractor), and the innermost trajectory (usually near the inside tyre of the rearmost trailer axle group). Tail Swing measures the swing-out of the rear corners of the truck and/or trailers, which usually occurs during the start of the turn, and which can be a safety risk to cyclists, roadside furniture, and vehicles in the adjacent lane. Frontal Swing measures the swing out of the front of the vehicle near the exit of the turn, due to the front overhang, which again indicates a safety risk to other road users and to roadside furniture. DoM and MoD are measurements of the frontal swing of semi-trailers, which often exceed that of the truck or tractor.

2.2 Low-speed manoeuvrability models

A number of approaches to simulating low-speed vehicle manoeuvrability have been used over the last few decades. Each is a compromise between accuracy, efficiency, the number of vehicle input parameters required, and flexibility to cope with multiple manoeuvre types.

The “WHI formula” (developed by the Western Highway Institute in 1970) is a simple geometric relationship for determining the low-speed swept path of an articulated vehicle (Prem, de Pont, Pearson, & McLean, 2002). Although the formula has proven useful, it has no means for predicting tail swing or frontal swing behaviour, and relies on predetermined coefficients based on the prescribed path in question. Wang and Linnett (1995) developed a kinematic model which is capable of determining the paths of any point on a vehicle or vehicle combination as it follows a path with respect to any vehicle reference point. However, the model requires that the path be mathematically described and analytical definitions of real road data are not readily available, preventing its application to generalised road assessment applications. Erkert *et al.* (1989) used a bicycle model and the "tractrix" concept to determine vehicle motion, and the model is able to track multiple reference points. Again, the model requires analytically defined paths, limiting its scope for generalised manoeuvres.

McGovern (2003) developed a spreadsheet-based method to calculate the required vehicle motion to turn within the constraints of a given entry gate and confining walls (of a repair yard for example). The approach is similar to the tractrix method but solves the problem using a step-wise geometric method. The model is limited in its application to turning within the restraints of a given geometry, and cannot (without modification) be applied to problems in which a prescribed path is followed. Morrison (1972) developed a low-speed turning model which included non-linear tyre mechanics to incorporate tyre scrub effects, but thereby also introduced the need for tyre stiffness parameter data. The model uses an iterative solution method making the model computationally demanding.

Alternative methods for simulating low-speed manoeuvrability include multi-body dynamics simulation packages such as TruckSIM or Adams. Using multi-body dynamics software is arguably potentially more accurate as many more aspects of the vehicle are modelled, but this results in significantly increased vehicle parameter data required, significant model setup time, and significant licence costs for the specialised software. Intermediate complexity software add-ons such as AutoTurn (for AutoCAD) are also available, but require an additional licence.

3 MANOEUVRABILITY MODEL

The GeoTrack tool is based on simple kinematics using the tractrix method, meaning that only simple vehicle dimensional data are required for the simulation. These are limited to only: front and rear overhangs, wheelbases, hitch locations, and the locations of any other relevant reference points. This allows the tool to assess vehicle designs at a very early concept stage. The tool has been implemented in MATLAB, and offers two simulation streams: one for the prescribed PBS low-speed turn manoeuvre, and one for a generalized manoeuvrability assessment for a given road geometry. The model and post processing have been highly optimized, resulting in processing times in the region of a few seconds.

A flowchart of the GeoTrack tool functionality is given in Figure 2. The user uses a simple interface to enter the basic dimensions of the vehicle combination, such as wheelbases and overhangs. The user is then presented with a choice to conduct a PBS assessment or generalised route assessment task. If a PBS assessment is specified, no further inputs are required, and the solver runs and generates the relevant plots for each PBS standard and saves the results to file. If the general route assessment is chosen, the user is required to additionally select and upload an image of the road section of interest from Google Maps (or similar). The user is then guided through the steps to scale the image, select the road boundaries, and specify a vehicle path to follow. The solver then runs and plots the trajectories of the vehicle superimposed on the uploaded image, and saves data to file.

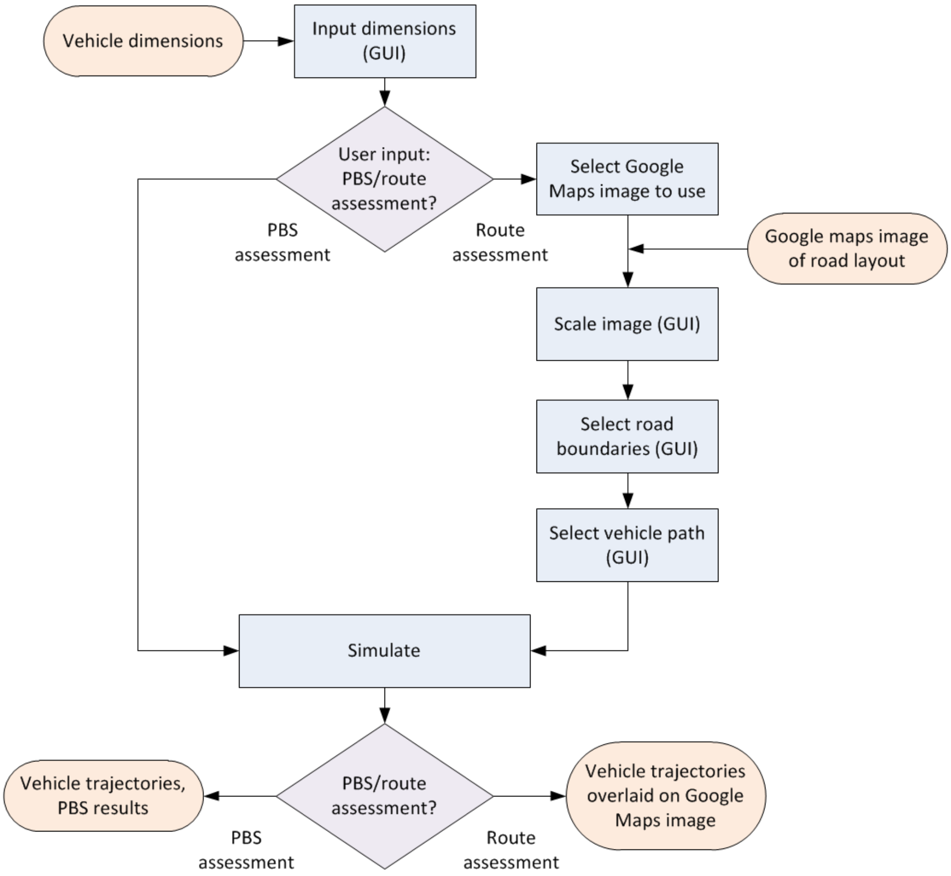


Figure 2: GeoTrack functional diagram

Results from a sample route assessment are shown in Figure 3, in which a vehicle has been assessed traversing a motorway offramp, followed by a 90° right-hand turn at an intersection. The results are overlaid onto the uploaded and scaled Google Maps image. The road boundaries (user chosen) and vehicle trajectories (calculated) are also shown. The results generated by a sample PBS assessment are shown in Figure 4, including an overview of the entire manoeuvre with an indication of the LSSP result (a), and close-up plots of the regions of Tail Swing (b) and Frontal Swing (including DoM and MoD) (c).

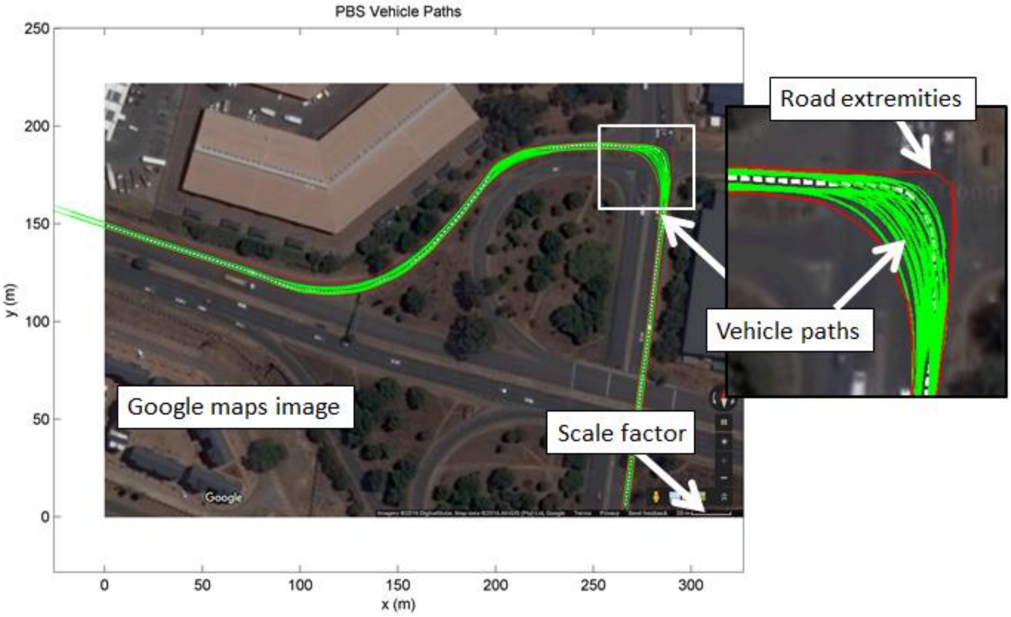
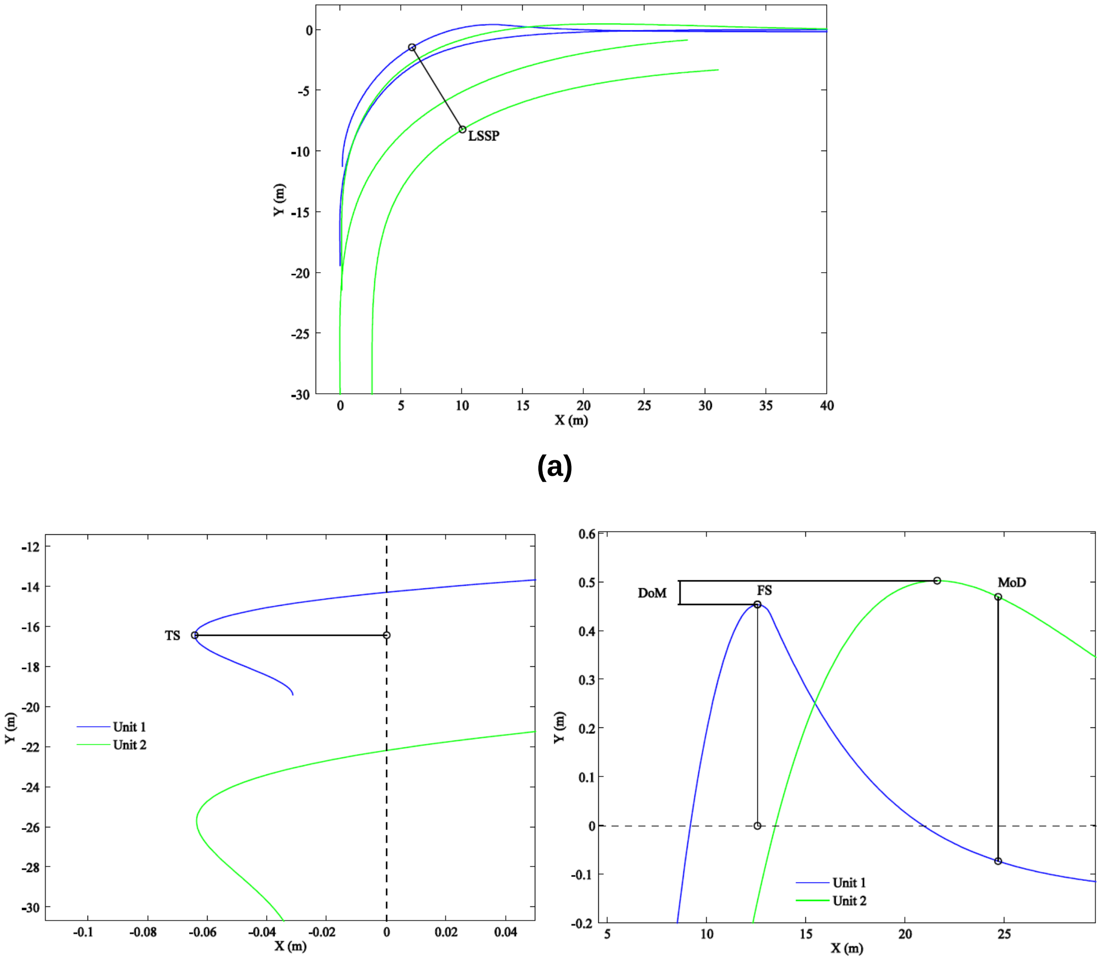


Figure 3: GeoTrack output, general route assessment option



(a)

(b)

(c)

Figure 4: GeoTrack output, PBS assessment option: (a) Swept path, (b) tail swing, (c) frontal swing, difference of maxima and maximum of difference

4 VEHICLE TESTING AND VALIDATION

An extensive simulation-based comparison between GeoTrack and TruckSIM, one of the leading vehicle simulation software tools available, demonstrated an average 2% discrepancy between results for a range of fourteen different vehicle configurations (de Saxe, 2012). GeoTrack achieved this with substantially fewer vehicle parameters and with greatly reduced model setup and solver processing time. Following this, a field test of the PBS 90° turn was conducted on a PBS timber vehicle, which is described below.

4.1 Testing overview

A rigid truck and full-trailer PBS timber combination was used for testing. Although the vehicle is within the legal 22 m combination length limit, it is designed for a Gross Combination Mass (GCM) in excess of the prescribed 56 tonne limit. A side profile of the vehicle showing its primary dimensions is shown in Figure 5.

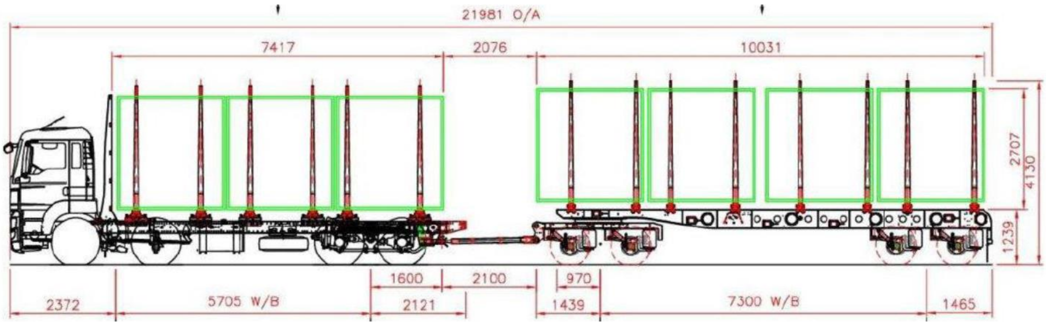


Figure 5: Rigid truck and full-trailer PBS combination used for validation

To track the trajectories of relevant reference points on the vehicle during the manoeuvre, a simple system comprising dowel sticks and coloured markers was used. Dowel sticks were fastened to the vehicle at relevant reference points (such as the rear and front corner extremities), aligned vertically so that the end of the dowel traced a path of the reference point a few centimetres above the ground. The driver was asked to stop every 1 m or so along the path, so that assistants could place coloured markers on the road beneath each dowel stick. At the end of the manoeuvre, the trajectories of all relevant reference points had been marked on the road surface at approximately 1 m intervals. The test vehicle fitted with the dowels is shown in Figure 6(a), and Figure 6(b) shows one of the markers.

(a) (b)

Figure 6: (a) Test vehicle, and (b) trajectory tracking method using dowels and markers

4.2 Data processing

Manually measuring the x-y coordinates of every marker in order to record and plot vehicle trajectories would be time-consuming and is prone to the accumulation of large errors. Instead, a novel data processing solution was developed comprising a camera and image processing algorithms implemented in Python. The procedure was as follows:

1. A digital camera was used to photograph the testing area, ensuring that each image overlapped with at least two other images. An example is shown in Figure 7(a).
2. The camera was calibrated using the method of Zhang (2000) to obtain the focal length, optical centre, and distortion coefficients of the camera and lens.
3. Each image was undistorted and "warped" using a perspective transform and the calibrated camera parameters, to generate a birds-eye-view of the scene. The corners of the concrete paving slabs were used to orient and scale the images during the warping process. Figure 7(b) shows the warped image of Figure 7(a).

4. Image stitching was used to align and combine each image into a compound birds-eye image of the testing region. Each marker location was digitally selected, and automatically scaled and saved to file. The compound image is shown in Figure 8.

(a) (b)

Figure 7: Image warping: (a) original image, (b) birds-eye view image after warping

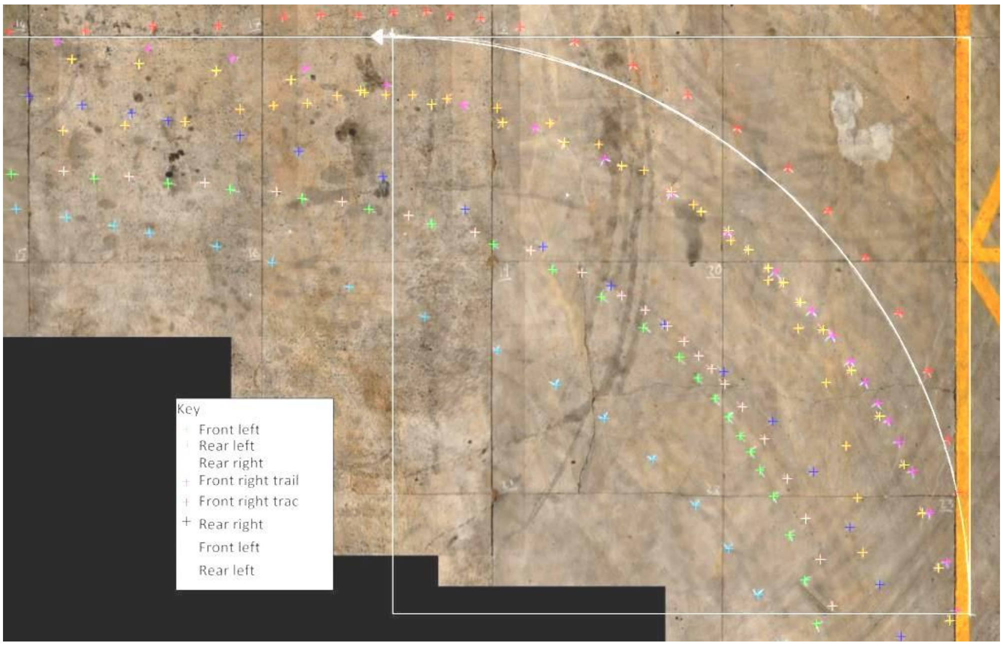


Figure 8: Composite image of the test area with vehicle trajectories

4.3 Results

The truck was simulated performing the manoeuvre using GeoTrack, and the simulation and field test results were compared. Figure 9 shows both the simulated (solid lines) and tested (dashed lines) trajectories for the relevant reference points. The results for each of the low speed PBS metrics is summarised in Table 1. The largest magnitude difference is in LSSP at 0.24 m (3.4%), which is very good considering the nearly 7 m swept path. The largest relative difference is in DoM at 8.8%, although this is a difference of only 0.03 m. Overall the comparison is very promising, especially considering that there are experimental errors inherent in the field test. Such errors in the field tests could have arisen from tyre settle during the intermittent stops, small errors in dowel alignment and marker placement, possible crabbing of the trailer (which wouldn’t have been detected), slight misalignment of the vehicle at the start of the test, and small uncertainties in the image processing steps. The cumulative experimental errors are estimated to be in the order of ±0.05 m.

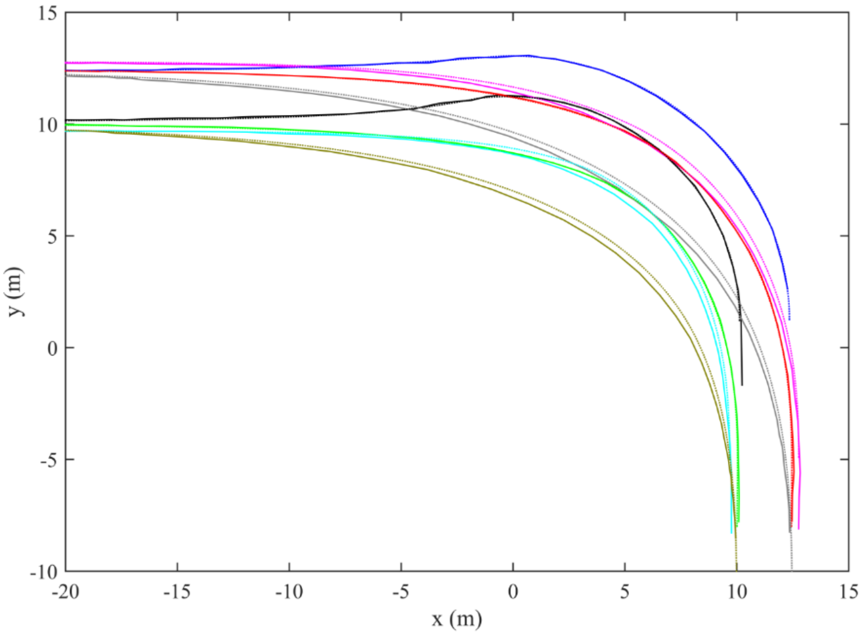


Figure 9: Field test vehicle trajectories (solid lines = GeoTrack, dotted lines = field test)

Table 1: Field testing results versus GeoTrack

Performance metric	Field test (m)	GeoTrack (m)	Difference (%)
Low Speed Swept Path	6.58	6.82	-3.4%
Tail Swing	0.32	0.32	+0.0%
Frontal Swing	0.56	0.59	-5.1%
Difference of Maxima	-0.31	-0.34	-8.8%
Maximum of Difference	0.34	0.34	+0.0%

5 CONCLUSIONS

1. GeoTrack is a computationally efficient tool for simulating the low speed manoeuvrability of heavy goods vehicles. The tool is compatible with multi-trailer combinations, and only requires simple dimensional input data.
2. The tool can be used to conduct a standard PBS-type assessment, or a generalised manoeuvrability assessment on any given road section using Google Maps.
3. The tool has been validated in both simulation and field tests, showing good accuracy with errors of only a few percent.
4. The tool is currently available for use internally at the CSIR, and on a consulting basis, but the tool may be released for commercial and/or public use in future.

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