The potential effects of Electronic Stability Control interventions on rural road crashes in Australia: Simulation of real world crashes

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Abstract

Twenty crash scenarios were developed based on actual rural road crashes obtained from an in-depth crash database. With the assistance of Robert Bosch (Australia) Pty. Ltd., the scenarios were simulated using vehicle models with and without Electronic Stability Control (ESC) fitted. In two of the scenarios, no simulation was necessary as the driver made no attempt to avoid a collision. In six scenarios, the attempt at simulation was unsuccessful. For the twelve remaining simulations that were successful, ESC was found to prevent a collision in ten cases and reduce the severity of a collision in the other two. Output plots from the simulations showing the timing and level of interventions enabled an analysis of how ESC was able to prevent or lower the severity of a collision.

Keywords

ESC, Simulation, Rural crash

Introduction

Electronic Stability Control (ESC) is a system which gives a driver increased control over their vehicle during emergency situations. ESC compares the driver's steering intentions with the vehicle's heading and intervenes by braking individual wheels to correct for any variance. ESC can also reduce engine torque, if required to allow the driver to maintain control of the vehicle. A vehicle equipped with ESC will endeavour to steer where the driver intends and is far less likely to skid. ESC cannot prevent a vehicle from skidding in all situations but allows the driver to maintain heading and stability up to the physical limits of the vehicle.

There have been many studies highlighting the benefits of ESC and the majority have shown a reduction in single vehicle crash rates of around 30-50% [1]–[15]. Even greater effectiveness is reported for specific types of crashes, especially where a loss of control might otherwise have occurred.

The physics and theory behind ESC are well known and documented [16]. ESC systems are developed and tested such that a manufacturer can predict very accurately how a vehicle equipped with ESC will react in a range of manoeuvres that may lead to loss of control. These manoeuvres are used to tune the ESC system on a test track. They resemble manoeuvres leading to loss of control in real crashes but they cannot possibly account for all crash scenarios.

Few studies to date have explored the link between the statistical reduction in vehicle crash rate and the way in which ESC is designed to function. There is no doubt that ESC is reducing vehicle crash rates but it is not clear how specifically the system is preventing real world crashes. Some features of ESC systems may be more critical than others. For example, crash reductions may be due primarily to a preservation of steering control, the ability to brake harder, the ability to turn sharply, or a number of other features. In addition, ESC may have different levels of effectiveness on different crash types. ESC may, for example, be less likely to prevent a crash on a dry, straight road than a crash on a wet, curved road.

This study aims to demonstrate how ESC systems operate to avoid, or lower the severity of, rural road crashes. Simulating crash scenarios, based on actual rural road crashes, and analysing the interventions made by the ESC system will allow a greater understanding of how the loss of control is avoided. In addition, the effectiveness of the ESC interventions in stabilising a vehicle during different types of crash or emergency manoeuvre can be analysed.

Methods

Data Set

Between March 1998 and February 2000, the Centre for Automotive Safety Research (CASR) conducted an in-depth investigation of 236 rural road crashes [17]. A large amount of data was recorded from each scene which was, in most cases, sufficient to enable a reconstruction of the crash to be made.

In order to select a set of crashes suitable for the current study, the following were excluded:

- Crashes which were not sensitive to the effects of ESC interventions (e.g. rear end, head on, side swipe, or right angle type crashes)
- Crashes involving motorcycles, trucks or busses as the primary loss of control vehicle
- Crashes involving pedestrians or non-motorised vehicles
- Crashes in which the driver was unconscious prior to the crash or there was suspicion of suicide

This left a sample of ninety six crashes from which twenty were chosen at random for simulation.

Each of the selected crashes was unique but could be grouped into a general crash mechanism category. In six cases, the vehicle oversteered when the driver overcorrected after initially travelling off the left side of the road. In two cases, the vehicle oversteered when the driver overcorrected after initially travelling off the right side of the road. In three cases the vehicle oversteered when the driver overcorrected after crossing the centreline. In two cases the vehicle oversteered after a sudden drop in surface friction. In two cases the vehicle understeered while the driver was braking heavily. In two cases, the vehicle understeered after a sudden drop in surface friction. In the final three cases the driver lost control of the vehicle in a way which did not fit into any of the other categories.

The crashes could also be grouped according to the severity of injury of the most injured person involved in the crash. In six cases, the most severely injured person was killed as a result of the crash. In another six cases, the most severely injured person was admitted to hospital as a result of the crash. In a further seven cases, the most severely injured person was either treated in hospital or by a local doctor as a result of the crash. In the final case, there was no injury to any of the involved parties.

Simulation Software

Robert Bosch (Australia) Pty. Ltd. agreed to provide assistance to this study by supplying software which could integrate with a vehicle dynamics software package to facilitate the simulation of an ESC equipped vehicle. Bosch Australia recommended a vehicle dynamics simulation package called CarSim, developed by Mechanical Simulation Corporation.

CarSim is able to accurately simulate the trajectory of a vehicle based on the characteristics of the vehicle, the environment and the driver's actions. CarSim uses detailed vehicle and tyre models and outputs comprehensive plots of vehicle properties over the course of the simulation. In addition, CarSim contains a complete driver model which is able simulate the actions of a driver. CarSim is not a crash simulator however and has no facilities for simulating any type of collision between vehicles or roadside objects.

The software used to simulate the interventions of an ESC system is a proprietary owned simulation package, called CSsim, developed by Bosch Australia. CSsim is able to interact with CarSim so that vehicles equipped with ESC can be simulated within CarSim.

Figure 1 illustrates how the input data is supplied to CarSim, which then communicates with CSsim to produce the outputs. The outputs consist of a three dimensional animation of the vehicle path and graphical plots of various vehicle parameters.

The CarSim software requires three inputs; vehicle data, environment data, and events data. The development of the three data components for each simulation was conducted according to a set protocol and is explained below.

Example Scenario
The following crash scenario will be used to demonstrate how the input data was developed in each case. The description of the crash is as given: On a Tuesday at approximately 7:50 am, a car was travelling down a narrow carriageway at a speed in excess of 130 km/h. As the vehicle came over the top of a crest, the driver was confronted with a truck straddling the centre of the carriageway. The truck was travelling in the opposite direction at a self reported speed of 15 km/h. The truck driver attempted to veer left to allow room for the car to pass. The driver of the car braked and veered right. The car yawed in a clockwise direction across the carriageway and onto the right hand side verge, narrowly missing the front of truck. The front left side of car struck a large tree, 4.5 metres from the carriageway. A site diagram of the example scenario is shown in Figure 2.

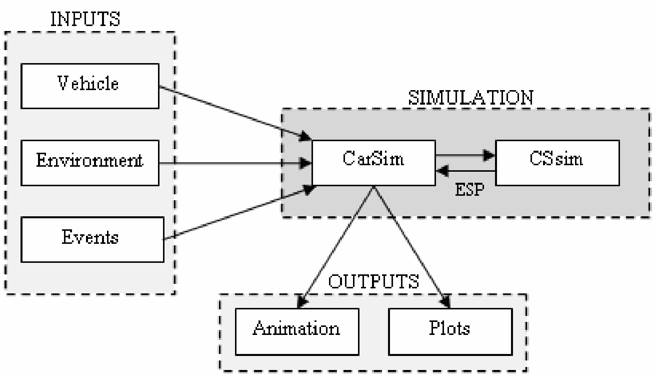

Figure 1: Illustration of data flow during simulation cycle

Vehicle Data
As part of their assistance for this study, Bosch Australia supplied two generic vehicle models equipped with ESC. The first vehicle model was a rear wheel drive sedan and the second was a front wheel drive small car. Both vehicle models were based on modern vehicles and were, on the whole, more stable that the actual vehicles involved in each crash scenario. For each simulation, the vehicle model which best represented the actual vehicle involved in the crash was used.

Example scenario
The vehicle in this scenario was a rear wheel drive sedan and so the rear wheel drive model was used.

Environment Data
The environment data set consisted of road section and road profile information as well as the friction values across the surface of the road and road side shoulders. The road section described the top down (or bird's eye) view of the road, in x-y coordinates. The road profile described the height of the road at each point along the centreline, in station-lateral offset coordinates.

As part of the in-depth investigation of each crash, a three dimensional site diagram was produced. For each simulation this diagram was used to obtain the coordinates of the centreline of the road. These coordinates were then used to produce the road section and road profile information.

Measuring the coefficient of friction of the road surface at the crash scene was not a part of the in-depth investigation process. Literature suggested that it was not appropriate to return to the crash scenes to measure the coefficient of friction as the value invariably changes considerably over time [18]. Instead, two sources were consulted in order to nominate typical coefficients of friction for various surfaces. These were the South Australian Department for Transportation, Energy and Infrastructure (DTEI) and Bosch Australia. DTEI conduct routine skid testing of the South Australia rural road network in order to ensure safe levels of friction are maintained. Bosch Australia, as part of their ESC tuning process, conduct skid tests on various types of surface. Based on the advice from DETI and Bosch Australia, a list of the coefficients of friction for different surface types to be used for this study was developed (Table 1).

The coefficients of friction were applied to the simulated road surface based the photographs of the site and road condition reports from the investigation of each crash.

Table 1: Coefficients of friction used for different surface types

Surface type	Friction coefficient
Dry sealed road	0.85
Wet sealed road	0.75
Dry unsealed road	0.70
Dry shoulder	0.60
Wet shoulder	0.50
Loose gravel road	0.50
Hail and sleet (sealed road)	0.50
Black ice/smooth wet surface	0.10

Example scenario

The site diagram was used to collect the coordinates of the centreline of the road and produce the road section and road profile information. The road was reported to be unsealed and dry so a coefficient of friction value of 0.7 was used. A coefficient of friction value of 0.6 was used for the roadside shoulders. Figure 3 shows the road section and road profile as well as the surface friction values used for the different parts of the road.

Events Data

The events data set consists of all the inputs to the vehicle over the course of the simulation, including initial speed, the timing and level of braking, as well as steering responses from the driver model. For each of the crash scenarios, the in-depth investigation of the actual crash provided information about these variables. This information came from marks on the road, driver statements, witness statements, etc. The initial speed in each simulation was usually set to match the speed from the actual crash.

Braking only occurred in a small number of the crash scenarios. In most of these, the driver appears to apply maximum braking at a certain point during the crash sequence. This point was matched in the simulations and then refined to match the vehicle trajectory in the simulation to that of the vehicle in the actual crash. More subtle braking applications were required in one simulation and these were timed/applied as accurately as possible given the available information.

The driver model consisted of four parameters; maximum steering angle, maximum steering rate, preview time, and driver path [19], [20].

The driver path is a line along the road that informs the driver model when and where to steer the vehicle. The path is defined as a guide to where the vehicle should be positioned, and the driver model attempts to achieve this position by steering the vehicle. The driver model reacts to changes in the path in different ways depending on the selected preview time, maximum steering angle, and maximum steer rate.

The preview time defines how far ahead the driver model 'looks' in anticipation of a change in the driver path (in seconds). This variable was used in each simulation to control how the driver model responded to the driver path. If a surprised response to a change in the driver path was required, a small preview time was used. Conversely, if a controlled response to change in the driver path was required, a large preview time was used. In this study, the values ranged between 0.60 seconds and 0.95 seconds.

The maximum steering angle defines the amount of travel (in degrees) in the steering wheel between full lock in either direction. It was set to 360 degrees in all simulations.

The maximum steering rate defines the speed at which the driver model is able to turn the steering wheel (in degrees per second). This variable was used in each simulation to control how quickly the driver model was able to respond to a change in the driver path. If a quick response was required, a high steer rate was used. Conversely, if a slow response was required, a low steer rate was used. For example, if the in-depth investigation reported that a driver steered quickly to the left to avoid an oncoming vehicle, a high steer rate would be used in the simulation. In this study, the value of the maximum steering rate ranged between 120 degrees per second and 600 degrees per second.

The trajectory of the simulated vehicle along the road depends on all of the driver model parameters (not just the driver path). In each case the driver model parameters were chosen and refined based on the circumstances of the actual crash, with the objective of matching the trajectory of the simulated vehicle with that of the vehicle in the actual crash.

Selecting suitable driver model variables was a difficult and time consuming process which involved many assumptions and much trial an error. Little literature exists on the implementation of driver models in crash simulations. It was therefore difficult to substantiate the values assigned to the driver model variables in each simulation.

Example scenario
Since the investigation estimated that the car was travelling at a speed in excess of 130 km/h, the initial speed of the vehicle was set as 135 km/h.

The driver is said to have braked as the vehicle came over the crest and was confronted with the oncoming truck straddling the carriageway. Full lock braking was applied to the vehicle as it reached the point in the crest where the driver would have been able to see the truck.

The driver is said to have steered to the right, and it is assumed that their intention was to pass the truck on the wrong side of the road. The driver path begins with the vehicle in the left lane and then suddenly veering to the right at the same point as the braking is applied. The driver path can be seen in Figure 3. The driver model was given a preview time of 0.8 seconds and a maximum steer rate of 120 degrees per second. This combination of variables was chosen so that the trajectory of the simulated vehicle matched the trajectory of the vehicle in the actual crash.

Simulation
For each crash scenario, a simulation was run once while the vehicle model had ESC equipped and once while ESC was not equipped. The results of the two simulations were then overlaid into a single output plot and analysed.

The output plot of each simulated crash scenario showed the difference between a vehicle equipped with ESC and a vehicle not equipped with ESC. Many variables can be looked at, but of particular note is that the timing and level of the ESC interventions at each individual wheel of the vehicle can be determined.

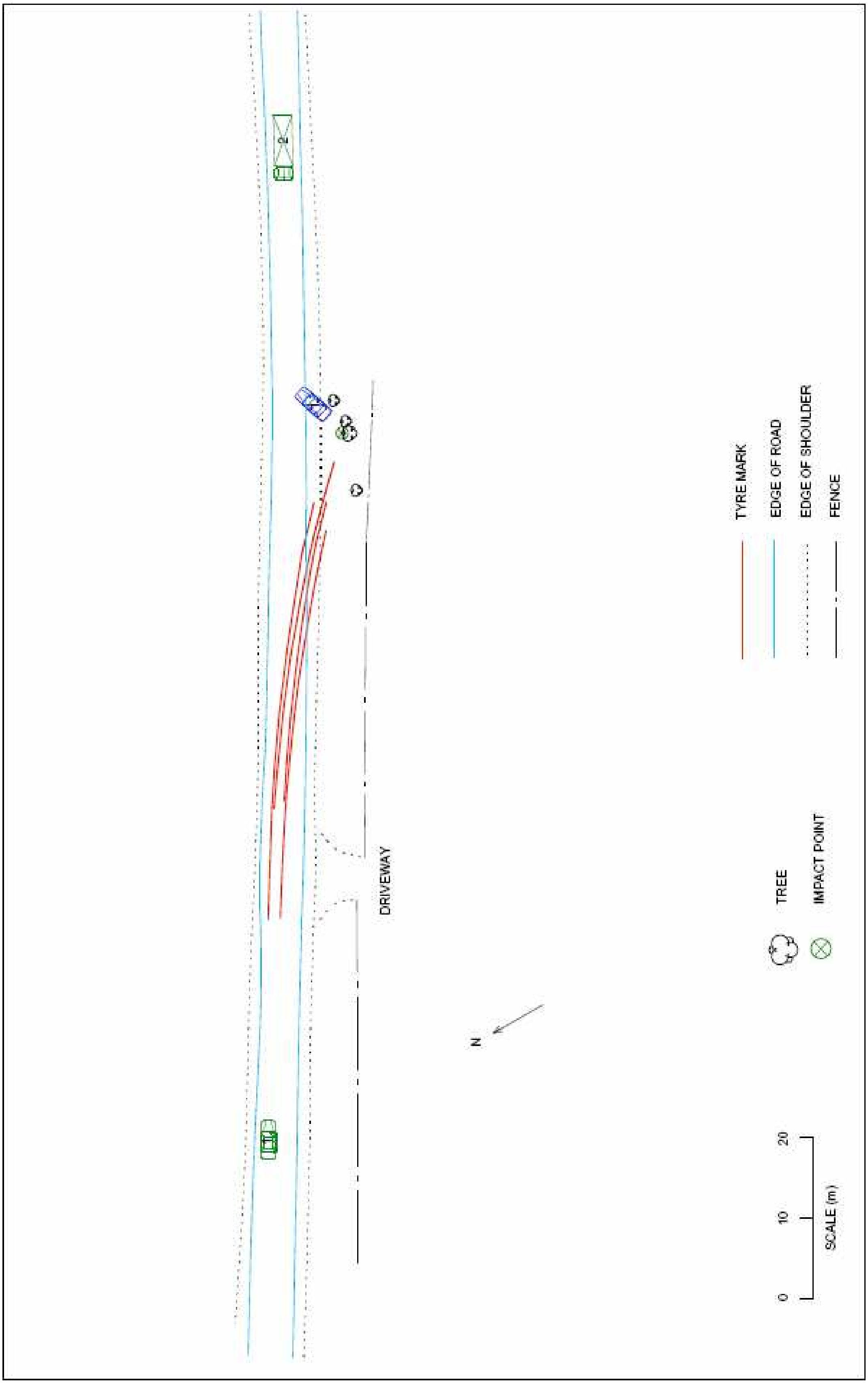

Figure 2: Site diagram of the example crash scenario

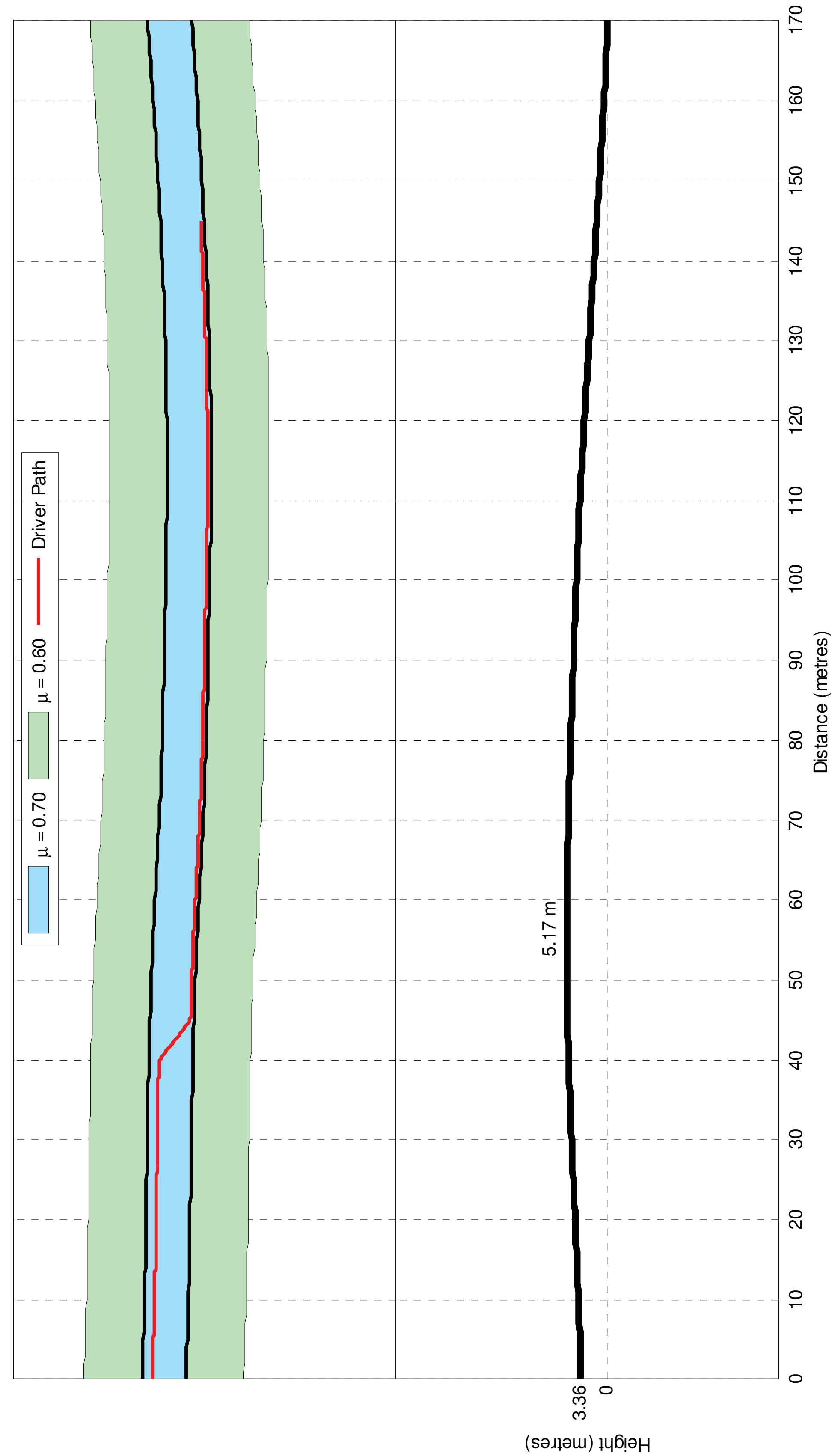

Figure 3: Road section, road profile, surface friction and driver path for the example crash scenario

Results

Simulations were completed for twelve of the twenty crash scenarios. In two of the remaining scenarios, no simulation was necessary as the driver made no apparent attempt to avoid a collision. In these cases, the ESC system would have had no effect on the crash outcome. In another six scenarios, the crash could not be sufficiently reproduced in the simulation to give a conclusive result. This was largely due to the limitations in using the supplied front wheel drive vehicle model. This vehicle model without ESC was particularly stable during cornering and showed little propensity to yaw upon a single steering manoeuvre. The authors had no ability to alter this behaviour since making changes to the model would have interfered with the effectiveness of its ESC system.

An overall summary of the result of ESC intervention on the crash outcome in each of the simulations is given in Table 2.

In ten simulations ESC allowed the vehicle to avoid the collision. In two of the simulations ESC would have reduced the severity of the collision (e.g. vehicle collided with a tree head-on instead of side-on).

In each simulation, the output plots were analysed to determine how the ESC interventions were able to lower the severity of a collision or prevent it altogether. Comparing the timing and magnitude of the interventions at each wheel with the current state of the vehicle shows how the ESC system mitigates the potential loss of control situations.

Each crash scenario is summarised below, along with the how the addition of ESC to the vehicle would have changed the outcome of the scenario and the major ESC interventions that contributed to this change.

Table 2: Result of ESC intervention on crash outcome

Effect	Number
Crash avoidance	10
Crash severity reduction	2
No effect	2
Inconclusive	6
Total	20

Simulation 1 (example scenario)
This crash scenario is described in the Method section under the Simulation Software heading.

In the same scenario, but this time equipped with ESC, the vehicle did not yaw but still collided head on with a road side tree. This however, was the only option to avoid the oncoming truck once the driver decided to steer to the right. A frontal collision with a tree was assumed to be a lower severity collision than a side impact as passive safety devices are able to be exploited (e.g. seatbelts, crumple zones, airbags). The animation of the difference in the trajectories of the vehicle equipped with ESC and the vehicle not equipped with ESC is shown in Figure 4. The red vehicle is equipped with ESC while the blue vehicle is not.

There were two major interventions by the ESC system, which are shown in Figure 5, that brought about the reduction in crash severity. The first occurred as the driver applied the brakes at the top of the crest (see point A). The ESC system limited the brake pressure and prevented the wheels from locking up which allowed the vehicle to remain responsive, steer away from the truck and then straighten. The second major intervention occurred as the driver steered back to the left in order to straighten the vehicle (see point B). Due to the shift in the vehicle's weight from one side to the other, there was a propensity for it to yaw in an anti-clockwise direction. The ESC system counteracted this effect by braking the front right wheel and allowing the vehicle to realign with the road.

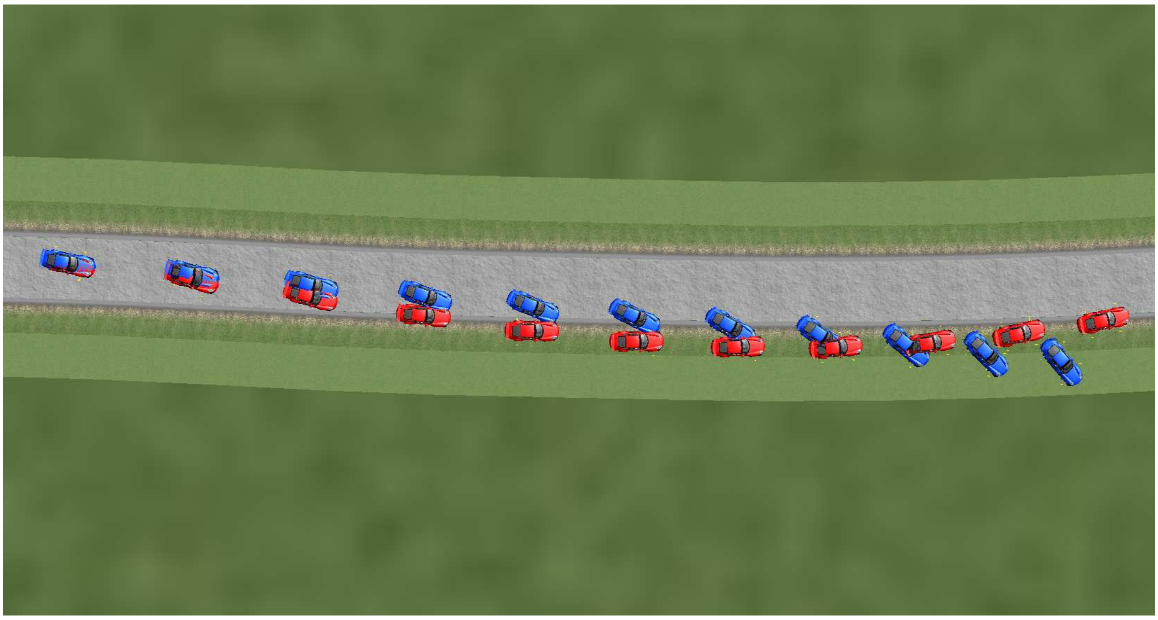

Figure 4: Simulation animation for the example crash scenario showing trajectory of vehicle without ESC equipped (blue) and with ESC equipped (red)

Simulation 2

On a Thursday at approximately 5:00 pm, a car was negotiating a blind right bend at a self reported speed between 60 and 65 km/h, when the driver was confronted with an oncoming vehicle straddling the centre line. The driver veered to the left to avoid a head-on collision causing the left wheels of the vehicle to pass onto the unsealed shoulder. The driver then overcorrected to the right, narrowly missing a guide post upon re-entering the sealed carriageway. The vehicle yawed in a clockwise direction across both lanes of the carriageway and across the far shoulder and the grassed verge. The left rear of the vehicle collided with a tree 2.5 metres from the edge of the carriageway.

In the same scenario, but this time equipped with ESC, the vehicle returned to the road, crossed the centreline a small distance and then returned to the middle of the left lane. The vehicle did not yaw at any stage and remained responsive to the driver's inputs resulting in a collision being avoided. There were two major interventions by the ESC system which enabled the vehicle to avoid the collision. The first occurred as the driver pulled the vehicle to the right in order to return it to the carriageway after avoiding the oncoming vehicle. Due to the shift in the vehicle's weight from one side to the other, there was a propensity for it to become unstable and yaw in a clockwise direction. The ESC system counteracted this effect by braking the front left wheel. The second major intervention occurred as the driver steered the vehicle back to the left in order to realign it with the left lane. Again, there was a propensity for the vehicle to yaw. The ESC system counteracted this by braking the front right wheel.

Simulation 3

On a Wednesday at approximately 2:10 pm, a car was negotiating a sharp left bend at a self reported speed of 40 km/h. It had been raining and the road was wet. As the vehicle came into the apex of the corner, the driver felt the vehicle sliding towards the incorrect side of the carriageway. The driver attempted to steer the vehicle to the left and applied the brakes. The vehicle continued to slide across the centre line on the wet surface, coming into the path of another car, travelling in the opposite direction. The driver of the second car pulled their vehicle onto the left sealed shoulder in an attempt to avoid the collision but was restricted by a guard rail bordering the bend. The front of the first car collided with the right front corner of the second car which was pushed sideways into the guard rail on impact.

In the same scenario, but this time equipped with ESC, the vehicle negotiated the bend successfully without yawing. The vehicle crossed the centreline a small distance but remained stable, returned to the middle of the left lane and continued travelling down the road. There was one major intervention by the ESC system which enabled the vehicle to avoid the collision which occurred as the driver felt the vehicle begin to slide and applied the brakes. The ESC system limited the brake pressure and prevented the wheels from locking up which allowed the vehicle to continue turning through the bend without skidding straight ahead. At the same time the ESC system allowed the braking at the rear left wheel to increase, which enabled the vehicle to turn more sharply through the bend.

Simulation 4
On a Friday at approximately 9:30 pm, a utility was travelling in the right line of a two lane highway at a speed in excess of 100 km/h. The driver was travelling their normal route home after consuming alcohol (BAC of 0.206). The vehicle was seen to suddenly veer left, crossing both lanes of the carriageway with the left wheels travelling onto the unsealed shoulder. The driver overcorrected the vehicle sharply to the right, travelling across both lanes before overcorrecting back to the left. The vehicle yawed in an anticlockwise direction across the carriageway and onto the unsealed left shoulder for the second time. The front right side collided with a pole four metres west of the sealed carriageway.

In the same scenario, but this time equipped with ESC, the vehicle remained stable and returned easily to the middle of the right lane after veering left and then right. There were two major interventions by the ESC system which enabled the vehicle to avoid the collision. The first occurred as the driver steered the vehicle back to the right, after the initial steer to the left. Due to the shift in the vehicle's weight from one side to the other, there was a propensity for it to become unstable and yaw in a clockwise direction. The ESC system counteracted this effect by braking both left side wheels. The second major intervention occurred when the driver steered the vehicle back to the left in order to re-align it with the middle of the right lane. Again, there was a propensity for the vehicle to yaw. The ESC system counteracted this by braking the right side wheels.

Simulation 5
On a Thursday at approximately 3:00 pm, a car was travelling at an estimated speed of 85 km/h, negotiating a left bend with an advisory speed of 55 km/h. While negotiating the bend, the right hand wheels of the vehicle travelled over the double centre lines. The driver overcorrected the vehicle to the left to avoid a collision with an oncoming vehicle. The vehicle yawed in an anticlockwise direction across the left lane and onto the unsealed shoulder where the left front corner of the car clipped a large tree 3 metres from of the carriageway.

In the same scenario, but this time equipped with ESC, the vehicle pulled to the left and travelled slightly onto the left side shoulder before correcting back to the right, into the middle of the left lane and continued down the road. There were two major interventions by the ESC system which enabled the vehicle to avoid the collision. The first occurred when the driver steered the vehicle quickly to the left in order to avoid the oncoming vehicle. Due to the shift in the vehicle's weight from one side to the other, there was a propensity for it to become unstable and yaw in an anti-clockwise direction. The ESC system counteracted this effect by braking both right side wheels. The second major intervention occurred as the driver steered back to the right in order to re-align the vehicle to the middle of the left lane. Again, there was a propensity for the vehicle to yaw. The ESC system counteracted this by braking the left side wheels.

Simulation 6
On a Thursday at approximately 10:30 am, a car was negotiating a slight right bend at an estimated speed of 150 km/h when the left wheels of the vehicle ran onto the left unsealed shoulder. The driver overcorrected to the right, crossing the centre line with the right wheels before overcorrecting to the left; avoiding a collision with an oncoming vehicle. The driver lost control of the car as it travelled back across the left lane and across the unsealed shoulder. The left front corner of the vehicle struck a guide post as it travelled onto the scrub verge. The vehicle collided with the branches of a tree 6 metres from of the carriageway, becoming airborne and rolling over.

In the same scenario, but this time equipped with ESC, the vehicle returned easily to the middle of the left lane after the initial excursion onto the unsealed shoulder. There was one major intervention by the ESC system which enabled the vehicle to avoid the collision which occurred as the driver steered the vehicle to the right after travelling onto the left side shoulder. Due to the shift in the vehicle's weight from one side to the other, there was a propensity for it to become unstable and yaw in a clockwise direction. The ESC system counteracted this effect by braking the front left wheel.

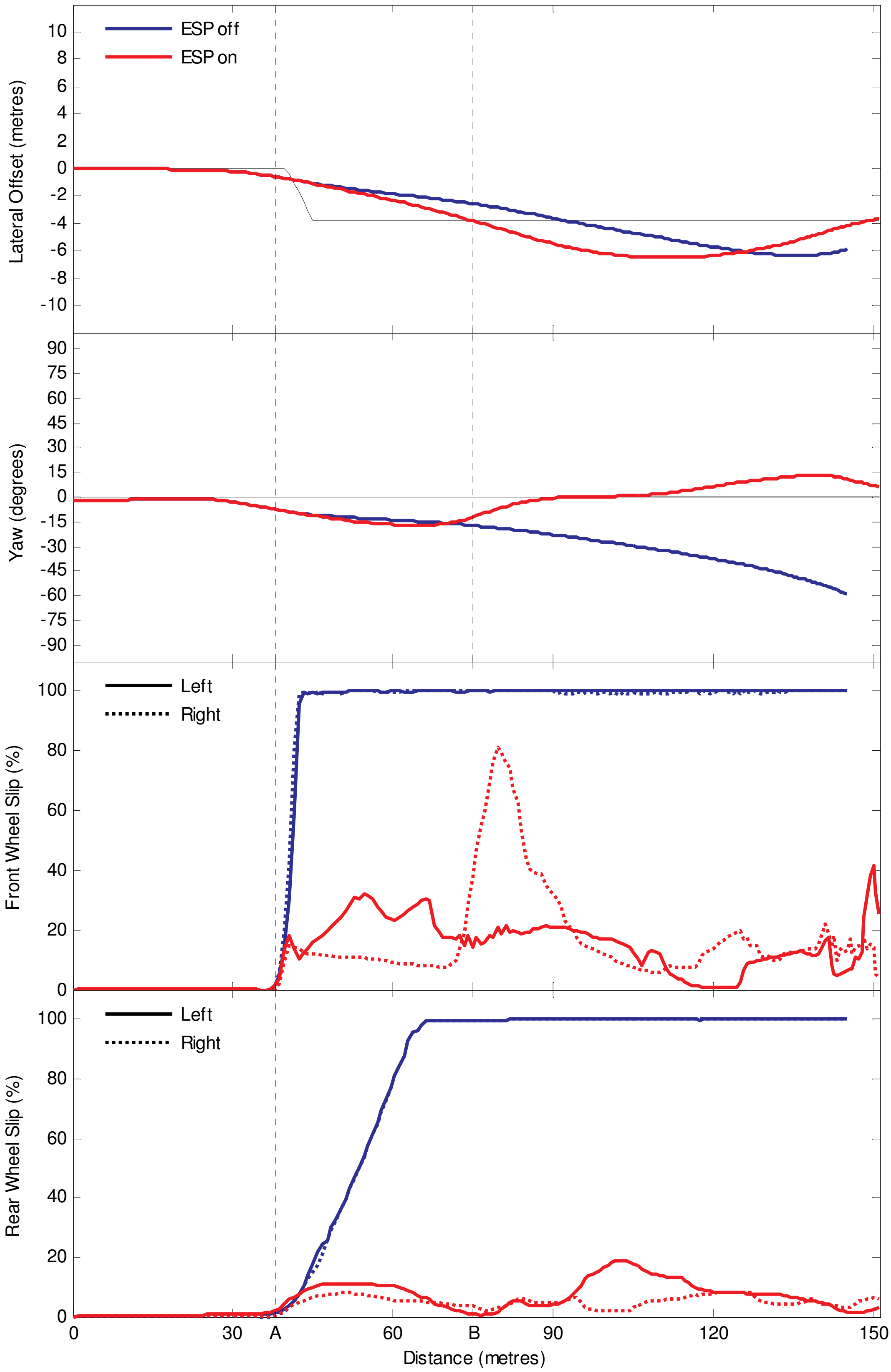

Figure 5: The effect of the ESC interventions on the vehicle's dynamics in the example crash scenario

Simulation 7

On a Friday at approximately 8:25 pm, a van was negotiating a slight right bend at an estimated speed of 115 km/h. It was raining heavily and the road was extremely wet. While negotiating the bend the van began to slide across the wet surface. The driver attempted to regain control of the vehicle but was unsuccessful. The vehicle yawed in a clockwise direction across both lanes of the carriageway and ran onto the right side unsealed shoulder. The left front wheel and door of the vehicle collided with a tree 6 metres from the edge of the carriageway.

In the same scenario, but this time equipped with ESC, the vehicle showed no signs of becoming unstable, crossed over the patch of low friction (which was approximately 45 metres long and encompassed both left and right wheels) without any effect and continued down the road. There were two major interventions by the ESC system which enabled the vehicle to avoid the collision. The first occurred as the vehicle crossed into the patch of low friction. When a vehicle aquaplanes it begins to skid straight ahead and spin in the direction it was steering. Because it was travelling through a slight right bend, the vehicle had a propensity to yaw in a clockwise direction. The ESC system counteracted this by braking both rear wheels; the left more so than the right. The second major intervention occurred as the vehicle responded to the first intervention by starting to spin too much to the left. The ESC system continued to brake the rear wheels but swapped the emphasis from the left side to the right. The vehicle then exited the patch of low friction aligned with the centre of the lane.

Simulation 8

On a Saturday at approximately 7:10 am, a car was travelling along a straight carriageway. The driver reported having consumed a moderate quantity of alcohol the previous night and had less than 4 hours sleep before commencing the journey an hour before the crash. The driver overtook a slower vehicle at an estimated speed of 120 km/h. When returning to the left lane, the driver overcorrected, causing the car to yaw in an anticlockwise direction across the left lane. The vehicle continued onto the left unsealed shoulder, careering into shrubs and trees 10-15 metres from of the road surface and rolled onto its right side.

In the same scenario, but this time equipped with ESC, the vehicle returned to the left lane after initially over shooting the middle of the lane by a small distance and continued travelling down the road. There were two major interventions by the ESC system which enabled the vehicle to avoid the collision. The first occurred as the driver steered the vehicle to the left in order to return it to the left lane. Due to the high speed and the shift in the vehicle's weight from one side to the other, there was a propensity for it to become unstable and yaw in an anti-clockwise direction. The ESC system counteracted this effect by braking both right side wheels. The second major intervention occurred when the driver steered back to the right in order to re-align the vehicle with the middle of the left lane. Again, there was a propensity for the vehicle to yaw. The ESC system counteracted this by braking the front left wheel.

Simulation 9

On a Thursday at approximately 7:35 am, a 4WD was negotiating a sweeping left bend at an estimated speed of 70 km/h. As the 4WD came over a crest the left front wheel ran onto the unsealed left shoulder. The driver overcorrected the 4WD to the right, crossing the centre line before overcorrecting back to the left. The 4WD yawed in an anticlockwise direction across the carriageway and an unsealed driveway. The right rear of the 4WD collided with a large tree located 4 metres from the carriageway.

In the same scenario, but this time equipped with ESC, the vehicle returned to the left lane after initially travelling onto the left shoulder. The vehicle only returned to the lane after crossing the centreline a small distance however. There were two major interventions by the ESC system which enabled the vehicle to avoid the collision. The first occurred as the driver steered the vehicle to the right in order to return it to the road. Due to the shift in the vehicle's weight from one side to the other, there was a propensity for it to become unstable and yaw in a clockwise direction. The ESC system counteracted this effect by braking both right side wheels. The second major intervention occurred when the driver steered back to the left in order to re-align the vehicle with the middle of the left lane. Again, there was a propensity for the vehicle to yaw. The ESC system counteracted this by braking the front right wheel.

Simulation 10

On a Wednesday at approximately 12:30 pm, a car was negotiating a blind left bend at a self reported speed of 70 km/h. As the driver negotiated the bend they were confronted with a truck straddling or driving close to the centre line. The driver of the car veered to the left to avoid a potential collision. Both left wheels of the car travelled onto the unsealed shoulder before the driver overcorrected to the right. The car yawed in a clockwise direction across the carriageway into the opposite lane where the front left corner collided with the front right wheel of the truck.

In the same scenario, but this time equipped with ESC, the vehicle did not yaw and was able to return easily to the middle of the left lane and continue travelling down the road. There were three major interventions by the ESC system which enabled the vehicle to avoid the collision. The first occurred as the driver steered around the bend and then increased the steering to the left in order to avoid the oncoming truck. Due to the shift in the vehicle's weight from one side to the other, there was a propensity for it to become unstable and yaw in an anti-clockwise direction. The ESC system counteracted this effect by braking the front right wheel once as the vehicle came around the bend and then again as the driver increased the steering input to the left. The second major intervention occurred when the driver steered back to the right in order to return the vehicle to the road. Again, there was a propensity for the vehicle to yaw. The ESC system counteracted this by braking both left side wheels. The final major intervention occurred when the driver steered back to the left in order to re-align the vehicle with the middle of the left lane. Once again there was a propensity for the vehicle to yaw and once again ESC counteracted the effect. This time by braking both right side wheels.

Simulation 11

On a Sunday at approximately 8:30 pm, a utility was travelling around a left bend on an unsealed carriageway at a self reported speed of 65-75 km/h. As the utility straightened into a straight section of road, the driver was confronted with oncoming headlights on the left side of the road. The driver of the utility braked and attempted to swerve to the right of the carriageway in an attempt to avoid a collision, skidding 36 metres on the unsealed surface. The utility and oncoming vehicle collided head on in the centre of the carriageway.

In the same scenario, but this time equipped with ESC, the vehicle remained responsive to the drivers steering requests and veered to the right, however a collision between the front left corners of the two vehicles would still have occurred. This type of collision was assumed to be of a lesser severity than a full frontal collision as it would result in a glancing blow and the impact point would be away from the drivers, who are situated on the right side of the vehicles. This point is debatable however as twisting collisions can sometimes be more severe and any left front seat passenger would have been closer to the impact point. There was one major intervention by the ESC system which brought about this reduction in crash severity which occurred as the driver became aware of the oncoming vehicle, applied the brakes and steered to the right. The ESC system limited the brake pressure and prevented the wheels from locking up which allowed the vehicle to respond to the driver's inputs and veer right. At the same time the ESC system allowed the braking at the front right wheel to increase. This counteracted the vehicle's propensity to yaw as its weight shifted suddenly to one side and it pitched forwards due to the braking.

Simulation 12

On a Tuesday at approximately 11:45 am, a station wagon was negotiating a left hand bend through a cutting. There were steep 45 degree embankments on both sides of the carriageway that consisted of deeply embedded rock to a maximum height of 8 metres. The weather conditions were severe (hail and sleet) and the driver was travelling cautiously at a self reported speed of 40-50 km/h. As the station wagon entered the cutting it ran onto black ice on the surface and the driver lost control. The station wagon left the carriageway to the left and mounted the embankment to a height of approximately 2 metres before rolling over back onto the road surface, landing on its roof.

In the same scenario, but this time equipped with ESC, the vehicle showed no signs of becoming unstable, crossed over the patch of low friction (which was approximately 15 metres long and encompassed both left and right wheels) without any effect and continued down the road. There was one major intervention by the ESC system which enabled the vehicle to avoid the collision which occurred as the vehicle crossed into the patch of low friction. When a vehicle enters an area of very low friction, it begins to skid straight ahead and spin in the direction it was steering. Because the vehicle was travelling through a left bend, it had a propensity to yaw in an anti-clockwise direction. The ESC system counteracted this by braking both rear wheels; the right more than the left, until the vehicle exited the patch of low friction.

Discussion

This study looked at the response of an ESC system to a set of rural road crash scenarios using software simulations. Each of the rural road crash scenarios was based on the events of an actual rural road crash, taken from an in-depth crash database. The actual crashes were selected from the database using specific criteria which isolated those that involved exclusively passenger vehicles or derivatives as the primary vehicle and were sensitive to the effects of ESC.

The aim of the study was to determine how ESC systems are able to prevent crashes from occurring or reduce the injury severity of crashes which do occur during real crashes on rural roads. Furthermore, any variation in the way ESC responds to different types of crash was sought.

The twelve completed simulations and their output plots gave detailed examples of how ESC operates to avoid or lower the severity of a collision during a real world scenario. ESC was able to prevent a collision from occurring in ten of the successful simulated scenarios and lower the severity in a further two. No major pattern to the response of ESC to different types of crash was observed.

Two crash scenarios were not simulated due to the lack of avoidance steering from the driver. A further six crash scenarios could not be successfully simulated due to difficulties with the vehicle models.

The method presented above contains a number of limitations along with a series of assumptions. As such, the results should be interpreted with caution. The vehicle models used did not have their associated ESC systems precisely tuned. This may prevent the timing and severity of the simulated ESC interventions from representing exactly the actions of a real ESC system that had been tuned to a real vehicle. Assumptions needed to be made about the friction of the road surface and the intended path of the driver which may not have been accurate. In addition, the driver model used was not designed for the purpose of simulating loss of control incidents. For this reason, a trial and error process was required in order to determine values for the driver model which produced the desired vehicle trajectory in each scenario. The aggregate affect of these limitations and assumptions appears to have biased the simulations to a higher average stability than that of the vehicles in the actual crashes. To overcome this higher stability in this analysis, initial speeds were increased (by no more than 20 km/h) in some simulations to generate instability.

Despite the inaccuracies in the simulations, the results give an indication of the way that an ESC system might react to rural road crash scenarios.

Future Work

Refinements to these simulations are planned with three major focuses. The first is to obtain vehicle models with properly tuned ESC systems. In particular a front wheel drive vehicle model which is able to yaw upon a single steering manoeuvre will be sought. The second focus is to obtain a more appropriate and customisable driver model. This would allow a more realistic steering input and the ability to model driver behaviour that can account for effects of blood alcohol, varying reaction time, and sudden steering motions. The third focus is to use software that allows the stochastic treatment of simulation parameters. This would allow the assumed values in the simulations (friction coefficient, driver path, etc) to be varied as well as highlight the sensitivity of the simulation to assumptions. The effect of these refinements should produce more accurate simulations and allow greater confidence in the results. A future aim will be to look at the effects of ESC on specific LOC scenarios in a probabilistic manner.

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