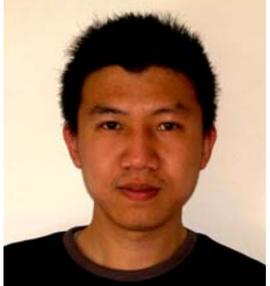


A PARAMETRIC STUDY OF COLLISION AVOIDANCE BETWEEN HEAVY GOODS VEHICLES AND CYCLISTS

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Abstract

Bringing more, possibly longer, articulated vehicles to urban areas for goods delivery provides significant benefits, in terms of lower fuel consumption and more efficient operation. However it may also increase the risk of accidents with vulnerable road users (VRUs) such as pedestrians and cyclists. Simulations of HGV cornering manoeuvres were carried out to examine the vehicle's cut-in and closing speed to the curb. A collision avoidance strategy was proposed and simulated, based on an assumption of constant acceleration for both the HGV and the cyclist. A left-turning manoeuvre was adopted to verify the effectiveness of the proposed collision avoidance strategy. Varying cyclist's speed and its initial distance relative to the HGV, the simulation results were mapped to estimate the proportion of accidents that could be avoided by such a system.

Keywords: Collision Avoidance, Heavy Goods Vehicles, Position Prediction, Cyclist Protection

1. Introduction

1.1 Statistics for HGV-VRU Accidents

Heavy Goods Vehicles (HGVs) play a crucial role in the freight industry, accounting for over 90 per cent of all freight moved by road in the UK (2009). Among all the HGV types, articulated HGVs carry 73 per cent of total tonne kilometres. Introducing more, possibly longer, articulated HGVs into cities for goods delivery would provide considerable benefits, in terms of lower fuel consumption and more efficient operation. However it may also increase the risk of accidents with vulnerable road users (VRUs) such as pedestrians and cyclists, who lack any protection in collision with vehicles.

The Transportation Research Laboratory (TRL) investigated HGV-related accidents in the UK between 2006 and 2008. They reported that on average, HGVs cause 27 deaths and 72 serious injuries to cyclists per year, and 72 deaths and 151 serious casualties to pedestrians (Robinson and Chislett 2010). TRL also specified various impact configurations for accidents leading to fatality or serious injury. They concluded that side-to-side impact makes-up the largest share of both fatalities and serious injuries: 43 per cent and 36 per cent respectively. Figure 1 shows the distribution of the impact configurations for HGV-cyclist accidents that resulted in the death of cyclist.

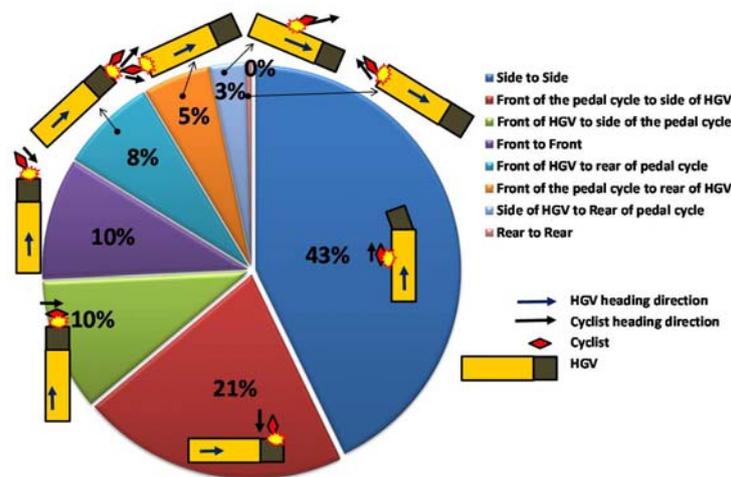


Figure 1 – Impact configuration distribution for HGV-cyclist accidents for fatalities (Robinson and Chislett 2010)

The Royal Society for the Prevention of Accidents (RoSPA) concluded that the collision configurations: ‘HGV turning left across path of cyclist’, ‘HGV and cyclist turning left’ and ‘HGV overtaking cyclist’ contributed to three quarters of cyclist deaths in collisions (2006). Both the statistics from TRL and RoSPA indicate that side-to-side collision is a major factor for HGV-cyclist accidents. Consequently, side-to-side collision will be the focus of the collision avoidance strategy investigated in this paper.

Two physical factors are implicated in side-to-side collisions between HGVs and cyclists. Firstly, large blind spots exist around HGVs, especially during cornering manoeuvres.

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Consequently the driver may not be able to see a cyclist in dangerous proximity. Secondly, HGVs often 'cut the corner' in urban streets, encroaching into the area where cyclists travel.

Many research projects have looked into protecting VRUs from heavy vehicles, mainly through providing the driver with better visibility of blind spots, either improved mirrors or video images, visible-light or infrared. Some technologies have also been introduced for warning HGV drivers about VRUs who stray too close, by harnessing radars, laser scanners or ultrasonic sensors to cover blind spots. To the authors' knowledge, existing technologies only give warning signals based on either detected distance or presence of an object in the detection range, without considering the motion information. Alarming drivers would not suffice to reduce the chance of collisions, as some drivers might fail to respond promptly and correctly in many cases. To make matters worse, sometimes alarms are distracting and annoying from the driver's point of view, and may be ignored or shut down by drivers.

2. Analysis of HGV Cut-In and Closing Speed

To investigate the cut-in introduced by a cornering HGV, a tractor-semitrailer vehicle combination negotiating a specific corner was simulated in MATLAB. The model was based on the Cambridge Vehicle Dynamics Consortium's (CVDC) test vehicle. Physical and dynamical parameters were obtained from Cheng (2009). A linear tyre model with low road-tyre friction coefficient was considered in the simulation.

2.1 Path Design

In the UK, the minimum allowable corner radii for simple junctions are 6m in urban areas and 10m if HGVs are considered (Department for Transport 1995; 2004). In this study the track was modelled as a 90-degree corner with straight lead-in and lead-out sections and inner path radius of 12m. This corner radius is too small for the vehicle to negotiate without substantial cut-in. Consequently, HGV drivers in practice would negotiate a tight corner like this, by steering out into the oncoming traffic lane at the entrance of corner and returning to their own lane near the end, so as to reduce cut-in as much as possible. To model such a path, sinusoidal increments were added to the constant radius, with the middle point of the arc being the outmost point of the curve. The section that connects a straight line and the arc was smoothed to avoid abrupt curvature changes.

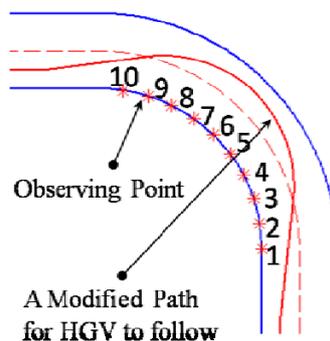


Figure 2 – Left-turning Corner Track in Simulation

2.2 3-DOF Vehicle Model for Articulated HGV

A yaw-sideslip vehicle dynamics model with three DOFs was used to express the tractor's lateral translation motion, yaw motion and trailer's yaw motion. Applying Newton's second law of motion to the model in Figure 3a:

$$F_1 + F_2 - F = m_1 a_1 \quad (1)$$

$$aF_1 - bF_2 + cF = I_1 \ddot{\psi}_1 \quad (2)$$

$$F_3 + F = m_2 a_2 \quad (3)$$

$$-eF_3 + dF = I_2 \ddot{\psi}_2 \quad (4)$$

Of the above four equations, a , b , c , d and e are dimensions shown in Figure 3(left). m_1 and m_2 are the masses for tractor and semitrailer respectively, while I_1 and I_2 are the moments of inertia. a_1 and a_2 indicate lateral acceleration and $\ddot{\psi}_1$ and $\ddot{\psi}_2$ are the yaw accelerations of the two units. F is the force generated at the hitch point between tractor and semitrailer. Defining Γ as the articulation angle between tractor and semitrailer, v the lateral speed of the tractor and u as longitudinal speed of the tractor, acceleration could be expressed as:

$$a_1 = \dot{v} + u\dot{\psi}_1 \quad (5)$$

$$a_2 = a_1 - (c + d)\dot{\psi}_1 - d\ddot{\Gamma} \quad (6)$$

F_1 , F_2 , F_3 represent linear tyre forces, which are assumed to be linear functions of the tyre slip angle with cornering stiffness C_1 , C_2 and C_3 individually. Introducing the steering angle of the tractor unit as δ :

$$F_1 = C_1 \left(\frac{v + a\dot{\psi}_1}{u} - \delta \right) \quad (7)$$

$$F_2 = C_2 \left(\frac{v - b\dot{\psi}_1}{u} \right) \quad (8)$$

$$F_3 = C_3 \left(\frac{v - (c + d + e)\dot{\psi}_1 - (d + e)\dot{\Gamma}}{u} - \Gamma \right) \quad (9)$$

To develop the driver model, i.e., the steering controller, it is useful to set the state variables as position and orientation error with respect to the road (Rajamani 2006), as shown in Figure 3b. The state vector X is then constructed as $[e, \dot{e}, \eta, \dot{\eta}, \Gamma, \dot{\Gamma}]^T$.

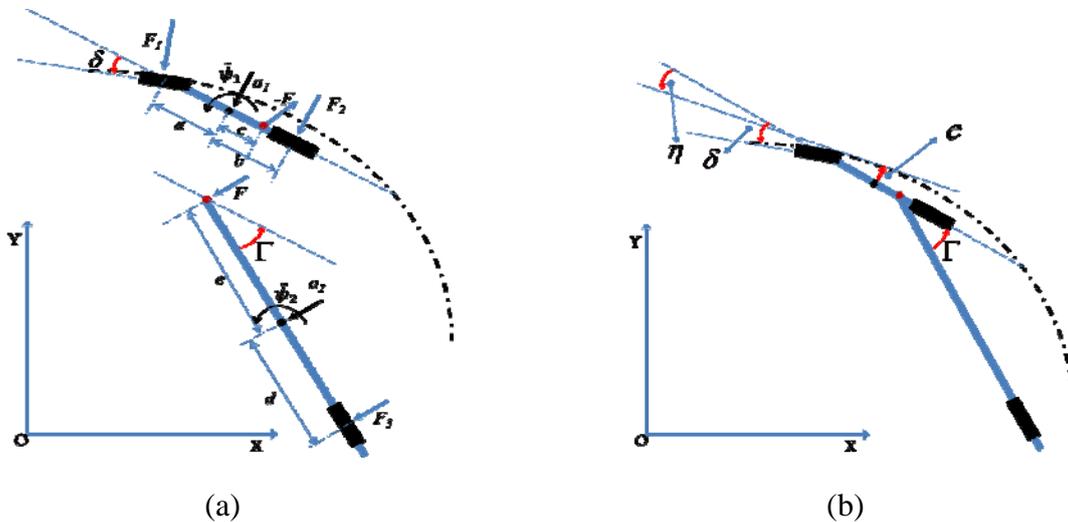


Figure 3 – 3 DOF Vehicle Model for Path Tracking

Where:

e , the distance of the CG of the tractor from the path centre line

η , the orientation error of the tractor with respect to the path centre line, at the tractor CG

e and η are defined as follows (Guldner, Tan et al. 1996),

$$\dot{e} = v + u(\dot{\psi} - \dot{\psi}_{des}) \quad (10)$$

$$\eta = \psi - \psi_{des} \quad (11)$$

$\dot{\psi}_{des}$ is introduced as the rate of change of the desired orientation of the tractor and expressed as: $\dot{\psi}_{des} = u/R$, in which R is the radius of curvature of the path.

Considering equations (5-11), the equations of motion equations (1-4) can be expressed in state-space form as:

$$H\dot{X} = AX + BU + E\dot{\psi}_{des} + F\ddot{\psi}_{des} \quad (12)$$

$$Y = CX + DU \quad (13)$$

Where U is the input vector in the form of $[\delta, 0, 0, 0, 0, 0]^T$; while Y is the output which contained only the path error of the preview point. This is set to 1m in front of the tractor. A PID controller was designed to ensure good dynamic performance to eliminate path tracking error y of the preview point, using a root locus method.

2.3 Cut-in and Closing Speed

‘Cut-in’ is defined as the amount a vehicle encroaches on the inner boundary of the traffic lane. It is quantified by finding the distance to a specific observation point (OP) on the lane boundary from the nearside of the HGV while the vehicle is passing by, as shown in Figure 2. Positive distance indicates that the HGV stays in its own lane and no intrusion to the cycle lane takes place; while a negative value indicates cut-in to the lane boundary.

The Closing Speed (CS) is introduced to quantify how fast the side of HGV approaches a specific OP when passing by. Negative values for closing speed indicate that the side of the HGV is approaching the inner lane boundary while the positive mean that the side of the vehicle is moving away.

A series of equally-spaced OPs were set along the inner boundary (Figure 2). Cut-ins and CSs for the whole corner were calculated. Here OP9 (a point close to the exit of corner) is discussed as an example. As shown in Figure 4, the largest cut-in of the semitrailer reaches -1.6m and the largest closing speed reaches -1.9 m/s. It takes approx. 3 seconds for the HGV to reach maximum cut-in from the lane boundary. Such a swift manoeuvre would likely be too fast for someone at OP9 to react. This might be a cyclist who tries to progress side by side with the vehicle or squeeze through the gap between the vehicle and the curb.

The Cambridge Vehicle Dynamics Consortium (CVDC) has developed an Active Trailer Steering system (ATS), which controls the trailer to follow the path of tractor, thereby reducing cut-ins (Jujnovich 2005). It is of interest to know the extent to which the ATS improves the motion in a tight corner. Running the simulation with ATS included while keeping other settings unchanged, the cut-in and closing speed to the same observing point OP9 are decreased, as shown in Figure 5. Cut-in has a maximum value at -0.6m and CS

maximum reaches -1m/s . Therefore, ATS reduces the problem considerably but does not eliminate it.

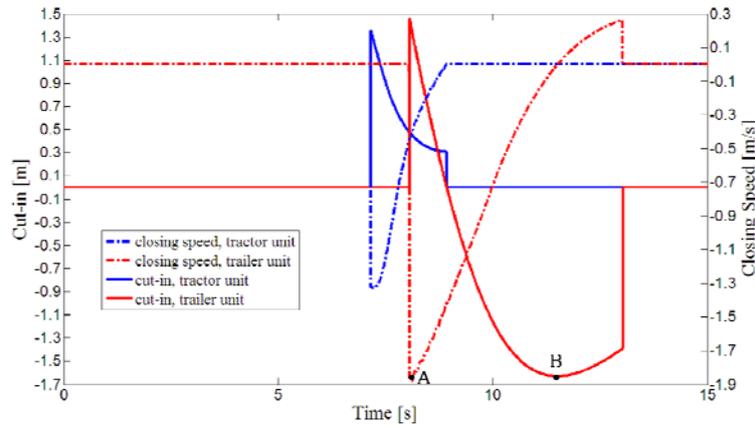


Figure -4 Cut-in and CS for OP 9 for normal artic-HGV travelling at 10km/h. The maximum CS occurs at point A, which corresponds to the front of the trailer passing OP9. The maximum cut-in occurs at Point B.

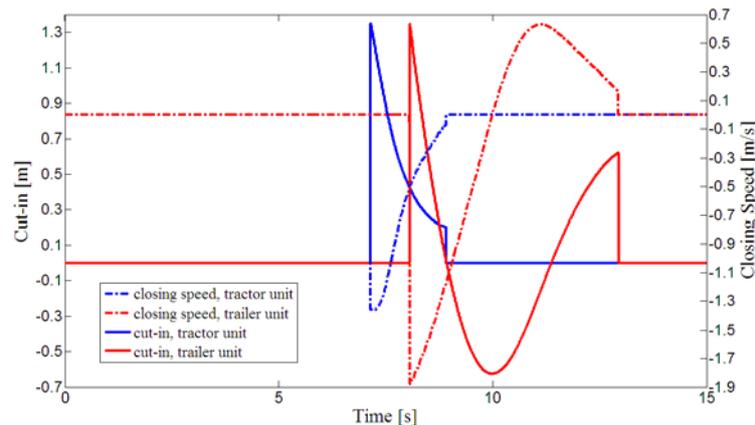


Figure -5 Cut-in and CS for OP 9 for HG V with ATS travelling at 10km/h

3. Collision Avoidance Strategy

It is thought that some collisions between HGVs and cyclists could be prevented by suitable intervention in the motion of the vehicle. Simulations have shown that imminent collisions with cyclists cannot be avoided by even abrupt steering input by the driver of an articulated vehicle. However, under many circumstances, a braking manoeuvre, if introduced in time, could slow down or stop the HG V and let the cyclist escape. The objective of this paper is to minimize the likelihood of accidents between VRUs and HGVs, especially side-to-side collisions, by employing sensors to detect the VRUS and a collision avoidance strategy to actively intervene in the vehicle’s motion when a potential collision is predicted. To predict potential accidents, several things are required: motion information of the HG V, motion information of the cyclist and time-to-avoidance.

3.1 Time-to-Collision and Time-to-Avoidance

Derived from traffic conflict techniques, Time-To-Collision (TTC) has proven to be an effective measure for rating the severity of conflict. It was first defined as ‘the time required for two vehicles to collide if they continue at their present speed and on the same path’ (Hayward 1972). TTC is calculated using equations of motion based on current position, velocity and acceleration. Time-To-Avoidance (TTA) is introduced to determine whether or not to perform warning and mitigation. Miller and Huang introduced a formula based on the assumption of constant deceleration to calculate TTA (2002):

$$TTA = t_r + \frac{\beta v}{\mu g} \quad (14)$$

Where, t_r the response time of driver, μ the estimated road-tyre friction coefficient, g the acceleration of gravity and v the current speed. β stands for a speed reduction factor, ranging between 0 and 1, and 1 represents the situation when a full stop is not needed.

Given TTA and TTC, a warning is issued when:

$$TTA - TTC < \gamma \quad (15)$$

γ is a threshold time used for tuning the timing of effective warning. A greater value of γ leads to more conservative behaviour.

The estimation of timing for a potential accident was approached from a vehicle-based perspective, and the concept of TTA was modified as a measure of time from the start of detection to the moment when the vehicle is brought to full stop under maximum braking torque. Therefore, Equation 3 was modified as:

$$TTA = t_s + \frac{v}{\mu g} \quad (16)$$

Where, t_s represents the system processing time, including the delay time in braking system. Within the time TTA, the HGV would fully stop and a collision could be just avoided; even if a cyclist is still in motion, impact would still be greatly mitigated, particularly because of a significantly reduced danger that the HGV wheels will run over the cyclist. Using this approach it is necessary to predict the future positions for both the HGV and the cyclist in the upcoming TTA seconds so as to determine whether a potential accident would happen or not.

3.2 Constant Acceleration Assumption

To predict future positions, it is assumed that both the HGV and the cyclist maintain their current accelerations, both angular and translational, as a constant value during the TTA time.

By collecting sufficient measurements of the position of the cyclist relative to the HGV, it is possible to estimate the acceleration of the cyclist. The centred difference approximation was adopted to estimate cyclist’s acceleration, with third order error being considered:

$$\ddot{P}_i(t-2h) = \frac{-P_i(t) + 16P_i(t-h) - 30P_i(t-2h) + 16P_i(t-3h) - P_i(t-4h)}{12h^2} + O_i(h^3) \quad (17)$$

Where, h the time step, t the current time. P_i in the form of P_x , P_y , and P_θ , indicating longitudinal position, lateral position and heading angle respectively. Correspondingly, \ddot{P}_i is in the form of \ddot{P}_x , \ddot{P}_y and \ddot{P}_θ , representing acceleration in longitudinal, lateral and yaw directions. The velocity of the cyclist can also be estimated for the same number of data points, but with an error term of higher order.

$$\dot{P}_i(t-2h) = \frac{-P_i(t) + 8P_i(t-h) - 8P_i(t-3h) + P_i(t-4h)}{12h} + O_i(h^4) \quad (18)$$

The future position of the cyclist, $P_i(t+TTA)$ can be integrated from $P_i(t)$ for TTA seconds, using the following numerical integration method:

$$\dot{P}_i(t+h) = \dot{P}_i(t) + h\ddot{P}_i(t) \quad (19)$$

$$P_i(t+h) = P_i(t) + h\dot{P}_i(t) \quad (20)$$

Future positions of the HGV were calculated in the same manner for the same period of the time TTA. The accelerations of the HGV can be measured using simple on-board instrumentation.

3.3 Threshold Distance

As future positions for both cyclist and HGV have been predicted, it is straightforward to compare the future motion envelopes of both parties to decide whether a potential collision is likely to occur. A parameter called ‘threshold distance’ is introduced to tune the decision about when to intervene with the brakes. The HGV brakes are activated when the predicted cyclist’s distance to the vehicle is less than the threshold distance at look-ahead time TTA (Figure 5). Clearly a larger threshold distance causes the vehicle to decelerate sooner to avoid an accident. However, a larger threshold distance will also cause more unnecessary interventions, which are referred as ‘false positives’, especially due to sensor noise or lateral oscillation of the cyclist.

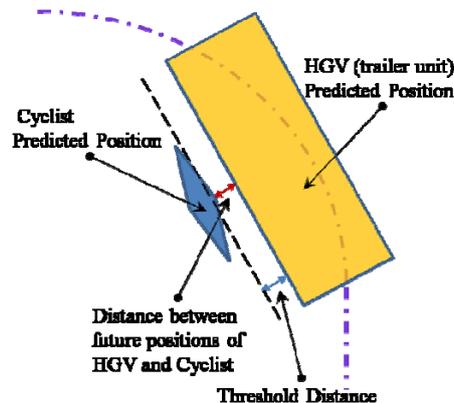


Figure 5 – Illustration of Threshold Distances

4. Simulation Model Setup

4.1 Overall Model

To verify the effectiveness of the aforementioned collision avoidance strategy, a simulation model was built in MATLAB, including a tractor-semitrailer vehicle model, a track with left hand corner, a cyclist model and algorithms for collision avoidance strategy.

As it was only necessary to know the position and the motion envelope for the cyclist, it was modelled simply as a rigid body. A rhombus was employed to represent the envelope for cyclist-bicycle combination, with two elbows of the cyclist plus two ends of the bicycle being the four corners (Figure 5).

4.2 Collision Avoidance Model

The collision avoidance model consisted of algorithms for cyclist detection, cyclist future position prediction, HGV future position prediction and potential accident assessment. To truly reflect vehicle-based detection and prediction behaviour, it was essential to convert the cyclist's relative positions to the HGV at each time step to the HGV's local coordinate system at the latest step when prediction is performed.

4.3 Modelling Sensor System

Numerous researchers have described how to accurately determine vehicle's states, like position, velocity and acceleration, using measurement and state estimates. This paper won't focus on the ego-motion estimation for the HGV, but will deal with how to obtain cyclist's positions by vehicle-based sensors, to provide a good estimate of the acceleration.

Ultrasonic sensors have been in use for parking assist on many types of vehicles. Compared with other sensor systems (RADAR, LIDAR, visual or infrared cameras), ultrasonic sensors are the lowest cost while being capable of providing good detection in the close range of the vehicle. As the objective being to detect cyclists in the vicinity of HGV, ultrasonic sensors provide a viable detection system. Considering the length of the articulated HGV, multiple sensors need to be used for full side coverage.

The geometric characteristics of the Field of View (FOV) were measured for sample sensors and modelled. The aim was to infer the cyclist's position relative to the vehicle, based on the detected distance from sensor. Several factors were considered in building the sensor model, such as FOV of a single sensor, range resolution, spacing and layout of sensors. The proposed layout of sensors is shown in Figure 6.

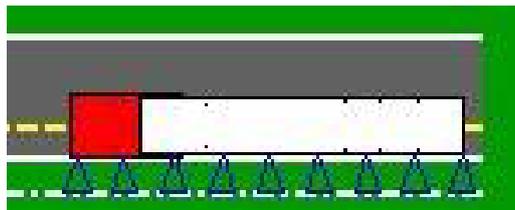


Figure 6 – Exemplary arrangement for sensors on the HGV

An ultrasonic sensor can measure the range of an object, but not its position. As illustrated in Figure 7, different coloured rhombuses represented different cyclist positions and attitudes,

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with same shortest distance to the sensor. Triangulation could be used to eliminate position ambiguity if the same point on the cyclist is detected by two sensors; however, much more sensors would be needed and crosstalk between sensors might be introduced.

Triangulation was not considered so as to maintain a low number of sensors. Knowing the sensor position on vehicle and the detected distance of the object, the position of the cyclist is assumed to be the point on the line perpendicular to the vehicle bodywork, at the detected distance away from vehicle. This assumption does not eliminate position ambiguity; nevertheless, it is the closest guess based on a single measurement. Since a single measurement of position does not suffice to infer cyclist’s orientation, a curve is fitted to the set of position measurements. This curve is differentiated to estimate the heading direction for the cyclist.

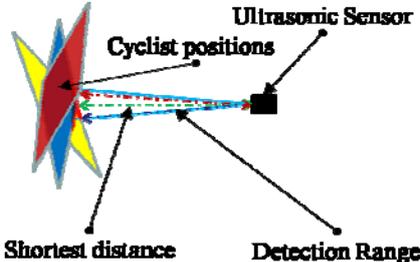


Figure 7 – Position and angle ambiguity in cyclist detection by an ultrasonic sensor

Figure 8 shows a snapshot of the HGV and cyclist in a manoeuvre in which they are both travelling at 10 km/h. The yellow rhombus represents the cyclist with the red blob being the detectable area (elbow and torso). The black wire boxes represented HGV’s future position after 1.5 seconds, while the blue rhombus indicates the cyclist’s future position after the same period of time.

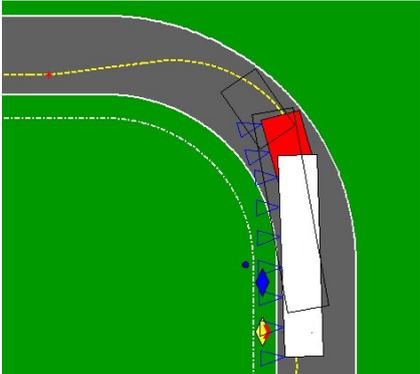


Figure 8 – Cyclist-HGV cornering manoeuvre, with future positions indicated

5. Parametric Study of the Collision Avoidance Strategy

5.1 Simulation Settings

A parametric study was performed for a set of different starting configurations and cyclist speeds, as shown in Figure 9. The HGV speed was fixed at 10km/h, while the start speed for

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cyclist varied from 0 to 20 km/h. The distance from the front end of the cyclist to the rear end of the HGV at the start of the manoeuvre was termed as ‘start distance’, and ranged from -20 to 20m. The threshold distance for the Collision Avoidance System (CAS) was set as 0.15m.

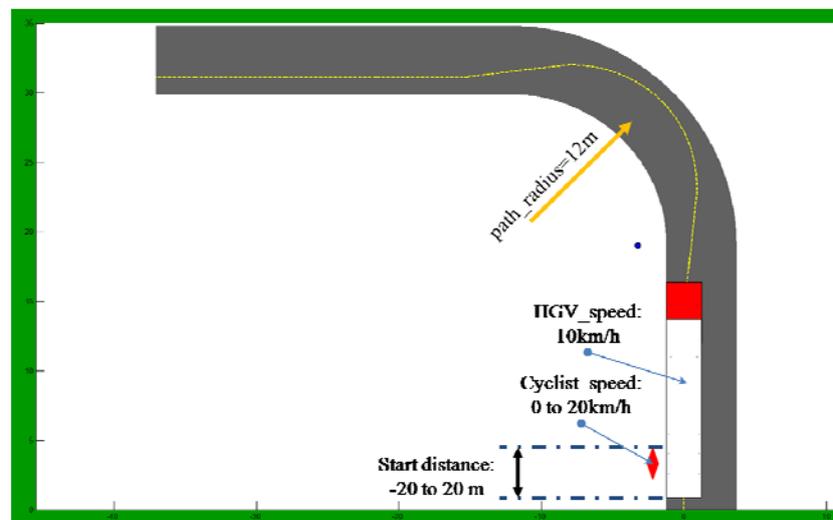


Figure 9 - Illustration of parametric study simulation settings

5.2 Cyclist Behavioural Model

Under some circumstances, if the cyclist travelled at constant speed it would bump into the side or rear end of the HGV in an ‘irrational’ way. Consequently, a simple behavioural model for the cyclist was added to exclude such a scenario. When approaching within 5m of the HGV, the cyclist observes the gap between the HGV and the curb. If the gap is smaller than the outmost width of the cyclist, the cyclist applies the brake.

5.3 Possible Outcomes

A set of simulations was conducted with the CAS turned off. Four different outcomes are possible for the manoeuvre, as illustrated in Figure 10. When the cyclist starts from very far behind the HGV with a relatively higher speed or from close behind the HGV with a lower speed, the cyclist cannot catch the HGV before it exits the corner. Such a scenario is termed as ‘HGV outruns Cyclist’ (Figure 10(a)). This case represents no hazard to cyclist at all. ‘Cyclist outruns HGV’ in Figure 10(b) is also a safe case. When the cyclist starts well ahead of the HGV, or travels at higher speed from just in front, the cyclist exits the corner before the HGV. Figure 10(c) shows the case in which the cyclist reduces speed because the gap between the HGV and the curb is too narrow, so that a collision is avoided. However, many cases end up in collision (Figure 10(d)).

If the CAS is activated, two more outcomes are possible. When a potential accident is predicted by the CAS, brakes on the HGV are triggered and the cyclist escapes (Figure 10(e)). Such a case was referred as ‘Collision avoided due to HGV’s braking’. In some cases, however, a collision may still occur, even though the vehicle brakes. This is the collision in Figure 10(d). ‘False Positive’ (Figure 10(f)) is also possible when a potential accident is predicted but in effect the cyclist was safe.

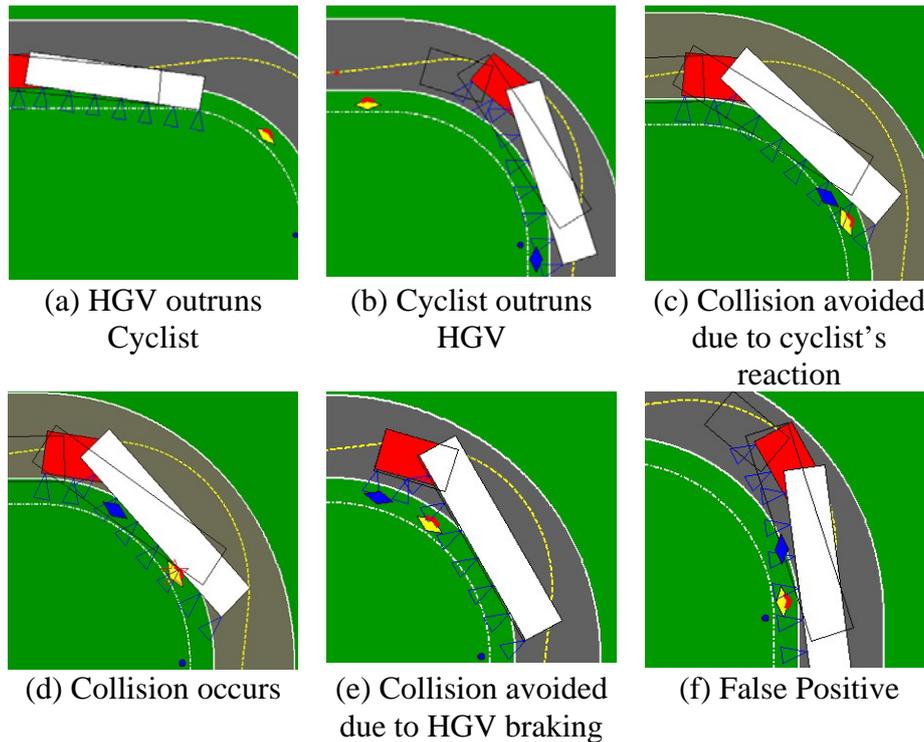


Figure 10 – Various Outcomes

5.4 Result Map Analysis

The aforementioned outcomes are plotted onto a map, with x axis being cyclist's start distance and y axis being cyclist speed. Various shaded areas represent the different outcomes. Cases with and without the intervention in HGV's manoeuvre are compared in Figure 11(a) and 11(b).

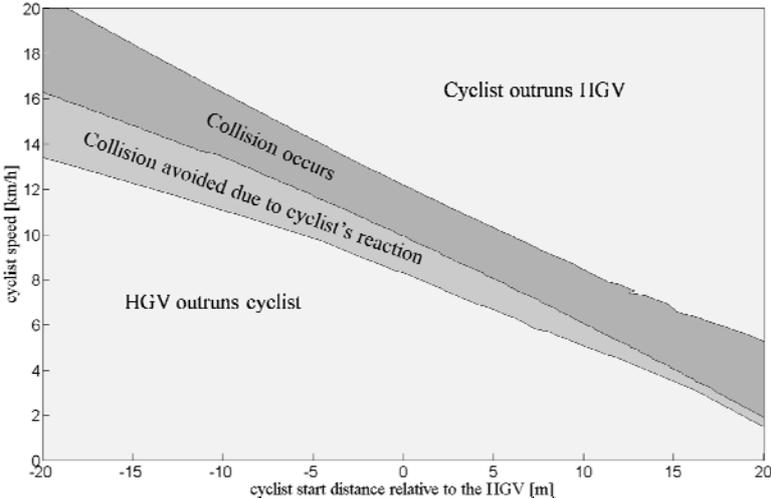
Figure 11(a) shows a diagonal 'stripe' of the parameter space where collisions occur, because the cyclist is in the wrong place during the period of cut-in. This can happen if the cyclist starts the manoeuvre near the front of the vehicle and moves slowly (bottom right of Figure 11(a)) or if the cyclist starts near the rear of the vehicle and moves fast (top left of Figure 11(a)), or for a range of parameter sets in between. Figure 11(a) also shows a wedge of the parameter space where the cyclist's natural collision avoidance behaviour should keep them out of the danger zone.

Figure 11(b) shows that the proposed collision avoidance strategy would prevent a large proportion of the accidents. However, there is a wedge of the parameter space at the high-speed end (top left). Where neither the vehicle, nor the cyclist can prevent the collision. In all of these cases, the cyclist starts behind the HGV and passes through the gap between the truck and the curb, into the danger zone. The shape of the 'cyclist reaction' wedge is slightly different for the two figures because of dynamic interaction between the vehicle's controller and cyclist behaviour.

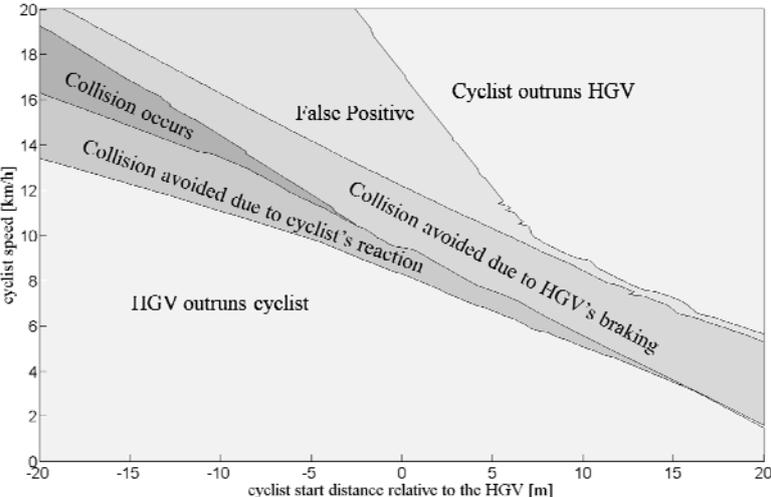
The 'False Positives' near the top of Figure 11(b) generally occur as the cyclist transitions from the straight path in to the curve. In this region the CAS predicts that the cyclist will continue in a straight line and collide with the turning vehicle; whereas, in fact the cyclist enters the curve with a consequent change in acceleration and the collision is avoided. In

these cases the truck would be slowed briefly by the controller and the cyclist would emerge ahead of the vehicle to the great relief of the driver.

Calculating the area for ‘Collision occurs’ cases in the two maps, it can be seen that the collision avoidance system can prevent accidents from happening over 80% of the parameter space.



a: collision avoidance system disabled



b: collision avoidance system enabled

Figure 11 – Maps of outcomes for an HGV speed of 10 km/h

Increasing the threshold distance can improve the performance of the collision avoidance system, but the flipside is that more false positives will be introduced, especially when lateral oscillation of the cyclist is considered. Optimisation of the threshold distance will be investigated at a later stage when the cyclist’s lateral oscillation is better understood.

6. Conclusions

- i. Statistics revealed that side-to-side collisions are the main cause of accidents between HGVs and cyclists.

- ii. When an HGV is traversing a 12m radius corner, the cut-in and corresponding closing speed to the road curb can be as high as 1.6m and 1.9m/s respectively. Active trailer steering reduces these to 0.6m and 1m/s.
- iii. A collision avoidance strategy, aiming at intervening in the motion of the HGV, was proposed. It extrapolates the position of the two vehicles by assuming constant acceleration. The constant acceleration assumption for both the low-speed HGV and the cyclist was verified to work for a whole cornering manoeuvre, apart from entry and exit points on the corner.
- iv. It is thought that the cyclist's position relative to the HGV can be measured with ultrasonic sensors, with sufficient accuracy.
- v. The parametric study showed that the suggested collision avoidance strategy would be effective in preventing accidents from 80% of cases in which an accident could otherwise have occurred.

7. Acknowledgements

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8. References

- Anon (1995). Design Manual for Roads and Bridges. Geometric Design of Major/Minor Priority Junctions. U. Department for Transport. **6**.
- Anon (2004). Design Manual for Roads and Bridges. The Geometric Layout of Signal-Controlled Junctions and Signalised Roundabouts. U. Department for Transport. **6**.
- Anon (2009). Transport Statistics Bulletin Road Freight Statistics 2009, Department for Transport.
- Cheng, C. (2009). Enhancing Safety of Actively-Steered Articulated Vehicles. Department of Engineering. Cambridge, University of Cambridge. **PhD**: 242.
- Guldner, J., H.-S. Tan, et al. (1996). "Analysis of automatic steering control for highway vehicle with look-down lateral reference systems." Vehicle System Dynamics **26**(4): 243-269.
- Hayward, J. C. (1972). Near miss determination through use of a scale of danger: 24-34.
- Jujnovich, B. (2005). Active steering of articulated vehicles. Department of Engineering. Cambridge, University of Cambridge. **Ph.D.**: 294.
- Miller, R. and Q. F. Huang (2002). An adaptive Peer-to-Peer Collision Warning System. IEEE Vehicular Technology Conference.
- Rajamani, R. (2006). Vehicle Dynamics and Control. New York, Springer.
- Robinson, T. L. and W. Chislett (2010). Commercial vehicle safety priorities-ranking of future priorities in the UK. London, Transport Research Laboratory.
- RoSPA (2006). Cyclists and Lorries Fact Sheet, Royal Society for the Prevention of Accidents.