Autonomous Vehicle Simulation Model to Assess Potential Collisions to Reduce Severity of Impacts

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Abstract: Autonomous vehicle safety has received much attention in recent years. Autonomous vehicles will improve road safety by eliminating human errors. However, not all automotive collisions can be avoided. A strategy needs to be developed in the event when an autonomous vehicle encounters an unavoidable collision. Furthermore, the vehicle will need to take responsibility for the safety of its occupants, as well as any other individuals, who may be affected by the vehicle's behaviour.

This paper proposes a control system to assist an autonomous vehicle to make a decision to reduce the risks to occupants potentially involved in highway motorway collisions. Before any decision can be made, the potential collisions need to be assessed for their effects. A quick and numerical method for evaluation of impact of potential collisions was developed. Assessing the Kinetic Energy of the vehicles before and after collisions is proposed as a method to assess the severity of collisions. A simulation model developed calculates the kinetic energy values and recommends an autonomous vehicle the motorway lane to drive into to cause the least severe collision impact. Different scenarios are defined and used to test the simulation model. The results obtained are promising and in line with the decision made by the subject expert.

1 INTRODUCTION

Autonomous vehicles is a major research area in automotive engineering, as research organisations and manufacturers have devoted a significant amount of attention to developing this subject. Models based on Automatic Emergency Braking have been developed and assessed, (Geronimi, S., Abadie, V., and Becker, N., (2016)). Furthermore, there is a significant amount of research which has been dedicated to collision avoidance (Harper, C. D., Hendrickson, C. T., and Samaras, C., (2016)). Lane-change manoeuvres have been assessed in collision avoidance methods (Cesari, G., et al. (2017)). It may not be possible to prevent all collisions, so attention needs to focus on what the vehicle can do when a collision is unavoidable. A new simulation model is developed which uses a simplified non-dynamic vehicle modelling to recommend an appropriate action to take to avoid or mitigate the collision. This approach is developed as an evolution to current Adaptive Cruise Control systems.

The paper is organised as follows. Section 2 discusses existing research in the field of autonomous vehicle collision avoidance and collision prediction simulation. Section 3 describes a considered research problem. Section 4 includes the calculations used by the simulation model while Section 5 discusses the development and implementation of the simulation model. Section 6 defines scenarios used to validate the model and analyses the results obtained. Section 7 concludes the results, and Section 8 highlights the next phase of the research.

2 BACKGROUND

A number of different trajectory planning algorithms have been developed. Anderson et al. (2010) developed an iterative method to evaluate upcoming hazards, and adjust vehicle control to produce the "best-case" vehicle path through the environment. The framework proposed is semi-autonomous and includes a human driver. Ammoun and Nashashibi (2009) developed a method for predicting the severity of collisions at crossroad junctions by calculating a time-to-collision, its duration and a

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percentage of area of the vehicle that intersects with another vehicle's area, using a dynamic model to assess vehicle behaviour in predicting the collision.

However, t a problem considered in this paper requires the severity of the collision impact to be calculated. Ammoun and Nashashibi (2009) discuss the use of a geometric approach to estimating vehicle behaviour. This approach is suited for a situation that needs reliable estimations quickly. Eidehall et al. (2007) developed Emergency Lane Assist (ELA), a safety function assessing dangers of changing lane, and if needed autonomously prevent dangerous manoeuvres. Vehicle position is determined using Cartesian coordinates. An evaluation of surrounding traffic defines points on the road which define areas of danger. A time for the Host Vehicle to reach these points is calculated. In this paper we use a similar methodology to the ELA system of assessing threats with the Cartesian coordinate method, evaluating a lane-change manoeuvre. However, Eidehall et al. presented a system designed to prevent a dangerous situation from occurring due to the manoeuvre. It does not need to prepare for a mitigation action.

Hayashi et al. (2012) developed a collision avoidance system which used both braking and steering, similar to the simulation model presented in this paper. Both systems included geometric trajectory planners and have similar goals. However, the system proposed by Hayashi et al. is limited in its mitigation decision, which instructs the vehicle to apply maximum braking only if it predicts an unavoidable collision. Also, braking applied through the steering manoeuvre is simply the maximum braking. As investigated in this paper, maximum braking through a steering manoeuvre at high speed may not be possible, and could result in a loss of control. The system proposed in this paper includes avoidance in its calculation of mitigation, with consideration of vehicle limitations on braking and maximum yaw rate.

3 RESEARCH PROBLEM

A motorway is considered as a controlled access highway where traffic directions are separated. The speeds are usually at the nation's maximum speed limit which can lead to collisions which can be fatal or result in a serious injury.

In the event of a hazard scenario on the motorway, an autonomous control system is needed to select the best course of action in such a way as to reduce the risks to those involved in potential collisions.

A three-lane motorway is analysed, with the Host Vehicle occupying the middle lane, as presented in Figure 1. It is assumed that the Vehicle Ahead, in the same lane as the Host Vehicle, stops suddenly, and the vehicles in the other two lanes decelerate as a reaction to the hazard in the middle lane. The Host Vehicle needs to evaluate what the best course of action is, whilst considering the potential collisions it may cause with Vehicles Behind itself and a lane change manoeuvre and a potential collision it can cause.

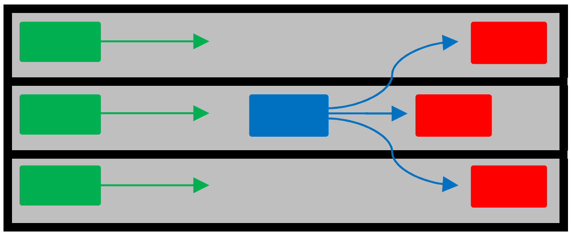

Figure 1: 3 Lane Motorway with Imminent Collision Ahead.

4 SIMULATION MODEL

This paper proposes a simulation model which can quickly provide metrics on which to base a decision for the Host Vehicle to assess which lane of a motorway it should drive into to avoid or mitigate potential collisions. The lane which would result in the least severe collision is selected. The severity of potential collisions is assessed by the following parameters: Impact Velocity, Required Rate of Deceleration to avoid the collisions, Kinetic Energy of collisions, and Velocity after collisions. Each metric has a single numerical value for each collision in each motorway lane, which can be calculated quickly and evaluated with other metrics in order to make a decision on which vehicle the Host Vehicle should collide with.

The Host Vehicle must apply braking to decelerate before a potential collision in order to limit any potential risk to those involved in the collisions. Braking will mitigate even the most severe collisions. For situations where no steering is required, full braking can be applied. For steering manoeuvres, more consideration is needed, as full braking cannot be applied without potentially destabilizing the vehicle.

The simulation model requires information about all vehicles including Current Velocity, Position, Rate of Deceleration and Mass. Rate of Deceleration is a complicated parameter value to obtain due to the speed at which the vehicles can receive and communicate their parameter values, as will be discussed in Section 4.4. Mass is needed for the Kinetic Energy calculations, which would only be available with V2V communication.

The SUVAT kinematic equations of motion used in the simulation model are as follows:

$$v = u + at \tag{1}$$

$$v^2 = u^2 + 2as \tag{2}$$

$$a = \frac{v^2 - u^2}{2s} \tag{3}$$

$$s = \frac{t}{2}(u + v) \tag{4}$$

where u is initial forward velocity, v is final forward velocity, a is acceleration, s is distance, and t is time. Constant braking is used to test the proposed algorithm. Dynamic braking will be considered in a future development.

4.1 Lane Change Trajectory

If a lane-change manoeuvre is required, a trajectory for the Host Vehicle is determined considering lateral displacement which effectively means 1 lane width. A sinusoidal wave is created for the trajectory, because this approach can accomplish a lateral manoeuvre whilst ending with an effective orientation change of 0. Using just the longitudinal distance to complete the manoeuvre, and lateral distance to change lane, x and y coordinates can be extrapolated from the sinusoidal wave. These coordinates can then be used to calculate the Radius of Curvature R parametrically as follows:

$$R = \frac{(x'^2 + y'^2)^{3/2}}{|x'.y'' - y'.x''|} \tag{5}$$

which is then inverted to find Curvature of Radius γ:

$$\gamma = \frac{1}{R} \tag{6}$$

Curvature of Radius is used to calculate a required Yaw Rate $\dot{\psi}$ to complete this steering manoeuvre, as given by Houenou, A. et al. (2013):

$$\dot{\psi} = \gamma . v \tag{7}$$

where v is vehicle speed. Another calculation for Yaw Rate is carried out in the simulation model in order to evaluate if a manoeuvre is possible given the limitations of friction. Blundell and Harty (2004) developed an equation for evaluating the maximum Yaw Rate that can be achieved due to friction.

$$\dot{\psi}_{friction} = \frac{\mu . g}{v} \tag{8}$$

where μ is the Coefficient of Friction (CoF), and g is Acceleration due to Gravity. If the required Yaw Rate exceeds the maximum Yaw Rate limited by friction, a steering manoeuvre cannot proceed.

4.2 Lateral Manoeuvre Braking

As long as Velocity or Acceleration are constant values, the kinematic equations of motion can be applied. An average rate of deceleration is assumed to be a constant value for a braking only manoeuvre, where the Host Vehicle stays in its current lane. In the case of the lane change manoeuvres, different considerations need to be made for the braking.

Firstly, Tyre Saturation which describes limitations of tyre performance laterally and longitudinally is calculated. In essence full braking cannot be applied if full steering is applied simultaneously. The braking for a lateral manoeuvre is calculated as follows (Rajamani, (2011)):

$$a_y = \ddot{y} + v_x\dot{\psi} \tag{9}$$

where a_y is Lateral Acceleration, and v_x is Velocity in x direction only determined as follows:

$$v_x = v\cos(\psi + \beta) \tag{10}$$

$$v_y = v\sin(\psi + \beta) \tag{11}$$

where ψ is the Yaw Angle, and β is Vehicle Sideslip Angle. β can be 0, as all calculations are based on the required Yaw Rate.

Further on, the maximum lateral acceleration $a_{y.max}$ is equal to the maximum longitudinal acceleration $a_{x.max}$, effectively creating a unit circle. As long as the limits of maximum acceleration a_{max} are set, a resultant value can be calculated. With the lateral acceleration calculated in (9), a resultant longitudinal acceleration a_x can be calculated from the unit circle using Pythagorean Theorem.

$$a_x = \sqrt{a_{max}^2 - a_y^2} \tag{12}$$

If a_{max} has unequal a_x and a_y is maximum, a_{max} has an elliptical shape, which is described by

$$\frac{a_x^2}{a_{x.max}} + \frac{a_y^2}{a_{y.max}} = 1 \tag{13}$$

a_x is calculated by solving the following equations:

$$a_y = a_{y.max}\sin(t) \tag{14}$$

$$a_x = a_{x.max}\cos(t) \tag{15}$$

where t is the angle subtended by the vector a_x and a_y.a_x is used in equation (2). However, the distance the Host Vehicle travels is calculated based on v_x as opposed to v. This is longitudinal Velocity, needed for calculating the longitudinal distance. Longitudinal distances of all vehicles are compared when points of impact are determined. In the case of steering manoeuvres a greater overall distance to travel is required than in the case of longitudinal only manoeuvres.

4.3 Vehicles Ahead and Behind

It is assumed that all Vehicles Ahead of the Host Vehicle in the lanes adjacent to the Host Vehicle's lane are closer to the Hazardous Vehicle, and therefore will have started decelerating. This information needs to be communicated to the Host Vehicle in the simulation model. The kinematic equations (1-4) calculate speed and distance arrays for all vehicles in the simulation.

The distances of the Vehicles Ahead have an offset distance-headway. This is the distance each Vehicle Ahead is from the Host Vehicle at the start of the simulation. With these headway distances, a separation distance between the Host Vehicle and Vehicles Ahead is calculated. The point when the separation distance becomes 0, is the point of impact between the two vehicles. This Point of Impact is recorded for all three potential collisions, and is used to determine the speed of the Vehicles Ahead and Host Vehicle, and the position of the Host Vehicle for a safety concern discussed in Section 4.4.

In addition to evaluating the potential three collisions ahead, the Host Vehicle needs to ensure it does not ignore the risk of Vehicles Behind itself from colliding into it. Therefore, calculations are made for three Vehicles Behind the Host Vehicle, but there is an added complexity.

The Vehicles Behind are further away from the initial hazard. Even with V2V, the Host vehicle will receive the information about the hazard and the simulation can begin before the simulation of the Vehicles Behind can start. If the vehicles were able to communicate their rates of deceleration before a decision had been made by the Host Vehicle then the same reducing velocity calculations would be made as for the Vehicles Ahead. However, it is assumed that the closer a vehicle is to the hazard vehicle, the earlier it will receive the necessary information and begin necessary calculations. The velocity and distance calculations need a rate of deceleration, as it cannot be assumed that these Vehicles Behind just proceed at their initial velocity. Therefore, a braking value needs to be assumed.

Inspiration for this calculation is taken from the UK Highway Code (Driving Standards Agency for the Department for Transport (2007)). It states a general guide to vehicle stopping distances. Modern cars will almost certainly achieve greater rates of deceleration, but these stopping distances do give a standard which motor vehicles should be able to match. For vehicles that have not communicated their braking values a braking assumption given by the Highway Code is used. In this way vehicles have a reducing velocity for the Vehicles Behind is calculated. Separation distances between the Host Vehicle and Vehicles Behind are calculated using the same approach as for the Vehicles Ahead.

4.4 Lateral Manoeuvre Safe Lanes

The decision modelling of the lane in which the collision will happen must guarantee that any collision that occurs has a zero-lateral offset. The effect that the lane change manoeuvres might have on a collision has to be accounted for. The point at which the steering manoeuvre is complete, which must occur before the point of impact, has to be determined.

Calculation of velocity and distance is set to the same time frame for each vehicle. This makes it possible to find the distances of all Vehicles Ahead and Behind at the time point when the Host Vehicle completes its lane-change manoeuvre. If any collision occurs before the lane-change manoeuvre is complete, the corresponding lane will be disqualified in the decision-making process.

4.5 Kinetic Energy

In order to determine and compare the kinetic energy before and after a collision for each vehicle, velocities of the vehicles need to be calculated. Conservation of Linear Momentum for Inelastic Collisions P is used to find the velocity of the vehicles which get impacted, where Vehicles Ahead are impacted by the Host Vehicle, and Host Vehicle is impacted by Vehicles Behind as follows:

$$P_j = M_j v_j, \qquad j = 1, 2 \tag{16}$$

$$\sum_j P = M_1 v_1 + M_2 v_2 \tag{17}$$

$$P_{before} = P_{after} \tag{18}$$

$$v_3 = \frac{\sum_j P}{M_1 + M_2} \tag{19}$$

where M_j denotes the vehicle mass, and subscript i denotes the vehicle number.

Whilst energy cannot be lost or destroyed, a comparison of the difference between the Kinetic Energy before the collision, KE_i, and after the collision, KE_f, shows how much of the kinetic energy will have been converted in the impact, which would deform the vehicles:

$$KE_i = \frac{1}{2} M_1 v_1^2 + \frac{1}{2} M_2 v_2^2 \tag{20}$$

$$KE_f = \frac{1}{2}(M_1 + M_2) v_3^2 \tag{21}$$

$$\Delta KE = KE_f - KE_i \tag{22}$$

5 SIMULATION DEVELOPMENT

5.1 Parameters

Motorway simulation is tested for different motorway scenarios. Vehicles Ahead and Behind are modelled using the following parameters:

- Longitudinal Distance from Host Vehicle (m),
- Lateral Distance from Host Vehicle (m),
- Velocity (m/s),
- Mass (kg),
- Rate of Deceleration (m/s^2) for Vehicles Ahead,
- Host Vehicle Velocity (m/s) set to be equal to the velocity of the Vehicle Ahead in the same lane,
- CoF,
- Host Vehicle Following Distance Time (s),
- Host Vehicle Maximum Deceleration $\left(\frac{m}{s^2}\right)$,
- Host Vehicle Maximum Acceleration (m/s^2).

5.2 Assumptions

We made a number of assumptions in the simulation model to perform the algorithmic calculations. These assumptions support the aims of the simulation model, aiding in the reliability and relevance of the outputs.

- All vehicles are assumed to be in the centre of lane, to determine Lateral Distances.
- Motorway is assumed to be straight, no directional control is required.
- All rates of deceleration are assumed to be constant.
- To determine if a lane-change manoeuvre is safe without causing a collision with Vehicles Behind, it is assumed that Vehicles Behind do not brake.
- The closer a vehicle is to another, the sooner it will receive data about that vehicle.
- Highway Code braking distances are satisfactory for the assumption of Vehicles Behind deceleration.

5.3 Motorway Lanes and Traffic

A UK three-lane motorway simulation is carried out, with a Vehicle Ahead and a Vehicle Behind occupying each lane. This means that all vehicles are initially set to a speed of 70miles/h (112.65km/h). The lane width is set to 3.75 metres, which is slightly larger than suggested in Leics.gov.uk (2016), but justifies the use of the simulation model.

5.4 Simulation Flowchart

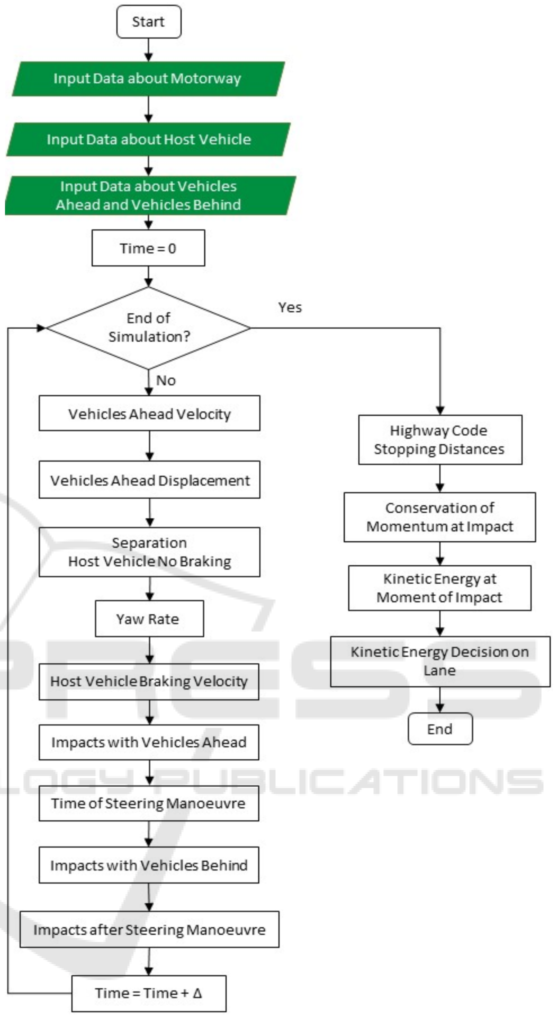

Figure 2: Simulation Model Flowchart.

The simulation model flowchart is given in Figure 2. First vehicle velocities, displacements, and the Host Vehicle's steering trajectory are calculated. The Kinetic Energy is determined based on the Highway Code assumptions of braking used for calculating the deceleration for the Vehicles Behind.

Once the Kinetic Energy values are calculated, a decision on the best lane to drive into is made and presented by the corresponding lane's ID number. The lane is selected following this procedure. Each lane has 2 potential collisions which are independent of one another. The two Kinetic Energy results, KE_i and KE_f, and Kinetic Energy difference, ΔKE, are calculated for both Vehicles Ahead and Vehicles

Behind, for each lane. A decision is based on selecting the maximum of the kinetic energy differences ΔKE obtained for each lane and then selecting the lane with the smallest ΔKE, in order to avoid the largest kinetic energy collisions. In the event that multiple lanes have identical Maximum ΔKE values, a minimum value will be selected from the Minimum ΔKE values of those lanes. If multiple lanes have the same maximum and minimum ΔKE values, the decision is made to progress to the lane with the lower ID, as this refers to the lane with the slower moving traffic.

The simulation is implemented using Matlab 2016a.

6 ANALYSIS OF RESULTS

Fifteen scenarios were defined to validate the simulation model. A benchmark scenario with parameters defined for each lane and both Vehicles Ahead and Behind are given in Table 1.

Table 1: Benchmark Parameters.

Parameter	Value
Mass of Vehicles Ahead	2000kg
Velocity of Vehicles Ahead	70mph
Headway Distance to Vehicles Ahead for Lanes 1 and 3	15m
Braking Values of Vehicles Ahead	$7m/s^2$
Mass of Vehicles Behind	2000kg
Velocity of Vehicles Behind	70mph
Headway Distance of Vehicles Behind	20m
ACC Time Host Vehicle	1.4s

To evaluate how each parameter influences the results, only one parameter was changed in each simulation scenario compared to the benchmark scenario. The results of all 16 simulations are presented in Table 2.

Each lane was assigned an ID number and the lane which was the best option for the Host Vehicle to be in was selected. The decision made in each scenario was in line with the subject expert decision.

In the event of equal values for both the minimum and maximum kinetic energy values for multiple lanes, such as in benchmark scenario 1, the decision was to select the smallest ID lane number, as in practise this should refer to the lane with the slowest moving traffic and closest to the emergency lane.

In scenario 2, ΔKE_Ahead in Lane 1 was higher, due to the difference in velocity at the point of impact. The impact velocity is dependent on the velocity of both the Vehicle Ahead and the Host Vehicle. However, it is not the case that reducing the Headway Distance always results in a higher ΔKE, as demonstrated in scenario 3. Scenario 4 reduced the velocity of the Vehicle Ahead in Lane 1, which means the impact velocity was lower. This difference resulted in a larger ΔKE, and is reciprocated in scenario 5 as a smaller ΔKE resulted from a higher initial velocity. In scenarios 6 and 7, the Rate of Deceleration for the Vehicle Ahead in Lane 3 was reduced, and in both scenarios this resulted in a lower impact velocity. Scenario 7 demonstrated that no collision occurred as there was no braking for the Vehicle Ahead in Lane 3. Scenario 8 increased the initial Headway Distance between the Host Vehicle and the Vehicle Behind in Lane 2 giving greater distance to apply deceleration and reduce the impact velocity. Scenario 9 reduced this distance, and whilst the impact velocity was reduced compared to the benchmark scenario, a lane- change manoeuvre was selected.

The simulation model was able to identify lanes where a lane-change manoeuvre was not feasible, and to disqualify it from the decision (scenarios 10 and 14). Scenario 10 demonstrated that the Velocity, of the Vehicle Behind in Lane 1 resulted in that Lane being disqualified as a lane-change manoeuvre cannot occur safely. Scenarios 11 and 12 demonstrated the effect Mass had on the Kinetic Energy calculations, and an unfavourable "selfish" decision made. This highlights the need for further investigation as the effect of a collision on the other vehicles would introduce a more altruistic decision. Increasing the ACC time in scenario 13 did result in Lanes 1 and 3 having a higher ΔKE_Ahead compared to the benchmark scenario, but not considerably, and lane 1 was selected. Reducing CoF in scenario 14 resulted in both Lanes 1 and 3 being disqualified, causing a lower achievable maximum yaw rate, and the lane-change manoeuvre was not possible. Scenario 15 had the effect of reducing the braking for the lane-change manoeuvre, increasing the ΔKE_Ahead compared to the benchmark scenario. Scenario 16 demonstrated a higher ΔKE_Ahead for Lane 2 when the Deceleration was reduced, but did result in a lower ΔKE_Behind.

It is worth noting that this decision process resulted in an undesirable decision in scenarios 11 and 12. The only parameter changed was the mass of one vehicle. The smallest mass vehicle was selected in both scenarios. Using the conservation of momentum in equations (16) to (19) this resulted in a higher velocity after the impact with the vehicles. This is not altruistic, and the decision made by the Host Vehicle can be considered "selfish".

Table 2: Simulation Results and Decision. All Kinetic Energy Values are in 10^4 scale (J).

Scenario	Parameter Changed	Lane 1 ΔKE		Lane 2 ΔKE		Lane 3 ΔKE		Lanes Closed	Decision
		Ahead	Behind	Ahead	Behind	Ahead	Behind		
1	Benchmark Scenario	1.6653	0	0.7178	5.236	1.6653	0	N/A	Lane 1
2	Headway Ahead Lane 1 - 14m	2.0062	0	0.7178	5.236	1.6653	0	N/A	Lane 3
3	Headway Ahead Lane 1 - 11m	1.5757	0	0.7178	5.236	1.6653	0	N/A	Lane 1
4	Velocity Ahead Lane 1 - 69miles/h	2.1588	0	0.7178	5.236	1.6653	0	N/A	Lane 3
5	Velocity Ahead Lane 1 - 71miles/h	0.5461	0	0.7178	5.236	1.6653	0	N/A	Lane 1
6	Braking Ahead Lane 3 - 6.9m/s^2	1.6653	0	0.7178	5.236	1.1029	0	N/A	Lane 3
7	Braking Ahead Lane 3 - 0m/s^2	1.6653	0	0.7178	5.236	0	0	N/A	Lane 3
8	Headway Behind Lane 2 - 43m	1.6653	0	0.7178	1.4692	1.6653	0	N/A	Lane 2
9	Headway Behind Lane 2 - 15m	1.6653	0	0.7178	4.0182	1.6653	0	N/A	Lane 1
10	Velocity Behind Lane 1 - 74miles/h	1.6653	0.182	0.7178	5.236	1.6653	0	1	Lane 3
11	Mass Ahead Lane 1 - 2100kg	1.706	0	0.7178	5.236	1.6653	0	N/A	Lane 3
12	Mass Ahead Lane 3 - 1500kg	1.6653	0	0.7178	5.236	1.4274	0	N/A	Lane 3
13	ACC Time - 1.5seconds	1.6837	0	0.0268	4.5815	1.6837	0	N/A	Lane 1
14	CoF - 0.6	0	1.0415	0.7178	5.236	0	1.0415	1 and 3	Lane 2
15	Max Overall G - 0.8	4.7837	0	0.7178	5.236	4.7837	0	N/A	Lane 1
16	Host Vehicle Max Braking - 8m/s^2	1.6653	0	6.0729	3.4865	1.6653	0	N/A	Lane 1

7 CONCLUSIONS

A novel simulation model is proposed to inform a decision making process on the outcomes of several potential collisions in a motorway situation. The simulation model can be used when a hazardous vehicle in the same lane as the Host Vehicle comes to a sudden stop. This requires a fast simulation and decision making process. The kinematic equations of motion used simplify the complex task of assessing the impact of a potential collision.

The developed decision process proved to be satisfactory in all but two scenarios. A more altruistic decision would be beneficial, where the effect of the other vehicles and not just the Host Vehicle needs to be considered.

The model is able to simulate the velocity and displacements of 6 motorway vehicles in 3 lanes, as well as the Host Vehicle. From this it can calculate impact velocities which are then used to assess the severity of the potential collisions. The simulation model is also able to determine whether a potential lane-change manoeuvre would result in a collision before the manoeuvre is completed, and therefore disqualifies that lane as being unsafe. The use of kinetic energy is suitable for the decision process, and does give an indication to the severity of a collision, but more in depth metrics can be developed to evaluate the severity of the collision such as deformation and passenger cell acceleration.

8 FUTURE WORK

This paper proposes numerical metrics to be calculated and used to evaluate potential collisions, and to select the best lane the autonomous Host Vehicle should drive into. The simulation model and decision process proposed rely on all required data being available. This would rely heavily on V2V communication. But V2V may not be widely available, although a decision would still need to be made. Without V2V communicating the masses of each vehicle, a kinetic energy based decision is not possible to make. However, the decision can be made considering impact velocities and braking distances, which could be obtained without V2V.

Further development will remove some of the stated assumptions. Dynamic deceleration values to include the effects of resistance forces would improve the accuracy of calculating vehicle velocity.

Collision modelling will provide insight into how automotive collisions can be assessed by the simulation model. The kinetic energy calculations proposed are suitable for the lane-change decision, but could be further developed to introduce focused metrics on assessing collision severity, such as vehicle deformation and passenger cell acceleration.

Both decisions based on kinetic energy and velocities can be considered by applying a Multi Attribute Decision Making (MADM) method. Different MADM methods will be analysed including TOPSIS, Analytical Hierarchy Process (AHP), and Analytical Network Process (ANP). MADM will introduce altruism to the decision process, considering the effects of the collision for the Host Vehicle and the other vehicles in the collision.

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