SIMULATING URBAN TRAFFIC IN TRAINNING SIMULATORS

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Abstract:

This paper describes the state of the art in modelling urban traffic and a traffic model in urban environments for its implementation in simulators, specially in training simulators.

The model simulates simultaneously some hundreds vehicles, pedestrians and traffic lights that can surround the vehicle that the user drives. The model includes different degrees of aggressiveness of simulated drivers and different types of vehicles. In addition, it has been implemented the introduction of anomalous situations in the traffic, as presence of obstacles, abnormal manoeuvres of certain vehicles, etc. Since it is oriented to applications in real time, it is necessary to obtain a balance between the model realism and the calculation speed. It must be considered several subjects as the maximum number of vehicles and pedestrians, the type of vehicle model and its number of degrees of freedom, the complexity of the driver model and the model used for the traffic lights regulation in the city. In order to obtain this balance, it has been adopted solutions like considering the city environment divided in street sections, crossings and sectors that diminish the interaction between the vehicles that form the traffic, using simplified vehicle models that allow a sufficiently realistic representation of the behaviour or to make the traffic lights regulation only in the zone next to the user vehicle. In this way, the model presents an immediate application in simulators for drivers training and driver behaviour analysis.

The implemented model is also of application to studies of traffic control through the adjustment of the traffic lights regulation or to the evaluation of the impact that can have on the traffic the cut or opening of new tracks or streets.

KEY WORDS: traffic simulation, traffic model, driving simulator.

1 Introduction and state of the art.

The first studies about the traffic phenomenon and the first developments of traffic behaviour models were preformed during the 30s of the past century. The first one were those statistical models that lately evolve towards hydraulic models. Dr. Nathan H. Gartner, Dr. Carroll J. Messer and Dr. Ajay K. Rathi in their work “Traffic Flor Theory”, (1999), [14], make a complete compilation of traffic behaviour theories that are accepted by the scientific community.

Traditionally, traffic simulation models have been used to carry out traffic studies in cities and their surroundings in order to design and modify the road layout, as well as to implement a specific traffic light regulation on existing roads.

Recently, the scientific community is putting a lot of effort in understanding the theoretical and experimental basis of the traffic flow physics [4, 12]. To a microscopic scale, the movement of vehicles has a lot of particularities so that each car is controlled by an individual with his own behaviour, together with a set of physical conditions. To a macroscopic scale, the vehicles show a behaviour that may be assimilated to the formation and phase transition phenomenon that appear in many system physics [4, 12, 14]. Nevertheless, the interactive behaviour of the vehicles treated as the movement of particles, seems to be above the laws of the mechanics, and the built up of a solid theory about the traffic flow is showing as a real challenge.

In order to describe to individual dynamics and behaviour of a vehicle a huge set of microscopic models have been presented, all these models differ on the details of the vehicles interaction and the response time, making their equations similar to those of cellular automats [4, 12]. These results have constituted an important progress in the description of the macroscopic behaviour, obtained from the microscopic dynamics. Nevertheless, when the models are compared with reality a lot of discussion still arise, not only in the macroscopic behaviour but in the individual dynamics of the vehicle [3,4].

However, during the last few years, there has been growing interest in driving simulators. This is because they have proved themselves to be a highly useful tool for training and instructing drivers, particularly professionals (bus, truck and emergency drivers, etc.). For this reason, more and more traffic models specifically focussed towards this field are being developed.

According to how the set of vehicles comprising the traffic is analysed, traffic models can be classified in three groups:

- Macroscopic models. These study the phenomenon of traffic from a global point of view, without going into the details of individual vehicle interaction.
- Microscopic models. They study traffic phenomena by taking each individual vehicle as a starting point and analysing how it interacts with the rest, therefore obtaining the global traffic state.
- Mesoscopic models. These bring together the characteristics of both previous types by taking individual vehicle behaviour into account as well as global traffic parameters.

According to the theoretical basis of the model, traffic models may be classified into:

- Hydraulic models. They are based in the study of the traffic taking as starting point an hydraulic simile. This approach may be classified as macroscopic, so that it does not study the behaviour of each vehicle at each moment, but it considers the traffic as a flow (mass of the vehicles) that is moving inside a given ducts (streets, roads, etc).
- Statistical models. These models start from experimental results of the traffic in given areas. In those areas, the traffic conditions are measured, studied and related with the different traffic parameters. In this way, by measuring a set of simple variables, the traffic conditions in different areas may be deduced. Moreover, by means of applying operative research techniques, a set of alternatives may be proposed that improve that traffic conditions in the study area. This type of models may be classified as macroscopic, so that they study the phenomenon from a global point of view.
- Particles models. These models take as starting point the behaviour of each vehicle as precise as possible, and the interactions with the rest of the traffic. The global behaviour of the traffic may then be obtained as a result of the study of the behaviour of the complete set of vehicles. These type of models are obviously microscopic, so that they have as basis the individual behaviour of each vehicle.
- Neuronal models. These models are based in the application of genetic algorithms, cellular automats and neuronal networks. They allow to improve the precision of the model by adjusting the behaviour equations of the vehicles or micro traffic, by means of linear regression.

Generally speaking, although microscopic models are in theory the most detailed and realistic, they present difficulties when compare with reality in the study of traffic at great scale.

In the context of the macroscopic models of traffic, and considering that an equilibrium relation between the velocity and the density of the traffic ($v=ve(\rho)$) Lighthill and Whitham [15] and Richards [17] developed the first traffic flow continuity theory, the LWR theory (Lighthill, Whitham and Richards):

$$\rho t + (\rho ve(\rho))x = 0 \qquad (1)$$

This no linear model is able to explain the wave formation that correspond to the traffic jam formation in the traffic flow. But due to the supposition made in the model that the equilibrium velocity is reached instantaneously, the models fails to describe more complex phenomenon.

Non equilibrium models were developed later [1, 4, 24, 28, 30], based on the continuity equation and another equation that describes the vehicle acceleration. This acceleration behaviour consists on a delay or anticipation of the reach of the static equilibrium condition of the density – velocity, that express the reaction time of the drivers due to changes in the traffic conditions in their surroundings. Once the equilibrium condition is reached, the non equilibrium models are reduced to the equilibrium equation.

The first non equilibrium models were developed considering homogeneous conditions of the road, and their natural evolution were the non equilibrium and non homogeneous models, which allow considering changes in road conditions such as accidents, discontinuities, etc.

Finally, more complex models able to consider every phenomenon associated to the traffic exist. Nevertheless, the high theoretical content is opposed by the high difficulty for the derivation, adjustment and implementation of their equations. Moreover, there exist references in the literature which suggest that a simple continuous model correctly implemented may give the same results as a higher order model. Intuitively, this may be true when the traffic conditions (velocity and density) are measured in long time intervals (5 minutes), and not so when there are measured in short time intervals (30 seconds).

Currently, the most commonly used approach for setting out the equations governing individual vehicle movement is the so-called “social force” model [12, 13, 5. It is based on the fact that at each moment of time t, a driver i, changes the speed v_i of their vehicle depending on traffic conditions and the behaviour or state of neighbouring vehicles.

This is the type of model that has been used in this work while taking a particularly close look at a special case, which is the vehicle following theory [6], [7], [8], [9].

The traffic model being developed is for application in a driving simulator. This requires the behaviour and movements of vehicles surrounding the user-driven vehicle to be represented as realistically as possible, therefore, a purely microscopic type traffic model will be implemented.

The following sections describe the most important elements and sub-models of the model developed.

2 Geometric description of the city.

In order to carry out the traffic simulation, the traffic model needs to have information on the geometry and elements in the traffic flow environment. In this study, the starting point is the definition of the real geometry of a city on a two dimensional CAD map.

When undertaking a geometrical description of a city, two different techniques have been traditionally adhered to. In one technique, the roads are divided into cells, so that vehicle movement is controlled by taking account of the rules governing the occupation or liberation of these cells [5], [17]. The other technique is to take the middle line of the lanes as the paths followed by the vehicles, and which are made up of a series of entities (straight lines and arcs), or of a series of points [18].

This latter path method is the one chosen for undertaking the traffic model. This decision was taken because a definition of paths allows a better control of vehicle movement, particularly if dynamic models are being dealt with, which are the ones implemented in this model.

The geometric information passed to the traffic model is the one relative to lanes, junctions connectivities, signposting, etc.

This information is grouped in different categories:

- Streets. Data describing a section of street between two junctions. Each section of street is considered as a series of points with certain associated information, such as point co-ordinates, average vehicle passing speed, etc.
- Lanes. A list of lanes comprising each section of street. Their direction of flow is specified along with their width and some special features, such as their being a bus lane, for example.
- Nodes. All information concerning junctions and roundabouts in the city is included. For each of these, a list of all possible connectivities between access and exit lanes is included, with their corresponding probability.
- Signals and signs. A list of all the signals and signs existing in the city: traffic lights, stop signs, give way signs and pedestrian crossings. For each sign is specified which lanes are affected by it and its relative position on each lane.

3 Traffic model.

Depending on whether the simulator is to be used for traffic studies or traffic light regulation, or as a driving simulator, the simulation is either carried out over the whole of the city [14], [16], or only over a limited area [1], [2], [5]. In the first case, macroscopic models are used, while in the second case the models are microscopic.

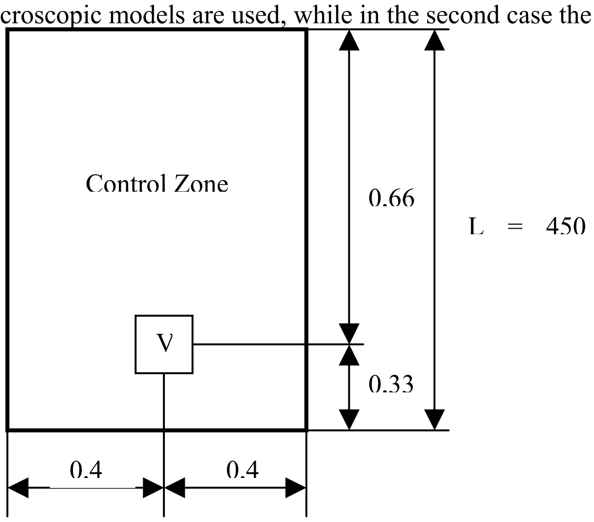

Figure 1. Control zone geometry

3.1 Control zone

This work has developed an implementation for a driving simulator, therefore the latter approach has been chosen. The traffic is calculated and represented only in a zone near to the user vehicle, which is called the control zone. The zone used is rectangular in shape and is centred in front of the vehicle. Its configuration and size can be seen in figure 1.

The traffic model takes account of both vehicle and pedestrian behaviour.

3.2 Segmentation of the city

The mobiles making up the simulation, both vehicle and pedestrian ones, are created and destroyed within the limits of the control zone. They are introduced at the points of intersection between this zone and the access lanes, and are destroyed at the points of intersection between the control zone and the exit lanes. In order to determine these points, the intersection of the control zone with each and every one of the city's lanes, must be calculated. However, given that the total number of lanes in the city is very great, it is not possible to perform this process in every cycle as calculation speed decreases considerably. To solve this, the city is segmented into square shaped sectors of such a size that the control zone cannot be occupying more than four at a time, as can be seen in figure 2. Therefore, when calculating the intersections, it needs only be done for the lanes in the sectors that are in the control zone.

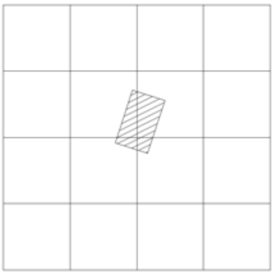

Figure 2. Division of the environment into sectors.

3.3 Traffic conditions

Different traffic densities can be established for each zone of the city. The traffic density for a simulation is expressed as a percentage of the total number of vehicles that can be handled simultaneously by the model. It is also possible to establish an additional independent density for pedestrians, which is expressed as a percentage of the total number of vehicles in the simulation.

The traffic model developed takes account of different types of vehicles and drivers. The following types of vehicles can be distinguished: small cars, medium cars, vans, trucks, buses and motorcycles. As for drivers, three types are distinguished according to how aggressive they are: aggressive, moderate and passive. Aggressiveness determines each driver's way of driving. To be precise, it affects the abruptness of manoeuvres, driving speed, acceptable rates of acceleration, safety distance, etc.

4 Driver model.

The aim of the driver model is to simulate real driver behaviour.

The driver model developed consists basically of a variant of vehicle following theory habitually used in traffic behaviour study [1], [14], [15], [19].

The general behaviour of the traffic model is based on the fact that each vehicle is associated with a lane whose middle line it tries to follow, which is called a path. Each path has a list of the vehicles that can be found on it. In this way, the situation of the surrounding traffic is determined at each moment, which is what conditions the driver's behaviour. The functions of the driver model are as follows:

4.1 Determining the steering angle.

In order to determine what manoeuvres the driver must carry out on the steering wheel, a reference point is established on the path followed by the vehicle at a certain distance ahead, towards which the driver must continually try to steer. This distance is proportional to the speed of the vehicle, thereby avoiding the vehicle taking any tight bends on the inside, and at the same time ensuring stability on large radius bends. The reference distance value is given by:

$$d = \frac{u}{4} + 2$$

A value of 2 metres is added to the proportional speed component to avoid the vehicle becoming unstable at very low speeds and oscillating along the path.

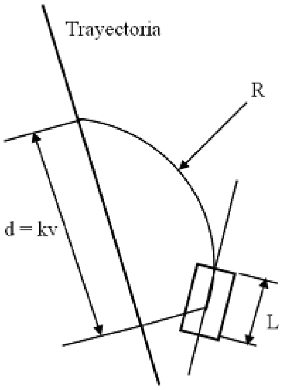

Figure 3. Determining the wheel steering angle.

Figure 3 shows the calculation of the wheel steering angle. Once point P has been determined, the radius of the arc passing through this point, through the centre of the vehicle turning point, and which is a tangent to the longitudinal axis of this point, is calculated. Therefore, by knowing the vehicle's wheelbase, the theoretical wheel steering angle will be:

$$\delta = \arctan\left(\frac{L}{R}\right)$$

The steering wheel angle will be equal to the wheel steering angle multiplied by the steering ratio. As it is the theoretical wheel steering angle that is being dealt with and does not include the slip angle, a regulation is performed on this angle by means of a PD (proportional-differential) type control, as follows:

$$\alpha = c_p \cdot \delta + c_d \cdot \frac{d\delta}{dt}$$

where:

α :	Angle performed on the steering wheel by the driver.
δ :	Theoretical steering angle of the front wheel.
c_p :	Proportional control component coefficient.
c_d :	Differential control component coefficient.

The value of the proportional control component c_p is the steering mechanism ratio. In this case:

$$c_p = 16$$

The differential component coefficient value has been defined as a result of a series of tests with vehicles moving along different types of path at different speeds, thereby obtaining the optimum value of:

$$c_d = 2$$

4.2 Determining manoeuvres on the accelerator and break.

A reference speed is established, which the driver will try to keep to, and which is associated to a reference distance. The set of both determines the manoeuvre to be performed by the driver.

The rate of acceleration is determined by means of a PD control that acts on the difference between the reference speed and that of the vehicle and whose output is converted to accelerator and brake percentages as follows:

$$M = c_p \cdot e + c_d \cdot \frac{de}{dt}$$

where:

M : Accelerator or brake percentage in the vehicle model.

e : Speed error, that is, the difference between the reference speed and the real speed of the vehicle.

c_p : Proportional control component coefficient.

c_d : Differential control component coefficient.

Firstly, we calculate the acceleration that the vehicle must experience in order to reach the required objective speed according to the expression:

$$a = \frac{e \cdot |e|}{2d}$$

where:

e : Speed error, that is, the difference between the reference speed and the real speed of the vehicle.

d : Reference distance.

The proportional coefficient is calculated in such a way that if the acceleration obtained is less than the average acceleration corresponding to the type of driver, the acceleration of the vehicle will be that calculated. To the contrary, if the acceleration obtained is greater, the acceleration of the vehicle will be equal to the average. Should the acceleration obtained be negative, the driver will brake as much as necessary, whatever the value may be, in order to avoid any possible collision. Therefore:

If $a \geq a_m$

$$c_p = \frac{|a_m|}{\mu \cdot g \cdot e} \cdot 100$$

If $a < a_m$

$$c_p = \frac{|e|}{\mu \cdot g \cdot 2d} \cdot 100$$

To determine the differential control component value, successive tests have been made bearing in mind the relation between c_p and c_d, an optimum value of $c_d = 3$ having been obtained.

As may be foreseen, this control presents certain problems when the reference speed and that of the vehicle are very similar and close to zero. When this happens, the reference distance, which is used as a convenient way of changing the objective speed, is also taken into account, thereby eliminating the lack of definition. The pedal or brake percentages are obtained directly using the following expression:

$$M = \frac{a}{\mu} \cdot 100$$

The speed and distance references that are acted on by the PD controls and which determine the driver manoeuvres, are the most restrictive among all the set of references that are active. The different references that can be used are as follows:

- Reference associated with the path. The reference speed is calculated at a point located on the path followed by the vehicle, located at a distance from the latter that is proportional to the square of its speed. This is the reference distance and has the following expression:

  $$d = \frac{u^2}{2a_m} + 2$$

  where:

  u : Vehicle speed.

  a_m : Acceptable acceleration according to driver type.

  A value of 2 metres is added to the component proportional to the square of the speed to avoid the vehicle becoming unstable at speeds close to zero. Figure 4 shows a calculation diagram for this reference. This reference corresponds to that dictated by the street layout, and therefore, by the generic speed limitation.

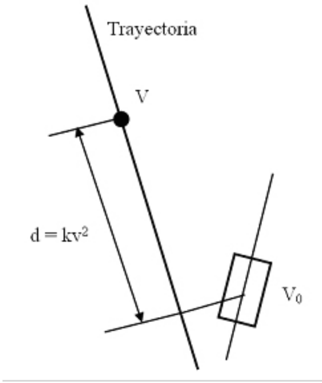

Figure 4. Determining the speed reference.

- Reference associated with signposting and signals. Certain signals and signs impose a reference speed, as in the case of traffic lights, stop signs and give way signs. The associated reference distance coincides with the point where the sign is located or the corresponding stop line.
- Reference associated with vehicle following. The reference speed corresponds to the speed of the preceding vehicle, and the reference distance is located behind this vehicle at a distance that depends on the aggressiveness of the driver, the driving speed and both vehicles' deceleration capacity
- Reference associated with lane change. When a driver changes lanes, they consider two references simultaneously, located respectively in the lane of origin and the destination lane. This is done to make the vehicle adapt to the traffic conditions while partially occupying both lanes.
- Reference associated with a junction. This reference is calculated when there is a chance of the vehicle colliding with another at a junction and has to stop. The reference speed is zero and the reference distance is located a few metres ahead of the point where the collision would take place, depending on the size of both vehicles.

Of all the different references calculated in each situation, the driver takes the one that turns out to be the most restrictive, that is, the one that involves the greatest deceleration or least acceleration of the vehicle.

4.3 Choosing the route.

The driver of the vehicle has no pre-established route associated from when they become part of the simulation, but decides which route to follow each time a junction or roundabout is reached.

The decision making process is random and is based on the probabilities that are associated with each of the possible connectivities that can be chosen by the driver in the lane they are in when they reach the junction.

The decision making occurs when the vehicle is located at a determined distance from the access to the junction. This depends on the vehicle's speed and the driver's degree of aggressiveness. Once this point has been reached, the vehicle enters what is called the junction approach phase. During this phase, the driver carries out no lane change manoeuvres until they leave the junction, thereby maintaining the choice of connectivity.

4.4 Carrying out manoeuvres.

The driver model decides which manoeuvres will be carried out and executes them. The most usual manoeuvres are: acceleration, braking, following a vehicle, lane changes and adapting to road signs.

In order to make a decision, the surrounding traffic conditions are taken into account.

Each vehicle has information associated about the path where it is located, as well as the paths it will take if it is near a junction and has already chosen the corresponding connectivity. In turn, each path possesses information about adjacent paths. Since each and every one of the paths of the scenario contains a list of all the vehicles located on them at a given moment, one particular vehicle can obtain information about all the others around it, and whose behaviour might affect it.

4.4.1 Behaviour in street sections.

When a driver is in a section of street, their behaviour is directly influenced by the vehicle preceding them in the same lane. Each driver has an objective speed established according to the street they are driving along, their degree of aggressiveness, and the type of vehicle being driven. If the lane they are driving along is clear, they will carry on, tending to drive at their objective speed. However, if there are other vehicles ahead moving below their objective speed, the driver will try to change lanes in order to overtake them. To do this, they will check the state of the traffic in the adjacent lanes.

However, firstly, two parameters must be defined which are important for checking the lane change manoeuvre:

- Distance between stopped vehicles.

This is the distance separating the vehicle from the one ahead when it has come to a stop, for example, in a queue at a red light.
The value of this distance is given by:

$$d_{p_i} = \frac{l_i}{2} - 3 \cdot c_{a_i} + 5$$

l_i and c_{a_i} being the length and aggressiveness coefficient of the vehicle behind.

- Following distance.
  This is the minimum safety distance that a driver will want to keep with the preceding vehicle according to their degree of aggressiveness. Vehicle 1 being the rear vehicle, and vehicle 2 the one ahead, this distance is determined by the following expression:

  $$d_{s_1} = d_{p_1} + \frac{l_2}{2} + \frac{\left|a_{m_1}\right| \cdot c_{a_2}}{2} + u_1$$

  where:

  d_{p_1} : Vehicle v1 distance between stopped vehicles.
  l_2 : Length of vehicle v2.
  a_{m_1} : Acceptable acceleration according to degree of aggressiveness.
  c_{a_2} : Aggressiveness coefficient of v2.
  u_1 : Speed of vehicle v1.

  Apart from the distance between stopped vehicles, we have the term $\frac{\left|a_{m_1}\right| \cdot c_{a_2}}{2}$, which considers driver aggressiveness and the term u_1, which is the distance run by vehicle v1 estimating a reaction time for the driver of approximately one second.

According to traffic conditions in the adjacent lanes, two cases may arise:

- The driver changes lanes.
  The driver checks the state of the traffic in his left hand lane, and if there is not any or they decide that this lane is not possible, then they check the right hand lane.

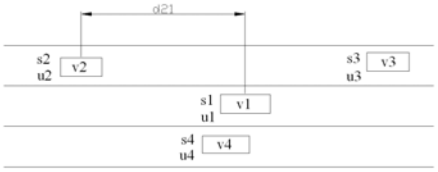

Figure 5. Vehicle v1 trying to change lanes.

Figure 5 shows a situation where the driver of vehicle v1 has to decide if a lane change manoeuvre is possible. The parameters that appear are the following:

s_i : Length travelled from the beginning of the path.
u_i : Vehicle running speed.
$d_{ij} = s_j - s_i$: Difference between the lengths travelled by vehicle v_j and v_i, respectively.

Taking account of these parameters, in order that the vehicle can begin to change lanes, a series of conditions must be met, by both the vehicle ahead, v3, and the rear vehicle, v2.
As for the vehicle ahead, one of the following conditions must be met:

Condition 1: $s_1 + \frac{l_1}{2} + d_{p_1} < s_3 - \frac{l_3}{2}$ y $u_3 > u_1$

Condition 2: $s_3 - s_1 > d_{s_1}$

These conditions imply that the distance between the vehicle attempting to change lanes and another moving ahead must be greater than the distance between stopped vehicle, the speed of the vehicle ahead being greater. If this is not the case, the distance between both must be greater than the following distance separating vehicle v1 from vehicle v2.

As for the rear vehicle, one of the following conditions must also be met:

Condition 1: $s_1 - \frac{l_1}{2} > s_2 + \frac{l_2}{2} + d_{p_2}$ y $u_2 < u_1$

Condition 2: $s_1 - s_2 > d_{s_2}$

These conditions imply that the distance of the vehicle under study from another moving behind it, in the lane parallel to it, must be greater than the distance between stopped vehicles, the speed of the rear vehicle being less than that of the one ahead. If this is not the case, the distance between both must be greater than the rear vehicle following distance.

Meeting these conditions will ensure that the overtaking manoeuvre can be safely carried out, with the vehicles involved having sufficient reaction time.

- The driver is unable to change lanes.

  In this case, the driver will remain in the lane where they are and will adapt their behaviour to following the preceding vehicle, with regard to which, the driver will attempt to keep a distance dependent on their degree of aggressiveness, and the speed and deceleration capacity of both vehicles. However, even though the driver is in this situation, they will continuously try to change lanes.

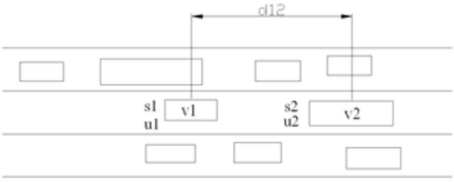

Figure 6. Vehicle v1 in following mode with regard to v2.

Figure 6 shows the situation where a vehicle is in following mode because of being unable to change lanes.

4.4.2 Behaviour at junctions and roundabouts.

At junctions and roundabouts, driver behaviour with regard to the manoeuvres they can perform varies according to what has been said for the street section case.

Firstly, lane changes are not allowed either at the junction access or inside it, which is why the associated references are not taken account of.

Secondly, the vehicle driver acts according to two new additional references obtained from the intersections between the different connectivities making up the junction.

When the vehicle is close to the junction access or inside it, its behaviour is determined by the position it keeps relative to other vehicles located on the junction connectivities. The right of way at an unmarked junction depends on the visibility between both vehicles.

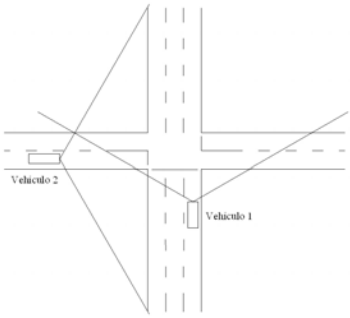

Figure 7. Angle of visibility of two drivers when approaching a junction.

In general, the vehicle having the other in its angle of vision will concede the right of way. For example, in the situation in figure 7, vehicle 2 will stop. If they cannot see each other, the one with the greatest degree of visibility will stop.

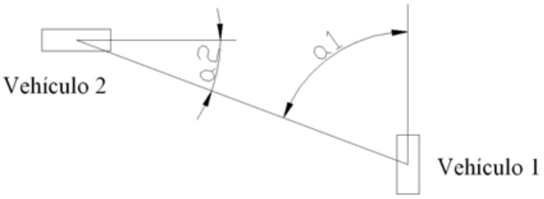

Figure 8. Degree of visibility of two vehicles.

The concept of degree of visibility can be seen in figure 8. It consists in calculating the angle of the straight line joining the geometric centre of the vehicle with that of the other, and calculating the difference between this and the car's angle of orientation. The smaller this difference, the greater will be the driver's degree of visibility.

4.4.3 Behaviour with regard to signposting and signals.

The traffic model takes into account four types of signs and signals: traffic lights, stop and give way signs and pedestrian crossings. Below is a detailed description of how the driver model behaves with regard to each.

- Traffic lights.
  The behaviour of a driver when faced with a traffic light depends on the phase of the light and the driver's degree of aggressiveness.
  If the light is green, the driver's normal behaviour is not affected, no matter what their degree of aggressiveness.
  If the light is red, the driver's behaviour depends on the distance from the lights. Normally, they will stop, except if they are very close and are an aggressive or moderate driver.
  If the light is amber, the behaviour of the vehicle also depends on the distance. In general, the more aggressive the driver, the more they will tend to accelerate to go through the light.
- Stop sign.
  The behaviour of a driver when approaching a stop sign depends basically on their degree of aggressiveness.
  If no other vehicles are present in the immediate vicinity of the junction, an aggressive driver will not usually slow down on approaching the sign. However, a moderate driver will reduce speed, while a passive driver will stop.
  If the possibility of an imminent collision exists, the driver will stop the vehicle whatever their degree of aggressiveness.
  If there are other vehicles in the vicinity of the junction, and there is a possibility of collision, the behaviour of the driver of the controlled vehicle is determined by the relation existing between the arrival times of each of the vehicles at the junction.
- Give way sign.
  The behaviour of a driver approaching a give way sign is determined in a similar way to that for a stop sign, depending basically on their degree of aggressiveness.
  In general, if there are no other vehicles in the immediate vicinity of the junction, an aggressive driver will not slow down. However, a moderate driver will slow down and a passive driver will stop at the white line, as if it were a stop sign.
  If there is a risk of imminent collision, the driver will stop the vehicle whatever their degree of aggressiveness
- Pedestrian crossing.
  If a pedestrian is on a crossing, the driver will stop the vehicle or reduce speed until the pedestrian has finished crossing the road.
  If there is no pedestrian, the behaviour of the driver will depend on their degree of aggressiveness. If it is a passive driver, they will reduce the speed of the vehicle on approaching the crossing. However, if the driver is moderate or aggressive, the speed will be maintained.

5 Vehicle model.

Cinematic vehicle models have usually been used in traffic simulation in order to simplify simulator development and minimise the amount of computation resources needed [1], [19]. However, these models mean less realism in the simulation, since the behaviour of the vehicles is totally pre-determined, so all of them move precisely along the same paths.

This is why we have developed a dynamic model, which permits a more realistic vehicle movement and behaviour. With this model, the vehicles describe different paths according to the specific parameters of the vehicle or driver. For example, different lines of curves can be appreciated as a result of vehicle characteristics. Typical driver error situations can even be simulated, such as skids or spins.

The model used for simulating traffic vehicle behaviour is a model that uses a vehicle with no width and a one wheel axle. The model possesses five degrees of freedom: longitudinal and transversal displacement, yaw angle, front wheel rotation and rear wheel rotation.

Figure 9 shows its geometry as well as the most important variables and parameters.

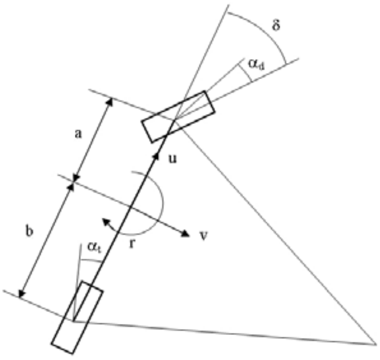

Figure 9. 5 GDL vehicle model.

The inputs to the vehicle model are the three basic manoeuvres that can be performed by the driver: steering wheel turning angle, accelerator pedal percentage and brake pedal percentage.

The equations governing vehicle movement are as follows:

$$\sum F_x = F_{x_{R1}} + F_{x_{R2}} = m \cdot (\dot{u} - v \cdot r) \qquad [1]$$

$$\sum F_y = F_{y_{R1}} + F_{y_{R2}} = m \cdot (\dot{v} + u \cdot r) \qquad [2]$$

$$\sum M_z = F_{y_{R1}} \cdot a + F_{y_{R2}} \cdot b = I_z \cdot \dot{r} \qquad [3]$$

$$\sum M_{R1} = M_{M_{R1}} + M_{F_{R1}} - F_{x_{R1}} \cdot r_{R1} = I_{R1} \cdot \dot{\omega}_{R1} \qquad [4]$$

$$\sum M_{R2} = M_{M_{R2}} + M_{F_{R2}} - F_{x_{R2}} \cdot r_{R2} = I_{R2} \cdot \dot{\omega}_{R2} \qquad [5]$$

Equations [1], [2] and [3] define the movement of the vehicle bodywork, while equations [4] and [5] represent the rotation movement of the front and rear wheels respectively. The meaning of the variables and the parameters is as follows:

m : Total vehicle mass

$F_{x_{Ri}}$: Longitudinal force generated on wheel i

$F_{y_{Ri}}$: Transversal force generated on wheel i

$M_{M_{Ri}}$: Traction torque on wheel i

$M_{F_{Ri}}$: Brake torque on wheel i

r_{Ri} : Wheel i dynamic radius under load

I_{Ri} : Rotation moment of inertia in wheel i

Traction torque on the wheel is calculated from the maximum engine torque, which forms one of the parameters of the vehicle model. Vehicles are modelled as if they had an automatic gear box. For this reason, a hyperbolic function has been established that gives the engine torque value for any vehicle moving speed, as can be seen below:

If $u < 5$:

$$M_{M_{Ri}} = \frac{\mu \cdot m \cdot g \cdot r_{Ri} \cdot 5}{2} \cdot acel$$

if $u \geq 5$:

$$M_{M_{Ri}} = \frac{\mu \cdot m \cdot g \cdot r_{Ri} \cdot 5}{2u} \cdot acel$$

where:

$acel$: Accelerator percentage expressed as a per unit number.
μ: Friction coefficient between tyre and road surface.
u: Vehicle speed.

Vehicle movement differential equations are solved by the trapezoidal rule method, using an integration pass of three thousandths of a second.

The outputs provided by the model are: vehicle centre of gravity co-ordinate X, vehicle centre of gravity co-ordinate Y, vehicle yaw angle and angular velocity of the vehicle's wheels. Since this is a simplified model, it does not provide outputs corresponding to all the degrees of freedom of a rigid body. In order to be able to represent these degrees of freedom (pitch and roll) in a visual display unit, the calculation of these angles has been implemented by using two mass-spring-damper type models uncoupled with the vehicle model, whose configuration is shown in figure 10. The excitations corresponding to these models are the longitudinal and transversal accelerations of the vehicle respectively. Using these models enables the pitch and roll of the vehicle to be represented in an approximate visual form, with a considerably lower development and computational cost.

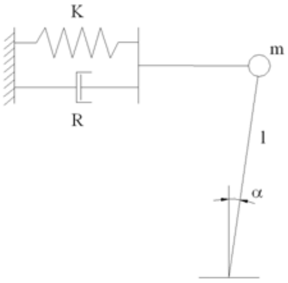

Figure 10. Uncoupled model for pitch and roll.

The equation governing this model's behaviour is:

$$\sum F_x = K \cdot x + R \cdot \dot{x} = m \cdot \ddot{x}$$

where:

$$x = l \cdot sen\alpha$$
$$\dot{x} = l \cdot \cos\alpha$$

$\ddot{x}$: Excitation of the model, which is calculated from the longitudinal or transversal accelerations, depending on whether it is wished to calculate the pitch or roll angles respectively.

For each excitation value, the value of angle α can be obtained, corresponding to pitch or roll.

Determining the parameters l, K and R is done in the following way:

l: Represents the height of the vehicle's pitch or roll center.
K: Represents the vehicle's pitch or roll stiffness. This stiffness is calculated in an approximate manner from the pitch and roll angles adopted by the vehicle when it reaches the maximum acceptable values for the longitudinal and transversal accelerations respectively.
R: Represents the damping for the pitch and roll movements. One fifth of the corresponding stiffness is set as an approximate value.

6 Pedestrian model.

The traffic model not only considers vehicle, but also pedestrian simulation. Since the model has been developed in this particular case for an urban environment, pedestrian simulation is of great importance.

Pedestrians can interact with vehicles in two different ways. Firstly, on pedestrian crossings when they are preparing to cross the road, and secondly, when, on certain occasions, a pedestrian decides to cross the road at an inappropriate place. In order to optimise the computational resources needed, in the first case, pedestrians are only introduced around junctions or roundabouts, since it is there that they are more likely to interact with vehicles. However, the second case is deemed to be a driving incident for training purposes and the pedestrian can cross at any point.

7 Traffic light regulation model.

The algorithm used to carry out traffic light regulation does not simultaneously control the state of all the traffic lights in the city, but only controls those that are in the control zone. The traffic lights are regulated following a junction by junction method.

Firstly, the junctions to be regulated are selected. These junctions are all those in the street where the user vehicle is to be found and which in turn are in the control zone.

The traffic lights deemed to belong to each junction are those located at the end of the junction access lanes, at the beginning of the exit lanes and at the end of the exit lanes. Regulation is applied to the latter so as to have control over the traffic leaving the junction and be able to be prepared for the vehicle to turn in some direction.

The process performed by the control algorithm is as follows:

- Each junction is assigned a main traffic light, with regard to which all the other lights at the junction are regulated. This traffic light is the one located at the end of the street section from which the user vehicle would access the junction.
- There is also one single master traffic light in the simulation which is used to regulate each and every main light at the junctions. This traffic light coincides at every instant with the main traffic light of the first junction ahead of the user vehicle. Its phase depends on the amount of simulation time passed since the beginning of the exercise. When the user vehicle passes the master traffic light a new one is selected, its phase being recalculated depending on its distance from the previous master traffic light and the average speed of the traffic.
- The phases of all the junction main traffic lights depend on the phase of the master traffic light, which in turn depends on their distance from the latter and the average speed of the traffic.
- For every junction, the phases of the traffic lights located at the end of the access streets depend on the main junction light. If they are on the same street, their phase is the same. If this is not so, their phases are opposite.
- The phase of the traffic lights located at the beginning of the exit roads are flashing amber if there is a pedestrian crossing, or green if there is not one.

8 Conclusions.

In this work, a traffic light model for implementation in a driving simulator in an urban environment had to be developed. Therefore, the model needed to be suitable for real-time execution, and in turn, provide a high degree of realism that would favour the user becoming immersed in the environment.

This goal has been achieved, since the model is capable of functioning in real-time using only a percentage of the available computational resources while complying with the requirements for the number of vehicles simulated and control zone size. It has thus been shown that it is possible for a greater number of vehicles in a proportionally greater control zone to be simulated.

This computational speed is due, above all to the roads being assimilated into continuous paths along which the vehicles move and their association using lists, completely unlike models using division in cells or a two dimensional processing of the driving environment.

What is more, the use of simplified dynamic models to simulate vehicle movement is highly realistic without requiring a significant increase in the computational resources needed.

It can also be seen that the use of a purely microscopic model does not affect traffic realism, particularly when dealing with a generic city. Individual driver behaviour and their decision making in the zone nearest to the interactive vehicle can be faithfully reproduced without the need to solve complex traffic flow calculations throughout the entire city.

The same may be said of the traffic light simulation implemented. It can be executed with few resources being consumed and, at the same time, the state of all the traffic lights affecting the traffic simulated in the control zone is provided following a logical sequence.

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