CAR-FOLLOWING MODELS. COMPARISON BETWEEN MODELS USED BY VISSIM AND AIMSUN

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Traffic simulation is a powerful tool used in the analysis of traffic systems. A traffic simulation model consists in several sub-models, each of them simulating specific behavioural aspects. These sub-models include among others the car-following models, which control in the simulation the specific interaction between leader vehicle and follower vehicle. The main groups of models are: Gazis-Herman-Rothery models (GHR) [1], safety distance models (Gipps [2]) and psycho-physical models.

In the last decade, in Romania, the use of simulation tools in order to assess traffic impact increased. The relatively high number of software packages, namely VISSIM, AIMSUN, PARAMICS, MITSIM, TRAFSIM and others, leads to an increase need to compare the traffic simulation models in order to underline the differences between each software approach. This article describes the car-following models used by the most common software packages in Romania, namely VISSIM and AIMSUN. This analysis forms the basis for choosing an appropriate model for practical applications, in order to have a robust and fit-to-purpose simulation.

Keywords: traffic, car-following models, simulation, AIMSUN, VISSIM

1. Introduction

In the past decade, in Romania, the use of software packages for traffic simulation in the analysis and assessments increased significantly. Also, worldwide the practitioners and the researchers increased their efforts to develop new powerful software in accordance to the rapid evolution of the computational power of computers.

In this current background, it is highly important to have a robust description of the car-following models that sit at the heart of traffic simulation as basis for the simulation software, along with a detailed comparison. The main purpose of this article is to show the key features of the car-following models in order to identify their advantages and disadvantages by a thorough examination of various simulation results developed using the same assumptions and same objectives, without pointing to a specific software, but instead offering

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information that might justify either choice depending on the various analysis purposes.

Traffic simulation is an analysis tool efficient and highly valued in present design and reconfiguration activities for various road projects not only on urban level. It also gives the possibility of choosing the optimal option regarding traffic coordination.

This article consists in a synthetic analysis of the theoretical background for microscopic simulation regarding the description of vehicle interactions. Typical applications for traffic simulation are road project where it is necessary to have an assessment of the traffic impact in various situations and also where it is necessary to have an environmental analysis for the impact of different traffic option reorganization. A traffic simulation consists in a series of sub-models that mathematically describe the driver behaviour, such as: speed adjustment, safety distance adjustment, lane change model, car-following model, platoon effects and other various effects.

The commonly known study regarding software comparison is the one written by Brockfeld [3]. The key result of the comparison showed that all the packages that were tested, simulated the traffic in similar way, showing that in average the modelled traffic represents 84% of the observed traffic. The second chapter of the article describes the car-following models for two of the well known software AIMSUN and VISSIM, while the third chapter will illustrate a comparison between the two based on a simulation. The article ends with some conclusions on the results for the case study and future research.

2. Car-following models

A car-following model simulates the behaviour of the follower car driver, which will adapt the speed based on a leader vehicle, placed on the same lane. A vehicle is represented as a follower if it is determined by the vehicle in front to adjust and circulate with a certain speed in order to avoid collision. Usually the follower's actions are described by speed and acceleration, as shown in the Gipps model [2]. The elements of the simulation are presented in the figure 1. The key variables of the car-following model are:

a_n – acceleration of the vehicle n [m/s^2]
x_n – position of the vehicle n, [m]
v_n – speed of the vehicle n, [m/s]
Δx – distance between vehicles, [m]
Δv – speed difference between vehicles, [m/s]
v_n^{prop} – suggested speed for the vehicle n, [m/s]

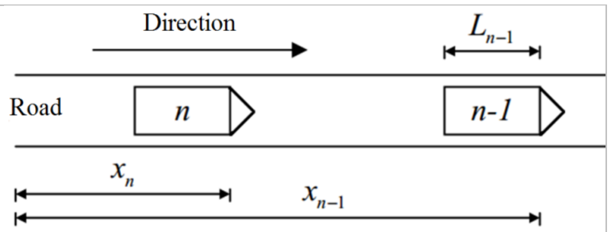

Fig. 1. Vehicle following pattern

L_{n-1} – length of the vehicle n-1, [m] S_{n-1} – effective length of the vehicle n-1, [m] (=L_{n-1}+safety distance) T – reaction time, [s]	

2.1. Classification of the car-following models

2.1.1. General car-following models - Gazis-Herman-Rothery class (GHR)

For the GHR models [1], the relation between follower and leader is described by a stimulus-response function. The main assumption suggests that the follower acceleration is proportional to its speed, to the speed difference between the two vehicles and to the distance between them (Brackstone şi McDonald, [4]). The acceleration of the follower (vehicle n) for a given time t is calculated according to the GHR model as follows:

$$a_n(t) = \alpha \cdot v_n^{\beta}(t) \cdot \frac{v_{n-1}(t-T) - v_n(t-T)}{(x_{n-1}(t-T) - x_n(t-T))^{\gamma}} \quad (1)$$

Where $\alpha > 0$, β and γ are the parameters of the model used to give various weights to the variables of the model, v_{n-1}, x_{n-1} are the speed and position of the leader vehicle.

2.1.2. Safety distance models

The most common model for this class is the Gipps model [2], that consists in an improvement of the original safety distance model developed in the 1959 by Kometani and Sasaki [5]. This class of models assumes that for each 16km/h from the speed, the follower will adopt at least one length of a vehicle as distance to the vehicle in front. In the Gipps model, the vehicles are either circulating with free-flow speed or are circulating in platoon, being influenced by the vehicle in front. The headway between vehicles is considered safe if the successor can react to the action of the vehicle in front without being necessary to overtake it. In this case, the model assumes that if there is no difference in the speed of vehicles, then there is no reaction of the successor.

2.1.3. Psycho-physic models

This class of models was developed by Brackstone şi McDonald [4]. The model assumes that the follower reacts randomly to small variations in the speed of the leader. A psycho-physic model creates a simulation more similar to real decision in traffic. The research in perception psychology showed that a driver has a series of limits for the stimuli that will induce a reaction.

The model is based on two key assumptions:

- For large distance, the driver of the follower car is not influenced by the size of the speed difference
- For small distance, for a specific speed or distance that marks a threshold, the driver of the follower car may not react

The psycho-physic models use various thresholds or psycho-physic action points, that determine changes in the behaviour of the driver of the follower car for various reactions to speed and distance modification between the leader vehicle and the follower only if thresholds are reached. (Leutzbach, [6]). Only after reaching the threshold, the driver considers the change in the behaviour of the leader and will react to modify its kinetic variables (Wiedemann and Reiter [7] or Fritzsche [8]).

2.1.4. Fuzzy-logic models

The Fuzzy-logic models class uses fuzzy sets that represent either decision elements with subjective and vague description, as for example “too close” to the vehicle in front, or logic rules, as for example: if the vehicle is “too close”, then it will decelerate immediately.

This class of models works with the assumption that drivers are able to assume and estimate on the speed of the leader vehicle. Fuzzy-logic data sets can superpose in some situation, so in this case, it is necessary to define a function of probabilistic density to evaluate the way in which the driver observes the variables, as for example the way in which the driver estimates the speed of the leader as high or moderate.

Previous research considered the introduction of fuzzy-logic data sets in the development of GHR models or psycho-physic models. Recent experiments used this type of data sets to model the traffic using different techniques and simulation engines developed by the Northeastern University (Al-Shihabi şi Mourant [9]).

Even though in the past 50 years the development of various models to simulate the car-following behaviour expanded, there still are opportunities for research and innovation in this specific field. Currently, the car-following model used into simulation is chosen by the specialist based on practical criteria of ease in use, fit-to purpose and data availability.

The traffic simulation, and therefore the car-following models are often used to assess the changes in network parameters caused by measures planned to be implemented, as for example: changes in traffic flow volumes, speed or vehicle density for various network sections, delays, queue lengths or travel time between nodes of the network.

2.2. AIMSUN's car-following model

AIMSUN's car-following model [10] is based on the safety distance as key variable, as proposed by Gipps [2].

The main assumption is that vehicle can be free or constrained. In the case of constrained follower vehicle, its speed is adapted in order to keep a safety distance from the leader vehicle. If the follower can react to the actions of the leader without collision, then the distance between them is considered safe. When the vehicles are not constrained, the speed of the vehicles is limited by the desired speed and the maximum desired acceleration. The following variables are used:

a_n^{max} – maximum desired acceleration, [m/s2]

d_n^{max} – maximum desired deceleration n, [m/s2]

$\widehat{d_{n-1}}$ –estimation of maximum desired deceleration by vehicle n-1, [m/s2]

The speed of the vehicle n in the [t,t +T] time interval, is:

$$v_n(t+T) = \min\{v_n^a(t+T), v_n^b(t+T) \qquad (1)$$

The maximum desired speed of the vehicle n, considering the leader vehicle at the moment t is:

$$v_n^b(t+T)=d_n^{max}\cdot T+\sqrt{(d_n^{max}\cdot T)^2-d_n^{max}\cdot\left[2\{x_{n-1}(t)-s_{n-1}-x_n(t)\}-v_n(t)\cdot T-\frac{v_{n-1}^2(t)}{\hat{d}_{n-1}}\right]} \qquad (2)$$

The vehicle length, S_{n-1}, consists in the length of the vehicle, including a safety distance between vehicles. According to AIMSUN manual, there are two ways for the follower to establish the deceleration of the leader, namely first, consists in the assumption that the driver can make an accurate estimation of the deceleration, thus its estimation equals the leaders' deceleration and second, it assumes a calculation step in order to estimate the leaders' deceleration as the average between leaders deceleration and follower deceleration.

2.3. VISSIM's car-following model

VISSIM [11] uses a car-following model based on a psycho-physic model developed by Weideman in 1974 and improved over the years, until its last improvement in 1999. The figure 2 shiws the the driver perception thresholds and the regimes formed by these thresholds.

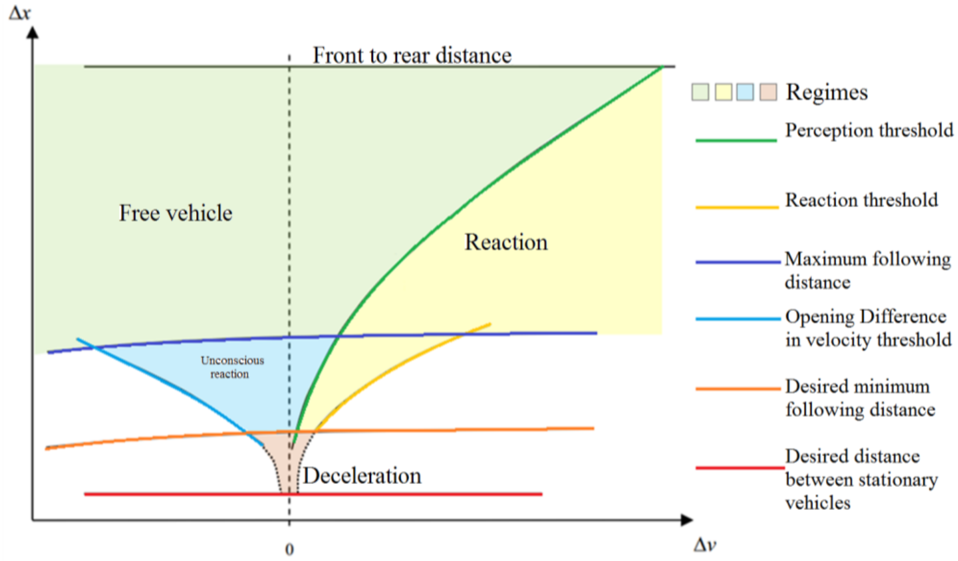

Fig. 2. VISSIM's car following model - thresholds
(Adaptation VISSIM user manual [11])

The above thresholds set the limits for various regimes of the car following model, by using a minimum desired distance threshold, a reaction boundary and a perception threshold.

Table. 1

Threshold of the VISSIM model

Threshold X_s	desired distance between stationary vehicles	$X_s = L_{n-1} + a_1 + S_{1n}a_2$ (3)
Threshold X_{min}	desired minimum following distance	$X_{min} = X_s + b, \quad b = (b_1 + S_{1n}b_2)\sqrt{v}$ (4)
Threshold X_{max}	maximum following distance	$X_{max} = X_s + e\,b$ (5) $e = e_1 + e_2(R - S_{2n})$ (6)
Threshold A	Describes the point from which the driver of the follower is getting closer to a slower vehicle	$A = (\frac{\Delta x - L_{n-1} - X_s}{c})^2$ (7) $c = (c_1 + (S_{1n} + S_{2n})c_2)c_{const}$ (8)

Where:a_1, a_2, , b_2, c_1, c_2, e_1, e_2 are calibration parameters;

S_{1n}, S_{2n} - are randomised parameters that simulate the behaviour of the driver of the follower vehicle n.

R is a random number generated based on a normal distribution;

As observed in the Fig. 2, these thresholds define 4 regimes for a vehicle, namely: free driving regime, approaching regime, deceleration following regime, emergency regime; each regime controls the acceleration of the follower in order to avoid collision.

3. Experiments simulation for the comparison of car-following models

The experiment consists in loading onto a a section of road with a single lane, a leader vehicle and a follower vehicle, traveling with an initial speed set at 60km/h. The follower was given a front to rear distance of 25m. The follower has no speed restrictions, but it will need to adapt its speed relatively to the vehicle in front, which will pass through a speed rectrion area (to 30km/h), considered after 400 m from the begining of the road section. The restriction area is considered to have a length of 300m. The assumption of the model is shown schematically in Figure 3. The lane changing model, the longitudinal vehicle motion model and other behavioural driver and vehicle models were used based on the default parametres, considering the specific interest on the changes in the car following models used.

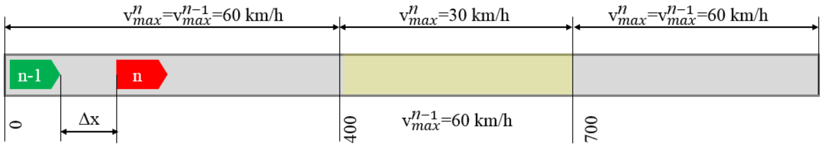

Fig.. 3. Experiment assumption (source: authors)

The results of the simulation that models the analysed situation refers to the following variables, namely speed, acceleration and distance between the two vehicles. The figure 4 presents the results obtained for the simulation undertaken using AIMSUN.

Following the simulation using AIMSUN, the desired distance between the two vehicles for the desired speed of 60 km/h is 15m and the follower adapts the speed and acceleration to obtain that distance. The desired distance for the initial speed of 60 km/h is reached in 20 seconds. Also, the leader changes its behaviour to adapt the speed to the proposed restriction of 30km/h, by deciding on a series of successive decelerations. The follower changes its speed too as a result of distance variation, but in its case a delay will occur. The delay is given by the reaction time considered, but once the speed is again stable, the distance between vehicles is reached again a constant of 15m. After passing the speed restriction area, the leader accelerates to reach the desired speed of 60 km/h and the follower has the same pattern, showing symmetry between the following process for acceleration and deceleration.

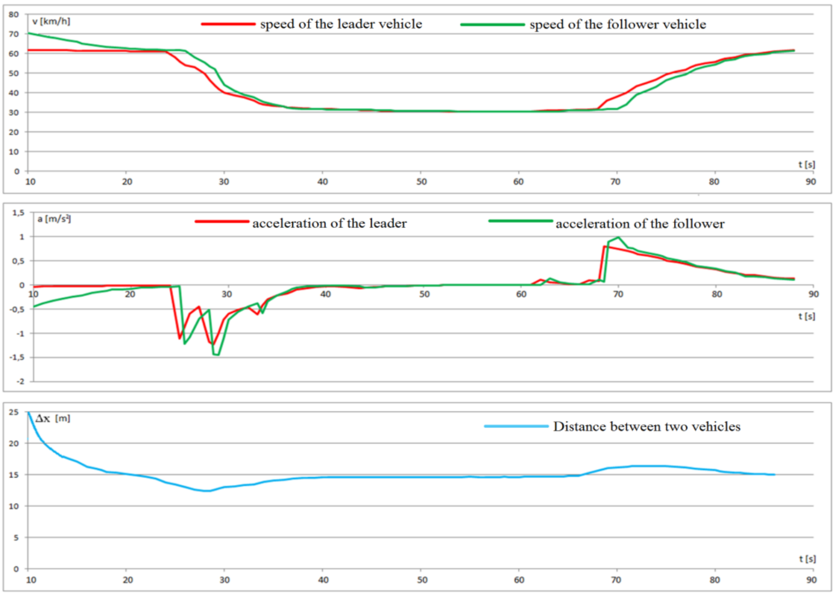

Fig. 4. Speed, acceleration, distance for the simulated situation using AIMSUN

The figure 5 presents the results of the same variables obtained from the simulation using VISSIM (that works with a psycho-physic model).

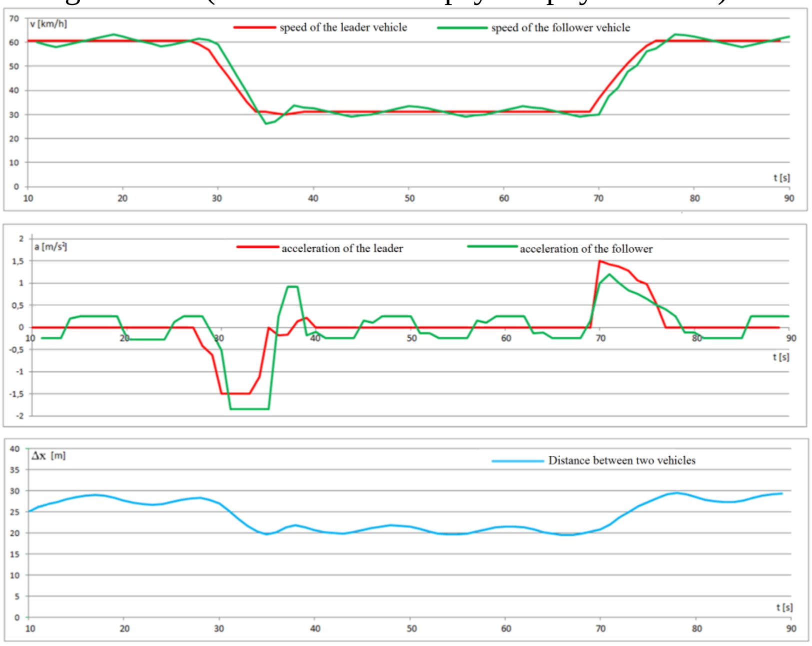

Fig 5. Speed, acceleration, distance for the simulated situation using VISSIM

The desired distance between the two vehicles for the desired speed of 60 km/h is 27m. Once the follower reaches the stability threshold for the speed difference a model of acceleration intervenes in order to simulate the real behaviour of the driver. This acceleration model gives to the follower vehicle a series of deceleration followed by oscillating acceleration with the same size, which will determine a realistic pattern of the driver's behaviour. At the entrance in the restriction area, the leader uses its entire deceleration capacity to adapt its speed to the newly imposed speed limit of 30 km/h, while the follower enters the emergency driving regime to adapt. In this case, the desired distance is 22m.

Comparing the two software programs, it is observed that VISSIM models an inexact throttle control by applying a small acceleration rate to the follower at each simulation step, with an important side effect of switching driving regime in the case of the follower even though the leader is driving at constant speed. This approach makes the simulated driving course of events more close to observed traffic [6].

The effect on the kinetic parameters of the follower as result of the parameters used in the Weidemann model is underlined by a apparent instability of the acceleration curve that has also an effect on the speed curve and implicitly on the desired distance between vehicles. The reaction of the follower is similar also for the entrance process, and for the exit process into/from the speed restriction area. Without taking inot consideration the oscillation of the acceleration, it is observed that the follower reacts to the leader behaviour, with a delay given by the reaction time of each other.

The Weidemann model induces an oscillation to the acceleration during the approaching regime, thus generating an apparent instability of the acceleration curve. This oscillation has a secondary effect that consists in the fact that the follower varies its speed even if the leader travels with a constant speed, which leads to atypical behaviour. As an example, as shown in figure 5, for t=27s, the leader decelerates while the follower still has an oscillating positive acceleration, even though the follower vehicle should have entered the emergency regime. But the model detects the leader's behaviour and by consequence even though the oscillation in the approach regime is not complete, the follower will enter the emergency regime.

The model used by AIMSUN uses as the reaction time the length of the simulation step; in this case the follower reacts to the leader's changes in the behaviour in the next step of the simulation. The same reaction time is given to all the vehicles in the system. On the other hand, VISSIM does not define a specific reaction time, because it uses a transition time between driving regimes.

4. Discussions

As shown, the microscopic traffic models have to be selected based on the assessment needs in order to address the considered issues and to obtain fit-to-purpose results. So, a car-following model must be capable of simulating the amplitude of the drivers' reaction to various external stimuli and also to give a stable estimation of the reaction time. Both models have parameters that affect the reaction magnitude that influences the average speed, flow, density and queue length. The car-following model is responsible to obtaining an exact simulation of the driving course of event in real traffic because of the impact given by the reaction magnitude. As observed, the two models use a rough approximation for the driver's reaction time. In order to improve the approach we suggest a more detailed approach by using a reaction time for each individual driver loaded into the network.

In order to obtain realistic and robust results, a calibration process must be undertaken for all the parameters of the model, taking into consideration a series of behavioural types. This is a very difficult process, but VISSIM is able to assign various behavioural models to various vehicle groups.

Having slower reaction of the follower to the leader's actions is more realistic, because of the platoon effects encountered in the real stream, leading to delayed reactions to the leader vehicle, thus modelling in an accurate way the real driving behaviour. The micro simulation models use frequently a high number of parameters, as shown, as for example desired speed, desired distances, various thresholds, regimes, behavioural factors of the driver etc. All these parameters must be calibrated in order to provide robust and fit-to-purpose results. The duration of the calibration process increases with the number of the parameters that need to be calibrated. In this respect, it is desired to use models with accurate simulation of the real traffic but with a limited amount of parameters. The common, the practitioners tend to use default parameters, well known or benched marked, but this practice leads to results that are not showing the real situation, but only can give an imagine on the overall effect of the measure in an unrealistic manner.

In the case of AIMSUN, the reaction magnitude depends on the difference between the estimation of the leader deceleration and the normal deceleration rate of the follower. On the other hand, in the following regime the desired distance between vehicles depends on the follower's and the leader's maximum deceleration, their speed and reaction time.

In the case of VISSIM, this software offers several calibration parameters for calibrating the reaction magnitude, either by using the thresholds or by using specific regime parameters.

Comparing the two models that have been studied in this article, VISSIM has a greater number of variables and parameters to be calibrated then AIMSUN. The analyst has the possibility to set those parameters in various ways, the easiest one being the graphical display that leads to the ease of the work regarding parameters declaration, nevertheless the difficulty of establishing the values of the parameters is still one of the great simulation issues.

On the other hand, AIMSUN uses models with a limited number of parameters and a friendly interface to define them, resulting in an ease of parameters definition and also an ease of calibration procedure with similar robust results after the simulation run. Nevertheless, the question remains whether the reduced number of parameters used in the Gipps model is sufficient for an accurate description of real car drivers. A high number of parameters used for the development of the model give to the analyst the possibility to consider and realize various types of traffic simulation, adapted to the real life conditions.

5. Conclusions

This article describes and compares the car following models used by the most used two software packages in Romania. Also, it contains a synthetic presentation in a classified manner of the main types of the car-following models.

The two software packages - VISSIM and AIMSUN - have different approaches regarding car-following simulation used to asses this category of behaviour. Nevertheless, the simulations have offered similar results for both car-following models.

In terms of calibration, VISSIM has a variety of calibration parameters that allow the practitioner to obtain fit-to purpose results, while AIMSUN needs the use of a supplementary model variable to aproximate in realistic manner the driver's behaviour.

The output results show that VISSIM uses a car-following model that gives more precision in evaluating driver's real life behaviour. Also, we observed that VISSIM offers a more detailed possibility in calibrating the reaction magnitude, thus providing the simulation of the queuing process closer to reality.

The simulation outputs show that VISSIM models a more aggressive behaviour with acceleration and deceleration rates with higher values ($2 m/s^2$) for the leader vehicle when entering a restriction area, while AIMSUN models a more relaxed behaviour using a gradual deceleration with values between 0.5 to 1.5 m/s^2.

This article is useful for practitioners that are interested in a thorough study of the mathematical models that forms the basis of the simulation packages they often use. Also, it is providing valuable output on how the two simulation software packages model the following regime and the driver's behaviour in this regime, giving an insight of the approximations and simplifications of each car-following mathematical model.

We consider that this article supports a continuation perspective for this research in order to provide an overall background for the totality of the sub-models used in traffic simulation. The next steps of the research will consider the behavioural patterns of vehicles while travelling in a platoon, the process of queuing at junctions and also the identification of various solutions to optimise traffic flows.

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