The University of York Department of Computer Science

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Callum Hewitt

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Supervisor: Lilian Blot

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Abstract

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1 Introduction

The terms 'autonomous vehicle' and 'self-driving car' were once thought of as science fiction, but as of recent, they have become our reality. Google's Self-Driving Car Project is gaining traction, with cars currently driving in Milton Keynes and four different US states [3]. Tesla Motors have deployed a beta version of their Autopilot system into all of their vehicles produced since September 2014. The system has been blamed for both saving and ending lives [4] [5]. 2016 has been a big year for autonomous vehicles and with that comes an even bigger push for robust and secure autonomous systems. The possible benefits of autonomous vehicles cover a lot of different areas of concern.

The main issue it addresses is safety. Autonomous vehicles would be able to react to incidents on the road much more quickly than a human driver would. A human's 'thinking distance' can often determine whether someone survives an accident or not. This distance can also be greatly increased if the driver of the vehicles is under the influence of alcohol or narcotics. An autonomous vehicle however, would be able to react to accidents much more quickly than a human, reducing the thinking distance greatly, improving road safety.

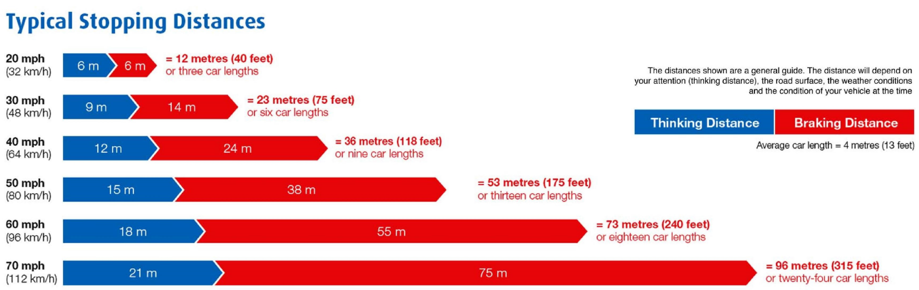


Figure 1.1: Diagram from Rule 126 in the UK Highway Code [1]

Autonomous vehicles could also make transport more efficient. Research by Mersky in April 2016 suggested that fuel conservation control strategies could make autonomous vehicles up to 10% more fuel efficient than current EPA fuel economy test results [6] *TODO: Read this article*. Having vehicles which are fuel efficient is becoming increasingly important, with landmark climate change deals such as 'The Paris Agreement' introducing limits on greenhouse gas emissions globally. The introduction of electric vehicles into the car market is also an important factor to consider, as the range of such vehicles still has not managed to match that of their gasoline counterparts. More efficient driving strategies introduced by autonomous vehicles could reduce this gap.

Congestion contributes to fuel loss in quite a large way. In the US in 2014 an estimated 3.1 billion gallons (11.7 billion litres) of fuel was wasted due to congestion [7]. Automating typical driving activities and communications between vehicles, in situations such as lane changes, could reduce congestion and improve efficiency. Unsafe lane changes don't even have to result in a crash to cause delays. If a car brakes due to a car merging unsafely it can cause a ripple effect, creating a traffic jam.

Autonomous vehicles also offer a level of comfort not currently available today. In a world where autonomous vehicles are commonplace, it is not hard to imagine people doing work, reading or relaxing in their car instead of having to focus on driving.

However, today there are still a number of concerns surrounding autonomous vehicles. One of the major concerns is over the reliability of the systems governing the vehicle. These systems need to be responsive and accurate and they cannot afford to fail in such safety critical environments. Already concerns over Tesla's Autopilot system are impacting the image of the company, and the system isn't even out of beta testing yet [8].

In order to address these concerns safely, we can create simulations which test our autonomous systems. These simulations can test the reliability of our systems. Researchers at the University of Texas set up the Autonomous Intersection Management (AIM) project, which aims to " create a scalable, safe, and efficient multiagent framework for managing autonomous vehicles at intersections" [9]. The project managed to apply their tested intersection software in a mixed reality test using a real life autonomous vehicle [10], demonstrating how simulations are vital tools when testing these safety critical systems.

In this project we make a number of assumptions. Firstly we assume that the sensors resolving the positions of the vehicle and it's surrounding obstacles are perfectly accurate. We also assume that the vehicle can communicate reliably with other vehicles. These assumptions are existing areas of research for autonomous vehicles but are not considered in this paper. The main focus here is on how autonomous vehicles can self-organise to minimise delays in traffic with effective, safe lane merging.

The aims of this project are as follows:

- Attempt to generalise the AIM codebase such that other simulations can be created for non-intersection related situations.
  - If the codebase proves difficult to refactor, new simulator code will need to be created
- Use the new codebase to create a decentralised system for managing lane merging.
- Use the new codebase to create a centralised system for managing lane merging.
- Compare the effectiveness of both strategies.

Creating these simulations helps to determine the effectiveness of two different strategies and also provides a codebase within which future simulations for other situations can be created.

2 Literature Review

This section. ALL NEW TEXT

2.1 Multiagent Traffic Management: A Reservation-Based Intersection Control Mechanism

The AIM protocol defined in this paper is a framework designed for managing autonomous vehicles at intersections. Ensuring that vehicles pass through the intersection safely, and efficiently. The paper assumes a world in which all vehicles are fully autonomous, under similar conditions laid out in chapter 1.

To test the AIM protocol the researchers created a simulator. This simulator compares the effectiveness of the AIM protocol against traffic lights, stop signs and overpasses. It also provides controls over spawning characteristics, driver properties and provides useful statistics. chapter 3 describes how this simulator was modified such that it could be expanded into simulating other autonomous vehicle related solutions.

The AIM protocol (as it stands in this original paper) is based on a simplified model of real-world intersection traffic. All vehicles are travelling at roughly the same speed and none of them are trying to turn. This principle is something I'd like to adopt in my work, starting from very simple traffic models, before expanding to something more complex.

The AIM protocol uses a centrally managed system to organise cars, with vehicles performing a 'call-ahead' to the system, creating reservations for the vehicle. During the reservation a vehicle must be in the intersection, which is divided into reservation tiles. This centralised system works almost as well as an overpass as vehicles are almost continuously flowing through the grid.

The paper defined a number of ways of measuring the success of a system. The primary concern of course is safety, no collisions can be permitted by these systems. The second measure of success should be efficiency, which breaks down into two areas. Throughput, which is the amount of traffic that can be handled by the system and Delay, which is the effect on the overall travel time of the vehicle. Throughput can be quite a qualitative measure; does a system successfully handle traffic if it adds another hour to the travel time of the vehicles? Delay is more quantitative. Both average delay and maximum delay must be considered. We should not dramatically increase one vehicle's journey time for the slight reduction of another.

Centralised systems have a number of advantages, primarily that the autonomous vehicles don't have to do any messy V2V (vehicle-to-vehicle) communication with each other at the intersection, their path through was booked well before the vehicles reached the intersection. However, using a centralised system means that there is a single point of failure. If the reservation system is down and cars are coming towards it, there could be quite serious consequences.

Decentralised systems are more fault tolerant, as vehicles can react to each other dynamically, rather than placing faith in a reservation within single system. This means that when unexpected events happen, such as crashes, lane closures and contraflows, vehicles can be more self-reliant and deal with these unforeseen circumstances.

2.2 A model for the structure of lane-changing decisions

This paper models driver behaviour in real world circumstances, creating a structure characterising the decisions a driver has to make before determining whether to change lanes. The argument the paper makes is that modelling driver behaviour makes it easier to deal with bottlenecks such as roadworks and accidents. In other words, it supports the idea of using decentralised drivers as opposed to a controlling system.

This paper is designed to be used with the car-following model citep[Gipps1981] which limits a driver's braking rate in order to calculate a safe speed relative to the preceding vehicle.

//Add maths

The model itself is constructed as a flowchart, in which each node is a decision the driver must make.

1. *The selection of lanes* There are three lane types to consider here. The first is the present lane, where the driver is currently driving. The second is the preferred lane, which is adjacent to the present lane on the side the driver eventually wishes to turn. The target lane is the lane in which the driver is considering moving into.

//Add maths

2. *The feasibility of changing lanes* This depends on a number of factors. The lane must not have any physical obstructions or other vehicles in the way. The group also defined a maximum deceleration before a lane change became unfeasible.

   //Add maths

3. *Driver behaviour close to the intended turn* If the driver is close to their intended turn then they will always attempt to change into their preferred lane. Only if blocked will they consider moving into another lane. 'Close' varies depending on regional differences and the level of traffic, but in the model, 10 seconds travel of the turn at the driver's desired speed was used.

4. *Urgency of changing lanes* The urgency of changing lanes increases as the driver gets closer to their turn. The willingness of the driver to brake harder and accept smaller gaps increases as the driver gets closer to their intended turn.

5. *Transit vehicles and lanes* Transit lanes are lanes dedicated solely for public transport and other high occupancy vehicles. These include vehicles such as buses, taxis and carpool cars. These vehicles are known in the model as 'transit vehicles'.

6. *Entry of nontransit vehicles into transit lanes* If there is an obstruction in the present lane, it is often considered to be a valid reason for a non-transit vehicle to enter a transit lane.

7. *Departure of nontransit vehicles from a transit lane* Once the obstruction has been cleared, nontransit vehicle must move back into a valid lane. This forced departure does not affect vehicles that are close to their intended turn.

8. *Driver behaviour in the middle distance* A driver is considered 'remote' if they are far from their intended turn. In this instance, the turn has no effect on the behaviour of the driver. However, when the driver is neither remote nor close, the effect of the turn starts to change the behaviour of the driver, removing some lane changes from consideration. The distance at which this happens, again, varies from region to region and on traffic conditions.

9. *Relative advantages of present and target lanes* If the driver has not yet been forced to change lanes by any other factors, then they can look at the relative advantages of the present and target lanes, considering obstructions and then determining which lanes obstructions will have the least effect on their safe speed.

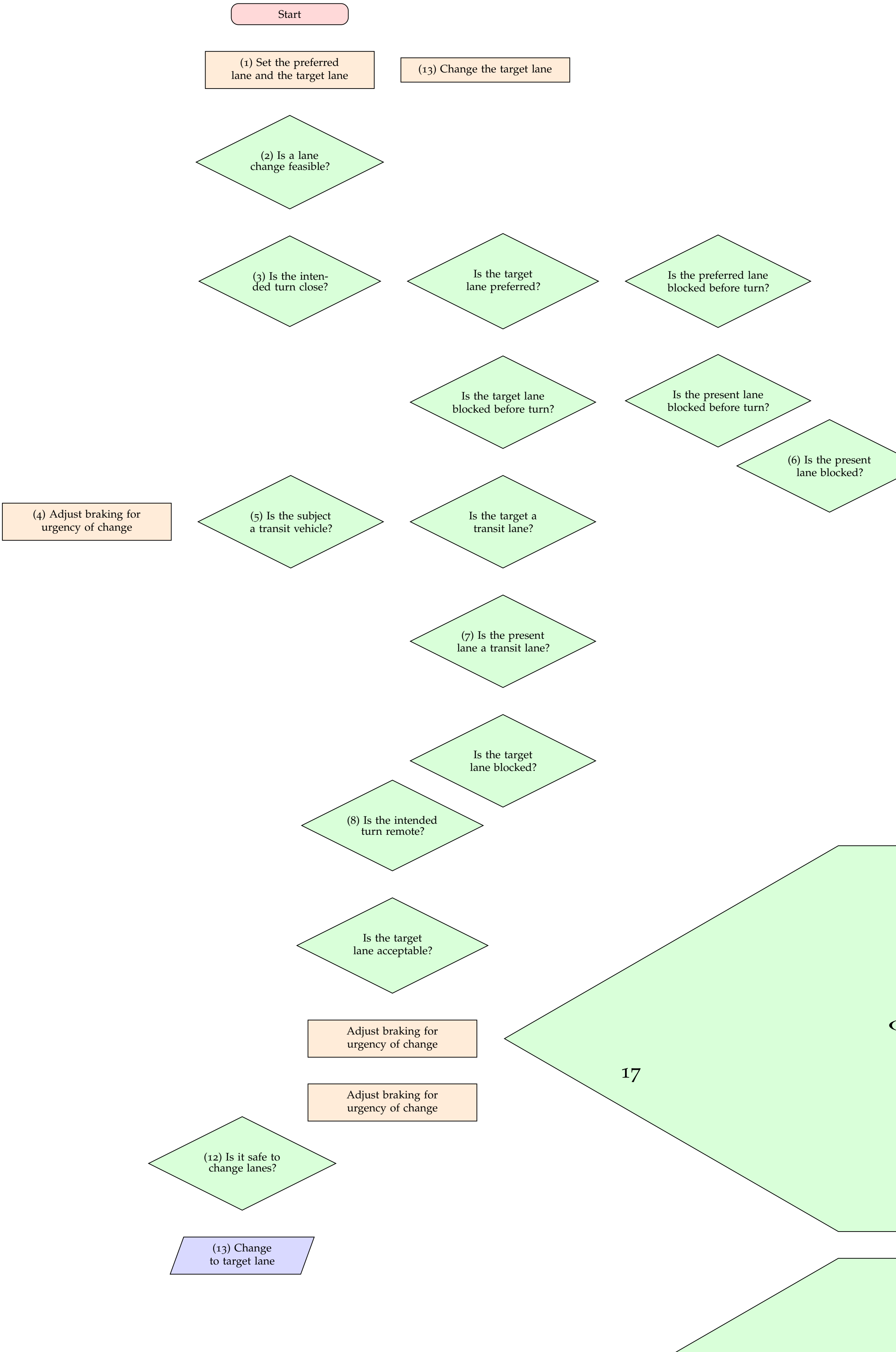
10. *The effect of heavy vehicles* If obstructions are level with each other or beyond the range a driver considers, then the driver considers the next heavy vehicle in each lane, as if it were the leading vehicle in an ordinary car following situation. The driver then selects the lane which will give them the higher speed.

11. *The effect of the preceding vehicle* If there are then no heavy vehicles, the driver considers the speed possible in each lane and then changes if they gain a 'sufficient' speed advantage. This is again, subjective, depending on the present lane, target lane and the type of vehicle.

12. *Safety* After the driver makes their considerations they must then check that they can change safely. This is left until last because the level of safety required by a driver is likely to vary based on their urgency and reasons for changing lanes.

13. *Changing the target lane* If the driver has decided not to change to the preferred lane, then the model considers a lane change in the opposite direction and adjusts the target lane accordingly.

2.3 General Lane-Changing Model MOBIL for Car-Following Models


Start
(1) Set the preferred lane and the target lane
(13) Change the target lane
(2) Is a lane change feasible?
(3) Is the intended turn close?
Is the target lane preferred?
Is the preferred lane blocked before turn?
Is the target lane blocked before turn?
Is the present lane blocked before turn?
(6) Is the present lane blocked?
(4) Adjust braking for urgency of change
(5) Is the subject a transit vehicle?
Is the target a transit lane?
(7) Is the present lane a transit lane?
Is the target lane blocked?
(8) Is the intended turn remote?
Is the target lane acceptable?
Adjust braking for urgency of change
Adjust braking for urgency of change
(12) Is it safe to change lanes?
(13) Change to target lane

3 Implementation

3.1 Generalising

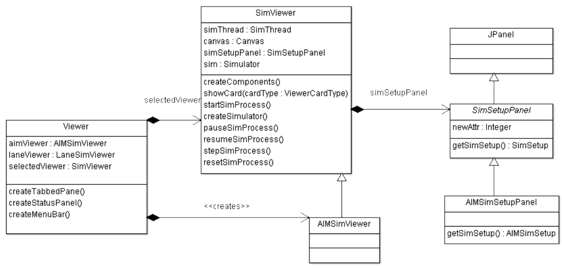


Figure 3.1: Changes made to Viewer structure. Created SimViewer class to contain all GUI elements related to SimSetupPanel and Canvas. Subclasses of this deal with their own simulators separately.

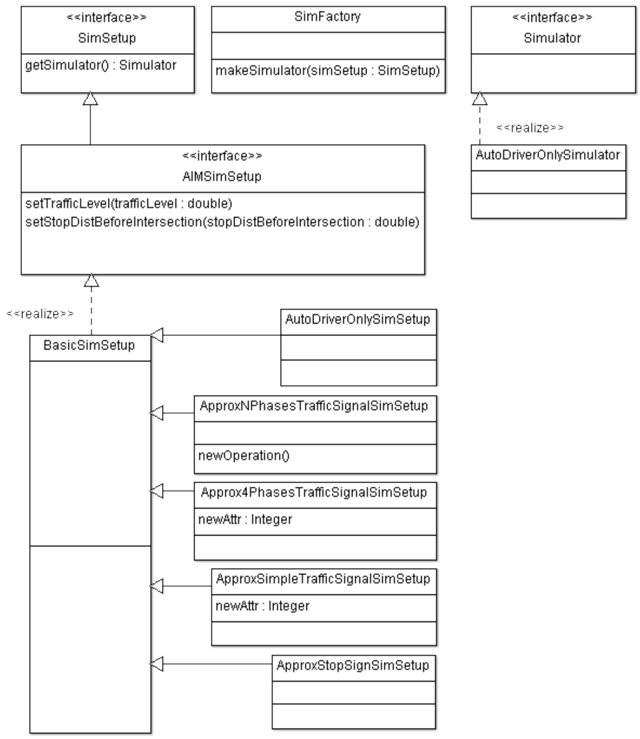


Figure 3.2: Changes to Sim structure. SimSetup is now generalised. Only job is to produce a simulator object when called by SimFactory.

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