The University of York Department of Computer Science

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Undecided Title

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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 [2]. 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 [3] [4]. 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.

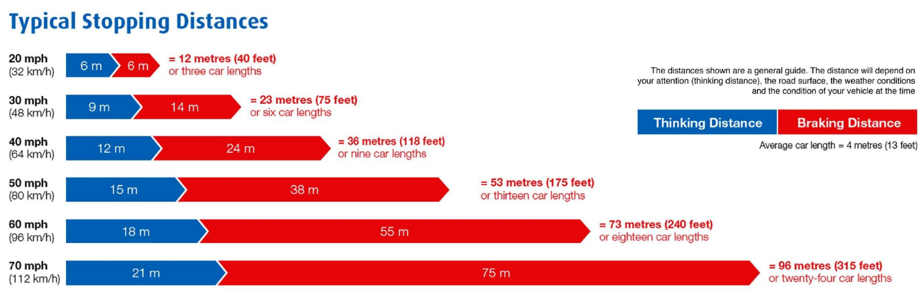

Figure 1.1: Diagram from Rule 126 in the UK Highway Code [1]

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 [5] *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 [6]. 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 [7].

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" [8]. The project managed to apply their tested intersection software in a mixed reality test using a real life autonomous vehicle [9], 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

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

- Introduction
  - Motivated by traffic light problems -> My work is motivated by lane change problems evidenced in Jorge A. Laval [10]
  - Set in a world of fully autonomous vehicles.
  - Overpass is optimal solution, what is optimal for my work?
- The Model
  - Using a simplified model of real-world intersection traffic -> No turning, roughly same speed. Worth considering my model to start with. How can that model be adapted?
  - How do we measure success? 1) Safety is critical. No collisions allowed! 2) Efficiency
  - Throughput: How much traffic can be handled. Difficult to measure, qualitative claims only made.
  - Delay: Effect on overall journey of the vehicle. No vehicle's travel time sacrificed for another dramatically. Consider both average delay and maximum delay!
- Overpass, Traffic Light Theory
  - Simplifications due to car interactions and acceleration to calculate lower bound traffic light delays.
- The Simulator
  - Useful sizing stats in this section.
  - Spawning characteristics, driver properties, three actions the driver can take, relevant decision logic.

- Testing simulator with no big changes. Constructing current system
- Simplification from earlier no longer applies to light model.
- "Call ahead" system -> Could be applied to a centralised model for lane changing.
- Intersection divided into reservation tiles -> could be applied to lane changing too.

- Empirical Results
  - Measuring overloaded systems vs light traffic
  - Increasing granularity tests -> At least as high as the number of lanes

2.2 Lane-changing in traffic streams

- Introduction
  - Attempt to create a qualitative understanding of lane changing impacts on traffic flow.
  - Lane change triggers disruption -> triggers other changes
  - Considers freeway as a series of interacting streams linked by lane changes
  - Combination of multiple stream models
- The Model
  - Based on the Kinematic Wave model: https://en.wikipedia.org/wiki/Kinematic_wave
  - Not really sure of the maths here. More research required.

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

- Introduction
  - Drivers want to increase their own utility

  - Drivers have a strategic view of lane changes -> They have a target destination that might require them to change to a specific lane
  - "Politeness factor" - Drivers often consider the loss of utility of other drivers. Introducing a politeness parameter varies a driver's response from altruistic to egotistical
  - Optimal politeness parameter -> MOBIL: Minimizing Overall Braking Induced by Lane Changes
  - Consider US driving rules and European driving rules (Symmetric vs Asymmetric with reversed Asymmetric for the UK)
- The lane-changing model MOBIL
  - Safety criterion says that after a lane change deceleration of car behind doesn't exceed a given safety limit.
  - Incentive to change needs to be greater than the switching threshold, which is drivers utility gain + politeness factor * follower's utility gain
  - Right lane bias with left lane priority for European rule roads
- Application to multi-lane traffic simulations
  - Intelligent Driver Model -> Guarantee's crash free driving. http://www.traffic-simulation.de/
  - Maximum politeness = Maximum throughput on both lanes. As density of traffic starts to get over 20/km/lane lane changes decrease as fewer suitable gaps start to appear.

2.4 A model for the structure of lane-changing decisions

- Introduction
  - Modelling individual driver behaviour makes it easier to deal with bottlenecks such as road works or accidents. This behaviour is easier to simulate at a driver level. Modelling only driver behaviour instead of systems for dealing with the overall system (centralised).
  - Drivers need to reconcile short and long term aims.
  - This paper refers to how the decision to change lanes is made, as opposed to the mechanics of changing lanes.

- Concerning Driver Behaviour
  - Three questions:
    1. Is it possible to change lanes?
    2. Is it necessary to change lanes?
    3. Is it desirable to change lanes?
  - Assumptions include: Drivers has a goal to travel from X to Y in safety within a given time. This is translated to a number of specific quantitative objectives.
  - Factors influencing driver changing lanes decision
    1. Physically possible and safe to change lanes
    2. Location of permanent obstructions
    3. The presence of transit lanes
    4. Driver's intended turning movement
    5. Presence of heavy vehicles
    6. Speed
- The Model
  - The model covers the entire motorway experience. Entering -> Travelling -> Exiting
  - Behaviour changes based on proximity to driver's exit.
  - Fits in with car following model. Same as that adapted in Arne Kesting [11]
  - Flowchart summarising decision process as well as mathematical decision process in paper.

3 Implementation

3.1 Generalising

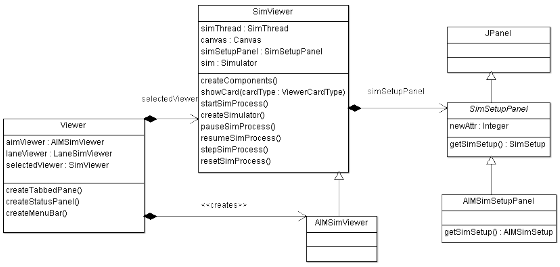

Figure 3.1: Changes made to Viewer structure. Created SimViewer class to contain all GUI elements related to SimSetupPanel and Canvas. Subclasses of this deal with their own simulators separately.

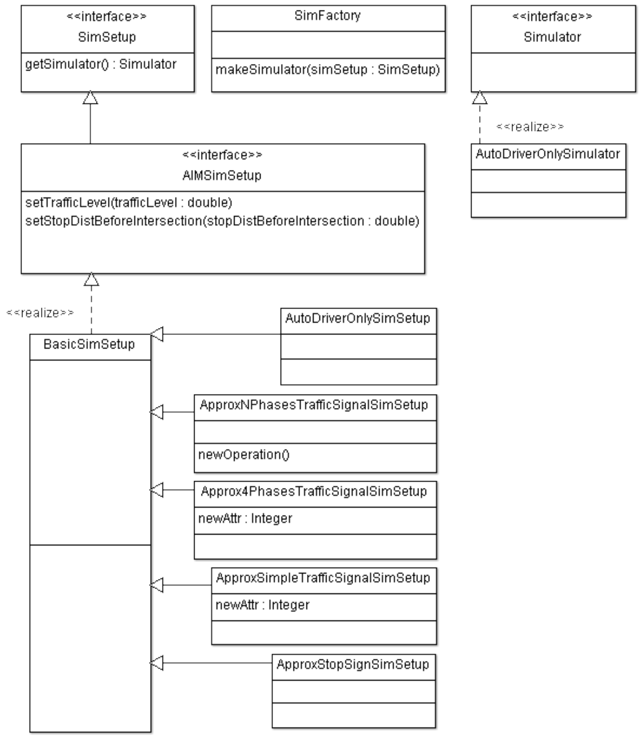

Figure 3.2: Changes to Sim structure. SimSetup is now generalised. Only job is to produce a simulator object when called by SimFactory.

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