Assessing and Modelling the use of Mobile Phones in Causing Traffic Jams

Victoria Murray

Bachelor of Science in Computer Science with Honours
The University of Bath
April 2009

Assessing and Modelling the use of Mobile Phones in Causing Traffic Jams

Submitted by: Victoria Murray

COPYRIGHT

Declaration

This dissertation is submitted to the University of Bath in accordance with the requirements of the degree of Batchelor of Science in the Department of Computer Science. No portion of the work in this dissertation has been submitted in support of an application for any other degree or qualification of this or any other university or institution of learning. Except where specifcally acknowledged, it is the work of the author.

Signed:

Abstract

Traffic jams are a natural phenomenon of everyday life, affecting thousands of drivers on British roads. Despite laws in England making the use of hand-held mobile devices whilst driving illegal, many drivers continue to flaunt this law. This project will assess, through an agent based model (ABM), the impact that drivers who use mobile phones have on the traffic flow of a section of road. The number of models and simulations which currently exist to simulate this sort of influence on traffic jams are few and far between so this project aims to address this issue. The resulting model is constructed showing traffic with a varying number of drivers on the road, including some mobile-phone using drivers. The project then looks at the results of running a number of experiments using the model to ascertain the affects that the mobile-phone using drivers have compared to a road with no mobile-phone users. There is a discussion at the end on ideas for the future of this project, in terms of potential improvements and enhancements, and the direction that others in the future can take this project.

Contents

List of Figures

List of Tables

Acknowledgements

I would like to thank my supervisor Marina De Vos for supporting me throughout the project and helping me through difficult aspects of it.

I would also like to thank my parents for always being there and encouraging me, particularly through the hard times.

Finally I would like to thank Thomas Kelley for his continuous support and proof reading at the end.

Chapter 1

Introduction

1.1 Traffic Jams

Every day thousands of people use road networks to travel between places as they carry out their daily lives. One of the most annoying phenomenons on British motorways, and indeed other main roads, is that of the traffic jam. Drivers are happily motoring on at a decent speed and suddenly, apparently from nowhere, a traffic jam has formed.

1.2 Mobile Phones

Mobile phones have become common in modern day society as people feel the need to constantly be in communication with others and readily have access to information. The use of mobiles phones while driving is a distraction to drivers and is known to cause traffic jams. People concentrate on their phone conversations, their attention is diverted from driving and thus they begin to slow down. With multiple drivers doing the same thing this inevitably becomes a big problem. In order to reduce this impact on traffic flow some countries have made it illegal to use a hand-held mobile device whilst driving, however some drivers are willing to ignore this and so the problem continues. Additionally the use of hands-free devices is still permitted although there is research to suggest that these also impact driver attention and thus result in traffic jams. The impact that this phone usage has on the surrounding traffic can cause problems as traffic jams result in tailbacks along the road and drivers become angry. Extreme traffic congestion turns the area into a massive bottleneck during rush hour resulting in a tremendous strain on daily commuters (Punam, 2007). This is a problem particularly prevalent on motorways

1.3 Traffic Flow Models

Traffic simulation models, such as TransModeler[1], have been available for a while and are often used in planning road works, constructions of new sections of road, as well as for forecasting the volume of traffic at certain times of the day. These models are important tools in planning all these activities as planners aim to reduce the impact they will have on

---

[1] http://www.caliper.com/transmodeler/default.htm

traffic flow. Less complex models have also been developed to analyse traffic flow and how traffic jams form. These are generally less commercial models, more focused on research into the field for general interest, such as the one created by Dr. Martin Treiber (*Traffic Modelling*, n.d.).

1.4 Project Aim

The aim of this project is to ascertain the effects that using a mobile phone while driving has on the traffic flow of a motorway. The main outcome of the project will be a model to show this affect.

1.5 Project Layout

The project starts with a review of the literature, in **Chapter 2**, which exists currently in this field of research for us to gain an understanding of what specific areas of traffic flow we might like to consider.

Chapter 3 looks at the main aims and objectives of the project, as well as considering some hypotheses which we will aim to test.

In **Chapter 4** we start to design the model and the experiments which will be run in order to collect data.

Chapter 5 includes a discussion of how the model was implemented, mentioning any amendments that had to be made from the original design.

Results of running the experiments, and an analysis of these can be found in **Chapter 6**.

Finally **Chapter 7** sums up the whole project and looks at potential improvements for the model as well as the direction in which it may be taken next.

Chapter 2

Literature Survey

2.1 Introduction

Every day millions of people take to the road in Britain as they carry out their daily lives; driving to work, taking children to school, making social visits to others. Whatever the need there are many cars on the road network each day. One of the most annoying phenomenons on British roads, mainly motorways, is that of the traffic jam. A section of traffic is flowing freely, and then suddenly, apparently from nowhere, a traffic jam occurs.

A traffic jam is defined as “a situation when all road traffic is stationary or very slow” (*Wiktionary - traffic jam*, 2008). Nagai, Hanaura, Tanaka and Nagatani (2006) note that traffic jams are a typical element which demonstrate the complex behaviour of traffic flow. The result of a traffic jam is extra time added to ones journey as the driver waits for the traffic jam to clear and for the traffic flow to improve again. The main annoyance is that often it is unclear why a traffic jam has occurred in the first place. In the study of traffic flow this is referred to as a ‘traffic jam without an obvious bottleneck.’ Some known causes of traffic jams are accidents, road works or large volumes of traffic. However, very often the traffic jam will appear to start independently of visible factors. Once cleared, the traffic returns to its normal flow rate and drivers do not have anything to ‘blame’ as such.

To begin an investigation into the causes for traffic jams it is necessary to look at the main factors surrounding the problem. One potential cause is road layouts, including roundabouts, traffic lights, and slip roads, where there is an intersection of traffic and vehicles must wait for other vehicles to move before they can do so themselves. There are then driver distractions, such as making mobile phone calls, drinking and/or taking drugs, or being very tired. These can lead to traffic jams as the concentration of a driver reduces and he pays less attention to what is going on around him.

2.2 Traffic Flow Theory

Traffic flow theory “describes in a precise mathematical way the interactions among vehicles, drivers, and the infrastructure” (*Turner-Fairbank Highway Research Center*, 2008). This is very important when producing traffic models and tools which simulate designs, for example of a new section of road.

Traffic flow theory has been studied for many years, particularly extensively in the 1950's and 60's. Both Nagel (1996) and Kuhne and Rodiger (1991) have shown that this theory is focussed on the relationship between three important variables of traffic flow; average velocity, v, traffic density (number of vehicles per km of road) - p, and the current flow (number of vehicles per hour) - q. These variables are related through $q = p \times v$, meaning that flow rate is worked out as a product of density and velocity.

The first considerations of traffic flow theory focussed on looking for time independent relations between j, p and v. An improvement to this was to look at dynamic (time-dependent) relations. In summary this is based on an equation of continuity, and assuming that the traffic flow (velocity) is only based on the density of traffic. Herman, Lam and Prigogine (1972) later developed a theory of traffic flow based on kinetic theory. After this came car-following models and then cellular automaton models, details of which are discussed later. (Nagel, 1996).

2.3 Traffic Jams

The phenomenon of the traffic jam, particularly prevalent on British motorways, is a nuisance experienced by drivers every day. Wright and Roberg (1998) note that traffic jams can occur from one of three ways;

1. A temporary obstruction, such as an accident.
2. A permanent bottleneck in the network, in an area that cannot deal with the volume of traffic.
3. Random fluctuation of the volume of traffic at different areas in a network, causing spill-back and queue formation.

Some studies of traffic jams focus on the 'critical value' of vehicle density. While density is calculated as the number of vehicles per section of a road, the critical value is the point at which the volume of traffic becomes too high and a traffic jam forms. Below this value the volume of traffic is low and vehicles can move freely. At a low density the traffic flow of a section of road is laminar (Kerner and Rehborn, 1996). That is, traffic is free to flow at a good rate and a traffic jam has not occurred. Kerner and Rehborn (1996) also go on to mention which of the parameters of traffic flow are most important when analysing traffic jams, as they demonstrate the key characteristics of traffic jams. These are;

1. The velocity of a traffic jam - the rate at which it is moving
2. The density of the traffic jam - how many cars per specified section of the road there are
3. The flux of the vehicles in the outflow - the rate at which vehicles at the front of the traffic jam break away from it and increase their speed again to return to a good flow rate

To illustrate the point of the critical value at which traffic becomes congested, Figure 2.1 is a graph from a paper by Nagatani (2002). At point 1 the traffic is flowing freely, and the flow of the traffic is linearly dependent on the density. By point 2 on the graph the flow of traffic is at the highest point it could be based on the current density of traffic. The area marked *metastability* is the area in which the flow of traffic is stable. This means the traffic is moving but very little would have to change in order for this state to be altered. In other words, a slightly greater density of cars would result in a traffic jam. At point 3 traffic is congested because the density of the traffic has got too large for the road and therefore the flow of traffic has been reduced.

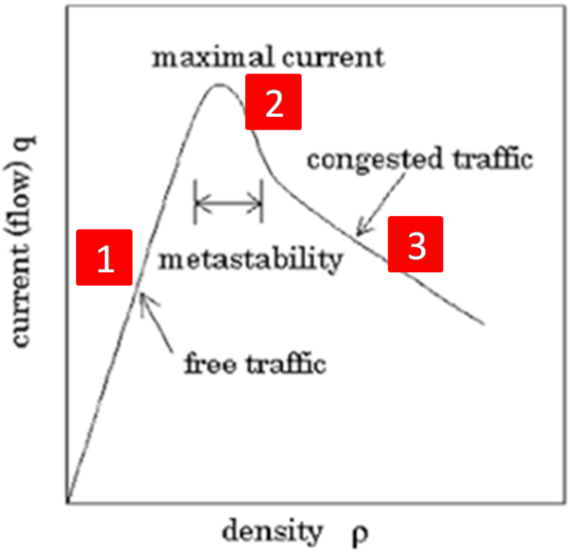


Figure 2.1: Traffic Flow Illustration

This graph is useful because it visually sums up the theory of traffic flow and represents the three main phases; free flow, free flow verging on congestion, and congestion.

2.3.1 Traffic Lights

Traffic networks in towns and cities can become extremely busy, particularly at peak times such as rush hours in the morning and evening. The ideal situation is for the road layout to help stimulate good traffic flow, to avoid the situation of traffic jams. One of the ways in which this can be achieved, in theory, is by using traffic lights. However research suggests that traffic lights can sometimes lead to causing traffic jams.

2.3.2 Roundabouts

Roundabouts are another method of traffic flow control used on road networks in most countries. Campari1, Levi1 and Maniezzo (2004) note that roundabouts have a positive effect on traffic flow because cars do not always have to come to a complete standstill, as is the case with traffic lights. Campari1 et al. (2004) also state that roundabouts are used because of “their importance for the limitation of traffic jams.”

2.4 Agent Based Modelling

There are essentially many ways to model traffic flow; a simple way would be to use mathematical equations, known as equation-based modelling. A different approach is to use agent based modelling (ABM) to simulate the traffic flow, and there are many benefits associated with doing this. The main difference between these two approaches is the way in which the model is created and executed. Agent based models use a number of agents which simulate the behaviour of entities in the real world system, for example cars in a traffic network. When the model is run the agents interact according to this behaviour. Equation based models work by creating a model as a set of equations, and the model is executed by evaluating these equations (Parunak, Savit and Riolo, 1998).

2.5 Modelling Traffic Flow

Traffic simulation models have existed for a while now and are used for a variety of purposes, mainly to simulate traffic flow on a certain stretch of road. Models can be found in a few separate categories, the names of which describe the techniques used to create them. The main categories are; microscopic, macroscopic and mesoscopic. This report will only focus on the first two, as mesoscopic models are a smaller subset of traffic models than the other two, and tend to fall into one of the other categories anyway.

2.5.1 Microscopic Models

Microscopic traffic models take a more defined view of the traffic situation and consider each vehicle individually, rather than just looking at the network as a whole. They can model a significant level of accuracy of traffic conditions in a variety of conditions (Barcelo, Codina, Casas, Ferrer and Garcia, 2004). They look at driver behaviour and how this influences the overall result on the traffic flow. Microscopic modelling is often the preferred method of traffic flow modelling as it is closer to real life. These types of models take into consideration microscopic properties such as the position and velocity of individual vehicles. They also model the actions of each driver, such as acceleration, deceleration and lane changing (Kesting, Treiber and Helbing, 2008). They typically start with an individual vehicle, and analyse how this vehicle interacts with its neighbouring vehicles (Maroto, Delso, Felez and Cabanellas, 2006). Whilst these sorts of models start with microscopic properties so that one can observe the effect that one driver has on a network, the resulting model inevitably shows the overall outcome on the whole network (Das, Bowles, Houghland, Hunn and Zhang, 1999).

Microscopic models have a variety of uses in their domain. They are often useful for looking at traffic flow in a small area, but in greater detail, as they have more flexibility than macroscopic models. They provide this flexibility as they usually have a large number of model parameters (Fellendorf and Vortisch, n.d.). Microscopic models have become more widespread in use as computing power has improved (Chang, Wang and Ioannou, 2007).

Microscopic models are described by two elements; an acceleration function, and an update rule (Brockfeld and Wagner, 2006).

2.5.1.1 Car Following Models

The task of driving can be said to be composed of a number of sub-tasks, some related to the driver and some related to the motion of the car. One of these sub-tasks is car following which is defined by 'the task of one vehicle following another on a single lane of roadway' (Rothery, n.d.). Car following models are considered to be the simplest approach to traffic flow. The basic idea is that each vehicle is only affected by the vehicle immediately ahead of it. The rule for car-following is

$$\ddot{x}_n(t+\pi) = \lambda(\dot{x}_{n-1}(t) - \dot{x}_n(t)) \tag{2.1}$$

where t = time, π = reaction time, x_n = position of the n$^{\text{th}}$ car. The sensitivity coefficient λ may depend on the different parameters including distance between cars and the speed of the n$^{\text{th}}$ car. This rule basically says that a driver tries to adjust his speed (by accelerating or decelerating) depending on the difference in speed of the car in front (Bardzimashvili, 2003).

Most car following models are of the form

$$a(t+T) \propto \frac{v(t)^m}{[\Delta x(t)]^l}.\Delta v(t) \tag{2.2}$$

where this equation describes the motion of one vehicle. a is the acceleration, v the velocity. Δx is the distance to the car in front, Δv is the velocity difference to the car in front, and m and l are constants. T refers to a time delay between any stimulus and the response to it, for example the difference between the driver applying the brakes to the vehicle and the vehicle actually stopping (Chang et al., 2007).

2.5.1.2 Cellular Automata Models

Cellular Automata (CA) models are achieved by dividing a road section into cells, which are either empty or occupied by a vehicle. In these models time is modelled as a set of discrete steps. They use rules for braking and accelerating but also require additional rules for modelling random behaviour and actions. CA models are useful in the respect that they can be used to simulate large road networks efficiently, however they are not as accurate as time-continuous models (Kesting et al., 2008).

Barlovic, Santen, Schadschneider and Schreckenberg (1998) looked at the cellular automaton model proposed by Nagel and Schreckenberg (1992), which focussed on single-lane highway roads. The model is good because despite its relative simplicity it is accurate in showing how random traffic jams form. In this model the road section is divided into equal 'cells' and these can either be occupied by one vehicle, or unoccupied (Figure 2.2).

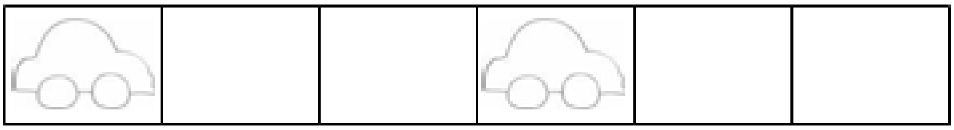


Figure 2.2: Cellular Automaton Diagram

In this model the state of a car is based on its current velocity. In order to calculate the state of the whole model at time $t + 1$ the model uses four rules which are applied to all cars simultaneously, at time t. These four rules are:

- **Rule 1: Acceleration**
  If the velocity of a particular vehicle is less than the maximum possible velocity and the distance to the car in front is greater than $v + 1$ then speed can be increased: $v \rightarrow v + 1$. This will ensure that vehicles who have space to accelerate do so in order to maintain good traffic flow
- **Rule 2: Braking**
  If a vehicle at position i sees a vehicle at position $i + j$, it reduces its speed: $v \rightarrow j - 1$. This ensures that a vehicle does not crash into the vehicle in front.
- **Rule 3: Randomization**
  Using a random probability p a vehicle reduces its speed: $v \rightarrow j - 1$. In real life people drive at a speed lower than the maximum speed permitted, even when there is space to accelerate. This rule mirrors this behaviour by getting some vehicles to brake randomly.
- **Rule 4: Driving**
  Each vehicle moves forward i positions. This is a simple rule which ensures that vehicles continue to move.

This model is a good basis for looking at microscopic models and presents this notion in a clear and simple manner, but with useful effects.

2.5.2 Macroscopic Models

Macroscopic traffic models, or continuum models as they are sometimes referred to, are described as ‘the collective dynamics of the traffic flow.’ They are considered as the less helpful of the two types of models described in this report. This is due to their modelling traffic at a more abstract level than microscopic models. They do not look at individual vehicle units, but consider the overall effects of a section of traffic on the traffic flow. They look at the general aspects of a traffic system such as the average speed of all the vehicles on the road, and the density of the traffic (Paruchuri, Pullalarevu and Karlapalem, 2002).

A paper by Tampere and v Arem (2001) describes macroscopic models as looking at the “dynamics of traffic flow on an aggregate level”. This means the models look at the overall traffic flow variables, rather than being concerned with each of the individual vehicles. These types of model all use a general rule for describing traffic flow which shows that the density of traffic increases over time as the flow rate decreases, and vice versa. This rule is known as a ‘continuum equation’. To build the model, further equations are added to this equation which describe how the vehicles as a whole behave.

Maerivoet and Moor (2008) identify four characteristics which are key to macroscopic modelling; density, flow, occupancy and mean speed. Density basically shows how crowded a section of road is, measured in vehicles/mile for example. This is quite generalised because it does not consider specific properties such as the length of each vehicle, as in the real world this would vary a lot. Flow, or flow rate, is a measurement of how many vehicles per hour, or more formally “the total distance travelled by all vehicles in the measurment region, divided by the area of this region”. Flow is calculated using the following formula;

$$q = \frac{N}{T_m p} \tag{2.3}$$

N is number of vehicles and T is the time interval. The ‘occupancy’ characteristic is a measure of how long a vehicle was at the measurement location, when we talk about detectors used to measure traffic flow on a section of road. Mean speed is simply the average speed of vehicles in the traffic stream measured in kilometres/hour.

The important thing to note about these four characteristics is that are macroscopic; they do not help to model each of the vehicles individually but consider how the whole stream of traffic behaves, as each of the characteristics are measured over all the vehicles.

2.6 Technologies

2.6.1 MASON

MASON is a multi-agent toolkit written in Java and can be used for many different types of simulations “with a special emphasis on swarm multi-agent simulations of many agents”. It is an open-source, free system allowing anyone to utilise its capabilities. MASON is flexible as it allows for programmers to add and remove features easily from a simple starting point. The system is good for users as it allows for many types of simulation to be created because it is not too specific. What this system provides over other simulation systems is the ability to detach the model from the GUI very easily, and also to be used on a number of different platforms, as Java is platform independent. (Luke, Cioffi-Revilla, Panait, Sullivan and Balan, 2005).

2.6.2 NetLogo

NetLogo is another multi-agent programming language which is fairly straight forward to use but allows for complex situations to be modelled. The models work by users instructing ‘agents’ to behave in a certain way, according to procedures written in the language. NetLogo lets users look at the difference between micro-level, and macro-level behaviours of agents (Tisue and Wilensky, 2004). This is a suitable language for creating traffic flow models since, as we have seen, these types of models are either microscopic or macroscopic.

2.7 Existing Models

We have touched on the fact that there already exist a number of models which simulate traffic flow in a variety of different forms. Before we can consider what a new model may look like we need to evaluate the strengths and weaknesses of these existing models. There are hundreds of models available, but for the purpose of this project we will be selecting just a handful of these to look at. This should nevertheless give us a representative picture about the types of models available.

2.7.1 VISSIM

VISSIM is a microscopic simulation tool which allows users to model traffic flow at quite a detailed level. It is a discrete model, showing changes in the model state at each time step. (Fellendorf and Vortisch, n.d.). Fellendorf and Vortisch (n.d.) investigated how useful VISSIM is as a traffic simulation tool. The tool itself is based upon the Wiedemann model, presented by Wiedemann and Vortisch (1994), which states that a driver can be in one of four different driving 'modes'.

1. **Free Driving**
   While there is no car immediately ahead of a driver, or rather there is no need for the driver to react to a car ahead, he tries to reach and maintain his desired speed
2. **Approaching**
   In this instance a driver is approaching a car whose speed is lower than that of the himself, so he must decelerate to match that speed and maintain a minimum distance between himself and the car in front
3. **Following**
   This is where a driver follows a car in front with no conscious braking or accelerating, and maintains a minimum distance
4. **Braking**
   A driver decelerates at a high rate in order to maintain a minimum distance, mainly due to the car in front braking harshly

The driver moves to and from each of these modes as necessary. The driver thinks about what mode he needs to move to next, based on perceptions of speed; this is a psychological aspect to the model. Additionally there are physiological effects which restrict the driver's perceptions about what is going on around him. Hence the model is known as a 'psycho-physical car-following model.' (Fellendorf and Vortisch, n.d.). The model goes on to define further rules for lane changing as an extension to the simple model.

This model is one of the simplest in terms of its complexity and what it can achieve, however this does not mean it is any less valid than more complex models. It is useful due to it being relatively easy to implement but yet still yields good results.

2.7.2 CORSIM

CORSIM (COrridor SIMulation) is another traffic flow tool and the most widely used one in the US Owen, Zhang and Rao (2000) [1]. CORSIM is very useful as a traffic flow simulation as it has many strengths, and is arguably more useful than the aforementioned VISSIM. Its strengths include;

- Being able to model various different types of road networks, including inter-sections (cross roads and T-junctions for example), multi-lane roads and slip-roads.
- Its ability to model different levels of traffic flow, from free flow traffic to congested traffic. It also allows users to see the impact that an incident, such as a car breakdown or a vehicle collision, has on the traffic flow.

---

[1] Page 1143, Section 1, Paragraph 5

- Being able to model a variety of traffic management controls such as traffic lights and roundabouts. This is important as these are aspects that appear in the real world and have been found to have an impact on traffic flow.

CORSIM has a variety of other strengths which relate more to how users can interact with the tool, such as being able to use external data input.

While CORSIM appears to be a very useful tool, and probably more so than VISSIM, it has the same aspect lacking; any consideration for mobile phone drivers. It is able to model a variety of traffic situations and to this end it provides us with a lot of useful insight as to how traffic simulation tools are constructed to yield meaningful results.

2.8 Driver Behaviour

We have previously mentioned in this project that there are a number of areas which can be considered under the broad field of traffic flow theory. Whilst the road layout and conditions of the road are one factor to look at, we can also consider the effect that drivers themselves have on traffic flow. This includes psychological factors such has how drivers think and react to road situations, and how they decide to control the vehicle. A study by Brackstone, Sultan and McDonald (2002) looked at the effects of driver behaviour, particularly with respect to how this impacts on intelligent transport systems (ITS). A particularly important area of driver behaviour is ‘dynamic driver behaviour’ such as car following, whereby drivers use the brake and accelerator to maintain a minimum distance between the car ahead. This is interesting because it links back to the earlier research we found concerning car following models. Clearly driver behaviour is a major factor which needs to be considered when designing and implementing certain traffic models.

2.9 Mobile Phones

Limited studies have been carried out into the use of mobile phones while driving and how this leads to traffic jams. The few studies and reports which do exist have not led to the creation of simulation models showing their results.

In a study by the University of Utah (*Live Science*, 2008) researchers found that drivers using mobile phones took longer to complete a journey because they drove more slowly on highways (equivalent to British motorways) and over-took other drivers at a relatively slow speed. This then has a cascading effect on the traffic flow and causes other people to slow down, eventually resulting in a traffic jam. The researchers explain that during medium- and high-density traffic situations those using a mobile phone were twenty per cent less likely to move into a less busy lane, would drive at 2mph slower than usual, and on average took an extra fifteen to nineteen seconds to travel along a 9.2 mile stretch of highway. Another study by Redelmeier and Tibshirani (1997) found that a driver using a mobile phone when driving was four times more likely to have a vehicle collision than those who did not make mobile phone calls whilst driving.

2.9.1 Hand Held Devices

As previously mentioned, some countries have made the use of hand-held mobile phones whilst driving illegal, claiming that the concentration required to physically hold the device and interact with it causes drivers to lose concentration on driving. However, studies have been carried which show that there is no distinction between hand-held and hands-free mobiles when looking at how drivers who use phones while driving react to them. A study by Patten, Kircher, stlund and Nilsson (2004) asked drivers to complete a simple conversation and a more complex conversation on both a hand-held and a hands-free phone and the results of these four tasks were compared. The results showed that the task itself (simple vs complex conversation) had an impact on the reaction times of the drivers, but the type of phone used had no impact at all; "the mobile telephone modality [type of phone] would appear to be of little consequence when solely considering the conversational aspect of telephoning. Far more important for driver distraction, in regard to mobile telephones, is the content and the complexity of the conversation per se."[2] This study appears to contradict the argument put forward by those governments (including the British Government) who have made the use of hand-held mobile phones whilst driving illegal on the basis that it causes drivers to lose concentration on driving.

2.9.2 Hands Free Devices

As many countries, including England, have made the use of hand held devices at the wheel illegal, drivers have had to turn to hands free devices in order to continue making and receiving calls in their vehicles. Whilst this is legal practice in the UK there is a lot of debate surrounding this topic and whether the concentration required from a driver is as great as when using a hand-held device. The idea is that a hands free device causes less of a distraction as the driver is not physically holding the device and concentrating on maintaining their hold of it, as well as successfully steering their vehicle. While this element is taken care of, there is evidence to suggest that the driver needs as much concentration to hold a conversation as they would if they were using a hand held device. As Eby, Vivoda and Louis (2006) note, "there is ample research showing that the use of either hand-held or hands-free cellular phones can lead to unsafe driving patterns" and "hands-free cellular phone use..has been shown to be equally distracting [as hand-held phone use]."

Research has shown that the use of hands free mobile phones by drivers has a negative effect on a number of different aspects. These include the drivers' reaction time, for example how quickly they react to a change in speed of the car in front, lane changing, ie whether a driver bothers to move to a free lane, and their workload. The impact on all of these then causes drivers to slow down. (Alm and Nilsson, 1994).

This research is useful as it shows that drivers who use a mobile phone whilst driving do slow down more than those who do not. Having said that there is a then a gap between this effect and a link to traffic jams, and this is where the research area needs to be improved upon. It appears there is currently no research which confirm this direct link.

---

[2] Page 349, Section 5, Paragraph 2

2.10 Summary

The information gleaned from looking at the literature in this field provides a good basis for deciding upon which route to take next. The main aim of this survey was to discover what kind of models currently exist and equally, what is lacking.

The main conclusion to be drawn is that there are currently a wide range of models available, from those which model simple one-lane sections of roads, to more complicated models which take into consideration different road types and vehicles. What seems to be lacking however are models which take into account drivers who use mobile phones at the wheel, and what the impact of this may be on the traffic flow of a section of road. What has also been discovered is that there is no distinction between the two types of phone (hand held and handsfree) when it comes to concentration required by the driver to hold a conversation on a mobile phone. This would suggest that a traffic model designed to simulate the effect that using a mobile phone whilst driving has on traffic flow would not need to make a distinction between the two phone types.

Chapter 3

Research Objectives & Hypotheses

3.1 Objectives

The overall objective of this project is to assess and model the use of mobile phones in causing traffic jams. Having studied the literature surrounding this field of research we can now develop some more specific objectives;

1. The approach to this project will be an agent based model, as this seems to be the usual choice for developers of traffic flow models
2. The model will be focussed on how users of mobile phones have an effect on traffic jams, due to their driving slower than other drivers - this is the main influence that drivers with mobile phones appear to have, as has been discovered from reading the literature
3. There will be an investigation into how altering the variables in the model will change the outcome
4. We will investigate how long it takes for traffic jams to form under certain conditions

These objectives will be achieved by implementing a traffic flow model. The functional requirements for this model are;

1. Allow users to change a range of variables in the model
2. The model may include a GUI
3. The code should adhere to conventional coding practices

The only non-functional requirement for the model is:

1. The model should be developed in Java

The following requirements are unlikely to be included in the model;

1. The model will not take account of road layouts, such as traffic lights, slip roads

2. The model will not take account of pedestrians
3. There will be no consideration of road types other than a motorway
4. The model is designed to represent an area of a road, rather than a whole network (other road types, pedestrians etc)

3.2 Hypotheses

After considering all of the literature looked at in the previous chapter we have been able to create a couple of hypotheses which we intend to verify later in the project, once the model has been created. These hypotehses are;

1. Drivers who use mobile phones have a negative impact on traffic flow, causing traffic jams to form more quickly than when no mobile phone using drivers are in the traffic stream
2. The more drivers there are who are using mobile phones, the quicker a traffic jam will form

Chapter 4

Design

4.1 Introduction

The design aspect of this project is more difficult to document due to it being a research project. A research project such as this needs more of an evolutionary development because the specific details of what the model should look like are undefined, and we are unsure as to how many of the objectives can reasonably be implemented. This project is more based around what we hope to achieve, and whether in the end this is actually possible, so to this end no particular framework is going to be used to help with the design aspect.

Having said that there are a number of areas of the project for which we can create some design criteria for based on what we hope to achieve. It will be necessary to define the characteristics of the agents, the environment, and also to look at the results we can extract from the model. The following sections look at each of these points separately to determine how we will be able to implement a model which will yield meaningful results. The ultimate aim is to achieve the objectives set out in the previous chapter (Chapter 3).

4.2 Vehicles - Agents

The resulting model for this project is to be an agent based model, therefore principles of agent based modelling need to be applied. Burmeister, Haddadi and Matylis (1997) note that using agent-oriented techniques means that all the software development processes are rolled into one concept, ‘agents’, and so a system which models a collection of agents is known as a multi-agent system (MAS). In the model we are to create, cars will be the entities modelled as agents.

4.2.1 Agent Type

Wooldridge (2008) identifies a number of different types of agents, each with varying abilities. For this project cars will be implemented as purely reactive agents[1]. 4.1 is a diagram of a purely reactive agent.

Purely reactive agents are the simplest type of agent. They simply react, at each time step,

---

[1] Page 33, Chapter 2, Section 6

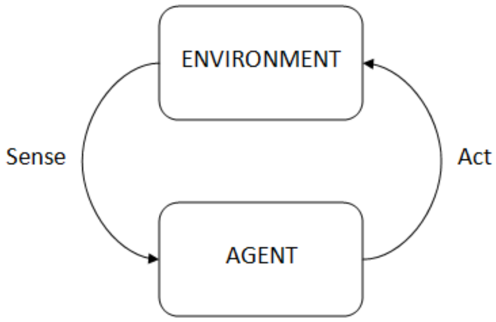


Figure 4.1: A Purely Reactive Agent

to the current conditions of the environment. This means that they have no memory and therefore do not learn from previous experiences within their environment. Wooldridge (2008) identifies a simple function which we can use to describe these types of agents;

$$Ag : E \rightarrow Ac, \tag{4.1}$$

where Ag is an agent, E is the environment, and Ac is the action which the agent chooses to take based on the current state of the environment. This will be how the car agents work within our model, simply reacting to the current situation and adjusting their next speed as necessary. Whatever type an agent is, ie whether it learns from its history or not, they all have one thing in common; a goal. All agents take actions in order to achieve some desired goal. Dastani, van Riemsdijk and Meyer (2006) note that the goals which agents have determine the decisions they take and actions they perform. Then a goal can be defined as a state which the agent is striving for by using the actions which are available to it. Using all this information about purely reactive agents we can now determine the environment, actions, and goal for the agents in our model.

- The **agents** in our model will be cars
- The **environment** will be a single lane road
- The two main **goals** of each agent will be to reach their maximum speed, and not crash into the vehicle in front
- The main **actions** which the agents can take are;
    1. Slow down (decelerate)
    2. Speed up (accelerate)
    3. Stop (set speed to zero)

4.2.2 Agent Attributes

There will only be one type of agent in the model, a car, and every car will have a number of attributes. However each vehicle will have different values assigned to their attributes in order to make them all behave slightly differently. In order to simulate the behaviour of vehicles we need to decide what attributes will be required, and the values for each. Table 4.1 shows what these attributes will be, along with their possible values, and also an explanation as to why each of them is needed.

Table 4.1: List of Vehicle Attributes

ATTRIBUTE	**VALUES/VALUE RANGE**	**REASON**
Speed	4 - 5.67	Each vehicle needs to move forward at a certain speed, which is initially set to be a value between 0 and 2
Maximum speed	minimum distance - 0.1	Each vehicle wants to drive at a maximum speed slightly less than their minimum distance, to ensure they can maintain this distance
Minimum speed	0.01	Unless forced to, a vehicle should not drive at a speed lower than 0.01, so that it is always making progress
Minimum distance	maximum speed - 0.01	Each vehicle has a minimum distance that it wants to maintain from the car in front
Driver type	0 or “mobile-user”	To model cars who have drivers who use mobile phones a variable is used, which is set to ‘mobile-user’ if the driver uses a mobile phone and ‘0’ otherwise

More details about the chosen language, NetLogo, will be explained in the next chapter, however we should note here how speed, time and distance are modelled in the environment. Time is an aspect that is in-built in NetLogo, because it works by changing the model state at each time ‘tick’. The values shown in the table under ‘speed’ variables are really the distances to be travelled by each vehicle. Then by applying the standard speed, distance, time equation we can see that the overall effect is that speed is in fact being modelled;

$$speed = \frac{distance}{time} \tag{4.2}$$

4.2.3 Other Characteristics

In the above section we have identified the main attributes which will simulate the characteristics of vehicles in the model. In addition to this there are a few rules which the vehicles will have to adhere to, and the vehicles will have to be set up in a certain manner each time the model is run. These are all described below;

1. The vehicles will move forwards only, never turning at all, and not going backwards.

2. When vehicles reach the end of the ‘world’ they will enter the world again from the front. In this way the simulation will be modelled as a continuous traffic stream, rather than coming to the end of a road/a dead end. In this way we will be modelling a motorway as closely as possible, as motorways are very long stretches of road on which vehicles rarely reach ‘the end’.

3. Initially the vehicles will be set up so no two (or more) vehicles occupy the same area, as they would not in real life. See explanation below (section 4.2.3.1) on the algorithm used to simulate this.

4.2.3.1 Vehicle Separation Algorithm

When the model is set up each time to be run, no vehicle should occupy the same area on the road, because this would not exist in the real world. In fact, to ensure that a car is not too close to any other vehicle it should at least be the minimum distance from the car in front. Below is the pseudo code for this algorithm;

```
separate cars
    for each car
        if there is a car in front of the current agent
            if the distance to the car in front is less
            than the minimum distance, then
                move backwards 1            //in order to increase the distance
                                              to at least the minimum distance
                separate cars               //keep calling the procedure until
                                              all cars are equally spread out
```

4.3 Car Following Algorithm

The car following aspect of the simulation is the key part to the model. This algorithm will be responsible for deciding how each vehicle will react to the current environment state. This algorithm essentially controls the whole of the model. Many of the different traffic models already existing were discussed in the literature survey, and we have chosen one of these as a basis for our model. This model comes from the cellular automaton model proposed by Nagel and Schreckenberg (1992) and looked at by Barlovic et al. (1998). There were four main aspects to the model, called ‘modes’ and each vehicle would choose one of the four modes to adopt at the next time step. Refer to section 2.5.1.2 in the literature review for full details of these.

1. Braking
2. Accelerating
3. Randomization
4. Driving

So this model is to be the basis of the model which we are going to implement. We will adapt some parts of it, and also we will need to add the mobile phone drivers to it, as this is the main aspect we are investigating. The following paragraphs detail certain parts of the algorithm and highlight the key aspects which will enable us to create a model which will enable us to prove, or disprove, our hypothesis.

```
for each car
    move forward at current speed
    if there is a car in front of you
        [section A]
    else
        [section B]
end
```

Initially each car moves forward its current speed, and then needs to check whether there is anyone in front of them. This is because the car at the front of the traffic stream will need to react differently to all the other cars who have another car in front of them.

SECTION A

```
if the distance between you and the car in front is less than your
minimum distance
    set speed to be the same as the minimum speed
else
    increase speed using ‘acceleration’ value
```

This section checks the distance between the current car and the car in front, and then that car either accelerates or decelerates depending on this distance. At this point the ‘delay’ value for cars with a driver who are using a mobile phone is taking into consideration, whether the car is accelerating or decelerating.

SECTION B

```
if the distance between the current car and the car at the front of
the stream is less than the minimum distance
    set speed to be the same as the minimum speed
else
    increase speed using the ‘acceleration’ value
```

This section takes care of the car that is at the front of the stream, as the specific calculations required for this vehicle are slightly different than for all other cars. Again the ‘delay’ value is taken into consideration for any cars who have a ‘mobile-user’ in the car.

4.3.1 Avoiding Collision

As described in the algorithm above the vehicles will avoid colliding with any other vehicles by ensuring that a vehicle never moves past the position of the vehicle in front. This is an important aspect to consider if we are talking about modelling traffic jams. In the real world, if a car in front is going very slowly, then the car behind must slow down in order not to crash into the car in front, and this slowing down causes a traffic jam (if there are enough cars slowing down). While there is the possibility in the future of adding a ‘colliding’ aspect to the model to see how long it takes for a car to crash into another one, initially we are just investigating how traffic jams form.

4.3.2 Speed Scaling

We previously mentioned how speed is modelled in the NetLogo environment, as cars will move a distance over each time 'tick'. There is an important point to consider when working out what speed scaling will be applied to the model, and this is as follows. When creating a model we want it to simulate the real world as closely as possibly. Choosing any random values for the speed wouldn't make sense, as it would have no real relation to the real world. For this reason we had to choose some sensible values which scale to the real world.

The maximum speed limit on British motorways is 70mph, however in reality drivers tend to drive at varying speeds around this value. This assumption is backed up by statistics from The Department for Transport[2]. Table 4.2 shows a snapshot of some of the data from this source which was used when deciding what values to use in our model.

Table 4.2: Car Speeds on Motorways

Speed Range	**Per cent of Cars**
<50mph	4
50-59mph	12
60-64mph	12
65-69mph	18
70-74mph	20
75-79mph	16
80-89pmh	15
>90mph	3
Total Cars Observed (thousands)	**423,289**

The source also noted that the average speed of all the cars was 70mph. As we can see there is quite a spread of speeds, therefore it would be unrealistic to set all cars in our model to travel at 70mph. According to the table 50% of all cars were travelling between 60mph and 79mph. This range would be a good range to use in our model rather than having a set maximum speed for all cars.

Another consideration was that using certain values for the speed caused the model to change state far too quickly to watch accurately, so we had to find values which would be suitable also for this purpose. By testing the model before fixing these values we discovered that a speed of 1 unit was too slow as the model updated at a very slow rate. Values of 9 and 10 made the model move extremely fast and it was too difficult to see the effects that were being created. After experimenting further with the modelling environment we decided on the scaling values for time and distance. These can be seen in table 4.3.

Table 4.3: Model Scaling for Time and Distance

Variable	**Unit**	**Scaling**
Time	1	15 seconds
Distance	1	15 miles

The resulting speeds, per 1 'tick' are shown in table 4.4.

---

[2] Source: www.dft.gov.uk/pgr/statistics

Table 4.4: Speeds

Distance	**Speed**
1	15mph
2	30mph
3	45mph
4	60mph
5	75mph
6	90pmh

So, in order to simulate speeds of between 60mph and 79mph the model will need to use values for distance between 4 and 5.2667.

Another aspect to point out from statistics from The Department for Transport is that they took into consideration other vehicles than just cars. Table 4.5 sums up this data.

Table 4.5: All Vehicle Speeds on Motorways

Vehicle Type	**Total Cars Observed (Thousands)**
Motorcycles	3,243
Cars	423,289
Cars Towing	2,934
Light Goods	63,161
Buses/Coaches	3,536
Heavy Good Vehicles	80,100
Total Vehicles Observed (thousands)	**576,263**

From this table we can see that cars accounted for almost 75% of all traffic on the road, therefore we feel it is suitable to only model cars in our model, rather than other types of vehicles as well. To re-iterate the point that our model is more about the mobile phone drivers than the types of vehicles, we feel that only modelling cars will not have a massive impact on the results.

The minimum distance value was something else to consider when deciding what values to use. Drivers in the UK are advised to abide by 'the two second rule' when driving on a motorway, which means that a driver should not be closer than two seconds distance between himself and the car in front. An estimation of this distance while driving is made by selecting a fixed point, watching when the car in front goes past that point, and counting the time until you yourself have gone past that point. This rule of thumb is noted in a paper by Taieb-Maimon and Shinar (2001) who says that drivers are advised to "maintain a headway of 2 [seconds]". However in reality a lot of drivers do not strictly adhere to this rule, either being more cautious than this, or driving at a distance less than two seconds to the next car. This decision is personal to each driver and is based on their own perceptions and what they think is acceptable. Therefore to simulate this in our model we have decided to vary the value of the minimum distance, making it 'personal' to each car, as would be the case in the real world. It is worked out with reference to the maximum speed, to ensure that a car wont travel at a speed greater than their minimum distance, otherwise they may continually be reducing their minimum distance.

4.4 Environment

As previously mentioned, the model is being simulated as a ‘continuous’ single lane section of motorway in order to simulate the real world environment where cars are usually on the motorway for a long time. The model will look something like this.

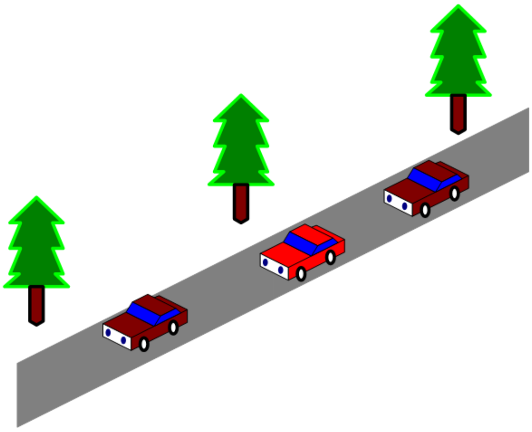


Figure 4.2: Model Design

Other design decisions were made about the environment, including aspects of the real world which would not be simulated in real life. Again this is because the main focus of this project is to assess how drivers who use mobile phones affect traffic jams, so too much time being spent on potentially unnecessary aspects would be a waste of time. The following list explains more about the environment;

1. The environment is modelled as a single lane section of motorway
2. Drivers do not overtake other cars or change lanes, as there are no other lanes to move to
3. The road is modelled as a continuous loop, with no slip roads which would change the number of vehicles on the road
4. The only type of vehicles to be modelled are cars, not other vehicles such as lorries and motorcycles

4.5 Interface & Design of Experiments

The main point of creating a traffic simulation model is to be able to extract data from it which we can use to verify whether or not our hypotheses were correct. To this end the model does not need to be be extremely user friendly with lots of functionality to play around with, but simply usable and useful. Once the model has been set up according to the designs detailed above it will then be necessary to run some experiments with the model.

Referring back to the two main hypotheses we created earlier, we expect this project to show that;

1. Drivers who use mobile phones have a negative impact on traffic flow, causing traffic jams to form more quickly than when no mobile phone using drivers are in the traffic stream
2. The more drivers there are who are using mobile phones, the quicker a traffic jam will form

In order to prove, or disprove, these two hypotheses we will need quantitative results from the model. Simply looking at the model as it is running to see the effects will be useful during the initial development of the model, in order to see how useful it is, but when it gets to the final model we will need to use graphs and data in order to back up the hypotheses, or not. Below are details as to how we plan to create the experiments, run them, and the data we expect to extract from them.

4.5.1 Hypothesis One

This hypothesis essentially looks at the difference between a road with no drivers using mobile phones, and one with. In order to prove this hypothesis we need to look at the two extremes. To run this experiment the following steps will be carried out;

1. Setup the model with x number of cars (no drivers with mobile phones)
2. Run the model for y ticks
3. Extract a graph which shows the speed of one of the cars - watch for the point at which the speed is reduced to zero, meaning the car is in a traffic jam
4. Repeat steps 1 - 3 but this time with all cars having drivers who are using mobile phones

In this way each time the experiment is run, using different values for the number of cars we will be able to compare the difference in the time it takes for a traffic jam to form between a road with all mobile phone users, and without.

4.5.2 Hypothesis Two

This hypothesis is focussed on the difference in time for a traffic jam to form when there is a low proportion of drivers who are using a mobile phone compared to when that proportion is higher. Again graphs will be used to extract data on how long it takes for a car to achieve a speed of 0, meaning they have got caught up in a traffic jam. The following steps will be carried out in order to assess the hypothesis;

1. Setup the model with x number of cars, with y number of those being cars who have drivers using a mobile phone
2. Run the model for z ticks
3. Extract a graph which shows the speed on one of the cars
4. Repeat steps 1 - 3, using the same number x of cars, but with a larger value for y

Again, the data collected from this set of experiments will be compared to work out whether the hypothesis was correct on not. This will involve comparing the data for every value of x chosen with all the values of y chosen to see if there is a difference when the value of y is low, compared to when it is high.

It should be noted at this point that however much we have aimed to design a useful model, and have designed experiments around the results we wish to obtain, this does not guarantee that we will be able to achieve all of this. Being that this is a new area of research it is, at this stage, unrealistic to assume that we will be able to achieve everything we have set out to.

4.6 Summary

This section of the project has aimed to create a design for our model and look at the ways in which we can go about proving the hypotheses that were set out earlier in the project. It is likely that some of the design criteria will change in the actual model as we find some elements that are infeasible, or discover new aspects that we wish to add to the model. The next chapter will briefly introduce the implementation side of this project to identify how the model was created.

Chapter 5

Implementation

5.1 Introduction

The previous chapter looked at the design criteria for the model and also at the experiments that were required in order to verify the hypotheses. The purpose of this chapter is to describe how the model was implemented, how useful the chosen environment was in aiding this implementation and any problems and issues we had when creating the model. We will touch on the experiments however the results of these, and a discussion of the validity of the model is left for the next chapter.

5.2 The Modelling Tool

Once the design of the model had been decided and how the experiments would be conducted to gain the results we needed, we then had to decide on how the model would actually be implemented. In the previous chapter we touched on the fact that NetLogo was chosen to be the modelling environment, so in this section we will identify the reasons for this choice and the other options that were available to us.

5.2.1 Java

Rather the using a tool which aids agent based modelling, another option would have been to create the whole model from scratch in a language such as Java. Java would have been a good choice due to the programming abilities of the author. The benefit of starting a model from scratch would have been that everything would have been created in accordance with the needs of this project, which would have allowed for a more flexible solution than being tied to the features of a tool such as MASON or NetLogo. On the other hand though creating a whole model from scratch would have been incredibly time consuming. Features which are available in pre-existing modelling tools would have had to be created, for example to control the timing of the modelling. Additionally the visualisation of the model would have been harder to create, whereas most of the agent based modelling tools are capable of producing graphics for the model created by the user, with no extra effort. To have added graphics to a model created in Java would have required a lot of effort, and it is important to remember that the purpose of the model we created is simply a tool with which to run experiments. We are not concerned with making an eye catching model, therefore it was suitable to use a program which has this functionality built in, despite the few restraints that this meant.

5.2.2 MASON

MASON (Multi-Agent Simulator Of Neighborhoods)[1] is a multiagent simulation tool capable of simulating many different types of models with a graphical interface. MASON is a popular choice when it comes to creating models because it is very flexible and can be used for a variety of applications from social science to artificial intelligence Luke, Balan, Panait, Cioffi-Revilla and Paus (n.d.). This tool can produce both 2D and 3D graphics from the models created, which helps users to visualise their simulations. While MASON was a potential candidate for creating our model, after further investigation it transpired that a lot more work would have to be done to enhance our understanding of the tool before we could begin to use it. Given that NetLogo appeared much more simple to use and yet would yield just as good results it was decided that MASON would not be chosen.

5.2.3 NetLogo

After Java and MASON had been considered we decided to look at the feasibility of using NetLogo to create our model. NetLogo is also a multi-agent modelling environment suitable for creating models for a wide range of purposes. Like MASON it generates both 2D and 3D visualisations of models created by users which is extremely useful. We investigated some of the models that are already available with NetLogo when downloaded, and were able to manipulate these to see how NetLogo works. We also discovered there were a couple of traffic flow models, and this is one of the reasons we chose to use NetLogo, having seen what the potential outcome of our model could be. It also appeared that NetLogo was slightly easier to use than MASON was, and so this cemented our decision to pick NetLogo as our modelling environment.

NetLogo models are made up of ‘patches’ and ‘turtles’. Turtles are the agents being modelled and they move over the patches in the environment. The patches can be changed to any colour to suit the needs of the programmer and therefore any design can be implemented to look like the required environment. The size of the world can be set to any size needed, based on an x and y coordinate, so the resulting world is based on a grid, which looks like the image in figure 5.1.

5.3 Implementation of Model

The model created for this project was, in the most part, implemented as per the design criteria set out in the previous chapter. However during the implementation it became apparent that in order for the model to work accurately a few things would have to change, and these changes are noted below. Once these changes had been made and the model was finished it was then in a state to start using for carrying out the experiments detailed in the previous chapter.

---

[1] http://www.cs.gmu.edu/ eclab/projects/mason/

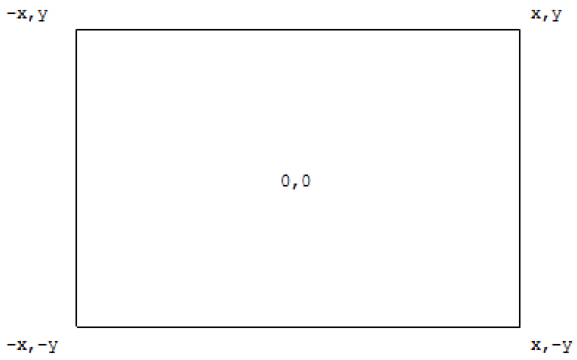


Figure 5.1: NetLogo Environment Grid

Figure 5.2 shows the interface for the model we created. The top section is the road being simulated, and the buttons/sliders underneath are used to manipulate and run the model. The red cars in the model are those which represent cars which have a driver using a mobile phone, and the blue cars are those without. The graph is the output which is being used to extract data from the model. It plots the speed of one of the cars for the duration of a 'run' of the model, and by then exporting this we can obtain the data at each time interval and use this to verify the hypotheses we created earlier.

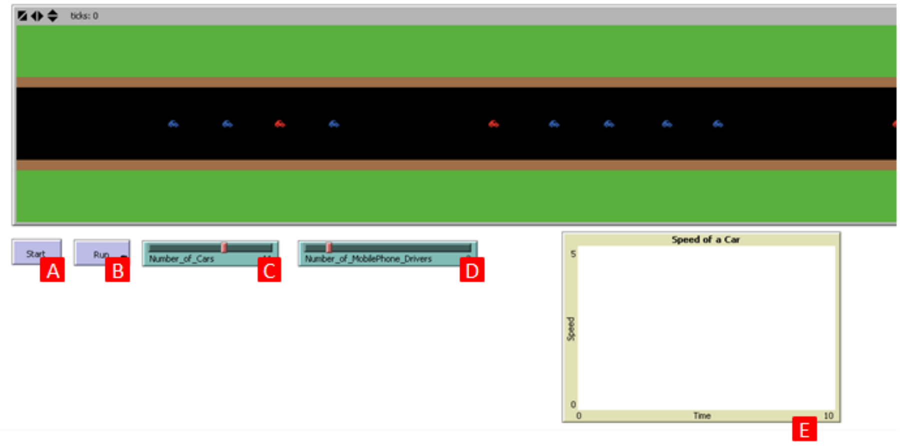


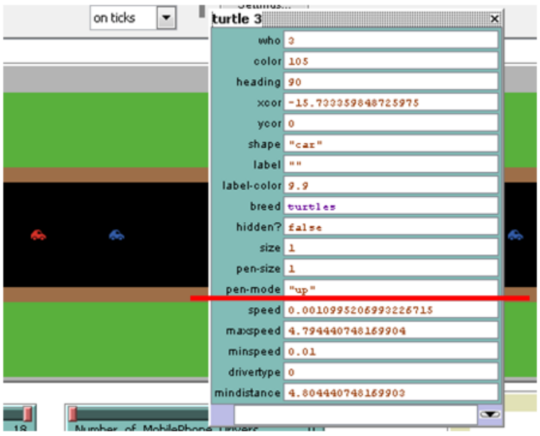
Figure 5.2: Model Interface

Below is an explanation of each of the buttons/sliders in the image.

- Button **A**: Setup - This button is used to set up the model each time the user wants to run the simulation. It resets all the environment and car variables and the graph in order for the model to be run 'afresh'
- Button **B**: Run - This button runs the model, and is set to be continuous, so the code inside the 'run' procedure is executed repeatedly until the user clicks the button again to stop the simulation.
- Slider **C**: Number_of_Cars - This slider is used to set the number of cars on the road, with values between 1 and 18.

- Slider **D**: Number_of_MobilePhone_Drivers - This slider is used to set the number of cars who have a driver using a mobile phone, with values between 0 and 18
- Graph **E**: Speed Graph - this graph will plot the speed of one random car during the simulation

Figure5.3 shows the 'turtle inspector' for one of the car agents. The inspector allows users to look at the state of an agent at any time they wish, showing the values of each of the variables. The variables above the red line are in-built in NetLogo so apply to all agents in any model. Those below the red line are the variables that we have added for the purpose of this project.



who 3
color 105
heading 90
xcor -15.733359848725975
ycor 0
shape "car"
label ""
label-color 9.9
breed turtles
hidden? false
size 1
pen-size 1
pen-mode "up"
speed 0.0010995206993226715
maxspeed 4.794440748169904
minspeed 0.01
drivertype 0
mindistance 4.804440748169903

Figure 5.3: A Turtle Inspector

5.3.1 Change of Algorithm

For the most part we were able to implement the model according to the design criteria and algorithm which were set out in the previous chapter. There was however one slight adjustment that needed to be made, and this was discovered after the first basic attempt at the model had been made. The problem was at the point in the algorithm where cars calculated their new speed. Initially we had thought it was sufficient for each car to work out their current distance to the car in front, and then set their speed higher if there was plenty of space between him and the car in front, or reduce their speed if the gap was smaller than defined. This was fine except for one element; the current distance between them and the car in front may be ok, but since cars moved forward at the start of every 'tick' ie before the distance was checked, this could mean that on the next tick the car would end up at a distance in front of the car in front, which evidently would not be simulating the real world correctly. It was therefore decided that at each time interval, as well as checking the current distance between a car and the one in front it would also be necessary to calculate the next distance between each car and the one in front to check that at the next step the distance between the cars would be sufficient. This is best explained with an example;

Say car A is at (0, 3) and has a speed of 3. Car B is in front at (0, 6) and has a speed of 2. We will say that the minimum distance car A wishes to maintain between it and car B is 3, so currently this distance is being maintained ($6 - 3 = 3$), and so using our original algorithm car A would not change its speed. However at the next time step car A will be at (0, 6) and car B will be at (0, 8), and now the distance between the two cars will be 2 ($8 - 6 = 2$), and this is less than the minimum distance.

To rectify this problem we added another check into the algorithm, so that after the current distance between each car and the one in front was checked, whether this distance was less than the minimum distance or not, another check was performed to check what the **next** distance would be, at the next time interval. The new speed was then calculated based on this distance, rather than the current distance. In this way we were able to ensure that the model simulated the real world as closely as possible, because in reality a driver would decide whether to speed up or slow down based on where the car in front would be next, not where it currently is. For example if a car in front is stationary but the distance between you and this car is greater than your minimum distance, this doesn't mean that you should speed up now, because if the car in front remains stationery you will end up crashing in to it.

5.4 Summary

The implementation of this model was relatively straight forward to accomplish and this was largely due to picking a good modelling tool in the first place. Although a few of the design criteria had to change we were able to produce a model which does simulate traffic flow and traffic jams relatively well, and definitely to the point where we are able to extract useful data from it. The next chapter will go on to discuss the experiments that were carried out and the results of these, as well as looking at the validity of our model. This will also include a discussion on whether or not we were able to prove the hypotheses which we set out earlier.

Chapter 6

Experimental Results & Analysis

6.1 Introduction

This chapter looks at the experiments that were carried out using our model. The purpose of these experiments was to be able to extract data from the model which could then be used to determine whether or not our two hypotheses were correct. There is also a discussion about the validity of the model we created and how this may have impacted on the results we obtained

6.2 Running the Experiments

While quantitative results of experiments run using the model are detailed below, the model did succeed in being able to model traffic jams when some drivers were using a mobile phone. This can be seen in the images below. Figure 6.1 shows the model before ‘Run’ is clicked, when the environment is first set up. Here the cars are all spread out across the road section.

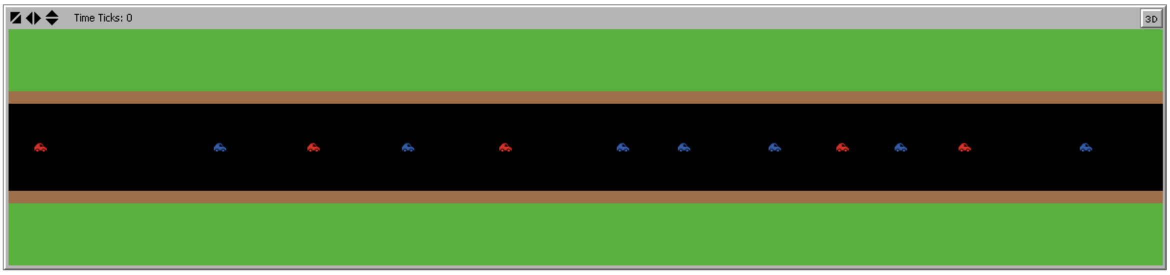


Figure 6.1: Simulation before being run

We can then see in figure 6.2, after the simulation has been run for a while, how some of the cars have ‘bunched up’ thus forming a traffic jam.

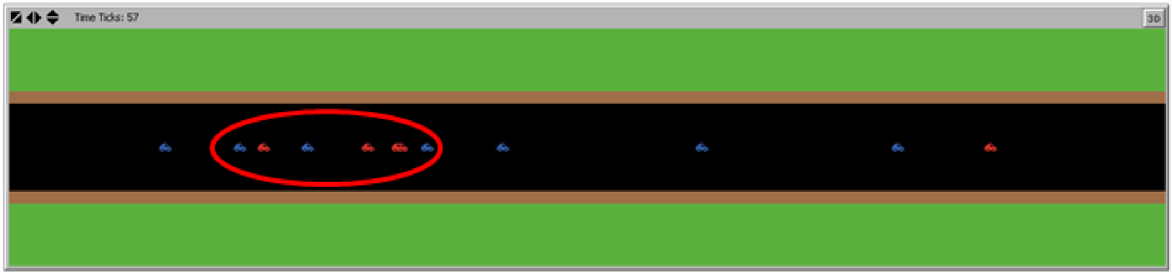


Figure 6.2: Traffic Jam

6.3 Running the Experiments

In order to determine the point at which a traffic jam occurred during each of the experiments we needed quantitative data. It was easy to look at the visual output of the model and see when a traffic jam had occurred but we needed actual data in order to use this to prove our hypotheses. We therefore decided the best way to do this would be to look for the first point at which the speed of the car remained at 0 for longer than 2 ticks (30 seconds), meaning that the car had not moved for a while. This would then mean that the car had got caught in a traffic jam. We decided on the value of 30 seconds having had a look at some of the literature, which unfortunately does not include data about how long a car is stationary before we can consider it to be stuck in a traffic jam. In part this is a very subjective aspect to traffic flow, which we have had to try to quantify. A discussion of the impact of this on the validity of our model appears later in this section.

When looking for points at which traffic jams occurred we looked for where the value for speed was ‘0’ three or more times in a row, then the calculation of how long the traffic jam took to form was based on the first time interval at which the speed was ‘0’. For example in the table 6.1 the speed of the car remained at 0 for four ticks, or one minute. In this case we would say that the traffic jam occurred after 7 mins 45 seconds (31 ticks) as this is the first time interval when the speed was 0.

Table 6.1: Snapshot of Experiment

Time (ticks)	**Speed**
30	1.869
31	***0***
32	***0***
33	***0***
34	***0***
35	1.613653433

The experiments were run according to the ‘design of experiments’ steps detailed in the previous chapter. To gain data to use to prove hypothesis one we ran the experiments three times. Below are explanations of our findings from running these experiments.

6.4 Hypothesis One

Our first hypothesis was as follows

> Drivers who use mobile phones have a negative impact on traffic flow, causing traffic jams to form more quickly than when no mobile phone using drivers are in the traffic stream

Table 6.2 shows the results obtained from running all the experiments twice. Due to the restriction of space on the page we have not included all the values from the repeated experiments but instead have shown just the average values based on both sets of experiments. For the full table see Appendix A.

The experiments for this hypothesis were run twice in order to gain an average for the results, rather than using only one set. To have gained even more reliable results the experiments could have been run several more times, but due to time constraints this was not possible. Additionally we really produced this model in order to start having a look at the effect of mobile phones in causing traffic jams, so experiments requiring a lot of time and effort would perhaps be better once the model is further improved. Nevertheless we gained some useful results from the experiments that were run using the model in its current state. For a selection of the experiment data and their graphs see appendix B.1.

The way we intended to verify, or falsify, this hypothesis was by comparing the time taken for a traffic jam to form with a road full of cars who have drivers using a mobile phone to a road with cars without drivers using a mobile. We ran thirty-six experiments; the model can fit a maximum of eighteen cars, and for each number of cars we had to compare them all being non-mobile phone cars to them all being cars with drivers using a mobile. The results we obtained were not as conclusive as we had hoped for. Table 6.3 sums up the overall findings of the experiments. What this shows is that on two occurrences (where an occurrence is defined as both experiments for a specific number of cars) no traffic jams resulted. On six occurrences it was the experiment with no mobile phone drivers which caused a traffic jam sooner than with all mobile phone drivers, and on nine occurrences this was the other way round.

If we ignored the two occurrences when a traffic jam did not occur at all then we can say that for 60% of the time a traffic jam occurred quicker when the traffic stream was made up entirely of cars who had drivers using a mobile phone compared to when it was made up of entirely cars without drivers using a mobile. Although this is not completely conclusive we can say that our hypothesis was going in the right direction, and clearly there is some correlation between the number of cars which have a driver using a mobile phone and the time it takes for a traffic jam to form. The purpose of these experiments was to determine whether our hypothesis was correct or not, but it has been observed visually that our hypothesis was correct. It appears that this is very difficult to quantify, and this is probably due to the way in which the experiments were conducted. We had no concrete data on which to base our experiment with regards to how long a car should remain stationary before it is considered to be in a traffic jam, so we had to use values which we felt were realistic.

Having said all of the above, we did say that in quite a few of the cases we found that when the traffic stream was made up of all cars which had mobile phone using drivers this resulted in a traffic jam occurring earlier than without. To look at this we can take a couple

Table 6.2: Results from Experiments

			Average from Two Rounds	
Experiment Number	**Number of Drivers**	**Number of Mobile Phone Drivers**	**Time Taken for Traffic Jam to form (ticks)**	**Time Taken (mins)**
1	1	0	n/a	n/a
2	1	1	n/a	n/a
3	2	0	n/a	n/a
4	2	2	n/a	n/a
5	3	0	n/a	n/a
6	3	3	138.5	34.63
7	4	0	69.5	17.38
8	4	4	n/a	n/a
9	5	0	108	27.00
10	5	5	326.5	81.63
11	6	0	21	5.25
12	6	6	52.5	13.13
13	7	0	44	11.00
14	7	7	44	11.00
15	8	0	22	5.50
16	8	8	18.5	4.63
17	9	0	23	5.75
18	9	9	20.5	5.13
19	10	0	29.5	7.38
20	10	10	20.5	5.13
21	11	0	13.5	3.38
22	11	11	18	4.50
23	12	0	23.5	4.52
24	12	12	13	0.67
25	13	0	21	2.91
26	13	13	11	2.38
27	14	0	23.5	3.29
28	14	14	21.5	2.55
29	15	0	12	2.75
30	15	15	13.5	1.90
31	16	0	19.5	1.68
32	16	16	11	1.52
33	17	0	15.5	1.54
34	17	17	24.5	4.28
35	18	0	7.5	1.75
36	18	18	4.5	1.00

Table 6.3: Overall Findings of Hypothesis One Experiments

	Occurrences
N/a (No Traffic Jam Occurred)	2
No Mobile Phones	6
All Mobile Phones	9

of the results from the experiments and analyse what we found.

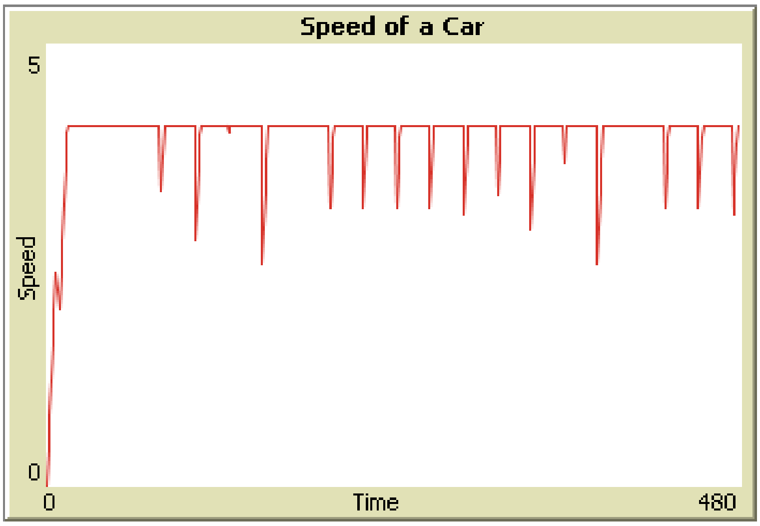


Figure 6.3: Experiment 9: 5 cars - all without drivers using a phone

Figure 6.3 shows the graph that was produced when running an experiment with five cars, all of which represented drivers not using a mobile phone. In this graph there were no points at which the speed of the car remained at ‘0’ for longer than forty-five seconds. Compare this to figure 6.4, the graph from the experiment with five cars, this time all of which had drivers using a mobile phone. On this graph we can see the point (circled in red) at which the car got stuck in a traffic jam. The difference between these two graphs is that when all the drivers were using a mobile phone a traffic jam occurred - quite far into the simulation, but nevertheless one occurred. This was not the case with the other experiment.

Using these two experiments we can show that our hypothesis was correct, and this was one of a few occasions where this was the case. We have discussed the reasons why the experiments may not have been able to prove this conclusively, but also that traffic jams were observed using the visual output where they occurred quicker when cars had drivers who were using mobile phones. We will now go on to discuss our second hypothesis.

6.5 Hypothesis Two

The other hypothesis we created earlier in the project was as follows

> The more drivers there are who are using mobile phones, the quicker a traffic jam will form

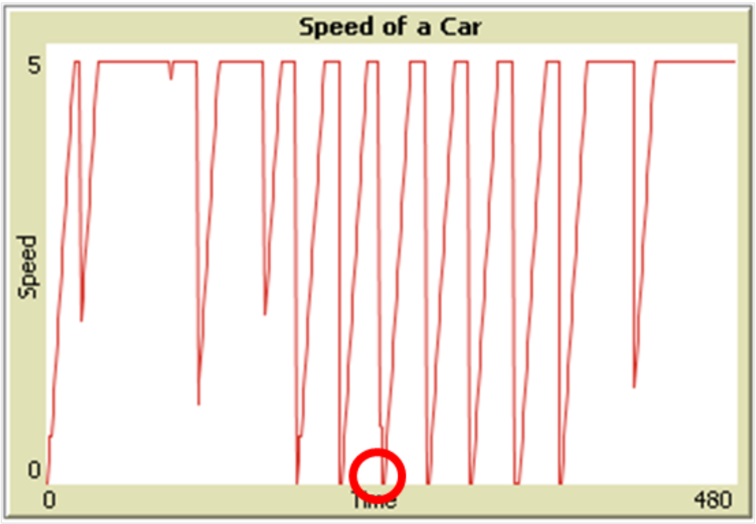


Figure 6.4: Experiment 10: 5 cars - all with drivers using a phone

In order to test this hypothesis we ran eleven experiments. Each time the number of cars was ten, but the number of those who were cars with a driver using a mobile went up, starting at one and finally to all ten. The results of these experiments are outlined in table 6.4

Table 6.4: Results of Experiments for Hypothesis Two

Experiment Number	**Number of Drivers**	**Number of Mobile Phone Drivers**	**Time Taken for Traffic Jam to form (ticks)**	**Time Taken (mins)**
1	10	0	19	4.75
2	10	1	15	3.75
3	10	2	28	7
4	10	3	26	6.5
5	10	4	31	7.75
6	10	5	30	7.5
7	10	6	20	5
8	10	7	16	4
9	10	8	19	4.75
10	10	9	24	6
11	10	10	17	4.25

A graph of these results is shown in figure 6.5. What the table and graph show us is that this hypothesis was not proved to be true by the results that we gained. Again however when we observed the simulations manually we found that on many occasions a traffic jam seemed to appear quicker the more cars who had drivers using a phone there were. The same criticisms of these experiments can be made as for the previous hypothesis, but nevertheless this is interesting data that can be used in order to help us further our understanding of the phenomena of traffic jams amongst drivers who use a mobile phone.

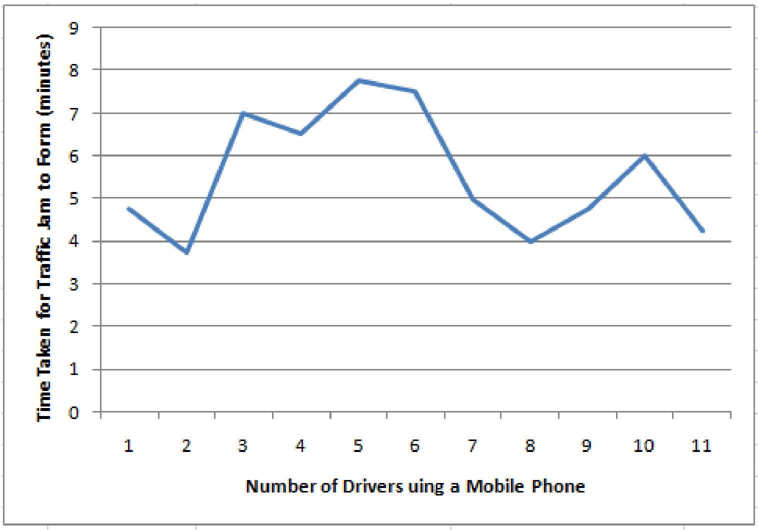


Figure 6.5: Graph of Hypothesis Two Experiment Results

6.6 Other Observations

Aside from looking at our hypotheses we found some other interesting points when we ran the experiments, which we had not originally considered but which can tell us some interesting things about drivers who use phones when driving, or more accurately about how this impacts on traffic jams.

One point that we noted was that on some occasions a car who was in a stream full of cars who had drivers using a mobile phone spent a larger proportion of their time in a traffic jam than a car who was in a stream which had no mobiles phone using drivers. Table 6.5 shows the total time spent in traffic jams for one car in each experiment. What this table shows is that there are ten occurrences on which it was the road full of cars with drivers using a mobile phone that spent the longest amount of time in a traffic jam, compared to when all those cars had no drivers using phones. This tells us that when a road is full of cars where all the drivers are using a mobile phone it takes longer for cars to get out of a traffic jam. The reason for this is that due to their driving slower than drivers who are not using a mobile phone it takes them longer to regain their maximum speed after a traffic jam, so each car must wait longer for the cars in front to move again after a traffic jam, thus their speed remains at 0 for longer.

If we use the data from only those experiments where the road was made up entirely of cars with drivers using mobile phones, then we can plot a graph of how long cars remained in traffic jams. This can be seen in figure 6.6. The blue line on the graph shows the time spent in traffic jams, and the red line is the ‘line of best fit.’ The blue line is fairly consistent to the best fit line, and from this we can say that the higher the ratio of cars with drivers using a mobile phone to those without, the longer cars will remain in traffic jams. This is another interesting finding from the experiments run and tells us more about the behaviour of cars which have drivers using a mobile phone.

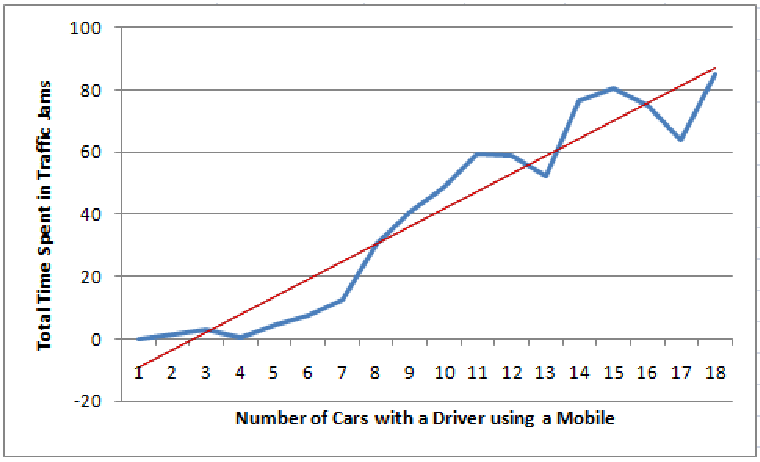


Figure 6.6: Time Spent in Traffic Jams

6.7 Validity of Model

An important aspect of this project to consider is how valid our model was and whether the results we have gained from it are completely reliable. This is a vital part of this project because it will also lead us to consider, in the next chapter, improvements and future work leading from this project.

With regards to the actual model we created we can say that this part of the project went well. We were able to produce a model which largely met the design criteria set out for it, and particularly we were able to provide a graphical output for the model, making results easier to view. A few iterations were required with more functionality being added at every stage before we got a model which we could use for extracting data. The positive aspects of the model are that it produces a good visible result regarding traffic jams as it clearly shows traffic jams which 'move' backwards over time.

If we compare our model to other models in this area of research we should point out the aspects of traffic flow which our model did not take into account. The first of these is driver behaviour, in particular the reaction time of drivers. When cars were forced to slow down due to a car in front slowing this included the slow down induced by using a mobile phone (2mph slower than drivers not using a mobile phone). However this calculation did not take into consideration the reaction time of drivers from the time they realise they need to slow down to the point when they apply the brakes of the car. This would have affected the results we gained slightly as this would have probably caused traffic jams to form more quickly than our results showed.

Another aspect that our model does not take into account is lane changing. Some traffic models show how traffic jams are formed my cars changing lane, often at 'inconsiderate' times, forcing drivers behind to slow down. Lane changing is a more difficult aspect to factor in to a model because of the dynamics that keep changing in not one but two lanes, and the fact that more than one car may change lanes at the same time. Having said that this does not mean that our model is useless because we stated from the beginning that lane changing would not be factored in, and were more concerned with how one lane traffic jams occur.

Many traffic flow models also tend to include slip roads (usually referred to as on- and offramps) in order to model the constantly changing density of traffic which is a characteristic of motorways. Adding slip roads which would add and remove cars at random intervals would change the dynamics of the road as cars already on the road section would probably have to slow down in order for new cars to enter the traffic stream. Again though this was not within the aims of this project which is why it was not included.

6.8 Summary

We have shown in this chapter the testing that was carried out in order to prove our two hypotheses. Although the results were not 100% conclusive we were able to show that our hypotheses did make valid observations about how quickly traffic jams would form, and were for the most part correct. We have identified the areas in which our model could have been improved, but the one which we created was of a good enough standard to use for our experiments.

Table 6.5: Time Spent in Traffic Jams

Experiment Number	**Number of Drivers**	**Number of Mobile Phone Drivers**	**Time Spent at Speed 0 (ticks)**	**Time Spent at Speed 0 (mins**
1	1	0	0	0
2	1	1	0	0
3	2	0	0	0
4	2	2	7	1.75
5	3	0	0	0
6	3	3	12	3
7	4	0	26	6.5
8	4	4	2	0.5
9	5	0	0	0
10	5	5	18	4.5
11	6	0	11	2.75
12	6	6	30	7.5
13	7	0	40	10
14	7	7	51	12.75
15	8	0	81	20.25
16	8	8	123	30.75
17	9	0	164	41
18	9	9	163	40.75
19	10	0	164	41
20	10	10	195	48.75
21	11	0	169	42.25
22	11	11	237	59.25
23	12	0	261	65.25
24	12	12	236	59
25	13	0	263	65.75
26	13	13	210	52.5
27	14	0	281	70.25
28	14	14	305	76.25
29	15	0	298	74.5
30	15	15	321	80.25
31	16	0	314	78.5
32	16	16	299	74.75
33	17	0	317	79.25
34	17	17	256	64
35	18	0	340	85
36	18	18	340	85

Chapter 7

Conclusions

7.1 Introduction

The original main objective of this project was to assess, through the creation of a model, the influence that drivers who use a mobile phone when driving have on the traffic flow of a section of motorway. Traffic jams are an annoying phenomenon for many people every day. The use of mobile phones is so widespread today that people expect to be able to contact and communicate with others no matter what task they are undertaking. In order to assess this effect we created a model for traffic flow which took this mobile phone usage while driving in to consideration. The previous chapters have described the work undergone to achieve this aim, and now we look to concluding all of our findings and discussing improvements on the model.

7.2 Strengths

The main strength of the model which we created is that it has proved useful in being able to run experiments with it and extract data from these. Given that we were investigating a relatively new area of research there was the potential that our outcome may not have been proved so successful. Strengths also reside in the fact that we were able to successfully factor in cars which had drivers using a mobile phone to the model. We did this based on data which we found in the literate so that it wasn't just a 'random' value - in this way we were able to produce a model which accurately simulated the real world.

7.3 Weaknesses

The weaknesses of the model which we produced have largely been discussed in the previous chapter. There were a lot of positive aspects to come out of the model, so whilst weaknesses also exist in it we have produced a good model. We would consider the main weakness to be that there is no flexibility in the model with regards to the cars which have drivers using a mobile phone. For these cars we included the 2mph slower speed that they drive at - but there is no way of changing this value, or to 'turn it off' for example if a driver may stop his mobile phone conversation. This isn't 100% true to the real world, and an aspect of the model which we would look to change in future developments of the model.

Another weakness is the fact that the model only simulates one type of road, and also in a limited capacity. In reality motorways have multiple lanes, cars move on and off the motorway via slip roads, and drivers change lanes fairly often. Additionally our model only looked at cars on a motorway rather than all types of road vehicles.

7.4 Improvements

In the previous chapter we touched on the validity of the model which we created for this project, and this provides the basis for us to consider the improvements that could be made to the model. The main improvement which could be made is to stop cars from ‘overlapping’. Although cars do not overtake other cars, as the minimum distance is always taken into consideration in the speed calculations, there does appear to be some overlapping of cars in the model. To improve the visual output of the model it would be better if this did not happen.

Another improvement would be to alter the calculations for the speed. As we have noted above the speed calculations take into consideration a 2mph slower speed for cars with drivers who are using a mobile phone. This is fine but an improvement on this would be the ability to vary this slow down. Realistically drivers usually spend only a portion of their total driving time talking on a mobile phone, answering and ending one or more calls within a journey, rather than starting a call when they set off and ending this call when they end their journey. In order to take this into the account the model could have a mechanism to vary this 2mph slow down in cars where the driver is using a mobile phone, so that when a driver ends a call their speed increases in line with the same calculations as cars without a driver using a mobile phone, and then reducing this again when the driver starts a new telephone conversation.

In terms of the model interface, for this project it was quite basic. We were mainly concerned with getting the model to work in order to be able to extract data from it. While all the commands in the interface do work there would have to be some further improvements before this could be used commercially. For example when a user selects the number of cars they would like on the road then the number of these which should be cars which have drivers using a mobile phone, there is nothing to stop users choosing more cars with drivers using a mobile phone than the total number of cars, and this causes the simulation to stop. Having said this the model is usable and works for the purpose intended for this project.

7.5 Future Work

Our model has made good steps towards considering the effect of mobile phones in causing traffic jams and has provided the basis for future work in this area. This future work could take many forms as there are many aspects which could still be added to this model. We looked at some of these in the last chapter in section 6.7 when considering the validity of our model.

The main area in which this project could be taken next is to add more aspects to the model in order to fully simulate a motorway. This would include adding slip roads to bring cars on and off the section of road. Another addition would be to include different vehicle types, including motorcycles and heavy goods vehicles, rather than just cars. This would add new dynamics to the model as other vehicles would drive at different speeds, for example the maximum limit for heavy goods vehicles on motorways in the UK is 60mph. This would also tie in to the lane changing aspect of motorways, which could also be added, to simulate how vehicles change lanes as they drive along the motorway. If we added different types of vehicles with varying speed limits this would cause some vehicles to change lanes and overtake other vehicles relatively often. If we were to also add a reaction time value to the calculations for slowing down, this would more accurately represent what happens in the real world.

Once the model was finally in a perfect state we could look to expanding the simulation into larger networks, to include different types of road such as dual carriage ways and roads with much lower speed limits. This would also include looking at adding road intersections such as roundabouts and traffic lights. In this way we would be able to simulate the real world even more closely.

7.6 Summary

This project has made a very good start in investigating the effect that the use of mobile phones have in causing traffic jams and the model which was created provides a visual representation of these effects.

Bibliography

Alm, H. and Nilsson, L. (1994), ‘Changes in driver behaviour as a function of handsfree mobile phones - a simulator study’, *Accident Analysis & Prevention* **26**(4), 441–451.

Barcelo, J., Codina, E., Casas, J., Ferrer, J. L. and Garcia, D. (2004), ‘Microscopic traffic simulation: A tool for the design, analysis and evaluation of intelligent transport systems’, *Journal of Intelligent and Robotic Systems* **41**, 173–203.

Bardzimashvili, T. (2003), ‘Analysis and simulation of traffic flow’, `https://www.msu.edu/~bardzima/files/Traffic.pdf`. [Accessed: 07 Dec 2008].

Barlovic, R., Santen, L., Schadschneider, A. and Schreckenberg, M. (1998), ‘Metastable states in cellular automata for traffic flow’, *The European Physical Journal B - Condensed Matter and Complex Systems* **5**(3), 793–800.

Brackstone, M., Sultan, B. and McDonald, M. (2002), ‘Motorway driver behaviour: Studies on car following’, *Transportation Research Part F: Traffic Psychology and Behaviour* **5**(1), 31–46.

Brockfeld, E. and Wagner, P. (2006), ‘Validating microscopic traffic flow models’, *IEEE Intelligent Transportation Systems Conference* .

Burmeister, B., Haddadi, A. and Matylis, G. (1997), ‘Application of multi-agent systems in traffic and transportation’, *Software Engineering - IEE Proceedings* **144**(1), 51–60.

Campari1, E. G., Levi1, G. and Maniezzo, V. (2004), *Cellular Automata*, Vol. 3305 of *Lecture Notes in Computer Science*, Springer Berlin / Heidelberg.

Chang, H., Wang, Y. and Ioannou, P. A. (2007), The use of microscopic traffic simulation model for traffic control systems, *in* ‘International Symposium on Information Technology Convergence’.

Das, S., Bowles, B. A., Houghland, C. R., Hunn, S. J. and Zhang, Y. (1999), Microscopic simulations of freeway traffic flow, *in* ‘Simulation Symposium, 1999. Proceedings. 32nd Annual’.

Dastani, M., van Riemsdijk, M. B. and Meyer, J. C. (2006), Goals in agent programming, *in* ‘AAMAS ’06: Proceedings of the Fifth International Joint Conference on Autonomous Agents and Multiagent Systems’, New York, NY, USA, pp. 1285–1287.

Eby, D. W., Vivoda, J. M. and Louis, R. M. S. (2006), ‘Driver hand-held cellular phone use: A four-year analysis’, *Journal of Safety Research* **37**, 261–265.

Fellendorf, M. and Vortisch, P. (n.d.), 'Validation of the microscopic traffic flow model vissim in different real-world situations'.

Herman, R., Lam, T. and Prigogine, I. (1972), 'Kinetic theory of vehicular traffic: Comparison with data', *Transportation Science* **6**, 440–452.

Kerner, B. S. and Rehborn, H. (1996), 'Experimental features and characteristics of traffic jams', *Physical Review E* **53**(2), 1297–1300.

Kesting, A., Treiber, M. and Helbing, D. (2008), 'Agents for traffic simulation'.

Kuhne, R. D. and Rodiger, M. B. (1991), Macroscopic simulation for freeway traffic with jams and stop-start waves, *in* B. L. Nelson, W. D. Kelton and G. M. Clark, eds, 'Proceedings of the 1991 Winter Simulation Conference', Daimler-Benz AG, Research Center, Traffic Engineering Division, Stuttgart, Germany.

Live Science (2008), `http://www.livescience.com/technology/080102-cell-phone-traffic.html`. [Accessed: 07 Dec 2008].

Luke, S., Balan, G. C., Panait, L., Cioffi-Revilla, C. and Paus, S. (n.d.), 'Mason a java multi-agent simulation library', `http://cs.gmu.edu/~eclab/projects/mason/papers/Agent2003Presentation.pdf`.

Luke, S., Cioffi-Revilla, C., Panait, L., Sullivan, K. and Balan, G. (2005), 'Mason: A multiagent simulation environment', *SIMULATION* **81**, 517–527.

Maerivoet, S. and Moor, B. D. (2008), 'Traffic flow theory', *arXiv:physics/0507126v1* .

Maroto, J., Delso, E., Felez, J. and Cabanellas, J. M. (2006), 'Real-time traffic simulation with a microscopic model', *IEEE Transactions on Intelligent Transportation Systems* **7**, 513–527.

Nagai, R., Hanaura, H., Tanaka, K. and Nagatani, T. (2006), 'Discontinuity at edge of traffic jam induced by slowdown', *Physica A: Statistical Mechanics and its Applications* **364**, 464–472.

Nagatani, T. (2002), 'The physics of traffic jams', *Reports on Progress in Physics* **65**(9), 1331–1386.

Nagel, K. (1996), 'Particle hopping models and traffic flow theory', *Physical Review E (Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics)* **53**, 4655–4672.

Nagel, K. and Schreckenberg, M. (1992), 'A cellular automaton model for freeway traffic', *Journal de Physique* pp. 2221–2229.

Owen, L. E., Zhang, Y. and Rao, L. (2000), Traffic flow simulation using corsim, *in* J. A. Joines, R. R. Barton, K. Kang and P. A. Fishwick, eds, 'Proceedings of the 2000 Winter Simulation Conference', Intelligent Transportation Systems (ITS) Department, ITT Industries, Systems Division, PO Box 15012, Colorado Springs, CO 80935-5012, U.S.A., pp. 1143–1147.

Paruchuri, P., Pullalarevu, A. R. and Karlapalem, K. (2002), Multi agent simulation of unorganized traffic, *in* 'AAMAS '02: Proceedings of the first international joint conference on Autonomous agents and multiagent systems', pp. 176–183.

Parunak, H. V. D., Savit, R. and Riolo, R. L. (1998), *Multi-Agent Systems and Agent-Based Simulation*, Vol. 1534 of *Lecture Notes in Computer Science*, Springer Berlin / Heidelberg.

Patten, C. J. D., Kircher, A., stlund, J. and Nilsson, L. (2004), 'Using mobile telephones: Cognitive workload and attention resource allocation', *Accident Analysis & Prevention* **36**(3), 341–350.

Punam, B. (2007), 'Avoiding traffic jam using ant colony optimization - a novel approach', *International Journal of Pattern Recognition and Artificial Intelligence* **16**(5), 61–67.

Redelmeier, D. A. and Tibshirani, R. J. (1997), 'Association between cellular-telephone calls and motor vehicle collisions', *The New England Journal of Medicine* **336**, 453–458.

Rothery, R. (n.d.), 'Car following models'.

Taieb-Maimon, M. and Shinar, D. (2001), 'Minimum and comfortable driving headways: Reality versus perception', *Human Factors: The Journal of the Human Factors and Ergonomics Society* **43**(1), 159–172.

Tampere, C. and v Arem, B. (2001), Traffic flow theory and its applications in automated vehicle control: a review, *in* 'IEEE Intelligent Transportation Systems Conference Proceedings', Department of Traffic and Transport, Oakland (CA), USA, pp. 391–397.

Tisue, S. and Wilensky, U. (2004), Netlogo: A simple environment for modeling complexity, *in* 'Presented at the International Conference on Complex Systems', Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, Illinois.

Traffic Modelling (n.d.), `http://www.mtreiber.de/`. [Accessed: 20 Oct 2008].

Turner-Fairbank Highway Research Center (2008), `http://www.tfhrc.gov/pubrds/janfeb99/traffic.htm`. [Accessed: 09 Dec 2008].

Wiedemann, R. and Vortisch, P. (1994), 'Einflu von verkehrssituation und verkehrsregelung auf das fahrverhalten auf bundesautobahnen'. [From:Research report BASt 2.9362 of the German HighwayAgengy].

Wiktionary - traffic jam (2008), `http://en.wiktionary.org/wiki/traffic_jam`. [Accessed: 02 Dec 2008].

Wooldridge, M. (2008), *An Introduction to MultiAgent Systems*, John Wiley & Sons Ltd.

Wright, C. and Roberg, P. (1998), 'The conceptual structure of traffic jams', *Transport Policy* **5**, 23–35.

Appendix A

Testing Documentation

			Round One		**Round Two**		**Average**	
Experiment Number	**Number of Drivers**	**Number of Mobile Phone Drivers**	**Time Taken for Traffic Jam to form (ticks)**	**Time Taken (mins)**	**Time Taken for Traffic Jam to form (ticks)**	**Time Taken (mins)**	**Time Taken for Traffic Jam to form (ticks)**	**Time Taken (mins)**
1	1	0	n/a	n/a	n/a	n/a	n/a	n/a
2	1	1	n/a	n/a	n/a	n/a	n/a	n/a
3	2	0	n/a	n/a	n/a	n/a	n/a	n/a
4	2	2	n/a	n/a	n/a	n/a	n/a	n/a
5	3	0	n/a	n/a	n/a	n/a	n/a	n/a
6	3	3	277	69.25	n/a	n/a	138.5	34.63
7	4	0	139	34.75	n/a	n/a	69.5	17.38
8	4	4	n/a	n/a	n/a	n/a	n/a	n/a
9	5	0	n/a	n/a	216	54	108	27.00
10	5	5	264	66.00	389	97.25	326.5	81.63
11	6	0	13	3.25	29	7.25	21	5.25
12	6	6	68	17.00	37	9.25	52.5	13.13
13	7	0	76	19.00	12	3	44	11.00
14	7	7	45	11.25	43	10.75	44	11.00
15	8	0	22	5.50	22	5.5	22	5.50
16	8	8	13	3.25	24	6	18.5	4.63
17	9	0	20	5.00	26	6.5	23	5.75
18	9	9	16	4.00	25	6.25	20.5	5.13
19	10	0	25	6.25	34	8.5	29.5	7.38
20	10	10	21	5.25	20	5	20.5	5.13
21	11	0	5	1.25	22	5.5	13.5	3.38
22	11	11	13	3.25	23	5.75	18	4.50
23	12	0	11	0.05	36	9	23.5	4.52
24	12	12	21	0.09	5	1.25	13	0.67
25	13	0	19	0.08	23	5.75	21	2.91

26	13	13	3	0.01	19	4.75	11	2.38
27	14	0	21	0.09	26	6.5	23.5	3.29
28	14	14	23	0.10	20	5	21.5	2.55
29	15	0	2	0.01	22	5.5	12	2.75
30	15	15	12	0.05	15	3.75	13.5	1.90
31	16	0	26	0.11	13	3.25	19.5	1.68
32	16	16	10	0.04	12	3	11	1.52
33	17	0	19	0.08	12	3	15.5	1.54
34	17	17	15	0.06	34	8.5	24.5	4.28
35	18	0	1	0.00	14	3.5	7.5	1.75
36	18	18	1	0.00	8	2	4.5	1.00

Appendix B

Hypothesis One Experiments Data and Graphs

Below are the part of the data and the graph from one of the experiments run for testing hypothesis one. Due to the size of these the full set for all the experiments run can be found on the CD-ROM attached to this project.

B.1 Experiment One

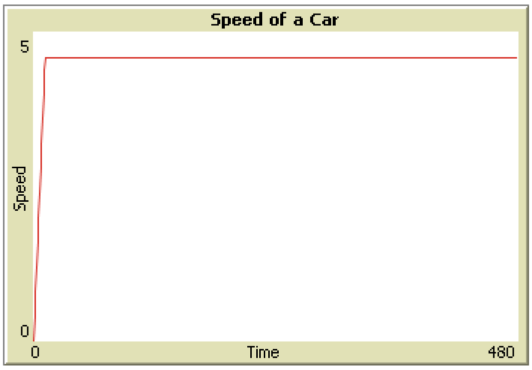


Figure B.1: Experiment One Graph

All other experiment data relating to hypothesis two can be found on the CD ROM

Table B.1: Experiment One Data

MODEL SETTINGS	
NumberOfCars	NumberOfMobilephoneDrivers
1	0
”speed”	
Ticks	Speed
0	0.002192
1	0.402192
2	0.802192
3	1.202192
4	1.602192
5	2.002192
6	2.402192
7	2.802192
8	3.202192
9	3.602192
10	4.002192
11	4.402192
12	4.589907
13	4.589907
14	4.589907
15	4.589907
16	4.589907
.....	....
461	4.589907
462	4.589907
463	4.589907
464	4.589907
465	4.589907
466	4.589907
467	4.589907
468	4.589907
469	4.589907
470	4.589907
471	4.589907
472	4.589907
473	4.589907
474	4.589907
475	4.589907
476	4.589907
477	4.589907
478	4.589907
479	4.589907