Modelling traffic flow at traffic light controlled junctions

Abstract

In many places where heavy traffic can be a problem measures are introduced to try and ease the pressure on the roads to aid the flow of traffic around the road system. Some of the methods used involve: traffic lights, roundabouts, one-way systems and more dramatically bypasses completely avoiding the problem areas. Traffic lights are often used often at junctions or road intersections to aid the flow of traffic from different directions. The purpose of the lights is clear and the theory behind them is sound; meaning that at a particular junction vehicles should regularly flow through, minimising the queue build up in any one direction. In practice this is a different matter, multiple sets of traffic lights are often in sequence, affecting the flow of vehicles from one to the next. The key to obtaining the optimum traffic flow is to adjust the timings of the traffic lights at the junctions so that the whole block is in a sequence with each other. Another viewpoint of the traffic flow problem is how the vehicles on the road interact with each other and with the control measures such as roundabouts and traffic lights. The individual actions of a vehicle can affect the smooth flow originally intended from the road design. For example, changing lanes in heavy traffic can mean that one lane cannot move forward even though the road is clear ahead because of stationary traffic. When considering an appropriate model for representing the situation we can take the view of the vehicles and traffic flow measures (for example traffic lights) as agents that interact with each other, being individual (the car or traffic light) but dependent on each other (cars have to stop when a traffic light ahead is red). The proposal for the paper is to look into this claim and investigate the effects traffic lights have on the flow of traffic. A model can be constructed to show this and can be interacted with to explore the effects of changing the frequency at which the lights change, whether they changed at an equal rate and the rate of traffic approaching from each direction, with both vehicles and traffic lights as agents if desired. This also involves elements of concurrency as vehicles will independently move and traffic lights change, all at the same time.

1   Introduction

An increasing volume of vehicles using the roads has meant that traffic congestion has in many areas become unreasonable. Examples can be taken from the UK's motorway system around London (M25), which on a daily basis is subject to huge traffic queues. In this situation there is very little that can be done to alter the situation without extending the existing capacity of the road. Although in other situations it is often within residential areas where traffic can build up causing problems for the particular road system and road users. These 'build-ups' can be caused by a number of different traffic control measures. They can be roundabouts, traffic lights, a poor road design, traffic calming measures (i.e. road bumps) and many other methods.

Two approaches to the problem of congestion can be taken; the methods suggested by Ehlert [8] involving the study of 'interactive agents' simulating vehicles to model the traffic scenarios before making changes to infrastructure. These *driving agents* are based on tactical driving; each agent has an aim of reaching some short-term goal, with each agent representing the behaviour of an individual vehicle type (e.g. car/bus/lorry). The second, more widely researched, approach involves altering the infrastructure (using a simulation first) for manipulating the flow of traffic, which behaves in a regular manor. This approach is more succinct with the theme surrounding this paper. Changing the physical layout may be a costly option to take, but if these changes are made based on a model, then there is a greater degree of certainty that the actions implemented will result in the desired affect. This can apply to all kinds of flow control measures, but for this paper we only consider the traffic problems surrounding traffic lights, as these are complicated

enough for an interesting study and fit in well with the Empirical Modelling (EM) perspective motivating this paper.

Managing the traffic flow at junctions can be difficult and often is the case that to efficiently control and 'shape' the traffic, traffic lights are required. Before any decisions can be made about the success of modifications at a said junction simulations should be carried out in order to assess the cost-benefit that would be achieved from the changes. This modelling procedure is where EM can prove to be useful, as it has been specifically designed to have an interactive environment enabling greater experimentation and investigation of the variables that can affect the flows.

From this we can establish that the main emphasis of the paper surrounds the use of an Empirical Modelling technique to solve an existing problem that many of us have experience in the real world, that of traffic congestion.

The main topics discussed in this paper are the prospective uses that Empirical Modelling can bring to the relatively specific (for simplicity and to gain and understanding of the concept's usefulness) area of study surrounding the manipulation of traffic flow at a traffic light controlled junction.

2 EM Techniques

2.1 Why EM – An Overview

Empirical Modelling is the simulation of experiences through the use of artefacts as the representations. These simulations are now constructed on a computer with the use of some kind of EM tool. Such a tool is the tkeden [11] environment which encapsulates the use of the eden language for logical dependencies, scout for screen layout and DoNaLD for 2D line drawing all developed at The University of Warwick. This tool is constantly being improved with additions for 3D modelling (Sasami) and a further version 'dtkeden' for creating distributed models over a computer network. This collection of tools provides the ideal environment for constructing models in which we are able to utilise the ideas of EM and its principle elements.

Three concepts of EM are the understanding of the artefact being modelled, the *observable* objects. The *dependencies* between these observable objects that are indivisibly linked together and the *agency* aspects, entailing groups of indivisibly linked elements acting as individual

agents in the environment; all of these together forming the artefact. For a clear example of an artefact see 'The Digital Watch Artefact' [6]. These concepts for EM can be summarised to be the model builders construal of the situation as they see it, refer to the 'liftBeynon2003' [9] model for an example of an individuals construal of a particular situation.

2.2 EM Perspectives

When considering a model which has a physical representation in the real world, such as the construction of a bridge, and in this case the management and eventual goal of optimising traffic flow at a junction, we can consider a number of different perspectives or viewpoints from which a model can be constructed. Depending on this viewpoint the aim for the completed model can be radically different. For the case of building a bridge consider the different objectives the person wishing to cross the opening would have; compared to an engineer looking at the strengths and elasticity of metal under the appropriate forces for the bridge and a designer wanting to make the bridge aesthetically pleasing. These objectives may complement, but can also conflict with each other and it is not always possible for the model builder to encapsulate every viewpoint in a model.

For the model concerning traffic flow there are a number of different viewpoints that potential models can be built around. These could be that of the engineer constructing or programming the individual traffic light and building the junction (if it does not already exist); the town planners wanting to alter or implement road systems; analysts measuring potential traffic flow and possible areas of congestion and government plans to improve congestion.

2.2.1 Traffic Flow Viewpoints

An engineer would want to know about the physical or electrical properties of the traffic light for making adjustments concerning the sequencing and smooth operation for traffic approaching from each direction. The town planners would be more interested in the possible configurations of road systems, their layout and design, incorporating the different control measures available to them. To an analyst the statistical elements of traffic flow would be of interest and the measurement of cars passing and the effects of experimenting with

changes to different agents within the model. With this in mind it is now possible to specify which viewpoint would be most appropriate to concentrate on for the purposes of this paper. The two most interesting viewpoints for building an empirical model are those of a town planner, designing the layout of a road system and that of the analyst, looking at the statistical side of the traffic flow problem. The model that will be associated with the discussions in this paper involve the study of a model based around the statistical perspective of traffic flow involving traffic light controlled junctions.

2.3   Related Models for Study

The issues presented for study involve looking at simulations that aid the resolution problems, evident in many places, of traffic congestion. Currently within the University of Warwick EM repository there are two such models that are related to the topics being investigated. The first is the Traffic Light Simulator (Mendis, 1997) and the second a Road Systems/Town Planning model (Gardner, 1999).

2.3.1   Traffic Light Simulator

This model is of a simple 'T' junction containing three traffic lights [4]. The traffic lights are independent agents that are linked together to form the operation of a junction (see Figure 1). The model runs for a specified number of ticks and the queues of vehicles (represented by a line) at a traffic light is reduced with outputs displaying the number of vehicles through each light and the total number of vehicles through all of the traffic lights.
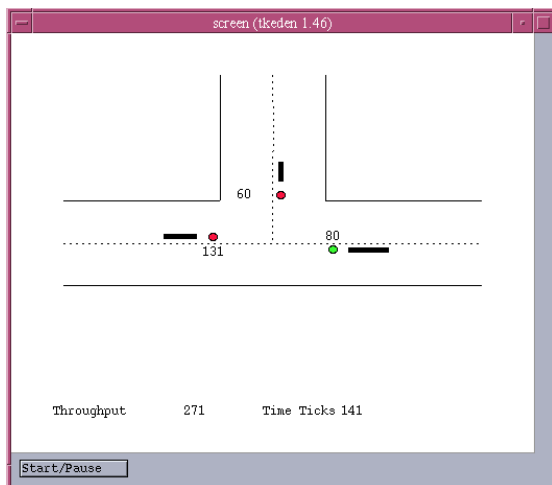

Figure 1 - Traffic Light Simulator

This is a simple model that shows some statistical elements but does not prove to be very useful for any real world application, and quite often the problems posing decisions for traffic lights will require the adjustment of different variables in conjunction with other agents, such and an adjoining set of traffic lights.

2.3.2   Road System / Town Planning Model

This is an artefact that allows the user to experiment with road layouts and create a 'town' in which a series of vehicles can move around (see Figure 2) [5]. Besides the road pieces the main traffic control measure is through traffic lights on a cross junction. This is quite a complex model and does well to simulate the possible road layouts that could be used, and from the viewpoint of the Town Planner this model would be useful to them for achieving their goals through experimentations with such a model. This can of course be extended further to provide more features that would match up to an idealistic construal of the situation for the town planner.
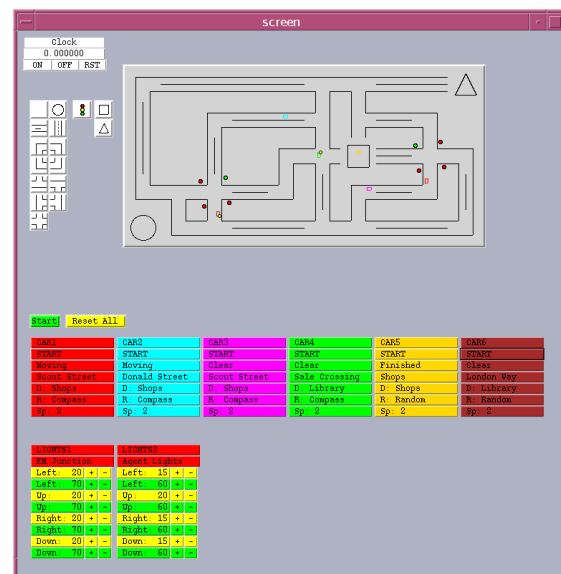

Figure 2 - Road System / Town Planner

This is purely a model for planning and utilises route planning algorithms for finding a particular location. This element of the artefact would not be the primary concern for the user and does not show statistical aspects of the traffic control measures as with the Traffic Light Simulator.

3   EM Modelling

The main purpose for the paper is to consider the actions that could be taken to control traffic congestion through experimentation with an empirical modelling technique. To utilise the benefits that can be gained from studying the problem from this perspective it seems appropriate to make use of the existing Traffic Light Simulator and to enhance it bringing it closer to the ideal model from the statistical viewpoint.

3.1   Model Building

The goal for the model built at the time of writing is to change the view of the model as an artefact and instead shift the boundary and view the 'T' junction as an agent itself, containing individual traffic light agents. Each of the traffic lights is dependent on each other for the particular junction and then the two connected junctions are then dependent on each other with regard to the traffic flowing from one to the next. The reasons for extending this existing model are to enhance the capabilities it can have for meeting greater statistical demands for the application area relating to these discussions. This also demonstrates the thinking behind such a model with EM and how it could be modified into a much more complex simulation for experimentation to affect the observables in the model.

3.1.2   Implementation

The main changes to the model in terms of how it functions is the greater statistical ability and a much clearer picture of how simple logic, attempting to equalise the traffic queues, can increase the number of vehicles passing through a junction. Through more sophisticated techniques and knowledge it would be possible to further increase the efficiency of the traffic lights. Each of the variables for the model can be experimented with through the tkeden command prompt allowing a user to investigate affects of actions in a more real world environment. This model still remains a construal of the real world from a combination of the authors understanding and that from the original model constructor.
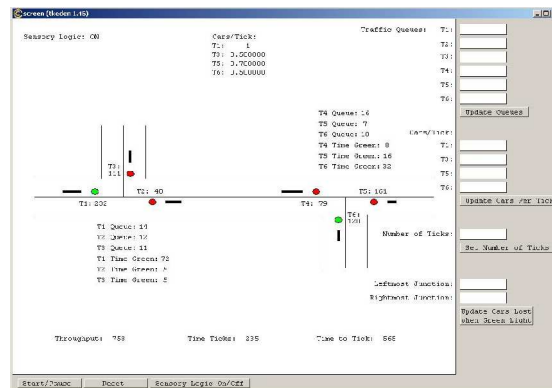

Figure 3 - Traffic Light Simulator Version 2

Figure 3 shows the Traffic Light Simulator as it appears now, with the modifications obvious to any user who has seen the original model. With the new layout and the added control features it is possible for the user to conduct more complicated experiments with a model closer to a real world scenario. This may not match up completely with how the individual may construe a particular situation, but the goal for the model is to demonstrate EM principles and also how these principles applied in a model, through agency, mean that it is possible to further extend the model into a more complex and flexible artefact for manipulation.

3.1.3   Statistical Features

The updates to the model have meant that many more of the variables that can be manipulated are more readily observable in the environment through the interface. The most significant addition is that of the second junction, with traffic from one flowing into the other and vice versa allowing for a more real situation, as junctions with traffic light are not always found in isolation. If this is the case though, it is possible to simulate an individual junction by reducing the queues and cars passing through from every direction to zero and again imitating one junction.

All of the features in the model are directed towards the particular viewpoint that is being used. The displays of the cars passing though a traffic light, the timings for each traffic light, the vehicles in the queue and the total throughput of vehicles through both junctions combined. This data can be used to analyse the traffic flows and based on experiments adjust values through eden to maximise throughput and minimise congestion. Even with just using the simple sensory logic for equalising the queues at a junction we can see that

the total throughput is greater and queues as lights are more distributed in comparison to the same settings with the logic turned off.

3.1.4 EM Tools

The main development tools for EM is tkeden, this has been specifically designed and matches the EM principles and objectives. It is relatively simple and flexible enough to construct the types of models that are required, although if large complex projects were undertaken using this tool, the code would become difficult to read and not good for representing the construal and demonstrating the purpose of EM. Although through very nature of EM the models that are constructed do not necessarily have to be completed in one, agency means that multiple aspects/agents building up the model can be individually developed and 'plugged into' the model using dependencies.

3.1.5 Further Extensions

The current version of the Traffic Light Simulator has been significantly improved, but there remain to be aspects that can be changed or added to fit better with the viewpoint it tries to fulfil. Obvious changes include having cross junctions as well as 'T' junctions, but to further add to this the ultimate goal is to have a model that is a cross between the Traffic Light Simulator and the Road System / Town Planner where a system of the junctions could be constructed, but remains to have the statistical element required of it. This might also satisfy the requirements for a town planner, as the system is capable of representing a network of roads along with the ability to display the flow of traffic around it and with the capability of experimentation with the volumes of traffic.

The main problem that remains with these suggested extensions are that it does not take into account the variations and individuality of traffic, including the differences due to the vehicle itself. Whether the traffic contains cars, busses or lorries can greatly affect the flow, along with the randomness that comes with modelling each vehicle as an individual agent as discussed by Alloyer [3], by generating scenarios for traffic flow. Incorporating this into a model would be extremely complex, but also could mean the model is almost an exact match to real world situations. Another useful method that could be implemented would be to have traffic lights dependent on each other (*communicating agents*) rather than operating on an individual basis. This then raises issues for communication and how this should be done.

4   Conclusion

The Empirical Modelling (EM) approach to this problem of traffic congestion has provided a critical view of many types of simulations that can be constructed, raising points that would not otherwise have been raised without taking the EM perspective and the individual construal of events. From the study of the topic a useful insight has been given demonstrating not only how a model can represent the environment, but also how an EM technique can be applied to a problem area before costly methods are implemented. Its methods of critical thinking and experimentation cause many other aspects to be considered upon tackling a problem to achieve come desired goal. The model building process that has accompanied this paper has shown the flexibility and usefulness of a model for the area concerning traffic flow/control and also how individual *agents* linked through *dependencies* creates a fully *observable* environment. Through this the model produced has achieved the goal for demonstrating how useful such an activity is with regards to the objectives for the simulation. There are many extensions that can be made; the current model is suitable for carrying out analysis on situations that do match the configuration that is given by the model.

When considering how suitable an application of EM this study has been it is important to look to the situation as a whole. Traffic flow is not rational, which reflects EM in that irrational actions are allowed in the models, not being too restrictive with what a user is permitted to do. Overall, EM is well suited as a method of analysing traffic flow in the case of the specific scenario modelled, but also for general cases.

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