Final Year Project Interim Report

Extended version of SUMO for real time vehicles' routing in smart cities

David Smith

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Supervisor: Professor John Murphy

Moderator: Dr. Soufiene Djahel

UCD School of Computer Science and Informatics
College of Engineering Mathematical and Physical Sciences
University College Dublin

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Table of Contents

Abstract

The purpose of my project is to contribute to the ongoing work that is being done on updating vehicle's routes during simulation runtime. To achieve this I am using the microscopic road traffic simulator SUMO (Simulation of Urban MObility), and I will extend this by developing additional features that will allow me to update the vehicle's defined route, instead of using the statically defined shortest path algorithms in SUMO. In this report I will detail the background research that I have done, including the current state of the art and related works with SUMO. Then I will describe some of its missing features, following from this I will explain my solution and how I plan to progress with my project through the next few months.

Acknowledgements

I would like to express my gratitude to Professor John Murphy, my project supervisor and Dr. Soufiene Djahel, my mentor, for their patience and guidance, their encouragement and useful critiques of my work. I would also like to thank Shen Wang who helped me without hesitation when I needed his assistance with TraCI.

Chapter 1: **Introduction**

At the core of my project is the problem of traffic congestion and how this problem can be alleviated. In large cities traffic congestion is caused by the volume of traffic closely approaching the maximum capacity of the road network. During rush hours it gets worse and with more people joining the road network every day, this problem will not go away on its own. It is infeasible for a government to match a road network improvement programme to the unrestricted trends in traffic growth.

The economic loss of traffic congestion is a huge factor, in the 39 metropolitan areas of the US with a population of 1 million or more, roughly one third of all vehicular travel takes place under congested conditions in which the average speed is half of its free flow value. About half of the congested traffic is on express ways, causing a delay of over half a minute per kilometre of travel. The other half is on other arterials where the delay amounts to 1.2 minutes per kilometre of travel. With some 75 million licensed drivers in heavily populated areas, each averaging roughly 16,000 kilometres per year in those areas, there are 1.2 trillion kilometres driven in metropolitan areas, this amounts to a total delay of 6 billion hours.[1] Back here in Europe the economic cost is an even bigger factor, with estimates of 200 billion Euro in losses due to traffic congestion in 2012. This is roughly 2% of Europe's GDP, and is more than double the American estimate of $101 billion. [2] So it is clear from this data that there is a significant enough reason for traffic congestion to be alleviated, and efforts have been made by navigation system companies. But these systems are still in the early stages of becoming fully fledged and highly reliable products, so in order to develop a more reliable system simulation must be used to develop an understanding of the traffic flows on road networks and how this traffic flow is affected if an accident occurs or road works are taking place.

In Europe a Dutch manufacturer called TomTom NV [5] has developed navigation systems for drivers and pedestrians, a US company Garmin [6] also developed a similar system. Both systems use GPS in order to establish your location and some routing algorithm to establish (generally) the fastest route to your destination. In some cases you can choose to avoid toll roads and motorways. TomTom has recently developed a system, known as TomTom Traffic, which provides users with precise and accurate real time information based on the state of the traffic and any congested routes ahead. It pinpoints exactly where your delays start and end. If the traffic situation changes then your TomTom will continuously look for the fastest route. It puts the user in control, by informing the user where incidents are and giving them real time congestion information, you can choose whether to stay on course or to take a detour. Garmin offer a similar live service that updates every two minutes to check traffic situations. Data is pulled from millions of other users, including mobile phone users, incident reports, radio feeds, news feeds, historical traffic data and fixed traffic sensors. These systems have only recently been introduced in Ireland, with TomTom Traffic only going live in 2011, and Garmin in 2010. Although these systems pull data from a lot of users, tens of thousands in Ireland, it is broadly limited by comparison to the amount of actual road users. It also uses the number plate registration systems on motorways. This is a fixed infrastructure installed by local authorities that tracks a number plate and how long it takes to get from one point to another. Again these systems are only installed on major motorways, and do not take into account arterial roads approaching or exiting these motorways. It is clear that although these systems are currently in use by millions of people around the world, its scope is rather limited when it comes to specific areas not monitored by sensors.

The main aim of this project is to develop a system using the microscopic traffic simulator (SUMO) that ensures real time update of the drivers routes (i.e. dynamic route update) upon detection of any abnormal increase in traffic congestion or as consequence of an accident. The end goal is to develop a model that will allow users to choose their route based on certain parameters, such as Ease of Driving. The mandatory objectives of my FYP are to familiarize myself with SUMO and TraCI, and to design and implement a mechanism to update the vehicles' route during the simulation runtime. The discretionary aspects are to implement vehicle routing heuristics, and to extend these heuristics by adding more selection metrics, such as travel time, the route with the lowest cost, easiness of driving, or a combination of two or more metrics. Finally the exceptional aspect of the project is to develop a Vehicular Ad hoc Network (VANETs) to control vehicles mobility during runtime simulation.

Chapter 2: **Background Research**

2.1 State of the Art

Inter vehicle communication (IVC) is currently transitioning from academic research to a feasible technology. However many aspects of IVC protocols, their parameters and configurations, as well as application specific adaptations are still to be studied. One of the key tools used in studying these IVC systems is simulation. In the past few years significant improvements have been made in the amount of realism that can be achieved using these simulators. In a paper by Stefan Joerer *et al* [4], they review the various simulation studies published at major vehicular conferences from 2009 to 2011, with a focus on reproducibility and comparability of these studies. The paper discusses the use of network simulators, physical layers and medium access. But for now I will just focus on the traffic simulator used. They have found that the use of certain mobility models have substantial influences on metrics like the number of unreachable nodes, the average path length and topology changes. In the paper they focus on the car-following model because most of the microscopic road traffic simulators are based on this class of model. This is because the car-following models derive future acceleration/deceleration decisions based on the velocity and distance of the vehicle and those ahead of it. This is a realistic representation of how a driver would decide their speed. Whereas models inspired by cellular automations divide roads into sections of a certain length that can be either empty or completely occupied by one vehicle. The velocity of a vehicle is modelled by occupying multiple segments in one discrete time step. The Wiedemann model was the first car following model , which has now been further developed to consider the physical and psychological aspects of drivers. It is currently employed in the VISSIM traffic simulator [7]. The two other car following models are Gipps and Intelligent Driver Models, both of which are available in SUMO. As you can see from the figure below, a lot of the papers they reviewed did not specify what simulator was used, but regarding the simulators that were specified SUMO was the most popular.

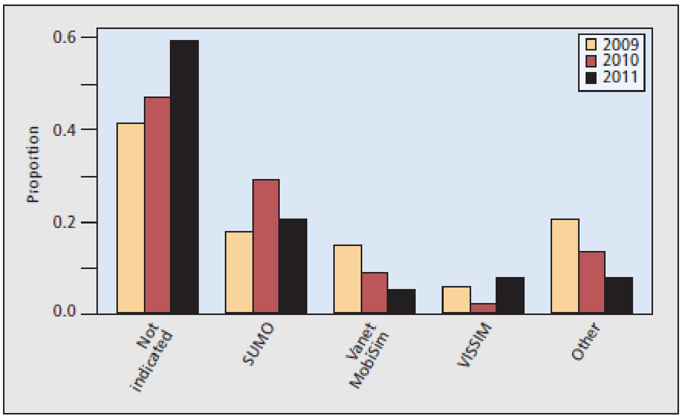


Figure 2.1: Distribution of road traffic simulators. [4]

PTV VISSIM is a microscopic multi-modal traffic simulator. It was developed by PTV in 1992 and is now the global market leader. Multi-modal simulation describes the ability to simulate more than one type of traffic, all these different types can interact mutually. In VISSIM these types are Vehicles, Public Transport, Cycles, Pedestrians and Rickshaws. Unlike the open source traffic simulators, such as SUMO , VISSIM is a commercial simulator. It is a highly realistic simulator, but since the sources are not available, extensions to the model cannot be built, i.e. experimentation is limited. Other commercial simulators include PARAMICS [8] and AIMSUN [9]. The fact that these simulators have an expensive licensing scheme, which is a major impediment to the academic research community, they are not widely adopted by academics. They are more regularly used by government departments such as transport or emergency services.

VanetMobiSim [10] is an open-source extension to CanuMobiSim user mobility framework, it is capable of producing realistic vehicular mobility traces for several network simulators.

The Street Random Waypoint (STRAW) [11] tool is another mobility simulator, based on the freely available Scalable Wireless Ad Hoc Network Simulator (SWANS). STRAW is able to parse TIGER [12] files and it also implements complex intersection management, although due to its reliance on SWANS it prevents any research using STRAW on other network simulators.

Simulation of **U**rban **MO**bility, (SUMO) [13], is an open source, microscopic, multi modal traffic simulator. It allows you to simulate how a specified traffic demand performs on a given road network. It is microscopic, which means each vehicle is modelled explicitly, it has its own route and moves individually through the network. The German Aerospace Center began developing SUMO in 2001 and since then it has been improved and has evolved into a suite of traffic modelling utilities which includes a road network capable of reading different source formats, demand generation and routing utilities. SUMO was developed as an open source simulator in the hopes that people like me and others working with the simulator, could suggest and implement improvements to the simulator helping to build a better and more realistic model. SUMO is not only a traffic simulator, but more so a suite of applications allowing you to prepare a road network and traffic demand for the network. It uses "netconvert" to take a network from Open Street Map or from other traffic simulators such as VISUM, MATsim or VISSIM. Once you have imported and converted a road network it will need traffic demand, and routes for each vehicle. "*jtrrouter*" is one of tools used to computing routes, "*dfrouter*" is another. These routing tools take the network and trips as arguments and produces a route file that contains the routing information for each vehicle defined in the network.

In 2006 SUMO was extended by allowing it to interact with an external application via a socket connection. This was developed by Axel Wegner *et al* from University of Lubeck, and was incorporated into SUMO's official release, this implementation refers to TraCI.

In a research paper by Vi Tran Ngoc Nha *et al* [15], the various routing algorithms that could be used in conjunction with SUMO or another traffic simulator, were described and critiqued for their merits and faults. The first of these algorithms that would be a suitable candidate of dynamic routing is Dijkstra. This algorithm finds the shortest path with the lowest cost from one node to all the nodes in a city map. Dijkstra is a worthwhile algorithm because it terminates once the destination node is found, i.e. shortest path found. Some other algorithms are unable to determine the shortest path until all the nodes are formed into an s.p. tree.

An alternative to this would be A* which uses a heuristic function instead of an optimal search algorithm, A* is able to then restrict the search space which in turn improves computation time. In my case, the search space would be reduced to the area where an incident has occurred, such as an accident or sheer traffic volume.

The paper then goes on to discuss how these route planning algorithms can be improved. For example the inputs that can be used as inputs for vehicles, such as road information, the current state of traffic and congestion on certain road networks, the destination information for the journey. Along with mobile information such as the fuel level, and other vehicle conditions and driver conditions, such as whether or not they are tired or need a break.

The best route selection criteria and algorithm evaluation metrics are critiqued, to identify the most appropriate route the metric's must be defined, such as travel distance, time, the ease of driving and the travel cost.

2.2 Related Works

INRIX, Inc.[16] is a provider of traffic information, it provides historical and real-time traffic information throughout the US and Canada and also most of Europe and Brazil. INRIX collects information about road speeds from almost 100 million anonymous mobile phones, delivery vehicles and lorries, along with other various fleet vehicles that have been equipped with a GPS device. All data collected is processed in real time and used to create traffic flow information for motorways and artirials across its user space.

As I mentioned in my introduction TomTom and Garmin have developed systems that alert drivers of any congestion ahead before they reach it, both TomTom and Garmin have a partnership with INRIX as a part of their data collection process, they also use many other sources as I mentioned above. They are both commercial services that cost quite a lot and considering they only work proficiently in big cities with a lot of user data and fixed infrastructure input, they may not be the best option for a some more rural users. The usefulness of these services is heavily reliant on their reaction times. They cannot always avoid congestion, since congestion can often be spontaneous due to an accident. Google Maps and Microsoft's Bing use statistical predictive analysis that suggest where congestion may begin and end, but due to the volatile and unpredictable nature of congestion and accidents, these tools are only useful to a certain extent. These predictive systems, which TomTom and Garmin also employ, rely on the recurring congestion trends, this only accounts for 50% of all congestion [17], so in order to determine the effect congestion has on traffic because of random incidents, simulation must be used. The system which I will build will simulate incidents and test the performance of re-routing vehicles based on the detection of these incidents.

An alternative to my work would be the research done by Juan Pan *et al* on *Proactive vehicle re-routing strategies for congestion avoidance* [18]. In their paper they outline how they would implement their system model. It composed of a centralized traffic monitoring and re-routing service, distributed across several servers, and a vehicle software stack for periodic traffic data reporting and for showing drivers alternative routes, this would be an embedded system or installed on a smart phone. The re-routing strategies they employ make use of travel time as the only factor for computation of the shortest path. The three re-routing strategies they discuss are Dynamic Shortest Path (DSP), which finds the path with the shortest travel time and assigns it to the vehicles selected to be re-routed. They also discuss the Random k Shortest Paths (RkSP) strategy, which computes k shortest paths for every vehicle that has been selected to be re-routed, then it assigns at random, one of the k shortest paths to each vehicle. The main reason for using such a strategy is to avoid simply moving the congestion elsewhere, by balancing the load on many nodes. The third re-routing strategy that is proposed is the Entropy Balanced k Shortest Paths (EBkSP). When moving from DSP to RkSP the computation time increases, this is a problem since the time to transmit the detour to the user needs to be transmitted before they pass the re-routing intersection, so if the re-routing algorithm took too long it would be useless. This is why they introduced EBkSP which improves on RkSP, it performs a more intelligent path selection by considering the impact of every selection on the future density of the selected nodes. In addition to this, EBkSP ranks the cars that are to be re-routed on an urgency function, that ranks the vehicles that get more adversely affected by the congestion first so they get re-routed first. In order to avoid the problem of shifting congestion elsewhere, the EBkSP algorithm associates a popularity measure to nodes that will be used in the future.

In order to implement a simulation of this model and evaluate the performance of the routing algorithms they make use of SUMO and TraCI. They implemented their routing strategies defined above using TraCI, so that when SUMO is run, it waits for a command from TraCI, when a command is received it runs the simulation for the specified about of time. In their simulation they used maps of Brooklyn and Newark. They modified the default routing algorithm to find the shortest paths using the travel time metric instead of the default distance metric defined in SUMO. They ran their simulations for 15 runs and gradually reduced the total number of users that adopted the re-routing system in order to establish the affect it has when less people use the system. Below is a figure which illustrates the flow through the network which they employed. In the results they presented, there is

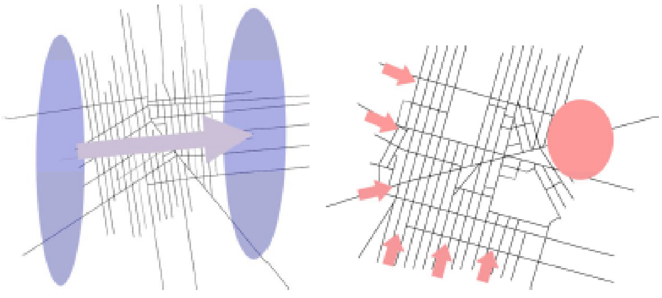


Figure 2.2: Flow of traffic on the network [18]

a significant decrease in travel time when implementing all three of the re-routing strategy compared to no re-routing and of the three strategies there is a clear step down graph with EBkSP having the best performance. By comparison to the no re-routing simulation there was an 81% decrease in travel time. They also tested against the level of compliance of the users, since it is unrealistic to assume all drivers in the network would have the system, but they found that even with a low level of compliance the re-routing strategies still worked quite well.

This project on proactive re-routing is very similar to mine since they evaluate various re-routing techniques, but it differs for mine because I will have to implement other vehicle routing heuristics such as Easiness of Driving, or the route with the lowest monetary cost instead of just travel time.

2.3 Missing Features

On the SUMO website they have a ticket system, whereby people can add tickets which are jobs that need to be done, sometimes something as simple as bugs or typos, but amongst the bugs are suggestions for more substantial improvements. They also include a student and support page with possible suggested projects. Among the list of projects are topics related to traffic science, information science and other issues.

The suggestions related to Traffic Science include Pollutant Emission modelling and Evaluation, this would involve modelling the amount of emissions from given road networks based on a realistic traffic flow for that network throughout an average day or week. Another suggestion was a traffic light comparative study, this would involve testing various traffic light algorithms performance for certain traffic loads.

When it comes to route choice and demand modelling there is a lot more suggestions. The evaluation of one-shot traffic assignment, which involves assigning a route to each vehicle on the network at the start of simulation. Another route choice suggestion is to come up with alternative methods for shortest path search in large networks, where just using Dijkstra would be highly computationally intensive. They also have two suggestions for induction loops, which are to use induction loop values for Highway demand generation or to extrapolate routes based on these values.

On this page they also suggest forecasting of Demand Time-Lines which would involve running simulations on real networks and using realistic traffic flow on the network, to work out at what times does traffic flow on certain nodes on the network become too much to the point where it causes congestion.

Within their traffic simulation models section they suggest concrete validation of simulation, this would be a huge task to be undertaken by a team like the Tapas Cologne project [20]. Another simulation model suggestion would be to simulate emergency service vehicles. This I feel would be a very useful simulation, since during rush hours, accidents often occur, and with road networks at their maximum capacity in most cases, it is very difficult for emergency services to reach their destination quickly. If you could run simulations for hundreds of destinations on a network from a hospital or police station it would surely prove as a great source of information for creating a specialized GPS system for emergency vehicles.

Another missing feature which would greatly affect congestion alleviation in SUMO is making use of the opposite lane for overtaking, since at the moment a vehicle is stuck on its side of the road, if a vehicle gets stopped behind a stalled or crashed car then it is essentially trapped, whereas in reality it would just overtake and keep going.

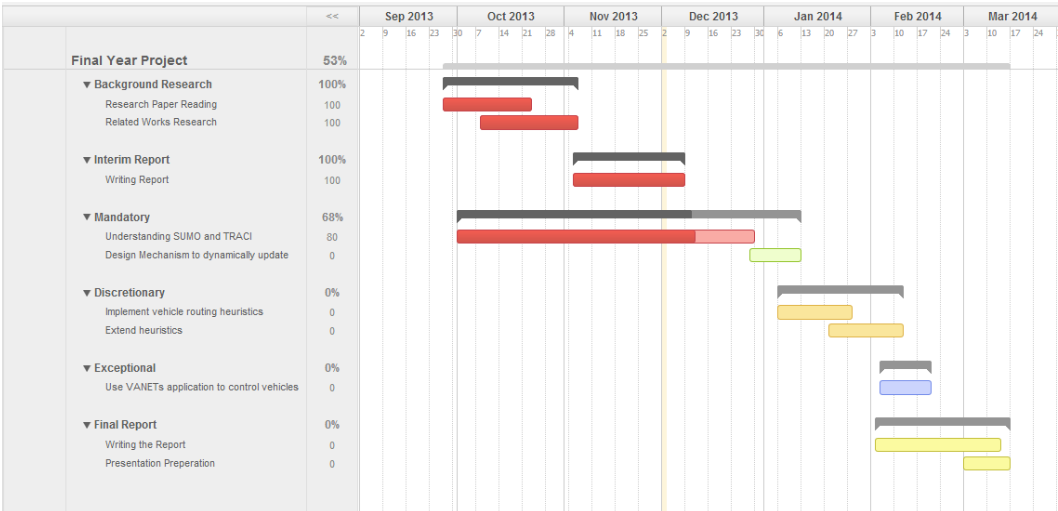
A problem that I encountered when initially importing maps into SUMO, Irish maps in particular, was the fact that SUMO is right hand traffic only, being of German design that is what you would except, but they hope to support left hand traffic in the future. One of the main reasons I felt there would be issues with simply running a simulation with right hand traffic is the use of filter lanes and other lane division systems that are part of the road network in Ireland, may not work correctly.

Lastly, under their simulation models section, they mention pedestrian flow, they would like to see this included, since during rush hours, pedestrian traffic has an effect in and around train station and bus stations. Where footfall would be very high, traffic lights have to alternate more often thus slowing down traffic. This would lead to a more accurate simulation.

Some major missing features that I have found while getting to understand SUMO, is how the route definitions are all made prior to runtime by default. In order to update these routes you have to implement TraCI alongside SUMO so that the routes can be redefined during runtime. This is the major flaw with SUMO that I will have to work around when building my model. Another missing feature is the way the route is calculated. As per the paper about Proactive re-routing, SUMO should have more than just the shortest path to calculate the route. At the moment it only takes into account the shortest path from the source node to the destination node and for my project I have been tasked with extending this so that other metrics are considered, or a combination of these metrics.

Chapter 3: **My Plan**

Below is a Gantt chart for my project. From the chart you can see what progress I have



made. For this report I had to read various research papers Soufiene gave me, which gave me a broader understanding of the traffic simulation topic, and I had to do some research of my own into other people and projects that they have been done using SUMO in order to establish what works out there relate to my project.

I have for the most part gotten to grips with SUMO and I am still working on TraCI. This involved Soufiene giving me small tasks each week such as importing maps from OSM or working through tutorials and reading the source code. TraCI proved more difficult to understand, even from the get go I found just working with SUMO to be relatively straight forward, but I had to seek the advise of Shen Wang when it came to TraCI because I hit a road block and couldn't make any progress. He cleared up my issues by pointing me in the right direction and telling me what source code I need to start looking through etc.

I haven't as of yet gotten started with updating the vehicles route during runtime but I plan to start it once my exams are finished. Since the start of my project during my weekly meetings I have been discussing the end goal of my project with Soufiene. As per the discretionary aspect of my project, I will have to implement some vehicle routing heuristics. I have done some thinking about this over the past few months and having spoken to Soufiene about different ideas we feel that implementing an Easiness of Driving metric would be an interesting heuristic to work with. Another suggestion he offered me was the fuel consumption metric or the travel cost (toll roads). Implementing each of these metrics would be difficult, but I feel coming up with the logic behind each metric would come quite naturally. I have been driving since the age of 17, and over the years you develop a natural ability to choose the shortest route, or route with no tolls, or even the route with the most relaxing roads. For example, you might like to go for a drive down to Waterford, I live in Kildare, so you could just pop onto the motorway and be there in a little over an hour or you could opt to avoid the motorway to have a more relaxing albeit longer journey on the country roads. I feel motorway driving can be quite boring at times despite the fact that its the quickest route to your destination. I feel I have enough experience driving to know what needs to be considered as part of these metrics, but coding them will be time consuming. I plan to start this as soon as I get some progress made with updating the vehicles route, the two topics will broadly overlap since getting the route updated flows into the routing heuristics aspect.

Once all of that is almost finished I would have to get started on using VANETs to control the vehicles mobility during runtime. Since this will more than likely be the most difficult part of my project, its completion will rely heavily on the time restrictions, since my final report and presentations are in mid March. I feel that if I get enough work done on implementing my project over the Christmas break, I will be within a good chance of finishing my exceptional aspect.

3.1 My Proposed Solution

As I mention above I feel Easiness of Driving and travel costs would be two metrics I am interested in implementing, once I figure out how to update the vehicles route during runtime, I will get to work on implementing these metrics.

As for the Easiness of driving, this metric will take into account at least the following basic aspects: the number of traffic lights or stops, the number of roundabouts and junctions, the number of lanes on a road, the density of traffic on the network, the travel time might also be a factor. The travel cost should be an easier metric to implement since you could either set a maximum travel cost or allow no travel cost. This would allow the algorithm to send the user through one or more tolls, or none if preferred. In order to implement this it would involve removing the edges that include tolls from the list of edges the algorithm can form its route from and allowing the route to be recalculated.

I also mentioned the fuel consumption metric, this metric would be significantly more difficult to implement, it would involve the size of the engine, the travel distance, the amount of stops, the average speed on an edge, the amount of time spent stationary, speed limits and other factors such as topology. This would be an added extra if I finished implementing the other metrics first, but I wouldn't consider it important.

If I get these metrics up and running I plan to implement the VANET to allow me to control the vehicles' mobility during runtime. Since the start of the project we have also discussed the evaluation of my project, it will involve comparing the results from the Tapas Cologne project to the results if I just implement my algorithms on a random city pulled form open street maps. By comparing the two I should be able to determine if my algorithm runs proficiently, it should be able to alleviate traffic congestion to a degree and allowing routes to be recalculated based on the metrics discussed.

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