Systems Modelling & Simulation: The Sharing of Traffic Knowledge

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***Abstract*—Advanced traveller information systems (ATIS) have seen a steady increase in popularity in the last decade among urban users. By providing travellers with relevant information, these systems have the ability to considerably increase traffic flow, but are limited by their penetration ratio among the city's population. In this work we simulate a road network where different levels of information percolation are tested as well as their usage policy. The analogy with real life is to assess the extent to which an ATIS can improve total travel time and road utilization, and quantify this usefulness by means of improvement of traffic flow on several metrics.**

***Index Terms*—Traffic Modelling, Simulation, Advanced Traveler Information Systems**

I. Introduction

In recent years, we have witnessed the increasing availability of computing-capable devices (*ubiquitous computing* [Krumm, 2016]), and the following increasing volume and accuracy of data sources for behaviour prediction (most notably, smartphone data). This presents a unique opportunity for *advanced traveller information systems* (ATIS) to improve the accuracy of their recommendations and other services, as well as the influence of these recommendations on overall traffic flow.

Urban areas have long been plagued by traffic-related problems, serving as prominent sources of stress, resource waste, and productivity loss for the city as a whole [Wang et al., 2012], [Çolak et al., 2016]. In a similar fashion, over-utilization of infrastructures can bring about the need for more monetary investments in maintaining the safety of the roads.

In this context, some applications surged as a way to tackle the stress of road users, like *WAZE* [Mobile, 2019]: a GPS application that enables sharing of information among users of the app as a way to better suggest alternatives to desired target locations.

The success of applications like *WAZE* raises curiosity into how strong this information percolation must be in order to actively improve traffic network usage as well as travel time for its users, along with other defined metrics. In this paper we explore how different percolation rates and operating policies of an Advanced Traveler Information Systems (ATIS) can impact the aforementioned metrics, while abstracting the problem as an event-based simulation on top of a graph structure.

From a realistic approach we can see our work supporting our hypothesis and at the same time provide an easy way to simulate this kind of problems. Depending on what kind of insights we derive and how strongly we prove (or for this matter, disprove) our hypothesis it would make sense to present this work to authorities responsible for infrastructure management of our region's traffic networks.

Our goal is to find an abstraction as a way to model traffic networks where we can simulate information percolation with respect to different policies of sharing such knowledge. The primary goal will be to test our hypothesis and verify what kind of insights this kind of work can provide, specially from a context of simulation. Our secondary goal will be to develop an infrastructure to simulate these kind of network problems. This last goal might be unfeasible within our time constraints but we believe some groundwork can be laid out, nevertheless our main focus will be at the primary goal.

II. Literature Review

This is not a novelty work and as such we should briefly describe some other advances that have been made with respect to intelligent systems in the context of traffic problems. It's also important to give some baseline knowledge about this domain.

A. Related Work

In search for similar work we used the following combinations of terms, in Google Scholar and ordered by relevance. Some readings come from following the citations of articles found in the search as well. For each article we give a brief summary.

▷ **event-based *AND* traffic *AND* macro *AND* simulation**

- [Burghout et al., 2005] - Doctoral thesis that investigates the possibility of integrating mesoscopic and microscopic traffic simulation models, combining the strengths of both approaches. Microspcopic simulation is used in areas of specific interest in the road network whereas a mesoscopic model is used in the simulation of the remaining areas. Employs a mesoscopic vehicle-based and event-based model as a common representation of the traffic flow in the micro and meso approaches. Proposes a framework suited for hybrid modelling, *MiMe*, that helps demonstrate the correctness of the obtained solutions. The author is also capable of concluding that the hybrid approach was able of increasing the quality of the simulation results.

- [Sultanik et al., 2005] - Introduces the Macro Agent Transport Event-based Simulator (MATES), an event-based application-layer simulator created to investigate the behavior of distributed agent-based systems running atop peer-to-peer networks. MATES appears as a system to test and compare distributed algorithms. This project, even though represents a macro event-based agent approach, misses the scope of our project.
- [Burghout et al., 2006] - Paper presented as an improvement to the previous work in [Burghout et al., 2005]. Combines a series of advances in simulation modelling, e.g. speed-density modelling and start-up shockwaves, with the previously mentioned hybrid mesoscopic–microscopic traffic simulation model. While the start-up shockwave advance does not prove of interest to us, since it regards the microscopic model, the speed-density modelling is of interest as it presents a new approach to the modelling of vehicle entrances in a link and the consequent impact in the link's flow.
- [Burghout and Wahlstedt, 2007] - Another improvement to the previous works in [Burghout et al., 2006] and [Burghout et al., 2005]. Introduces the use of adaptive signal control and bus-priority functions, simulated by a separate signal controller simulator (EC1-simulator). Any of the new two alternatives of control scheme presented, which reproduce the exact control behavior as implemented in the field, bring improvements to the simulation model as the average number of delays, stops and travel times was reduced. The improvement introduced in this paper is not of interest to us considering it represents an advance in the microscopic simulation.

▷ **(ATIS *OR* ATMS) *AND* simulation**

- [Adler et al., 1992] - Freeway and Arterial Street Traffic Conflict Arousal and Resolution Simulator (FASTCARS) is presented as a simulator designed for in-laboratory experimentation and data collection to estimate and calibrate predictive models. It implements three types of ATIS: Variable Message Signs, In-Vehicle Navigation Systems and Highway Advisory Audio. This work falls right under our proposal in the sense that we are also trying to evaluate the influence of information percolation on traffic networks and as such we simulate a system akin to ATIS and check its influence based on different operating policies.
- [Mahmassani, 1994] - A technical report detailing methodological and algorithmic constructs needed to match hardware and software of large-scale traffic systems. The problem to tackle is the specification and development of capabilities necessary to achieve in-vehicle route guidance Advanced Traveler Information Systems (ATIS) in together with Advanced Traffic Management Systems (ATMS) for better efficiency of traffic networks. Key functions of such systems would be to, even in the presence of partial/incomplete information, be able to optimize the overall performance of the system while still maintaining a good degree of fairness and reasonableness to individual users.
- [Mahmassani, 1998] - An extensive overview of developments in traffic simulation and dynamic assignment models for real-time Advanced Traveler Information Systems/Advanced Traffic Management Systems (ATIS/ATMS), with specific reference to the DYNASMART (Dynamic Network Assignment-Simulation Model for Advanced Road Telematics) framework, also mentioned in [Mahmassani, 1994]. Two approaches are taken to real-time route assignment, a centralized one and a decentralized approach which relies on heuristic local rules that react to observed measurements.

▷ **traffic *AND* graph *AND* simulation**

- [Cheng, 1996] - The work combines a knowledge-based system with the critical path method in order to obtain reschedules under time and resource constraints in a train traffic control environment. A network graph model is used to model the train traffic and a set of operations describe the behaviour of such model. When dealing with the delays, it's not always possible to obtain an optimum reschedule using only local information. For large scale delays the need for global information grows and the proposed method allows for optimum rescheduling and the ability to add new heuristics to the knowledge base makes the system more robust and extensible. It's also worth noting that such an approach is not limited to train traffic control.
- [Hewage and Ruwanpura, 2004] - A special-purpose simulation (SPS) tool is used analyze traffic flow patterns to optimize signal light timing at single junctions and in multiple-junctions road networks. It's designed to optimize three and four-way junctions and changes light timings based on the estimated demand of traffic from every possible direction. By using simulation it is possible to gather data and insights in an easier, less costly way. The demand estimation is not assumed to be constant but is rather taken as instantaneous readings, similar to the work we present to model the insertion of actors in the environment.
- [Miller and Horowitz, 2007] - A traffic simulator is presented with emphasis on customization and capable of macroscopic and well as microscopic simulation of free-flow traffic. The freeway systems are represented as graph data structures with edge weights being determined by the speed of vehicles in a given path. Vehicles can communicate with a central system to supply information such as location and speed as well as request shortest path data. Upon receiving the information from the central ITS, vehicles can opt to change or maintain their desired path. The simulator works on both user-generated data as

well as real data while keeping track of every vehicle's status.

- [Chinyere et al., 2011] - A methodology for the design and implementation of intelligent traffic lights control system was introduced. This methodology hybridizes two standard methodologies: the Structured System Analysis and Design Methodology (SSADM) and the Fuzzy Based Design Methodology. The objective is to determine major causes of traffic deadlock on road junctions, specially those of type "+" and eliminating logjam. The system was tested on an intersection known for its congestion problems in Nigeria and eliminated some of the problems raised by the authors.

▷ **from a previous iteration of this report**

- [Rossetti and Liu, 2005] - Allies the paradigm of Multi-Agent Systems (MAS) to the fulfilment of requirements imposed by Intelligent Traffic Systems (ITS). The abstraction of MAS is used to model complex urban traffic systems. This methodology proves improves the microscopic simulation by using a society of agents that share an environment and whose reasoning mechanisms, knowledge representations and learning abilities are widely flexible. The authors implement driver agents with cognitive and reactive representations as well as dynamically generating options based on the perception of the world at a given time and their reasoning process. From our point of view this poses an interest in how we can model individual actors in the simulation environment, as well as their decision-making capabilities.
- [Capela et al., 2014] - A new type of optimization algorithm, Inverted Ant Colony Optimization (IACO), was used for traffic management and vehicle distribution. It was shown that this approach not only improved the local space but the global space as well. The algorithm centers around the thought that vehicles while passing through a given road, free pheromones that signal their passage. This in turn allows other vehicles to change their trajectory when considering that a road might suffer from congestion if it has a lot of said pheromones. The idea of not choosing a path that is being taken by many other drivers can be beneficial for the driver, even when the alternative would not be his first choice is aligned with our hypothesis.
- [Guriau et al., 2016] - Cooperative Intelligent Transportation System (C-ITS), a new paradigm of ITS is discussed for efficient traffic state estimation and traffic control. This cooperation is made at three levels of action, (1) vehicles with Advanced Driver Assistance System (ADAS) adjust their behaviour to surrounding conditions, (2) information is exchanged with the infrastructure and (3) information is shared between vehicles. Cooperative models are introduced into a traffic simulator to assess the benefits of this emerging strategy. Simulation results give evidence of the benefits of the cooperative paradigm in terms of homogenization and safety.
- [Shang et al., 2017] - A two-layered model that captures the segregation of drivers in traffic networks due to information sharing and learning processes. This model does not assume perfect information, rather it starts from the principle that travellers form groups where information is shared among its members. Therefore, a decision is taken based not only on the user's experience but also on the decision of other group members. The two layers to this model are two interacting networks, a conceptual communication network (the cyber layer) and a day-to-day transport network capturing traffic information (the physical layer). The experiments made showed a strong positive correlation between the connectivity of the communication network and the convergence of the network.
- [Li et al., 2017] - An optimization model with different types of traveler knowledge is introduced. The model takes into account the capacity distribution across a large number of days (also referenced as scenarios) and splits travelers in two classes, those with access to perfect traffic information and those with information about expected traffic conditions and a confidence level. The objective of this work is to evaluate the impact of providing traffic information within a congested network.

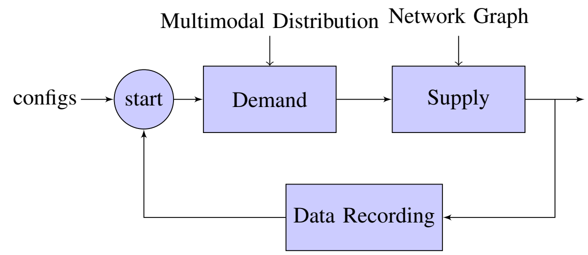

Fig. 1. Our simulation process, at a high abstraction level.

B. *Gap Analysis*

In Table I we aggregate the mentioned works based on their collection of features, this way we can understand how our work fits amongst the others and what gap we are aiming to fill.

III. Methodological Approach

In this section, both the methodological and theoretical aspects, namely the event-driven mesoscopic model design, will be analysed.

At a high abstraction level, our simulation work will follow the diagram in figure 1. We will use the decision tree to simulate the demand of the network, whose supply will be given by the graph that abstracts the traffic roads.

A. *Mesoscopic model*

For our approach, we designed a mesoscopic model in which the road network is represented as directed graph where each link represents a possible path that takes a model actor from one location to another. Each link saves information regarding the time it takes to traverse in a free flow situation,

TABLE I
GAP ANALYSIS MATRIX

Work	ATIS/ATMS	Macro	Meso	Micro	Event-Driven	Graph
[Adler et al., 1992]	X			X		
[Cheng, 1996]				X		X
[Hewage and Ruwanpura, 2004]			X			
[Burghout et al., 2005]			X	X	X	X
[Rossetti and Liu, 2005]				X		
[Miller and Horowitz, 2007]	X	X		X		X
[Capela et al., 2014]				X		X
[Guriau et al., 2016]	X			X		
[Shang et al., 2017]	X			X		X
[Li et al., 2017]	X	X				
Ours	X		X		X	X

the link's capacity and the link's volume, meaning the number of actors that are currently traversing it. With the referred data available we are capable of calculating the current time it takes to travel any given edge, using the following congestion function:

$$S_a(v_a) = t_a\Big(1 + 0.15\Big(\frac{v_a}{c_a}\Big)^4\Big)$$

Where $S_a(v_a)$ is the average travel time for a vehicle on a given link a; t_a is the free flow travel time on link a per unit of time; v_a is the volume of traffic on link a per unit of time and c_a is the capacity of link a per unit of time.

The link's volume is updated every time a new vehicle U_i enters L_i and every time a vehicle leaves L_i, in an event-based fashion.

The timestamps at which the actors start their respective routes are modelled using a mathematical distribution that can be given as input. By default, a Multimodal distribution that resembles the peak hours in urban regions is used.

B. Event-driven model

As previously referred in section III-A, we opted to use an event-driven model. As the simulation progresses, a priority queue containing all the simulation events is maintained. The queue is ordered by the timestamp in which the events occur. When an event is processed, it may generate new consequential events that are also added to the queue. The simulation finishes when the priority queue becomes empty.

Several type of events were modelled, namely:

- **Actor creation**: event responsible for inserting an actor in the road network by creating a *Start edge event* at the actor's route first edge. The insertion time of the actor in the network follows the aforementioned distribution.
- **Start edge**: event responsible for assigning to to an actor the link that actor will traverse next.
- **End edge**: the actor has finished traversing the associated link. If the actor has reached its destiny no more events are triggered, if not, a new *Start edge event* is created for the next link in the actor's route.
- **Accident**: event responsible for creating an accident in a given link, therefore reducing its capacity and increasing the link's normal travel time.

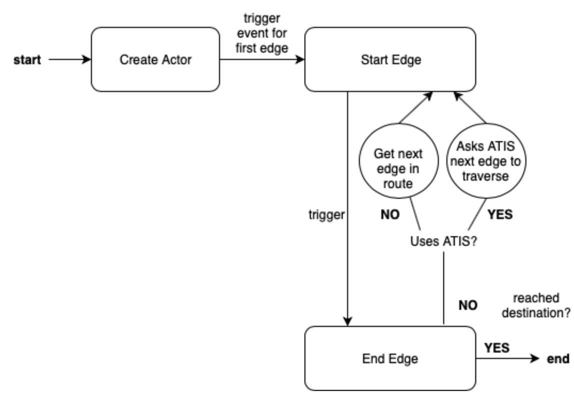

Fig. 2. Actor lifecycle

Figure 2 summarizes the lifecycle of an actor.

To begin the simulation, the queue is initialized with the all the *Actor creation events*.

C. ATIS module

The percentage of ATIS users in the network is another of the simulation parameters.

The actors that do not use ATIS, when deciding which link to traverse next, will see what is the next link in their initially assigned route and traverse it. Alternatively, the actors that do use ATIS will, at end of traversing a link, consult it, inquiring what is the link that takes the actor faster to the desired destination.

Regarding the ATIS, two distinct approaches were designed: in the initial one, the ATIS bases its estimates on the network current configuration, meaning that the estimate assumes that the time it will take to traverse a link in the future is similar to the time it currently takes to traverse the same edge. In the alternate implementation, the ATIS will make its predictions considering the actors starting timestamp distribution (see section III-A), assuming a correlation between the actual edge volume and its expected volume. The computed ratio is assumed to be constant for the correspondent link and is used to estimate the time it takes to travel that same link at any given time.

IV. Experiments

When running the experiments we based our daily profile usage from the work done in [Sunderrajan et al., 2018].

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