A MULTI-AGENT BASED TRAFFIC NETWORK MICRO-SIMULATION USING SPATIO-TEMPORAL GIS

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ABSTRACT:

A micro-simulation framework allows for the combination of several highly disaggregated models integrating direct representations of individual actors and specific processes within detailed space and time frames. For some modelling applications like traffic, disaggregation is often necessary in order to capture system non-linearities, to avoid the heterogeneity leading to aggregate biases when behaviour is non-linear, and to provide detailed information for process understanding and informed decision making.
The main objective of this paper is to develop a prototype of spatio-temporal multi-agent system for a micro-simulation of highway traffic at the peak traffic times. During the last few years, various authors have extended the paradigm and proposed various enhancements to strengthen its framework. This paper has integrated those findings with our own experiences of developing geospatial information system (GIS) for transportation studies and for analyzing travel behaviours.
The proposed methods were implemented by ArcGIS 9.2 utilization and customization. To evaluate the performance of the outlined method, some experiments performed by using actual road maps of a part of Tehran traffic network. Tests of the proposed methods are conducted and the results show the efficiency of the algorithm and support our hypotheses.

1. INTRODUCTION

As the numbers of vehicles and everyone’s daily average travelling have been increasing for many years, and as current forecasting does not predict a big drop of this trend, one should think about methods to have better efficiency in decreasing traffic jams. In this context, simulators are useful aids where the understanding of a phenomenon, that can be simulated, is quite difficult.

Simulators help to view the same phenomena at different levels of abstraction and hence aid in easy understanding for various users who have different knowledge of the phenomena under consideration. They are also useful where the effects of implementation of a policy are difficult to predict and the actual implementation of the policy is quite costly. Such simulations can be used to evaluate modifications not only under nominal conditions, but also under hypothetical scenarios that would be difficult to observe in the real world.

In recent years, microscopic traffic simulations have become an increasingly active field of research in transport engineering. In this approach, all elements of the transport system like roads, vehicles, and most importantly travellers are resolved allowing them to interact locally with other elements. In this context, microscopic traffic simulators can model traffic flow in a realistic manner. This modelling approach is in contrast with the more aggregate models implemented in current transport planning software used by transportation planners.
Combining space and time in a data model is a precondition for analyzing and understanding real world evolution and changing processes. A micro-simulation framework allows for the combination of several highly disaggregated models integrating direct representations of individual actors and specific processes within detailed space and time frames. For some applications like traffic, disaggregation is often necessary in order to capture system non-linearities, to avoid the heterogeneity leading to aggregate biases when behaviour is non-linear, and to provide detailed information for process understanding and informed decision making.

The main objective of this paper is to develop a functional prototype of spatio-temporal multi-agent system for the micro-simulation of highway traffic at the peak traffic times to find ways to increase highways’ efficiency. A traffic micro-simulation involves modelling each of the vehicles involved in the traffic and giving each vehicle a set of its own characteristics. The overall traffic can be viewed as a collective behaviour of each of the individual vehicles.

Background and some related works on microscopic traffic simulation are introduced in section II. Section III describes some general issues about agent-based simulation. In section IV, the methodology proposed for the traffic simulation based on multi agent approach is given. Finally, the conclusion of this paper and some future remarks are given.

2. BACKGROUND

Highways are modern means of transportation for individual motorized vehicles. To solve traffic problems in highways, some people think about increasing the number of lanes or even the speed limits. On the contrary, others suggest the decrease of the speed limit to avoid traffic jams. To find the best plan to

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increase highways' efficiency, software simulation can be very useful. It can help us to test solutions with less cost and effort.

Basically, simulations can be viewed at two levels named macro- and micro-simulations. Macro-simulations follow a top-down approach, focusing on the observable behavior of a system. They try to define and regenerate the observable behavior in terms of aggregate, abstract parameters, and their probability distributions. Modeling of system from this view results in losing some of the finer aspects of the system like individual vehicle behavior based on psychological traits in the case of traffic.

The macro travel demand modelling often is performed by transportation planners in a general structure called urban transportation modelling system (UTMS). The main advantage of this classic model is that any correct computation will yield same results but in this model decisions are decoupled from individual actors. In the other words, this modelling approach completely severs the connection to the individual travellers and all travellers going to the same destination are assumed to be equal.
Most aspects of complex systems like transportation, however, are highly nonlinear. Such systems are often extremely sensitive to initial conditions, and even infinitesimal perturbations to initial conditions can have arbitrarily large impact on the global system behavior. In the process of aggregating and abstracting information, macro models lose their sensitivity, and they capture the behavior of traffic only under idealistic conditions (Erol *et al*., 1998).

Micro-simulation is a bottom-up approach, where a complex system is viewed as a large set of small, interacting components. The main focus is on identifying the components in a system, discovering their local behaviors and the interactions among them. The global system behavior emerges from the local behaviors of the individual components, and their interactions (Erol *et al*., 1998).

In traffic simulation, micro-simulation involves modeling each of the vehicles involved in the traffic i.e. giving each vehicle a set of its own characteristics like the vehicle length, width and maximum allowable speed. Each vehicle interacts with others in a certain way, which depends not only on the relative positions and speeds but also on the psychologies of the drivers involved. In such simulation prototype, car following, lane changing and merging models must be developed. These models are vital components of any traffic simulation model so the accuracy of these models results in more accurate simulation of traffic flow. These models involve a high level of interaction between the vehicles, where the behaviour of each vehicle is influenced by the behaviour of the other, thus they need to react and to make decisions based on their knowledge of the assumed intentions of the other vehicle and of the surrounding traffic environment. These interactions require complex behavioural decision-making processes which can best be modelled by intelligent agent techniques.

In the past, single-lane car-following models have been successfully applied to describe traffic dynamics (Helbing, 2001). In the car following model of Newell (1961), or the "optimal-velocity model" (Bando et al., 1995), the acceleration of an individual vehicle depends only on the distance to the front vehicle. In some models the acceleration depends also on the velocity and on the approaching rate to the front vehicle (Gipps, 1981; Krauß, 1998; Helbing and Tilch, 1998).

In this paper, we used the recently proposed intelligent-driver model (IDM) taking into account more than one predecessor (Treiber *et al*., 2006).

A realistic description of heterogeneous traffic streams is only possible within a multi-lane modelling framework allowing faster vehicles to improve their driving conditions by passing slower vehicles. Hence, lane changing has been recently received increased attention (Laval and Daganzo, 2006; Coifman *et al*., 2005; Wei *et al*., 2000). In addition, Kesting *et al.* proposed a lane changing model assuming that a driver typically makes a trade-off between the expected own advantage and the disadvantage imposed on other drivers (Kesting *et al*., 2007). In this context, this model takes into account the behavioural characteristics of travellers.

The difficulties of modelling congested conditions in merging areas with some existing simulation models are well known. For example Prevedouros and Wang reported such problems with INTEGRATION, FRESIM and WATsim (Prevedouros and Wang, 1999). Some models, e.g. AIMSUN, use a user-defined maximum waiting time while a vehicle is attempting to change lane, after which it gives up and continues in the wrong direction, becoming a 'lost vehicle' (TSS, 2002).

Few studies in the literature dealt with vehicle interactions in detail. Kita (1998) and Kita and Fukuyama (1999) modelled vehicle interactions in a merging situation at expressway on-ramps, based on game theory. Kita *et al.* (Kita *et al*., 2002) presented a further improvement of the model, which takes into account the presence of leader vehicles, but there are still a number of simplifications in this model for example it assumes constant speed for travellers and it does not consider the minimum safe gap and behavioural parameters in merging situations.

Comparing to these works, our prototype uses a behavioural model to find more reasonable results when we define more complex situations. In addition, using GIS help better data handling and modelling especially in complex spatio-temporal situations as well as preferable presentation of traffic simulation.

3. AGENT-BASED SIMULATION

Multi-agent systems (MAS) are composed of autonomous, interacting, more or less intelligent entities. The agent metaphor has proven to be a promising choice for building complex and adaptive software applications, because it addresses key issues for making complexity manageable already at a conceptual level. Furthermore, agent technology can be seen as a natural successor of the object-oriented paradigm and enriches the world of passive objects with the notion of autonomous actors. Therefore, agent technology is a rapidly developing area of research and it has the potential to stimulate and contribute to a broad variety of scientific fields (Cicortas and Somsi, 2005).

Agents are computer systems with two important capabilities. First, they are at least to some extent capable of autonomous action – of deciding for themselves what they need to do in order to satisfy their design objectives. Second, they are capable of interacting with other agents - not simply by exchanging data, but by engaging in analogues of the kind of social activity that we all engage in our every day life: cooperation, coordination, negotiation, and the like (Wooldridge, 2002).

Agents are a part of an environment which can sense their environment. An agent has a plan and a goal and it can use its sensed knowledge in achieving them. In this regard, a vehicle with its driver can also be looked up as an agent because it is a part of an environment i.e. traffic, it can sense the environment by knowing other vehicles on road and how they move. That is, it looks at other vehicles on the road continuously and moves to reach its destination safely in the fastest possible way. That is, intelligent agents can be used to simulate the driving behaviour of individual drivers. The adaptability and flexibility of an intelligent agent make it possible to control various types of vehicles with different driving styles. Each agent can be equipped with its own behaviour settings to simulate personalized driving behaviour. This way, the simulated vehicles will behave realistically and the interaction between multiple drivers can be studied.

Generally, the motivation for multi-agent based simulations is based on the two simply but conflicting objectives:

i. The ability to accurately measure the influence of different multi-agent coordination strategies in an un-predictable environment.
ii. Realistically modeling adaptive behavior in multi-agent systems within a static environment.

The MAS allow solving problems collaboratively by coordinating the knowledge, goals and plans of autonomous intelligent agents. It offers certain advantages of: faster response, increased flexibility, robustness, resource sharing, graceful degradation and better adaptability of integrating pre-existing and stand-alone systems (Cicortas and Somsi, 2005).

4. METHODOLOGY

In this paper, the GIS-based multi-agent traffic micro-simulation approach utilized in order to determine dynamic traffic congestion in a highway. The proposed method uses a discrete time dynamic network assignment procedure that simulates network flow at detailed temporal resolutions.
The main steps of traffic agent-based simulation are shown in Figure 1.

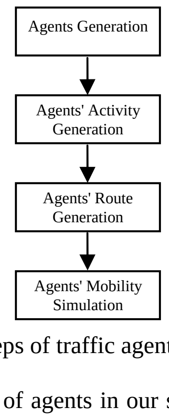

Figure 1. The main steps of traffic agent-based modeling

We identified three kinds of agents in our simulation prototype as follow:

1. Vehicles: any agent of this kind has some attributes such as its position (relative to current segment), its speed and lane position, its length, maximum acceleration and minimum deceleration. In addition, each agent has a plan which is an ordered collection of the highway segments telling which way it takes and a behaviour which is categorized to normal, cautious or aggressive.
2. Vehicle Creator: this kind of agent is a dedicated agent which takes care of creating new agents in the system based on the current time of simulation.
3. The highway segments: this kind of agent has a few constant attributes (length, number of lanes, max law speed limit, slope, and curve) and a few variable attributes (flow, density and mean speed). The constant attributes are fixed at start-up and variable attributes change during the execution of the simulation. All these attributes are part of the environment and can be perceived by vehicle agents.

Based on the main steps of traffic agent-based simulation shown in Figure 1, the first step is generating agent population. In the proposed methodology (depicted in Figure 2), vehicle agents are generated based on inductive loops' data. In this data, the numbers of vehicles that pass through the regarded inductive loop are specified. Activity and route generation form the plan of agents. All agents have their own plans about their destinations represented by ordered collections of the highway segments. We used the census data prepared for generating Origin-destination (OD) matrices to construct one-hour OD matrices. The travel desired routes are obtained from the classic model. All those routes which simultaneously pass thorough the highway under investigation must be extracted as agents' plans. The plan of an agent shows the used on-ramp and off-ramp and the ordered collection of the highway segments telling which way the agent takes.

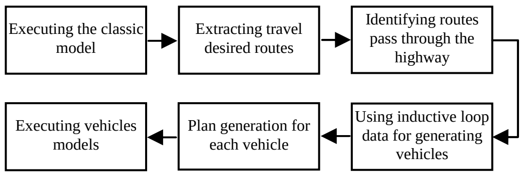

Figure 2. Flow-chart of the proposed methodology

Up to this step, vehicles were created as agents and plans were generated and assigned to them. Each agent by regarding its plan must interact with others in a certain way, which depends not only on the relative positions and speeds but also on the psychologies of the drivers involved. In the proposed approach, we used three vehicle models including car following model, lane changing model and merging model. Car following model describes how a car speeds up and brakes. The car following model used in this paper computes at each step of the simulation, a new acceleration depending only on the vehicle's speed as well as the speed and distance of the car ahead of it. Also, the lane changing model describes how a driver decides to change the lane. This decision is based on two main criteria for the agent: is it safe to go on the other lane? (Safety criterion) and do the agent get a reward to go on the other lane? (Incentive criterion) (Kesting *et al.*, 2007). Merging model is used for on-ramp and off-ramp locations as well as other spatially complex situations like accidents. Figure 3 shows the flowchart of executing routine of these models.

Every driver has the aim to reach his destination and he has certain selfishness with which he likes to achieve his aim that is the inclination to achieve the goal differs for different drivers.

In this context, we modelled the behaviour of drivers, as being cautious, normal, and aggressive.

In merging conditions, based on behavioural characteristics of the drivers involved, different scenarios may happen. When a driver is near the merging location or the location of the off-ramp that he must use in order to achieve his plan and he is not on the right lane, he must try to change his lane by satisfying the general lane changing criteria. Nevertheless if the distance to merging location is not far enough, based on characteristic behaviour of the driver, different scenarios are possible. If the driver is normal or cautious, he will brake and decrease his speed to increase the chance of a safe lane change. In the case he could not change his lane in a safe mode, he will continue his way and stop in merging location and wait for some time to reach the satisfied lane changing criteria. Nevertheless, if the driver is aggressive, he will change his lane by forcing the vehicle in the other lane to decrease its speed.

As it mentioned, the proposed method uses a discrete time network assignment procedure that simulates network flow at detailed temporal resolutions. In the other words, a message is sent to every agent at each step of the simulation, and they return an action depending on what they perceive and what their behaviour is described by its internal model. In this process some events are raised by agents or the environment. These events can be classified according to the categories in the work of Schumacher and Ossowski (2006). This classification is depicted in Figure 3.

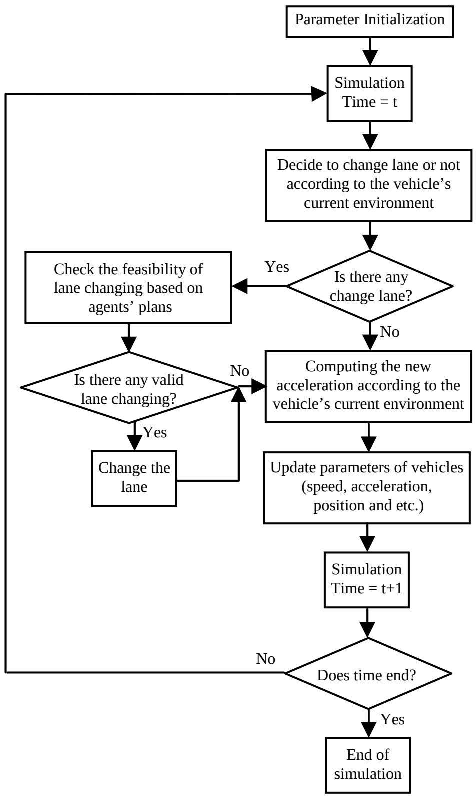

Figure 3. Flowchart of executing routine of the vehicle models

Generally, the proposed approach executes all agents' plans which simultaneously pass through the highway under investigation. So, we can obtain the results of interactions between the plans and the congestion happened. In addition, once the simulation is done we can assess the effects of different parameters on the highway performance and investigate the results of different plans to decrease the congestion.

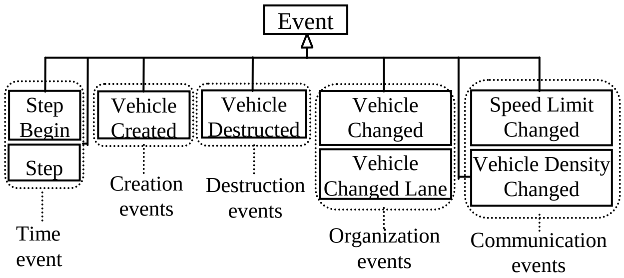

Figure 4. Events hierarchy diagram

GIS as a matured concept, has a great potential to accommodate a variety of transportation applications. Traffic modelling is one of these diverse applications. It is due to the fact that GIS has superior data management, visualization and analysis capabilities which are vital in planning processes. The proposed method was implemented in ArcGIS 9.2 which has a feature in architectural design, enabling it to be developed by COM programming in any visual environment. To evaluate the performance of the outlined method, we performed experiments using actual road maps of a part of Tehran traffic network at a scale of 1:2000 (Figure 5) and tested the proposed method for a highway in the study area (Figure 6). In addition, each result given up was performed on Intel® Core™ 2 Duo CPU T7300 (2 and 1.99GHz) with 2 GB of RAM.

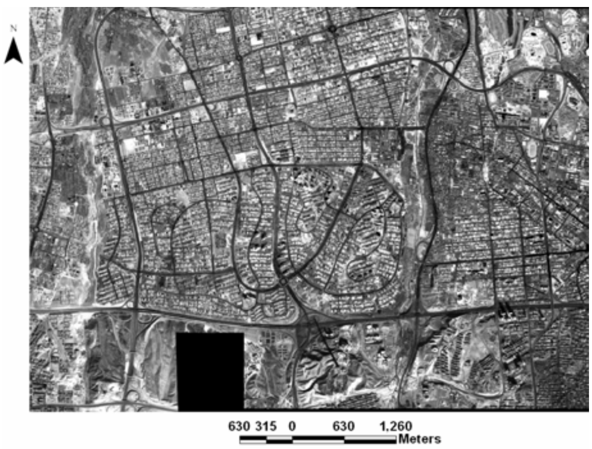

Figure 5. The study area

5. CONCLUSIONS AND FUTURE REMARKS

The main advantage of agent-based microscopic traffic simulations over traditional simulations is that it is more realistic. In addition, these simulations are distributed. The decentralized, partially autonomous and redundant nature of such simulations make them less sensitive to certain classes of faults. This decentralization, however, also makes it difficult to analyze these simulations.

The prepared prototype is only a primary system. To be a more complete and universal traffic simulator, many of the elements should be improved in the future work. As it mentioned, agent-based simulation is modular so it is extendible. In addition, for accurate results, micro simulation models must capture the rich and diverse behavior of drivers. Activity structures of agents help us to represent complex driver behavior and support integration of sophisticated control strategies.

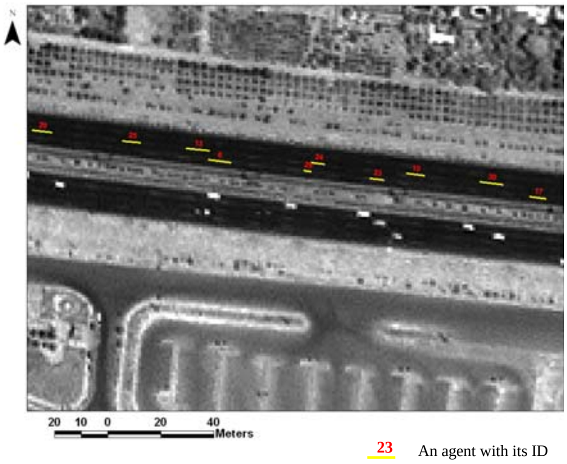

Figure 6. The simulation prototype

The emphasis of this paper is on the methodology proposed for simulating and investigating traffic congestion in a highway. During the last few years, various authors have extended the historical paradigm regarding traffic congestion modelling and proposed various enhancements to strengthen its framework. This paper has successfully attempted to integrate those findings with our own experiences of developing GIS for analyzing travel behaviour of commuters. Initial results achieved are promising in terms of efficiency of the proposed method.

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