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Information impact on transportation systems☆

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ABSTRACT

With a broader distribution of personal smart devices and with an increasing availability of advanced navigation tools, more drivers can have access to real time information regarding the traffic situation. Our research focuses on determining how using the real time information about a transportation system could influence the system itself. We developed an agent based model to simulate the effect of drivers using real time information to avoid traffic congestion. Experiments reveal that the system's performance is influenced by the number of participants that have access to real time information. We also discover that, in certain circumstances, the system performance when all participants have information is no different from, and perhaps even worse than, when no participant has access to information.

1. Introduction

With a larger distribution of personal smart devices and navigation tools, there are several novel sources for real time data collection and better means for information transmission. At the same time, Intelligent Transportation Systems (ITS), applying information processing, communication, sensing, and control technologies [21], have become more advanced and play a key role in improving transportation [20]. In this context, large amounts of data are processed and presented to the participant vehicles through their navigation systems. Surveys show that, in most of the cases, drivers trust real time information and follow the navigation recommendations [6]. However, the consequences of providing real time information to drivers, who are themselves participants in the data collection process, has not been investigated in much detail.

Information dissemination with feedback loops is a fundamental topic in all human complex systems where people make decisions by accessing real time information. Knowing details of future problems modifies people's behaviours and this possibly affects the entire system. This effect has been studied in several areas of human activity. For example, in financial markets, has been analysed the effect of private and public information. In [8], the market dynamics is explained by phases: boom, euphoria (with informational cascades), trigger and panic (with information avalanches). Another example is analysing the effect of transaction costs on the overall market efficiency when aggregating private information [3].

In this paper, we investigate the effect of information dissemination on transportation systems. The annual Traffic Report released in 2014 by the navigation device maker, TomTom, after analysing real world traffic data, reveals that the travel time is increased by 50% because of the common traffic shortcuts drivers take to avoid congestion [16]. The effect can be empirically observed, for instance, during daily commutes, when multiple drivers make the simultaneous decision to take the same alternative route, thus simply moving the congestion to the new road.

Unlike in existing research, [14,15,1,11] discussed in more detail in Section 2, we are particularly interested in investigating how the traffic is affected by the amount of drivers that receive information about the traffic situation. Intuitively, the more drivers are informed, the better the traffic situation should be. We investigate and analyse the conditions under which, drivers having knowledge of the current situation of the traffic system is detrimental to the system as a whole. For this, we built an experimental set-up based on a microscopic traffic simulation. The transportation system and the information dissemination in it is modelled and analysed in this paper through an agent based simulation.

This paper is organised as follows: Section 2 introduces related work done on the effect of information dissemination over

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transportation networks. Section 3 and Section 4 describe the computational model, experimental set-up and the numerical results. Section 5 presents the conclusion and the significance of our study.

2. Related work

There are some relevant studies on information dissemination in transportation systems using simulations. One category of studies look at how either local information (only about the neighbours) or global information (about the entire network) affects the global network performance. Our approach is different in the sense that we investigate the impact of information on the global network performance depending on the fraction of people that receive information. We analyse what is the effect of real time information dissemination and explain why this effect appears. Information is disseminated in real time and contains global details about how congested the roads are. This approach is important as it gives insights on the impact that massive use of real-time information can have on traffic. This can be useful for building more intelligent traffic control mechanisms where information is a steering tool.

Models of information dissemination have also been studied for networks with congested and uncongested nodes [14,15]. The information (details such as congestion, flow or occupancy) was either local or global. Information is used to control the node's outgoing traffic flow, influencing this way the routing choice for vehicles. In [15], urban street models were implemented for various topologies ranging from naturally evolved ones such as Bologna or London to grid-like cities such as Los Angeles or Washington. Both [15] and [14] show that the best performance is achieved when local information is used.

Information control systems for traffic planning in the presence of congestion has been researched by [1,9–11]. In [1], a fleet of taxi drivers from Singapore used a Web based application to specify trip origin, destination and departure time and receive route recommendations. Congestion was modelled as a relationship between flow and delay, model proposed by the Bureau of Public Roads (BPR). Congestion is estimated using traffic data from loop detectors, GPS location and time data from a roving fleet of taxis. The learned congestion model is used in multi-agent system (computing socially optimal paths) and also in a single agents route planning (computing greedy path). The study proposes an experimental comparison between actual taxi paths, with socially optimal and greedy path congestion-aware planning. The results show that socially-optimal congestion aware routing achieves 15% reduction in travel time.

Our approach is similar because we also select a fraction of drivers to receive recommendations. However, in the previous studies, the number of informed drivers is fixed to the taxi fleet. We investigate in more detail what happens when different percentages of traffic participants receive information. Another difference is that we do not estimate congestion, because, the fact that traffic participants use information makes the congestion prediction invalid.

Other similar studies analysing the effect of information on a traffic simulation are inspired from biological ants systems [4,5]. Information consists of route recommendations. There are infrastructure agents (roads) and vehicle agents. The vehicle agent knows the destination of the car, asks the environment for routing options and informs the road agent of its intention. Based on these details, the road agent estimates the future traffic intensity and gives a recommendation to the vehicle agent. This mechanism provides a better routing choice to drivers.

Understanding congestion is an important aspect in our study. In transportation systems, there are two parameters that are usually taken into consideration when defining congestion: the amount of traffic flow and the strength or the degree of congestion [17]. There are multiple causes for congestion: high traffic flow, bottlenecks (local reduction of the road capacity) and local disturbances of individual drivers in the flow [17,19]. While bottlenecks (caused by road obstructions or lane narrowing) are considered to be spatial and deterministic, local disturbances in the flow are stochastic (spontaneous and unpredictable). They can be triggered, for instance, by an abrupt break or by two trucks overtaking each other at different speeds or several other factors. In our experiments we create congestion using local disturbances.

Network performance is defined by transportation engineers combining the analysis of individual traffic elements. The most common variables used are speed calculated usually as travel time or the delays defined as additional travel time experienced by the traffic participants. The global network performance is then obtained by aggregating the individual travel times across the entire network [12]. A similar performance indicator was selected for our study. Another approach would be to calculate the fundamental diagram of the network mean flux and a function of traffic load [15]. In other studies network performance is defined as the relation between the filled fraction of the total network capacity and the jammed population of nodes [14].

3. Computational model

We investigate the effect of information dissemination on transportation systems when different fractions of drivers are informed. In order to gain an understanding of this effect, we use a computation model of the traffic flow, congestion formation and information dissemination.

The transportation system is simulated using an agent-based simulation. The system consists of agents (vehicle driver units) operating and interacting in a shared environment (road network). The behaviour of the entire system is the emergent behaviour of all its interacting elements. The agents know the road network, perform route calculations and move forward on their route with a certain speed and acceleration determined by a time-stepped car following model [2]. For this, the Intelligent Driver Model (IDM) is used [18,7].

A road Y, is characterised by a tuple with road length, minimum speed and maximum speed: $Road_Y = \langle v_Y^{\min}, v_Y^{\max}, L_Y \rangle$. Fig. 1 illustrates a typical IDM scenario. A vehicle i follows the car in front vehicle $i+1$ at a speed less than the desired speed of the road v_d, which is a value between $v^{\min}$ and $v^{\max}$. The current speed of car i, v_i is adapted to the speed of car $i+1$, v_{i+1} in order to maintain a gap distance greater than D_{gap}. Where D_{gap} is a parameter of the IDM model that specifies the preferred distance between cars. IDM calculates a realistic instantaneous acceleration (or deceleration) and displacement of vehicle i for a time step δt by taking into consideration its current speed and position (v_i and x_i), the desired speed (v_d), the current speed and the position of the car in front (v_{i+1} and x_{i+1}). In addition, there are parameters that specify vehicle length ($L_{vehicle}$), time headway (t_h) for safe acceleration and deceleration (to avoid collisions), and maximum acceleration and deceleration (a_{max}, d_{max}).

We analyse the effect of traffic information dissemination in the presence of congestion. For this, we introduce stochastic disturbances in the traffic flow to create a controlled scenario where congestion is persistent. Congestion is produced naturally as an emergent behaviour of cars interacting on roads (for example it can create self-organised stop-and-go waves, as described in [7]). This congestion naturally appears and disappears through the evolution of the traffic. For our study we need to regulate congestion and for this reason we artificially introduce disturbances.