A Dynamic Traffic Regulation System with Dynamic Rerouting

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Abstract

In this article we describe the ongoing development and analysis of DTRS: A Dynamic Traffic Regulation System with dynamic rerouting. Furthermore, we discuss the development of a cellular automata based microscopic traffic simulator which is used in testing and validating the methods and strategies of DTRS.

1 Introduction

For more than a decade there has been a great interest in developing Intelligent Transportation Systems (ITS). For an excellent review consult Yang[1]. The purpose of ITS is to help in resolving some of the major traffic problems encountered in all urban areas around the world. In particular, it is believed that using ITS it is possible to significantly reduce problems with traffic congestion.

The main idea behind ITS is that through better traffic management strategies we can utilize the existing road networks much more efficient. Several ITS are currently under development. Below we have listed some of these projects. It should be noted that we have also included traffic simulation tools in the list since they play an important role in testing and evaluating different traffic management strategies.

- ADVANCE: Advanced Driver Vehicle Navigation ConcEpt[2],

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- METROPOLIS: A modular system for dynamics traffic simulation[3],
- PARAMICS[4],
- PULSAR: Princeton University's Large-Scale Automobile Routing System[5]
- SATURN: Simulation and Assignment of Traffic to Urban Road Networks[6],
- SIMLAB: A SIMulation LABoratory for Evaluation of Dynamic Traffic Management Systems[7],
- STEER: Signals/Traffic Emulator with Event-based Responsiveness[8],
- TRANSIMS: The TRansportation ANalysis SIMulation System[9].

For more detailed information about these projects the reader is urged to visit the websites listed in the references. It should also be noted that at these sites many of the research articles published in relation to the projects are available on-line.

In this article we describe the ongoing development of an intelligent transportation system called DTRS: A Dynamic Traffic Regulation System with dynamic rerouting. The key components of DTRS are

- traffic regulation system,
- intelligent route planner,
- traffic monitoring system,
- traffic simulator.

The remainder of the article is organized as follows. In section 2 we give an overview of the structure and key components of DTRS. In section 3 we give a detailed description of the cellular automata based microscopic traffic simulation model used in DTRS. Finally, in section 4 we conclude the work presented here and outline directions for future work.

2 An overview of DTRS

Static route guidance systems operates as shown in the figure below.

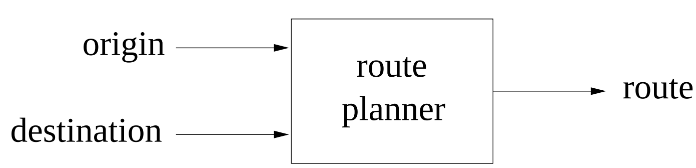

Figure 1: A static route guidance system.

The route planner generates an optimal route or path for the driver to follow through the road network from the origin to the destination point. If we assume the road network is implemented as a weighted directed graph where each weight is static and denotes the expected travel time of the corresponding road, then it is a trivial task to actually compute the optimal route. However, the static weights are clearly inadequate in reality where unforeseen events such as accidents, change in weather conditions, traffic congestion and road construction will jeopardize the route plans.

We have approached this problem by constructing a dynamic traffic regulation system which allows for dynamic and intelligent rerouting. Such a system is outlined in the figure below.

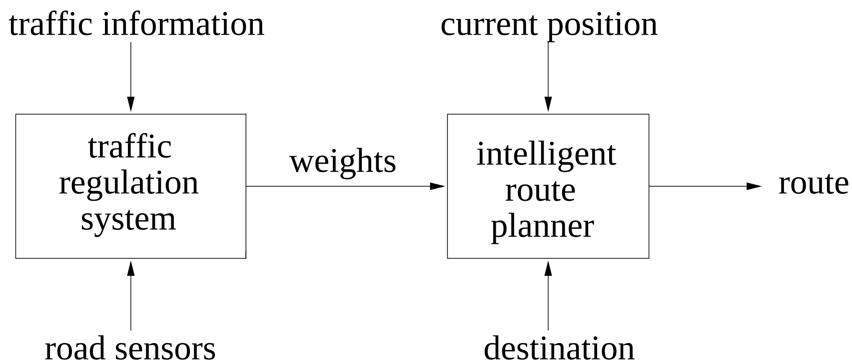

Figure 2: Outline of DTRS.

In our work we have made the assumption that the traffic regulation system receives information from a large network of road sensors collecting input from all roads covered by the regulation system. Other traffic information e.g. about accidents are also passed to the system. Based on the available information and a mathematical model the traffic regulation system calculates new weights to be used in determining the route. The new weights are broadcasted to all drivers. Once a driver receive the updated weights the intelligent route planning device will determine whether it is necessary to change the route plan. It should be stressed that in the case when there are several parallel roads that can be used, the system determines which road to choose in a stochastic manner, where the weights are taken into account. This choice leads to a compromise between the system optimum and the user optimum without any central control.

It is one of the main ideas in DTRS that each vehicle is equipped with an intelligent route planning device receiving information about the current traffic situation through updated weights. The great advantage in this approach is that the computation of route plans is distributed. A more detailed description of the intelligent route planner can be found in [10].

It is important to notice that our current model does not account for the important issue of expected future changes in the weights. Such changes could be expected from daily routine differences or from the simulation itself. However, our system is well prepared for daily routine differences as these may be stored locally, and as the local routing and rerouting routines used in the intelligent route planner may rather easily be extended to include time-dependent weights.

To test the traffic regulation strategies and the intelligent route planner we have developed a traffic simulation system. For a discussion of traffic simulation systems consult Yang[1] or Yang and Koutsopoulos[11]. In figure 3 we have shown how to operate DTRS in a simulated environment.

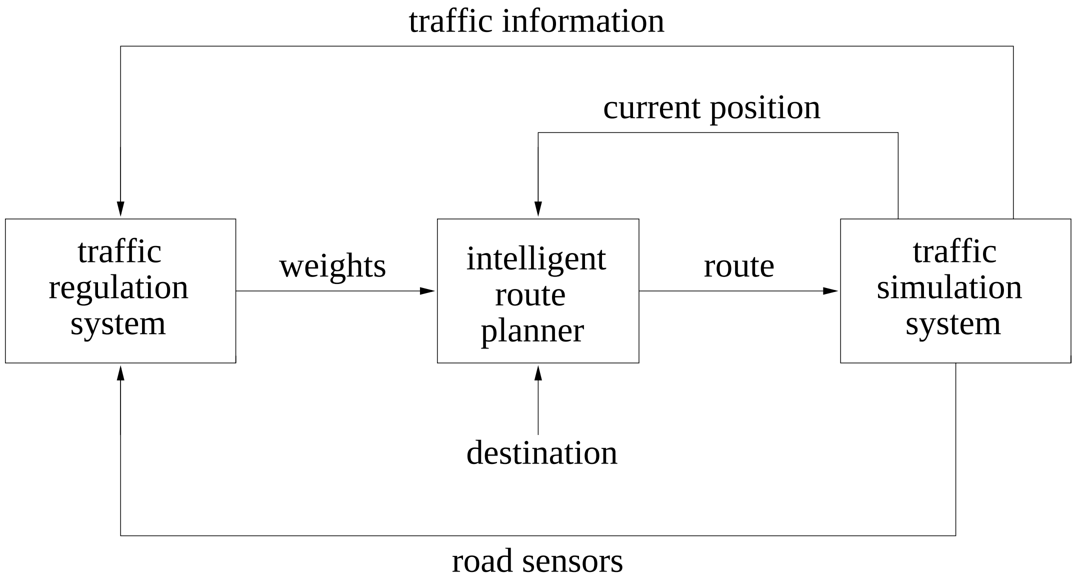

Figure 3: A simulation of DTRS.

3 Traffic simulator

It is clear from the description of DTRS given in the last section that the traffic simulator must be able to simulate the behaviour of indvidual drivers and vehicles. This observation lead us directly to the conclusion that the traffic simulator must be based on a microscopic traffic model instead of a flow based macroscopic model.

Several microscopic traffic simulation models have been developed, see Yang[1]. Not mentioned in the work by Yang is the more recent interest there has been in using cellular automata (CA) based models in large scale microscopic traffic simulations[12, 13, 14, 15, 16, 17].

To illustrate the fairly simple ideas in CA modelling we will first outline the simple single lane CA model developed by Nagel and Schreckenberg[12]. In this model the single lane road is represented by a set of adjacent cells that are either occupied by a single vehicle or free. The length of the cell is normally taken to be 7.5 m, see e.g. Rickert[17]. The position of the k'th vehicle at time n in this discrete system is simply the cell number denoted by $c_n^{(k)}$. Note that n is an integer indicating time in units of time step which usually is taken to be 1 s. The velocity of the k'th vehicle is $v_n^{(k)}$ and can take on integer values in the range $0, 1, \ldots, v^{(k)}_{max}$. Let $s^{(k)}_n$ denote the distance between the k'th vehicle and the vehicle in front of it, then the rules for updating the discrete CA model can be written[17]

$$
\begin{aligned}
v^{(k)} &= \min(v^k_n + 1, s^{(k)}_n, v^{(k)}_{max}) && (1)\\
v_{n+1}(k) &= \textbf{if}\,\textbf{rand}() < p_b\,\textbf{then}\,\max(0, v^{(k)} - 1)\,\text{else}\,v^{(k)} && (2)\\
c^{(k)}_{n+1} &= c^{(k)}_n + v^{(k)}_{n+1} && (3)
\end{aligned}
$$

where rand() returns a random number in the interval $[0, 1[$ and p_b is the probability for braking. In figure 4 we have shown two possible steps in the time evolution of a single lane CA model with two occupied cells.

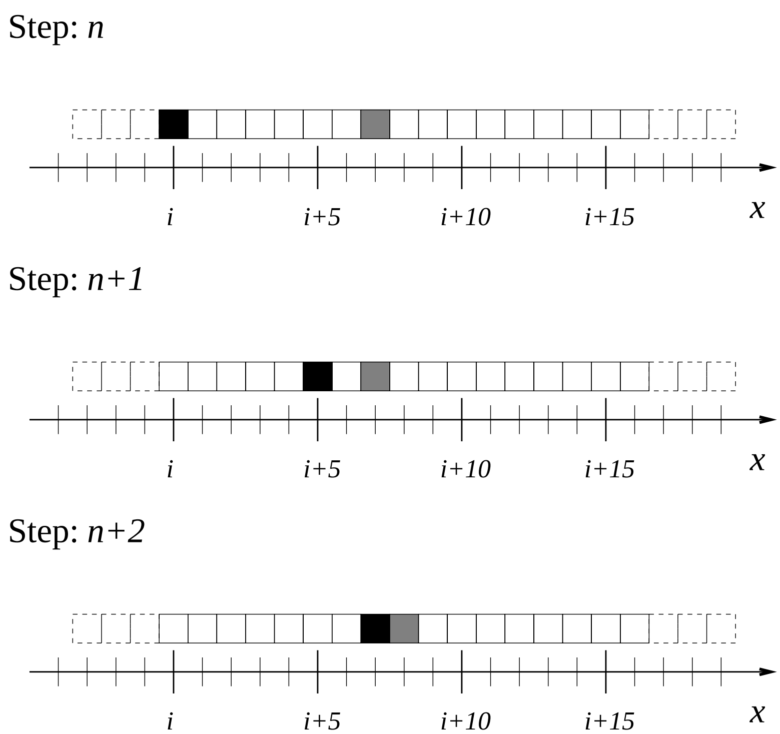

Figure 4: Time evolution of a single lane road.

The CA approach is very suitable in our case. Firstly, it is straightforward to implement a wide range of behaviours at the level of the individual driver/vehicle. Secondly, due to the inherent properties of the CA model it is very easy to parallelize the computation[14, 16] allowing for large scale simulations on multi-processor systems which we aim at.

In the DTRS traffic simulator we have developed, the above approach has been generalized. However, to simplify matters we have sofar only implemented two different road network elements; roundabouts and bi-directional two lane roads, see figure 5. Note that where a roundabout and a two lane road meet we have defined what we call a crosszone. This zone is simply used to indicate that we are close to a node of some kind and that special CA rules should be used in updating the vehicles. For instance it is no longer allowed to pass another car. The roundabouts have been designed so that in combination with the CA rules for movement in a roundabout we avoid grid-locks. Of course, grid-locks can still evolve on a larger scale in the system[18].

To update the vehicles we use 4 different set of CA rules

- CA rules for lane, which are composed of
  1. Basic rules for lane movement. Similar to the rules used above in the single lane CA model.
  2. Rules testing if it is possible to make a pass.
- CA rules for passing, which are composed of
  1. Rules for movement in the opposite lane. It should be noted that during the overtaking the vehicle is allowed to move with a velocity of $v_{max} + 1$.
  2. Rules that determines if it is safe to move back to the ordinary lane.
- CA rules for crosszone, which are simply the CA rules for lane movement with the modification that the distance to the node is taken into account.
- CA rules for roundabout, which are composed of
  1. Rules for entering the roundabout.
  2. Rules for movement in the roundabout.
  3. Rules for leaving the roundabout.

Which set of rules that is used in updating a particular vehicle depends upon its present location in the network. The complete and detailed description of the CA rules is given in [19].

To test the CA based traffic models used in DTRS we have made some flow measurements. The measurements were done on a single piece of road. The results are given in figure 6. We see that we obtain reasonable fundamental diagrams for the system. This is in accordance with observations made within the TRANSIMS project[20].

4 Conclusion

We have presented the components of DTRS: A Dynamic Traffic Regulation System with dynamic rerouting. Furthermore, a cellular automata based microscopic traffic simulator to be used as a tool and testbed in the further development of DTRS has been described.

Preliminary experiments done with the traffic simulator have indicated that the generated motion of individual vehicles is in accordance with what is observed in reality. The basis for this conclusion is the measured fundamental diagrams. However, much work

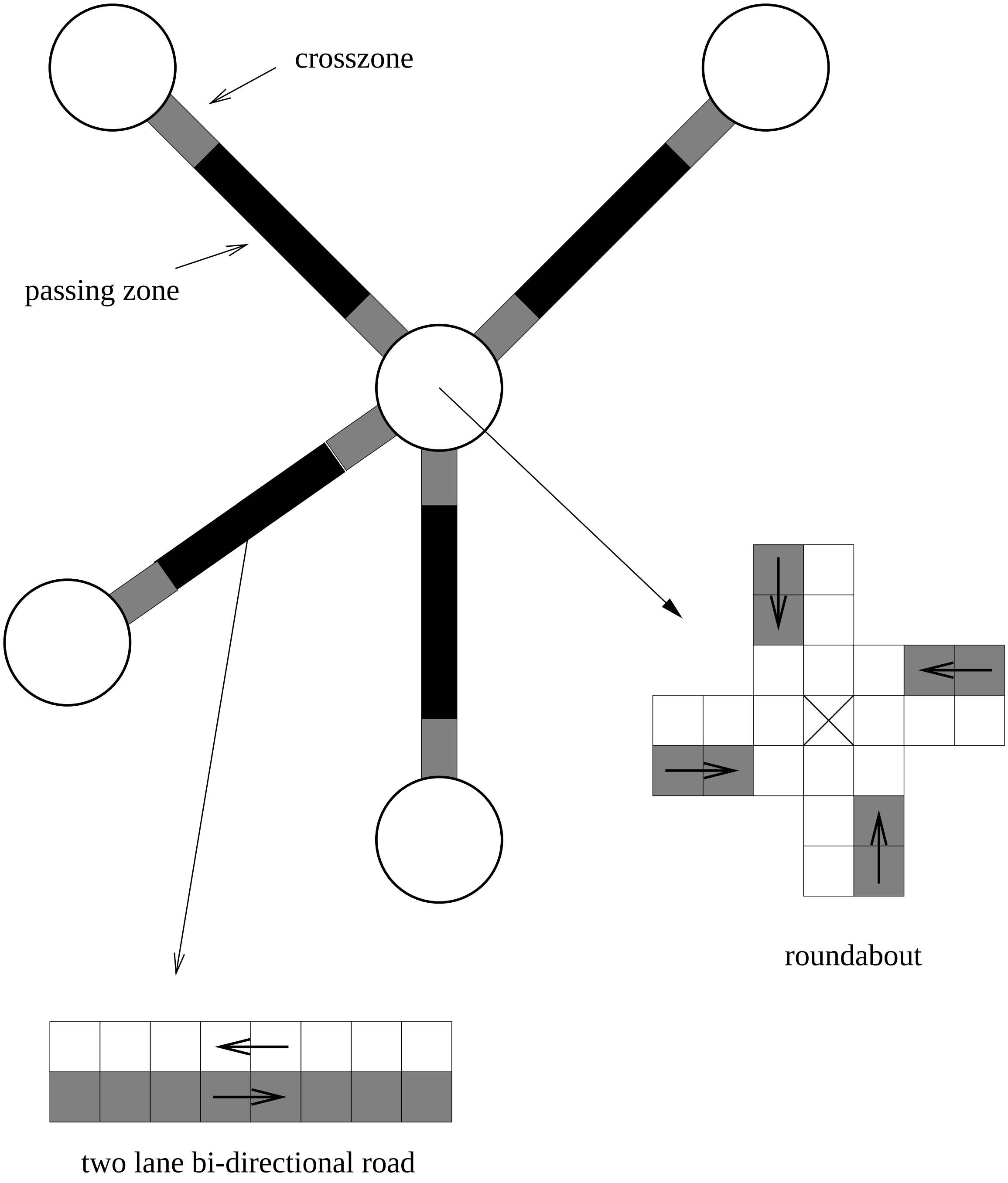

Figure 5: CA representation for DTRS road network. In the passing zone overtaking is allowed. The crosszone simply indicates that we are close to a node in the network. The arrows in the cells indicates the direction of the traffic.

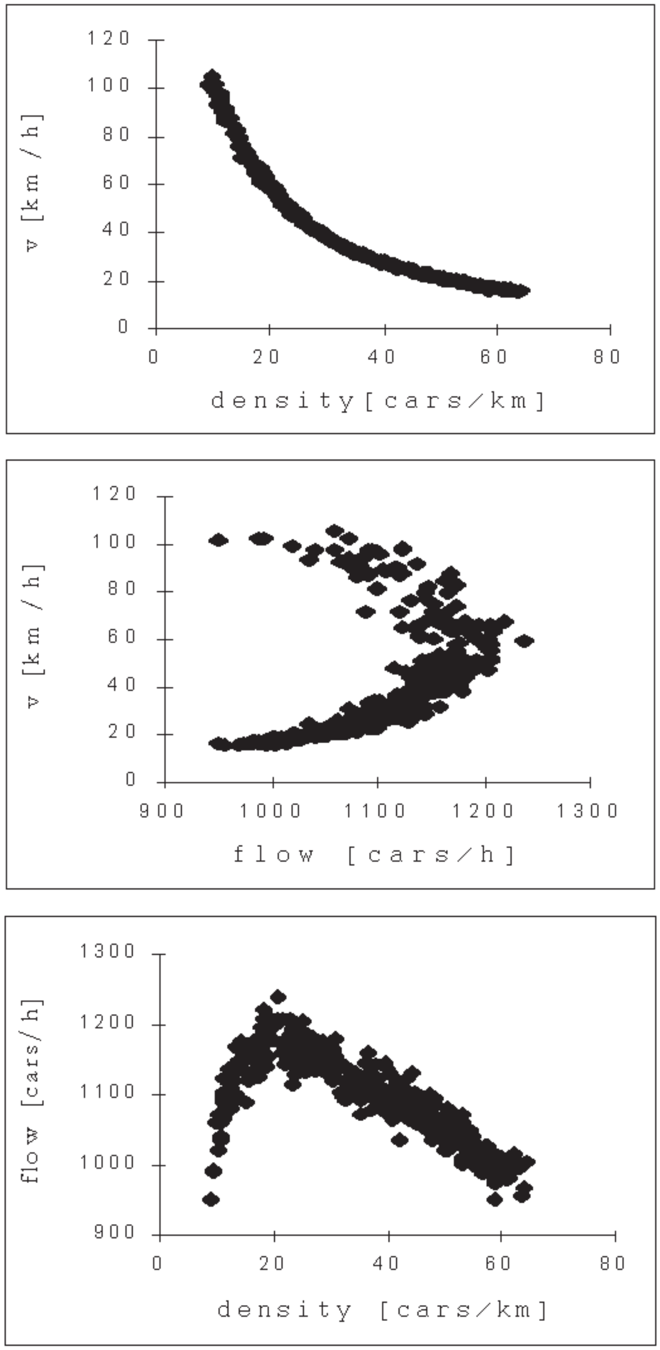

Figure 6: Fundamental diagrams obtained using the traffic simulator.

is still needed to make the traffic simulator more realistic. In particular, many network element must be developed, e.g. traffic lights and intersections.

Currently, we have a small protype of DTRS running on a single-cpu PC. We are in the process of evaluating and testing this system. As soon as these tests are succefully completed, we will port the system to the departments 24-CPU SGI Power Challenge supercomputer. This will allow us to study the behaviour of DTRS in large scale simulations.

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