Towards the introduction of an autonomous transportation line in a multimodal transportion system

Dihya Atmani
PHD student
IFSTTAR, France

Dr Fabio Galatioto
Research fellow
University of Newcastle

Dr Neila Bhouri
Research fellow
IFSTTAR, France

Dr Patrizia Franco
Research fellow
University of Newcastle

Pr Jean-Patrick Lebacque
Research fellow
IFSTTAR

Pr Margareth Bell
Research fellow
University of Newcastle

Pr Habib Haj-Salem
Research fellow
IFSTTAR, France

Abstract

This paper presents a new transport management system based on the concept of Autonomic Road Transport Support systems (ARTS). It presents the first attempt of setting, using an agent based model, which implement and assesses the agent's behaviours and transport impacts of the gradual implementation of an ARTS system by implementing a set of transitioning scenarios.

1. Introduction

The changing environment of the road transport system imposes new challenges on road traffic management research and applications. Some of today problems, such as increase in car use, causing congestion may be still present in the future and in the short- to medium-term will result in delays and elevated vehicle emissions. Congestion problems affect the economy and health with wider environmental impacts such as climate change. Solutions that address climate and air quality targets need scientific evidence and a wider knowledge base upon which to better inform decisions not just in the context of traffic management from day to day but also in longer term strategic land use planning with integration of public and non-motorised transport systems, to reduce the number of vehicle kilometres travelled, VKT, (Bell, 2008).

Thus, the need to assign road users to public transportation systems becomes an obligation. The best way to have an optimal assignment is to use Intelligent Transport Systems (ITS) technologies which provides us with real-time information. Today, interpretation of this real-time information is achieved through engineering judgement carried out by highly trained and experienced engineers who develop solutions in consultation with traffic managers and policy makers.

Operators have to deal with other issues such as air quality targets and those of climate change whilst maintaining a good level of service. For this reason the traffic needs to be managed more intelligently keeping in mind the spatial and temporal changes in traffic flow on the one hand but also respecting local policies (air quality, noise, parking restraint, heavy goods vehicle restrictions etc.) and the nature of the built environment and location of homes in respect of the network. The data processing and analysis to deliver such multi-objective traffic control and management requires sophistication beyond current control systems. This is why we chose to model the problem as a multiagent system.

2. Autonomic Computing

The term autonomic is derived from human biology Tianfieldand Unland (2004). Autonomic Computing (AC) is a software environment with has the ability of self-management and dynamic adaptations to changes in business policies and objectives. AC is a technology that comes into play where there is need to minimise cost and maximise efficiency through the management of resources and applications (IBM, 2005). In order to achieve this, timely and reliable decisions have to be made based on intelligent interpretation of information available from automatic systems. Although there is more or less an endless list with regard to the various self-properties of autonomic systems, the current research focuses more on the four classes provided by literature (Mannava and Ramesh, 2012;IBM, 2005;Marsh et al., 2004):

(i) "self-healing" – to discover, diagnose and act to prevent disruptions;
(ii) "self-protecting" – to anticipate, detect, identify and protect against threats;
(iii) "self-configuring"– to adapt dynamically to changes in the environment, using policies provided by the IT professional and
(iv) "self-optimising" – to tune resources and balance workloads to maximise the use of information technology resources.

Whilst IBM applies these properties to software they equally can be applied to other environments such as traffic management presented in this paper. Basically AC helps to address the complexity of network inefficiency by using technology to manage technology.

Application in Traffic management

The development of a state-of-the-art assessment tool to define, in an autonomic way, the status of the network and identify the extent to which a sub- optimal operation is affecting performance, compromises safety and erodes the environment, will provide valuable support for decision-making. Once realised, the AC assessment tool would be integrated with mathematical and micros-simulation modelling tools which can be used to design and tailor control mechanisms and interventions, while the autonomic system continues to monitor and adapt, the status algorithms continue to respond to network changes.

Whilst ways to resolve the problem need to be computed and implemented in real-time, mechanisms to recognise the deterioration in service level are required also. If accomplished, the resulting autonomic support system will allow for more effective routine decision making allowing networks to perform more efficiently in real-time spatially and temporally against multi-objectives (alleviation of congestion, reduction of emissions). The introduction of such an autonomic system will provide traffic operators with more opportunities to engage in areas of operation that currently have to be given a low priority (Bell et al, 2014).

This paper in section 2 presents the global aim and objectives of this project which strives to build a demonstrator of an autonomic system for traffic management. More specifically, to apply an autonomic traffic management system to the optimisation of lane changes on trunk roads and motorways. Section 3 describes the methodological approach and details the case study sites. This is followed by section 4 which presents the multiagent based model. Finally, the scenarios are described in section 5 and the computational study in section 6.

3. Global aim and objectives

The global aim of this work is to assess the need to introduce an autonomic transport system. To do so, we first model a muldimodal transportation system using an agent based environment. Then, we introduce, step by step, different transportation lines and evaluate the impact of each one of them on the system.

The specific objectives of the research are:

1. To investigate metrics to monitor the network performance suitable for optimising the flow balance across the network
2. To identify suitable scenarios that will represent the transition.
3. To analyse the data to create parameters that could be used to deliver self-optimisation property
4. To explore how to inform the autonomic property of self-optimisation.

In this way, the analysis will be mapped onto the self-optimisation property of an autonomic system and thus to identify the particular intelligent component of the status monitoring that makes the optimiser autonomic rather than automatic.

4. Problem formulation

Let us consider a network modeled as a multilevel structure where each level represents a modal sub-network which are the vehicular sub network, the railway network, the bus network and the autonomic network. Let G=(V,E) be a directed multimodal graph, where V is the set of nodes and E the set of arcs. We refer to each sub network with $G_m=(N_m, A_m)$, m ϵ M, Nmis the set of nodes of mode m and Am the set of arcs of mode m. We connect the nodes of different modes with walking arcs under the condition that the distance between the two nodes doesn't exceed a defined value β.

We assign to each arc a length L_{ij}, an average speed V_{ij} and a maximum speed V_{max}.

The travel time $c_{ij}(t)$ along the arc (i,j) of a given mode m is calculated by our simulation model.

Each vehicle is equipped with a communication device that allows the user to communicate with a central agent. A user is characterized by an identifying number n={1,…,N} where N is the total number of vehicles, the vehicles will be constantly submitting their position x_n and velocity v_n on the network

5. Multi agent based model for the multimodal transportation problem

5.1. State of the art on multiagent platforms

Many studies have been carried out to construct guidance systems in multimodal networks where the users equipped with information systems are provided with multimodal itineraries based on real time information during their journey. The most known platforms are the Transportation Analysis and Simulation System (TRANSIMS) which is an open source integrated transportation modeling and simulation toolbox for regional transportation system analysis, Multi-Agent Transport Simulation Toolkit (MATSim) which is a microsimulation platform implemented as a Java application that adopts the activity based approach to simulate travelers activities, Sacramento Activity-Based Travel Demand Simulation Model (SACSIM) which is a regional travel forecasting model used by the Sacramento Area Council of Governments to simulate each individual's full day activity and travel plan. We also quote the work of (Kamoun, 2007) and (Zidi,2006) who used a multiagent architecture to create a guidance system that assigns the travelers to a multimodal itinerary of minimal cost. Introducing guidance brings an important question: How to calculate an assignment scheme that keeps the system in equilibrium without penalizing the users? For this issue, (Ma & Lebacque, 2012) calculate the system optimal predictive dynamic assignment using a multiagent simulation based model combined with a cross entropy algorithm.

Our agent based model is a multimodal guidance application that was developed under JADE. Its aim is to provide users with an optimal multimodal itinerary. The main characteristic of our platform is that it considers a portion of travelers that are not equipped with an information device and chose their route based on their previous knowledge of the network.

5.2. Description of the multi-agent systems

In order to implement the scenarios described above, we use a multi-agent simulation model. As in the social welfare domain, the multi-agent approach is often used to support the design of complex systems where several decision scales have to be taken into account. Indeed, the multi-agent domain is adapted to study the effects of individual behavior of an agent on the collective behavior and vice versa (see Bazzan and Klügl,. 2013, Chen and Cheng, 2010, Bhouri et al., 2012). Therefore, we propose a multi-agent modeling to process our multimodal management problem.

These types of models seem to be the most suitable for our problem given its complexity and the interactions between the different types of entities involved in our model.

Our multi-agent architecture is constituted of three types of agents: User agents, central agents and central agents. Those agents are described as follows

5.2.1. Multi-agent architecture

A central agent is created for each intersection and calculates the shortest path for the users using a Dijkstra algorithm that evaluates not only the cost of the arcs but also the remaining capacity on them. Once he receives the requests from the users, he creates groups of users depending on their OD pair and on the preferred modes. Three cases are given to the central agent in order to calculate the shortest path

- Case1: The user is open to taking any transportation mode
  In this case, the central agent calculates the shortest path using the Dijkstra algorithm on the multimodal graph.
- Case2: The user excludes at least one mode
  The central agent removes the arcs corresponding to that mode from the network than calculates the shortest path on the remaining graph.

The second type of agents is called user agents and sends a travel request to the central agent with a message containing the OD pair and an ordered vector containing the preferred travelling modes. Once the agent gets a response, he moves along the network following a cellular automata model that will be described in the following section.
The arc agent is created for each arc and plays a very important role, since it is this agent that sends information to the central agent on the number of users present in the arc.

5.2.2. Cellular automata model

Cellular automata models are widely used in literature because they keep the main properties of a network while being relatively simple to use (Nagel and Schreckenberg, 1992; Maerivoetand De Moor, 2005).

At the entrance of an intersection, user agents send a travelling request to the central agent along with their preferred transportation modes. At time t=0, the central agent applies a Dijkstra algorithm to find the shortest path using the free travel times then sends back the following arc to take. This way, the shortest path is re-evaluated at each intersection. After the assignment of the agent is made on a given arc, the travel cost on that arc is updated as the experienced travel time by the user. The movement of users on the network is given as follows:

The user checks if the first cell of the arc is free and occupies it then verifies if the next one is free. If so, he moves along until the end of the arc. It is at this moment that the costs are updated as the travelling time experienced by the user. If the cell is occupied, the user waits in a buffer and renews his demand at the following simulation step. To move from one arc to another, the vehicle is buffered in a waiting queue until the first cell of the following arc is free, then he moves as described previously. The reader must also note that a buffer is created for each exit arc of an intersection but only one buffer is created at the entrance of the intersection.

When a user is assigned to a vehicular arc, the movement works differently than if it was assigned to a public transportation arc

To attend a public transportation arcs, the user must take a walking arc where he moves cell by cell. When the user attends the metro or bus node, he waits for the passage of the vehicle in an unlimited capacity buffer created at that node. The loading of the vehicles is made using a FIFO rule until the capacity of the vehicle is reached. As for the remaining users, they will wait for the following train/bus.

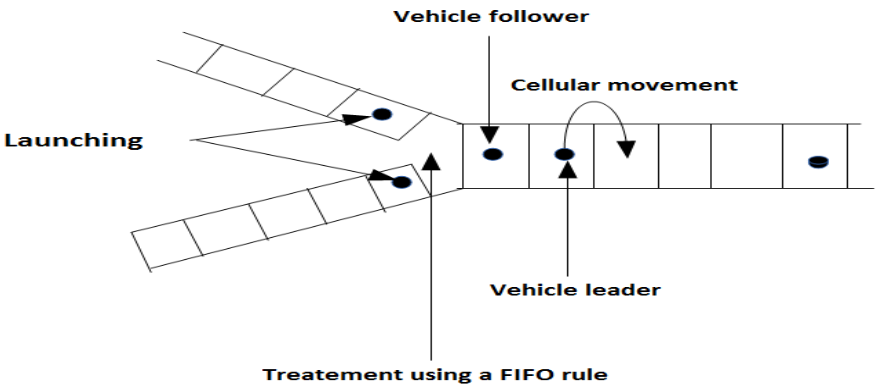

Figure1. Cellular automata model

6. Comparative study

In order to assess the need to introduce an autonomic transportation system, we will hold a comparative study where we introduce different transportation lines to the system and evaluate its impact on the overall system. The steps as described as follows

- First, we settle the base case scenario which consists of a simple road network relating an origin *o* to a destination *d.* We use the assignment rule on this network mentioned in the previous section (3.2.2) and evaluate how the travel time evolves depending on the number of users in the system.
- Then, we introduce a railway line that relates the same OD pair.
- After that, we introduce an additional bus line
- Finally, we will introduce the autonomic line.

We will compare the travel times of each scenario and discuss how the introduction of each line brought a change into the overall performance of the system.

7. Computational study

In this section, we present the computational result of our agent based simulation model for the dynamic multimodal assignment problem applied on the scenarios described above.

The simulations are computed on a small archetype graph of 10 nodes and 10 arcs. This graph has been chosen because it connects two rural regions with a 2 way motorway but also with a train line. The length of the train line is of 8 km, while the length of the motorway is of 6 km.

The speed of the train is set to 150km/h and the maximum speed on the motorway is set to 110km/h. The length of the rural arcs is of 1 km each and their speed is of 70km/h.

The arc relating nodes 3 and 4 represent the motorway, the arcs in red represent the railway line. All the other arcs represent vehicular rural arcs.

The users going from node 1 will have two choices: use their car or take the train.

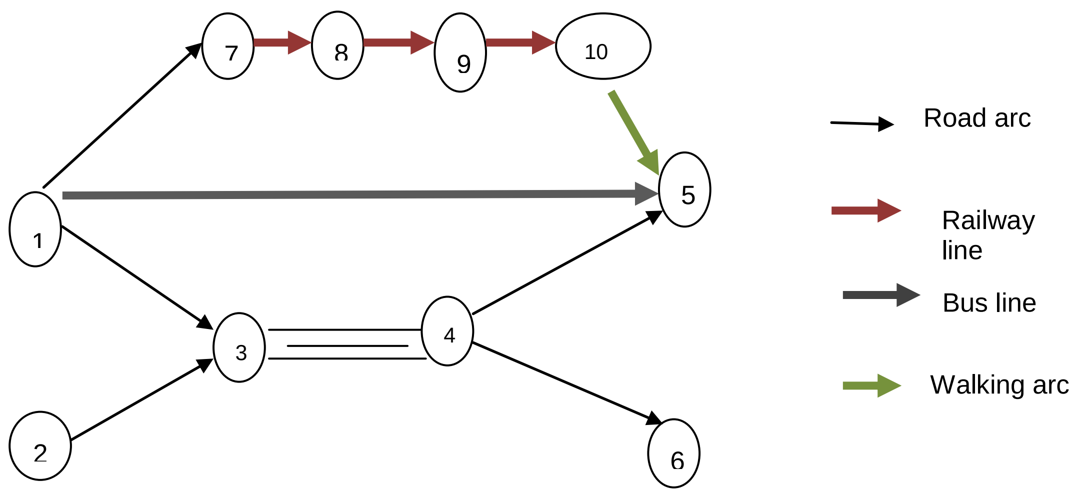

Figure2. Multimodal graph

The travel time on the railway line remains unchanged and is equal to 4.91 minutes (294.6 s) while the free travel time on the road path is equal to 4.41 minutes (265 s). This means that at time t=0 it would be preferable to take the car.

We run the multi-agent simulations on this scenario for 10 minutes with a number of agents equal to 1000 in order to observe how the vehicular travel time evolves over time and according to the number of users that take the motorway.

We observe that the travel time on the path ((1,3),(3,4),(3,5)), which is the competitor of the railway path, increases with the increase of the number of users on the path and reaches 600 s which exceeds the travel time that would have been experienced with the railway line.

We now run the same simulations, except that this time we assign some travelers to the train. We assume that a train takes 300 passengers and that it circulates every 5 minutes. We will treat the same number of agents except this time we will assign 600 to the train, so only 400 users will use the motorway and observe whether or not the congestion has been reduced.

This time, we realize that the travel time still increases with the number of users on the motorway except the average travel time is now equal to 485.004 s as it was equal to 509.4s in the previous scenario. We can conclude that the introduction of the railway line reduced the congestion on the motorway.

We will now introduce a bus line on the road path which will run every two minutes. Overall, 5 buses will be launched, each one with a capacity of 40 passengers. The demand will be then split up as follow: 600 users will take the train, 200 will take the bus and 200 will take their cars. In this scenario, the bus is allowed to take the motorway but doesn't have a reserved line yet. Meaning that, the travel time of the bus, same as the car, will depend on the number of users taking the motorway.

The average travel time after introducing the bus line is equal to 411.93 s which is slightly lower than the travel time experienced in the previous scenario.

Finally, we will introduce an autonomic line instead of the bus line. We assume that this autonomic line circulates on a reserved line and the speed of each autonomic vehicle is set to 130km/hr. Another characteristic of an autonomic line is that the distance between two vehicles is smaller than the distance between two regular vehicles. In order to take into account this aspect in our simulation model, we reduce the length of a cell from 10 meters to 8.5 meters.

The average time experienced after introducing the autonomic line is now equal to 365.24 s.

Figure 2 gives the comparison of the travel time of all three scenarios.

We can see that the figure representing the case where all users are assigned to the road network dominates all the other figures. Followed by the case where the users are split between the road network and the railway network. Meaning that the least travel time is experienced when there are three transportation modes present in the system.

We see that the itinerary gets the most interesting when we introduce an autonomic line. The cost is always low and does not increase in a fast way with the increase of the number of vehicles as it was experienced in the three first scenarios.

In fact, we observe an average travel time of 258.532 seconds which is a lot lower than the one experienced during the three first scenarios. This result is due first to the fact that even the static cost of this scenario is lower than the static cost of the previous ones due to the greater speed and the smaller inter distance between the vehicles. This itinerary becomes more interesting for the users which discharges the load exercised on the regular lane. Thus the cost on the arc (3,4) does not grow exponentially as it did in previous scenarios.

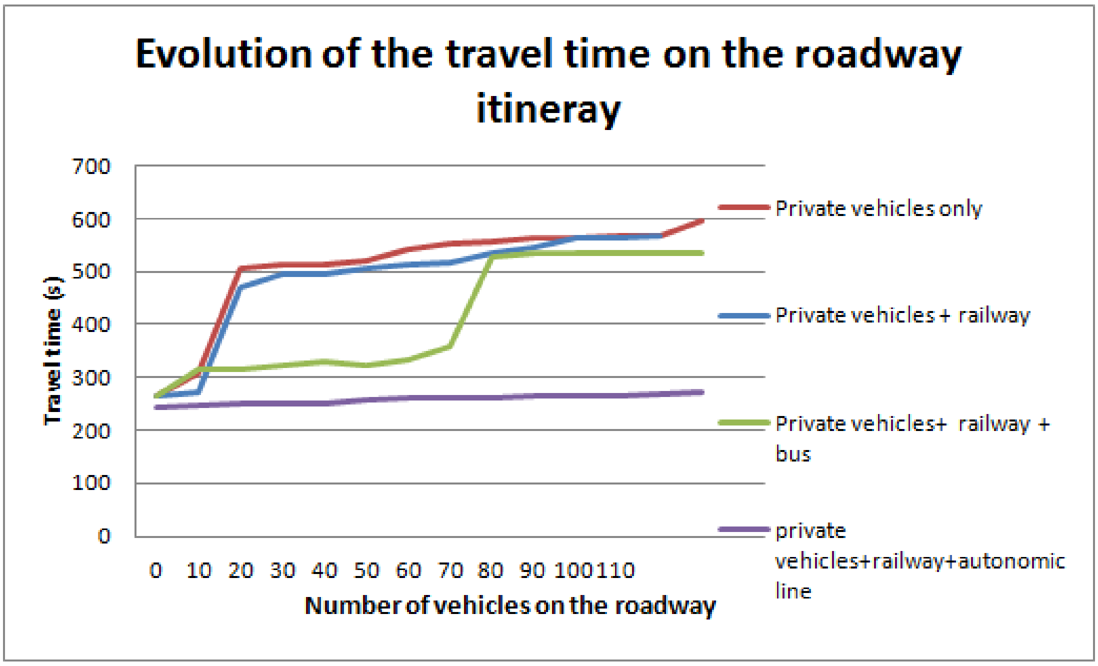

Figure 3. Comparison of the travel times in the three scenarios

8. Conclusion

In this paper a new frontier of research in transport management system, which is the implementation of the concept of Autonomic Road Transport Support systems (ARTS), has been identified. A first attempt of setting, using an agent based model, a hypothetical multi-modal transport network, which implement and assess the agent's behaviors and transport impacts of the gradual implementation of an ARTS system by implementing a set of transitioning scenarios has been presented.

The simulations show that introducing a train and a bus line that compete with the road itinerary reduces the average travel time of the users that take the motorway. However, the decrease is non optimal since the motorway still faces congestion problems. We believe that introducing an autonomous line will help solve this problem. The simulations and results will be presented in the final paper.

AKNOWLEDGEMENTS

We would like to present our acknowledgements to the COST Action project ARTS which helped fund this research.

References

[1] Bell, M.C. 2008. Environmental factors in future transport. Proceedings of the 40th University Transport Studies Group Conference Southampton. Foresight Intelligent Infrastructure Systems Project.

[2] Bell M.C., Hoogendoorn R.,Galatioto F. 2014."Autonomic Decision Support System for Traffic and Environment Management" IET Conference Publications, Volume 2014, Issue CP633.

[3] OECD 2008. Towards zero – Ambitious road safety targets and the safe system approach Organisation for Economic Co-operation and Development/International Transport Forum, Paris

[4] M. Peden, R. Scurfield, D. Sleet, D. Mohan, A.A. Hyder, E. Jarawan, C. Mathers (Eds.), 2004. World report on road traffic injury prevention, World Health Organization, Geneva

[5] IBM 2005. An architectural blueprint for autonomic computing: White Paper. IBM.

[6] Mannava, V. & Ramesh, T. 2012. A novel adaptive re-configuration compliance design pattern for autonomic computing systems. Procedia Engineering 30 1129 - 1137.

[7] Marsh, D., Tynan, R., O'kane, D. &O'hare, G. M. P. 2004. Autonomic wireless sensor networks. Engineering Applications of Artificial Intelligence 17, 741-748.

[8] Tianfield, H. &Unland, R. 2004. Towards autonomic computing systems. Engineering Applications of Artificial Intelligence 17 689-699.

[9] Nguyen, Q.T., Bouju, A. and Estraillier. P. (2012). Multi-agent architecture with space-time components for the simulation of urban transportation systems}. 15th meeting of the Euro Working Group on Transportation.

[10] Kamoun. M. A. 2007. Conception d'un système d'information pour l'aide au déplacement multimodal : Une approche multi-agents pour la recherche et la composition des itinéraires en ligne. PHD thesis, Université des Sciences et Technologies de Lille et l'Ecole Centrale de Lille.

[11] Zidi. K. 2006. Système Interactif d'Aide au Déplacement Multimodal (SIADM). PHD thesis, Université des Sciences et Technologies de Lille et l'Ecole Centrale de Lille.

[12] Zgaya, H. 2007. Conception et optimisation distribuée d'un système d'information d'aide à la mobilité urbaine : Une approche multi-agent pour la recherche et la composition des services liés autransport. Ecole centrale de Lille.

[13] Ma, T-Y. and Lebacque, J-P. 2012. Dynamic System optimal routing in multimodal transit network. TRB

[14] Bradley, M., Bowman, J.L. and Griesenbeck, B. 2010. SACSIM: An applied activity-based model system with fine-level spatial and temporal resolution. Journal of choice modelling

[15] Smith, L. , Beckman, R. , Anson, D. , Nagel, K. and William, K. 1995. TRANSIMS: Transportation analysis and simulation system. Ttansportation research board (TRB).

[16] Raney, B., Çetin, N., Völlmy, A., Vrtic, M., Axhausen, K.W. and Nagel, K.. 2003. An agent-based microsimulation model of Swiss travel: First results. Networks and Spatial Economics, 3 (1) 23–42

[17] Cormen, T.H., Leirson, C.E., Rivest, R.L and Stein, C. 2001. "Section 24.3: Dijkstra's algorithm". Introduction to Algorithms (Second ed.). MIT Press and McGraw–Hill. pp. 595–601. ISBN 0-262-03293-7.

[18] Nagel,K. M. Schreckenberg. 1992. A cellular automaton model for freeway traffic. Journal de Physique I, 2 , pp. 2221–2229

[19] Bazzan. A. L. and Klügl F. 2013. A review on agent-based technology for traffic and transportation. The Knowledge Engineering Review, page 1 of 29. & Cambridge University Press, 2013 doi:10.1017/S0269888913000118

[20] Chen B., Cheng H. H. (2010). A review of the applications of agent technology in traffic and transportation systems. Intelligent Transportation Systems, IEEE Transactions on, 11(2), 485-497.

[21] Bhouri, N., Balbo, F., Pinson, S. (2012). An agent-based computational approach for urban traffic regulation. Progress in Artificial Intelligence, 1(2), 139-147.

[22] S. Maerivoet and B. De Moor. Cellular automata models of road traffic. Physics Reports, 419, 2005