Artificial Intelligence Techniques in Traffic Control

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Abstract

Traffic Control is an area of increasing importance. During the last few decades, traffic demand has increased so rapidly that classical control mechanisms often exhibit serious limitations, thus calling for a new paradigm and decentralized solutions. Artificial intelligence techniques have turned out to be a highly promising field for solving the problems in this area, including large-scale decentralized traffic management done by agents. We present an overview of some recent approaches in traffic control with a particular focus on the use of AI technology. The described technologies and systems do either act (almost) on their own (with human support only in case of emergency) or may support human traffic managers. We also review some case studies, showing that the resulting systems have become mature enough to be applied to real-world systems and phenomena.

Introduction

The term traffic control summarizes a large variety of problems, all aiming at resolving dissatisfaction of individuals within a transportation system. When we are required to travel from A to B, we normally try to choose our method and route of travelling according to minimization with respect to two variables: travel time and travel cost. However, these requirements are very often somewhat incompatible, since fast travelling is usually tied to high costs, while cheap transportation is often slow. In many cases, particularly in car traffic, the driving route is chosen to be the shortest path between the origin and the destination. Although an individual will most unlikely select the truly shortest path upon non-technical means, the emerging use of navigation systems renders this assumption more and more realistic. The resulting problem is the simultaneous choice of the same route-sections by very many travellers and this in turn implies a high probability of traffic jam. Particular route (road) sections may be decided to be optimal either because of length or possible or allowed travel speed on that section. In the latter case, the section is assumed to offer fast transportation, hence is chosen by very many individuals. The goal of traffic control techniques is a systematic influence of the transportation network, such that vehicle streams are routed in order to achieve optimal link utilization. That is, a good traffic control scheme will be able to balance the load of travellers such that the maximum capacity of each transportation link is not exceeded.

Traffic Control Methods

Influencing and steering a transportation network can be done through several technical means:

- Traffic signals and dynamic signposts: Adaptive control of the green- and red-phases of traffic lights may significantly reduce waiting times at intersections. This requires optimization of – sometimes high-dimensional and nonlinear – model-equations. The time for numerical solutions of such equations can be reduced using artificial intelligence techniques. Some cities (e.g. Dresden in Germany) route vehicle streams on some sections using dynamic signposts in order to achieve better load balancing. Like before, this also results in hard optimization problems, which can be alleviated by artificial intelligence techniques
- Navigation recommendations: Some radio stations provide traffic information in their program to inform drivers of the current traffic situation, thus a driver can circumvent closed roads, delays by accidents or traffic jams thereby caused. The goal of these efforts is providing a **decision support** for a driver.

Broadly speaking, the most common artificial intelligence techniques are the following:

- Expert Systems: These can be classical **rule-based** systems, or employ more general forms of logic like **fuzzy logic**, resembling human reasoning more closely than crisp logic does.
- Self-Adapting algorithms: **Neuronal Networks** and **Bayesian Networks** have the capability of adapting themselves to a required behaviour during a learning phase. This class of algorithms also includes **Genetic Algorithms**, resembling Darwin's theory of improvement by selection of those individuals with best survival skills.
- Autonomously acting systems: Combining decision making techniques and self-adaptation principles gives powerful autonomously acting systems, known as **agents**.

The following table was taken from [Roozemond and van der Veer 1998], and shows some areas of traffic control in which genetic algorithms (GA), fuzzy logic (FL), neuronal networks (NN) and expert systems (ES) are applicable:

Application	*AI Technique*
traffic management	ES
data collection and monitoring	ES, NN
data analysis	ES, NN
route guidance	ES, FL, NN, GA
traffic control	
congestion control	ES, FL, GA
incident detection	ES, NN
traffic signal control	ES, GA

Traffic Control using AI Techniques

Many traffic control strategies are based on a **predict-and-control** approach, which utilizes – among others – the AI techniques shown in the table above. Often, such algorithms are combined and form the core of one or more *agents*, which then play the main part of the automated traffic control or management.

Agents are self-contained programs that can act on their own and on behalf of individuals or other programs. The central difference between agent based control of traffic and classical control algorithms is the decentralization of the control logic. Arguments for decentralization arise from the inherent complexity of large-scale transportation networks and the need to redistribute the responsibility and the workload in order to gain efficiency and simplify the global dynamics [Roozemond, 1999], [Nguyen-Duc et al., 2003].
In agent based traffic control, a traffic controller is replaced by a traffic agent host where different agents reside at different times [Wang, 2005]. A traffic controller hosts two types of agents: *Default control* agents shall ensure basic functionality in the absence of network connectivity. *Executing agents* compete for the right to handle a particular traffic situation. As it is clearly infeasible to implement a sufficiently large number of different control strategies within a single system, the decentralized agent approach offers a natural method of having a large variety of possible strategies available, each of which is known to one or more agents. The concrete decision which executing agent may handle the current situation is up to an arbitrator, which – on request – can also dispatch new control agents residing at a *remote global traffic operation centre*. At the core of each agent, decision making and situation assessment can be done by fuzzy logic or other rule-based approaches [Wang, 2005], [Clymer, 2002]. Neuronal networks, due to their power in adaptation to changing situations and their resemblance of human reasoning are another possibility of addressing the problem of control strategy selection [Roozemond and van der Veer 1998].

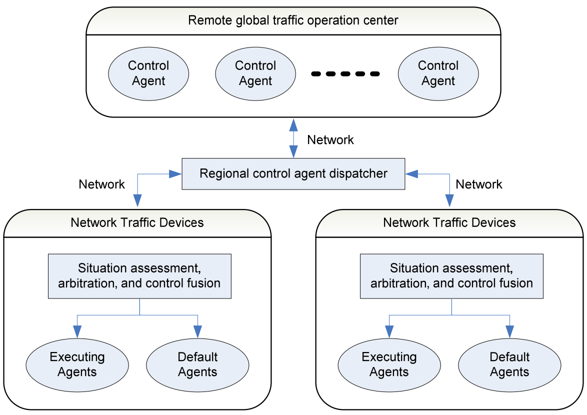

Figure 1 A Hosting Mechanism for traffic control agents [Wang, 2005].

Intelligent Agent Based Urban Signal Control System [Roozemond, 1999]: A well-known problem of optimization is the possibility of getting stuck at local optima. If agents are employed, then many agents may choose their locally optimal strategy, which may still turn out to be poor when considered globally. In [Roozemond, 1999], two architectures are described for resolving this issue: A hierarchical architecture with authority agents controlling a set of subordinate agents and a blackboard architecture, where agents indirectly exchange information through a common channel. The latter architecture leaves the final decisions up to each agent, while the former architecture employs the coordination agent for deciding upon the best strategy (hence selecting the global optimum from the local ones).

A system capable of real-time control and advice should be able to execute the following knowledge-driven actions [Roozemond, 1998], each of which can benefit from AI-techniques (cf. the table above): Data collection (the agent receives the current traffic state information at (given) time intervals), data analysis and interpretation (in order to assess the current and predict the future situation), control (in order to operate signals), and data distribution (since each agent should be able to handle problems on its own. This in particular requires *diagnosis capabilities* and the publishing of information to other agents).

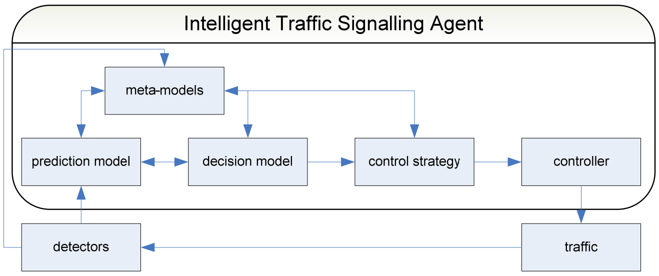

Figure 2 Actuated control strategy based on agents.

Figure 2 has been taken from [Roozemond, 1999] and schematically displays the internal components of an agent for traffic signalling. In addition to the fast loop of traffic control and feedback by the detectors, a slower loop for updating and improving the meta-models is also proposed in [Roozemond, 1999]. This once more shows that the self-adapting capabilities of AI-inspired algorithms provide fundamental benefits.
Other types of agents include *Road Segment Agents* (for data collection), *Area Agents* and *Route Agents* (both being authority agents) [Roozemond and Rogier, 2000]. Agents combined with computer vision techniques for controlling traffic signals has been described in [Deng et al., 2005].

Air Traffic Management with agents: The OASIS system [Ljungberg and Lucas, 1992] uses agents for different tasks ranging from trajectory management (collision avoidance) and wind modelling to sequencing and coordination. The sequencer agent utilizes classical search techniques like A*-algorithms to alleviate possible congestions through assigning different landing times. Those landing times are transmitted to the aircraft agents, whose internal panning components then deliver a plan how to achieve this target. More recent approaches exploiting a multi-agent coordination technique are to be found in [Nguyen-Duc et al., 2003].

Simulation with agents: Designing and testing control strategies often requires intensive simulations, which can be carried out with agents. Testbeds for simulating traffic require models for the behaviour of drivers. Agents offer an elegant method of incorporating uncertain knowledge and resembling human behaviour, while acting autonomously. Independent agents simulating single vehicles have been used for instance in a simulation of Singapore's drivers population [Jin and Lam, 2003]. The self-adaptation capabilities are another attractive aspect of such an approach. Agent-based simulators have also been tested on their capability of providing support in understanding complex traffic phenomena. At the core of Driving-agents, the decision component can be realized with rule-

based approaches (as done in [Dresner and Stone, 2004]) or using utility functions (as done in [Shiose et al., 2001]).
A concrete agent for microscopic traffic simulation is described in [Ehlert and Rothkrantz, 2001]: Here, behavioural rules for intersections and changing directions, traffic lights, car following, overtaking and switching lanes, collision detection and emergency braking, etc. have been defined and a prototype has been implemented.

Driving assistance with agents: Controlling a collective of vehicles using agents located at each vehicle is another possible application of agents. An interesting, physics-inspired approach in [Mamei et al., 2003] achieves self-organized behaviour by having the agents move according to force-fields generated by the agents themselves. As an example, each agent may generate a “force field” around itself reaching a minimum at, say a pre-defined distance. This force field will repel other agents, if the follow their internal rule forcing them to seek the local minimum of the superposition of all fields. The resulting distribution will tend to be a regular grid formation; hence local peaks of the traffic density are avoided.
Agents can also be used for dynamic routing, as shown by an ant-based control algorithm proposed in [Kroon and Rothkrantz, 2001]. Here, the trail-laying ability of ants seeking their way in an unknown environment is resembled by agents. Additional components of the system are responsible for collecting information from all vehicles. Similarly as done for floating car data, each vehicle can transmit its path and the time it has spent with traversing that path in order to ease route-finding for other vehicles.

Expert-Systems for route planning: Classical shortest-path algorithms like the Dijkstra-algorithm are usually employed for finding shortest paths, but recent proposals like [Eggenkamp and Rothkrantz, 2001] show that expert systems can actually outperform those methods in computation time. Moreover, the current traffic state can be taken into account; hence congested areas can explicitly be avoided. Internally, a route is represented by sequence of consecutive trajectories, each of which is labelled by “route”, “file”, “entrance”, or “exit”. Additionally, the system counts for possible detour. The quality of the returned routes is empirically found to be very good and the paths returned are indeed the shortest paths. However, the most important drawback of the approach is the construction of the rule-base, which is a very time-consuming task [Eggenkamp and Rothkrantz, 2001].

Case-Studies: In this paragraph, we give a short overview of some knowledge-based systems that have been developed in the last decade and have proven to work well:
KITS [Boero, 1999], [Boero et al., 1993]: This is a knowledge-based modelling environment. Support is provided for knowledge acquisition, build-up and on-line operation of knowledge-based management models [Kirschfink et al., 2000]. The basic principles of KITS are the two views on the knowledge modelling approach: The *functional organization view* is implemented by defining different knowledge-units being agents. *KITS agents* are the lowest-level knowledge unit and are able to perform fundamental tasks regarding supervision and management. The other view is the *topological organization*, which is based on a logical and spatial breakdown of the system into *problem areas*. A *KITS actor* is essentially a combination of various agents and different reasoning strategies and form another knowledge-unit of KITS model. The highest level tasks of the KITS model are represented by KITS Supervisors. Supervisors may either act as negotiators in the presence of inconsistent proposals, or as coordinating masters, or also as knowledge collectors and providers for the KITS actors.
TRYS [Hernandez et al, 1999], [Cuena et al., 1995]: Based on the concepts of KITS, this is a system providing decision *assistance* to human traffic managers. It is a model for

knowledge based traffic management and also employs agents for handling situations at different locations. The control model is based on a subdivision of the area of interest into problem areas (not necessarily disjoint, nor necessarily summing up to the whole area), each of which is “controlled” by an agent. A high-level authority agent (coordinator) is responsible for coordination and removal of inconsistencies among the proposals of the problem area agents. Fuzzy-logic is at the core of the physical structure of each agent.
FLUIDS [Kirschfink et al., 2000]: The experience with TRYS and KITS led to FLUIDS; a knowledge-based modelling environment for intelligent interfaces. As its predecessors, it offers decision support through an interface where the user can ask questions like

- *What is happening*…?: This requests the current traffic state from the system. Additionally, one can invoke a diagnostic engine providing answers to *Why is … happening*?
- What may happen if …?: Short-term prediction based on internal models provides support when confirmation of a given plan is demanded.
- *What to do if*…?: This shall give suggestions on how to improve the current situation based on assumptions and external scenarios.

Components for analysis of conversation and selection of appropriate problem solvers are at the core of FLUIDS.
CLAIRE [Scemama, 1994]: This is an expert system for traffic control which is designed to support handling congestion situations. It is available as a market product provided by the French company Alcatel and was finally integrated into the new Paris traffic control system SURF2000 [Boero, 1999].

Conclusions

We have presented a survey on some applications of AI technologies in traffic control. Most recent proposals incorporate agents, having classical AI techniques at their cores. Due to the decentralized nature of the agent-paradigm, this is a particularly suitable approach for handling systems with very many autonomous vehicles, as is the case for transportation networks. Decision support systems employing AI-techniques have been developed and successfully applied to real-world problems; some of which have been described here. See also [Bielli et al., 1994] for an overview. Completely different approaches, however, exist. As traffic optimization is in many areas also tied to numerical optimization, grid computing techniques have been tested as solvers for multidimensional transport models (cf. [Bahi et al., 2005]). The results are promising in every of the described fields, and AI techniques seem to be a valuable and auspicious building block for future traffic management systems.

References

[Clymer, 2002] John R. Clymer, "*Simulation of a Vehicle Traffic Control Network Using a Fuzzy Classifier System*", p. 0285, 35th Annual Simulation Symposium, 2002.

[Bahi et al., 2005] Jacques M. Bahi, Raphael Couturier and Michel Salomon “*Solving three-Dimensional Transport Models with Synchronous and Asynchronous Itera tive Algorithms in a Grid Computing Environment*”, Proceedings of the 19th IEEE International Parallel and Distributed Processing Symposium (IPDPS'05) – Work shop 13 - Volume 14, pp.253.2, 2005

[Bielli et al., 1994] M. Bielli, G. Ambrosino and M. Boero, eds.: “*Artificial Intelligence Applications to Traffic Engineering*”, Utrecht, The Netherlands (1994)

[Boero, 1999] Marco Boero, “*Case Studies of Systems: the KITS Model*”, ERUDIT Tutorial Helsinki, 3rd august 1999.

[Boero et al., 1993] Boero M., Cuena J., Kirschfink H., Krogh C., "*KITS: A general approach for knowledge-based traffic control models*", Technical Days on Advanced Transport Telematics, Brussels 1993, Belgium.

[Cuena et al., 1995] José Cuena, Josefa Hernández and Martín Molina, "*Knowledge-based models for Adaptive Traffic Management Systems*", Transpn. Res.-C, Vol. 3, No. 5, pp. 311-337, 1995, Elsevier Sciencc Ltd.

[Deng et al., 2005] Deng, L. Y., Liang, H. C., Wang, C., Wang, C., and Hung, L. 2005. "*The Development of the Adaptive Traffic Signal Control System"*. In Proceedings of the 11th international Conference on Parallel and Distributed Systems – Workshops (Icpads'05) - Volume 02 (July 20 - 22, 2005). ICPADS. IEEE Computer Society, Washington, DC, pp. 634-638.

[Dresner and Stone, 2004] Kurt Dresner, Peter Stone, "*Multiagent Traffic Management: A Reservation-Based Intersection Control Mechanism*", pp. 530-537, Third International Joint Conference on Autonomous Agents and Multiagent Systems - Volume 2 (AAMAS'04), 2004.

[Eggenkamp and Rothkrantz, 2001] G. Eggenkamp and Leon J.M. Rothkrantz, "*Intelligent dynamic route planning*", KBS & TRAIL Workshop, June 2001.

[Ehlert and Rothkrantz, 2001] Patrick A.M. Ehlert and Leon J.M. Rothkrantz, "*A Reactive Driving Agent for Microscopic Traffic Simulation*", KBS & TRAIL Workshop, June 2001.

[Hernandez et al., 1999] J. Hernandez José Cuena and Martín Molina, "*Real-time Traffic Management through Knowledge-based Models: The TRYS approach*", ERUDIT Tutorial on Intelligent Traffic Management Models (www.erudit.de) , Helsinki 1999, Finnland

[Jin and Lam, 2003] Ming Jin and Soi-Hoi Lam, "A virtual-reality based integrated driving-traffic simulation system to study the impacts of intelligent transportation system (ITS)", in Proceedings of the International Conference on Cyberworlds, 2003. 3.-5. Dec. 2003, pp.158-165.

[Kirschfink et al., 2000] Heribert Kirschfink, Josefa Hernández , Marco Boero, "*Intelligent Management Models in Traffic and Logistics*", ESIT 2000, 14-15 September 2000, Aachen, Germany

[Kroon and Rothkrantz, 2001] R. Kroon and Leon J.M. Rothkrantz, "*Dynamic vehicle routing using an ABC-algorithm*", KBS & TRAIL Workshop, June 2001.

[Ljungberg and Lucas, 1992] Magnus Ljungberg and Andrew Lucas, "*The oasis air-traffic management system*", in Proceedings of the Second Pacific Rim International Conference on Artificial Intelligence, PRICAI '92, Seoul, Korea, 1992.

[Mamei et al., 2003] Marco Mamei, Franco Zambonelli, Letizia Leonardi, "*Distributed Mo tion Coordination with Co-Fields: A Case Study in Urban Traffic Management*", p. 63, The Sixth International Symposium on Autonomous Decentralized Systems (ISADS'03), 2003.

[Nguyen-Duc et al., 2003] Minh Nguyen-Duc, Jean-Pierre Briot, Alexis Drogoul, and Vu Duong,"*An application of Multi-Agent Coordination Techniques in Air Traffic" Management*, Proceedings of the IEEE/WIC International Conference on Intelligent Agent Technology, p.622, 2003

[Roozemond, 1998] Roozemond, D.A. (1998), "*Self-optimising and self-organising urban traffic control systems*", 4th annual congress 1998 on Transport, infrastructure and logistics. December 15th, 1998 Scheveningen, TRAIL Research School, Delft

[Roozemond, 1999] D. A. Roozemond. "*Using intelligent agents for urban traffic control systems"*. In Proceedings of the International Conference on Artificial Intelligence in Transportation Systems and Science, pages 69--79, 1999.

[Roozemond and Rogier, 2000] Danko A. Roozemond and Jan L.H. Rogier, "*Agent con trolled traffic lights*", ESIT 2000, 14-15 September 2000, Aachen, Germany

[Roozemond and van der Veer, 1998] Danko A. Roozemond and Peter van der Veer, "*Usability of Intelligent Agent Systems in Urban Traffic Control"*, in Transactions on Information and Communications Technologies vol 20, © 1998 WIT Press, www.witpress.com.

[Scemama, 1994] Scemama, "*CLAIRE: A context-free AI-based supervisor for traffic con trol*", Bielli M., Ambrosino G., Boero M. (eds.), Artificial Intelligence Applications to Traffic Engineering, pp. 137-156, 1994.

[Shiose et al., 2001] Takayuki Shiose, Toshiyuki Onitsuka and Toshiharu Taura, "*Effective Information Provision for Relieving Traffic Congestion"*, in Proceedings of the 4th International Conference on Computational Intelligence and Multimedia Applications (ICCIMA'01), 2001

[Wang, 2005] Fei-Yue Wang, "*Agent-Based Control for Networked Traffic Management Systems*", in IEEE Intelligent Systems, vol.20, no.5, pp. 92-96, Sept/Oct, 2005.