Agent controlled traffic lights

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ABSTRACT: Due to several reasons, changing conditions in the environment do not always lead to changes in the traffic control units. The hypothesis of this research is that it may be useful to make use of self evaluating and self organising intelligent (urban) traffic control systems. In this research we focus on the applicability of autonomous intelligent agents within urban traffic control (i.e. traffic light systems). We consider the opportunity of building adaptive traffic control units based on intelligent agent technology that pro-act upon changes (short- and long term) in traffic in real-time. We expect that intelligent agent based systems in urban traffic control can provide a more balanced, co-ordinated and optimal setting of the signal control schema during operation.

KEYWORDS: Intelligent agents, urban traffic control, adaptive traffic control, pro active control, traffic light systems

INTRODUCTION

The quality of (urban) traffic control systems is determined by the match between the control schema and the actual traffic patterns. If traffic patterns change, what they usually do, the effectiveness is determined by the way in which the system adapts to these changes. When this ability to adapt becomes an integral part of the traffic control unit it can react better to changes in traffic conditions. Adjusting a traffic control unit is a costly and timely affair if it involves human attention. The hypothesis is that it might offer additional benefit using self-evaluating and self-adjusting traffic control systems. There is already a market for an urban traffic control system that is able to react if the environment changes; the so called adaptive systems. "Real" adaptive systems will need pro-active calculated traffic information and cycle plans- based on these calculated traffic conditions- to be updated frequently.

Our research of the usability of agent technology within traffic control can be split into two parts. First there is a theoretical part integrating agent technology and traffic control. The final stage of this research focuses on practical issues like implementation and performance. Here we present the concepts of agent technology applied to dynamic traffic control. Currently we are designing a layered model of an agent based urban traffic control system. We will elaborate on that in the last chapters.

ADAPTIVE URBAN TRAFFIC CONTROL

Adaptive signal control systems must have a capability to optimise the traffic flow by adjusting the traffic signals based on current traffic. All used traffic signal control methods are based on feed-back algorithms using traffic demand data - varying from years to a couple of minutes - in the past. Current adaptive systems often operate on the basis of adaptive green phases and flexible co-ordination in (sub)networks based on measured traffic conditions (e.g., UTOPIA-spot, SCOOT). These methods are still not optimal where traffic demand changes rapidly within a short time interval. The basic premise is that existing signal plan generation tools make rational decisions about signal plans under varying conditions; but almost none of the current available tools behave pro-actively or have meta-rules that may change behaviour of the controller incorporated into the system. The next logical step for traffic control is the inclusion of these meta-rules and pro active and goal-oriented behaviour. The key aspects of improved control, for which contributions from artificial intelligence and artificial intelligent agents can be expected, include the capability of dealing with conflicting objectives; the capability of making pro-active decisions on the basis of temporal analysis; the ability of managing, learning, self adjusting and responding to non-recurrent and unexpected events (Ambrosino et al.., 1994).

WHAT ARE INTELLIGENT AGENTS?

Agent technology is a new concept within the artificial intelligence (AI). The agent paradigm in AI is based upon the notion of reactive, autonomous, internally-motivated entities that inhabit dynamic, not necessarily fully predictable environments (Weiss, 1999). Autonomy is the ability to function as an independent unit over an extended period of time, performing a variety of actions necessary to achieve pre-designated objectives while responding to stimuli produced by integrally contained sensors (Ziegler, 1990). Multi-Agent Systems can be characterised by the interaction of many agents trying to solve a variety of problems in a co-operative fashion. Besides AI, intelligent agents should have some additional attributes to solve problems by itself in real-time; understand information; have goals and intentions; draw distinctions between situations; generalise; synthesise new concepts and / or ideas; model the world they operate in and plan and predict consequences of actions and evaluate alternatives. The problem solving component of an intelligent agent can be a rule-based system but can also be a neural network or a fuzzy expert system. It may be obvious that finding a feasible solution is a necessity for an agent. Often local optima in decentralised systems, are not the global optimum. This problem is not easily solved. The solution has to be found by tailoring the interaction mechanism or to have a supervising agent co-ordinating the optimisation process of the other agents.

INTELLIGENT AGENTS IN UTC, A HELPFUL PARADIGM

Agent technology is applicable in different fields within UTC. The ones most important mentioning are: information agents, agents for traffic simulation and traffic control. Currently, most applications of intelligent agents are information agents. They collect information via a network. With special designed agents user specific information can be provided. In urban traffic these intelligent agents are useable in delivering information about weather, traffic jams, public transport, route closures, best routes, etc. to the user via a Personal Travel Assistant. Agent technology can also be used for aggregating data for further distribution. Agents and multi agent systems are capable of simulating complex systems for traffic simulation. These systems often use one agent for every traffic participant (in a similar way as object oriented programs often use objects). The application of agents in (Urban) Traffic Control is the one that has our prime interest. Here we ultimately want to use agents for pro-active traffic light control with on-line optimisation. Signal plans then will be determined based on predicted and measured detector data and will be tuned with adjoining agents. The most promising aspects of agent technology, the flexibility and pro-active behaviour, give UTC the possibility of better anticipation of traffic. Current UTC is not that flexible, it is unable to adjust itself if situations change and can't handle un-programmed situations. Agent technology can also be implemented on several different control layers. This gives the advantage of being close to current UTC while leaving considerable freedom at the lower (intersection) level.

DESIGNING AGENT BASED URBAN TRAFFIC CONTROL SYSTEMS

The ideal system that we strive for is a traffic control system that is based on actuated traffic controllers and is able to pro actively handle traffic situations and handling the different, sometimes conflicting, aims of traffic controllers. The proposed use of the concept of agents in this research is experimental.

ASSUMPTIONS AND CONSIDERATIONS ON AGENT BASED URBAN TRAFFIC CONTROL

There are three aspects where agent based traffic control and -management can improve current state of the art UTC systems:

- Adaptability. Intelligent agents are able to adapt its behaviour and can learn from earlier situations.
- Communication. Communication makes it possible for agents to co-operate and tune signal plans.
- Pro-active behaviour. Due to the pro active behaviour traffic control systems are able to plan ahead.

To be acceptable as replacement unit for current traffic control units, the system should perform the same or better than current systems. The agent based UTC will require on-line and pro-active reaction on changing traffic patterns. An agent based UTC should be demand responsive as well as adaptive during all stages and times. New methods for traffic control and traffic prediction should be developed as current ones do not suffice and cannot be used in agent technology. The adaptability can also be divided in several different time scales where the system may need to handle in a different way (Rogier, 1999):

- gradual changes due to changing traffic volumes over a longer period of time,
- abrupt changes due to changing traffic volumes over a longer period of time,
- abrupt, temporal, changes due to changing traffic volumes over a short period of time,
- abrupt, temporal, changes due to prioritised traffic over a short period of time

One way of handling the balance between performance and complexity is the use of a hierarchical system layout. We propose a hierarchy of agents where every agent is responsible for its own optimal solution, but may not only be influenced by adjoining agents but also via higher level agents. These agents have the task of solving conflicts between lower level agents that they can't solve. This represents current traffic control implementations and idea's. One final aspect to be mentioned is the robustness of agent based systems (if all communication fails the agent runs on, if the agent fails a fixed program can be executed.

To be able to keep our first urban traffic control model as simple as possible we have made the following assumptions: we limit ourselves to inner city traffic control (road segments, intersections, corridors), we handle only controlled intersections with detectors (intensity and speed) at all road segments, we only handle cars and we use simple rule bases for knowledge representation.

5.2 TYPES OF AGENTS IN URBAN INTERSECTION CONTROL

As we divide the system in several, recognisable, parts we define the following 4 types of agents:

- Roads are represented by special road segment agents (RSA),
- Controlled intersections are represented by intersection agents (ITSA),
- For specific, defined, areas there is an area agent (higher level),
- For specific routes there can be route agents, that spans several adjoining road segments (higher level).

We have not chosen for one agent per signal. This may result in a more simple solution but available traffic control programs do not fit in that kind of agent. We deliberately choose a more complex agent to be able to use standard traffic control design algorithms and programs. The idea still is the optimisation on a local level (intersection), but with local and global control. Therefor we use area agents and route agents. All communication takes place between neighbouring agents and upper and lower level ones.

5.3 DESIGN OF OUR AGENT BASED SYSTEM

The essence of a, demand responsive and pro-active agent based UTC consists of several ITSA's (InTerSection Agent)., some authority agents (area and route agents) and optional Road Segment Agents (RSA). The ITSA makes decisions on how to control its intersection based on its goals, capability, knowledge, perception and data. When necessary an agent can request for additional information or receive other goals or orders from its authority agent(s).

For a specific ITSA, implemented to serve as an urban traffic control agent, the following actions are incorporated (Roozemond, 1998):

- data collection / distribution (via RSA - information on the current state of traffic; from / to other ITSA's - on other adjoining signalised intersections);
- analysis (with an accurate model of the surrounds and knowing the traffic and traffic control rules define current trend; detect current traffic problems);
- calculation (calculate the next, optimal, cycle mathematically correct);
- decision making (with other agent deciding what to use for next cycle; handle current traffic problems);
- control (operate the signals according to cycle plan).

In figure 1 a more specific example of a simplified, agent based, UTC system is given. Here we have a route agent controlling several intersection agents, which in turn manage their intersection controls helped by RSA's. The ITSA is the agent that controls and operates one specific intersection of which it is completely informed. All ITSA's have direct communication with neighbouring ITSA's, RSA's and all its traffic lights. Here we use the agent technology to implement a distributed planning algorithm. The route agents' tasks are controlling, co-ordinating and leading the ITSA's towards a more global optimum. Using all available information the ITSA (re)calculates the next, most optimal, states and control strategy and operates the traffic signals accordingly. The ITSA can directly influence the control strategy of their intersection(s) and is able to get insight into on-coming traffic.

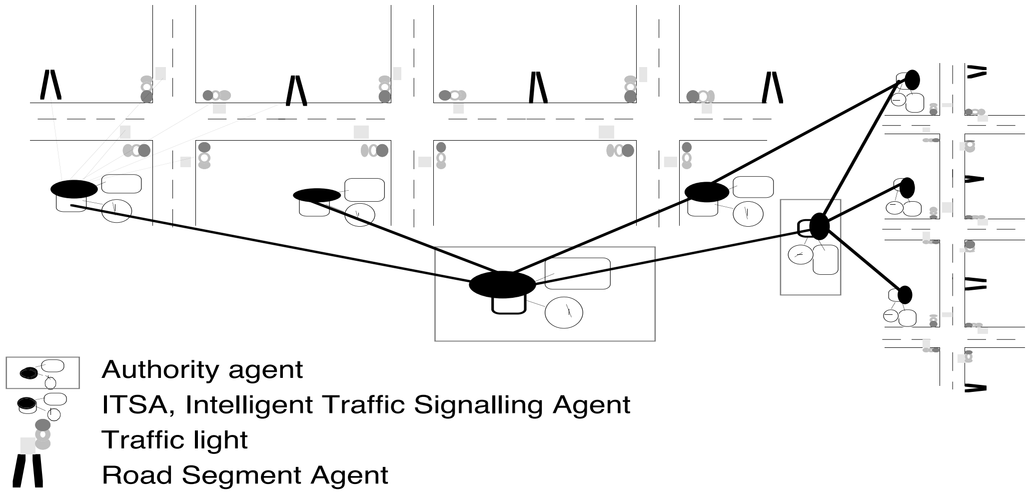

Figure 1:. Simple agent based UTC

THE INTERNALS OF THE ITSA MODEL

Traffic dependent intersection control normally works in a fast loop. The detector data is fed into the control algorithm. Based upon predetermined rules a control strategy is chosen and the signals are operated accordingly. In this research we suggest the introduction of an extra, slow, loop where rules and parameters of a prediction- model can be changed by a higher order meta-model.

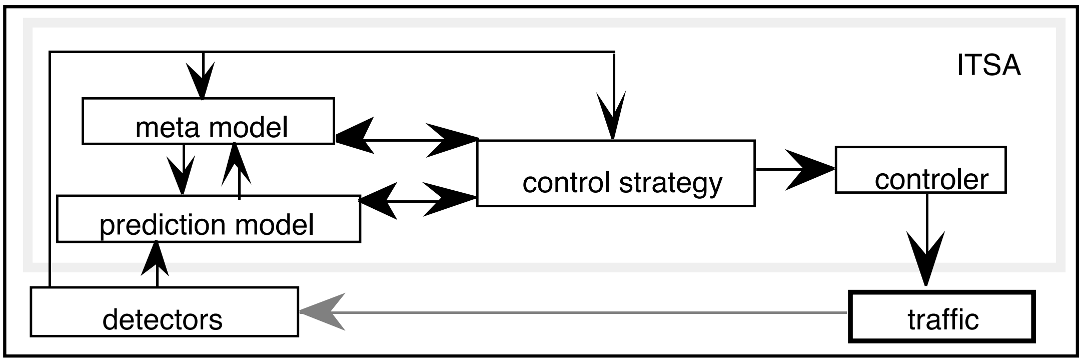

Figure 2: Actuated control strategy based on agents

5.4.1 ITSA model

The internals of an ITSA consists of several agents. For a better overview of the internal ITSA model-agents and agent based functions see figure 2. Data collection is partly placed at the RSA's and partly placed in the ITSA's. The needed data is collected from different sources, but mainly via detectors. The data is stored locally and may be transmitted to other agents. The actual operation of the traffic signals is left to an ITSA-controller agent. The central part of the ITSA, acts as a control strategy agent. That agent can operate several control strategies, such as anti-blocking and public transport priority strategies. The control strategy agent uses the estimates of the prediction model agent which estimates the states in the near future. The ITSA-prediction model agent estimates the states in the near future. The prediction model agent gets its data related to intersection and road segments - as an agent that 'knows' the forecasting equations, actual traffic conditions and constraints - and future traffic situations can be calculated by way of an inference engine and it's knowledge and data base. On-line optimisation only works if there is sufficient quality in traffic predictions, a good choice is made regarding the performance indicators and an effective way is found to handle one-time occurrences (Rogier, 1999).

5.4.2 Prediction model

We hope to include pro-activeness via specific prediction model agents with a task of predicting future traffic conditions. The prediction models are extremely important for the development of pro active traffic control. The proposed ITSA-prediction model agent estimates the states of the traffic in the near future via its own prediction model.

The prediction meta-model compares the accuracy of the predictions with current traffic and will adjust the prediction parameters if the predictions were insufficient or not accurate.

The prediction model agent is fed by several inputs: vehicle detection system, relevant road conditions, control strategies, important data on this intersection and its traffic condition, communication with ITSA's of nearby intersections and higher level agents. The agent itself has a rule-base, forecasting equations, knows constraints regarding specific intersections and gets insight into current (traffic) conditions. With these data future traffic situations should be calculated by its internal traffic forecasting model. The predicted forecast is valid for a limited time. Research has shown that models using historic, up-stream and current link traffic give the best results (Hobeika & Kim, 1994).

5.4.3 Control strategy model

The prediction of the prediction model is used in the control strategy planning phase. We have also included a performance indicating agent, necessary to update the control parameters in the slower loop.

The control strategy agent uses the estimates of the prediction model agent to calculate the most optimal control strategy to pro-act on the forecasts of the prediction model agent, checks with other adjoining agents its proposed traffic control schema and then plans the signal control strategy The communication schema is based on direct agent to agent communication via a network link. The needed negotiation finds place via a direct link and should take the global perspective into consideration. Specific negotiation rules still have to be developed. Some traffic regulation rules and data has to be fed into the system initially. Data on average flow on the links is gained by the system during run-time. In the near future computer based programs will be able to do, parts of, these kind of calculus automatically. For real-time control the same basic computer programs, with some artificial knowledge, will be used. Detectors are needed to give information about queues and number of vehicles. The arrival times can also be given by the RSA so that green on demand is automatically covered.

6. CONCLUSIONS AND FUTURE WORK

Adaptive signal control systems that are able to optimise and adjust the signal settings are able to improve the vehicular throughput and minimise delay through appropriate response to changes in the measured demand patterns. With the introduction of two un-coupled feed back loops, whether agent technology is used or not, a pro-active theory of traffic control can be met.

There are several aspects still unresearched. The first thing we are going to do is to build a prototype system of a single intersection to see if the given claims of adaptability and pro activeness can be realised. A working prototype of such system should give appropriate evidence on the usability of agent based control systems. There are three other major subjects to be researched in depth; namely self adjustable control schema's, on-line optimisation of complex systems and getting good prediction models.

For urban traffic control we need to develop self adjustable control schemes that can deal with dynamic and actuated data. For the optimisation we need mathematical programming methodologies capable of real-time on-line operation. In arterial and agent based systems this subject becomes complex due to several different, continuously changing, weights and different goals of the different ITSA's and due to the need for co-ordination and synchronisation. The research towards realising real-time on-line prediction models needs to be developed in compliance with agent based technology.

The pro-active and re-active nature of agents and the double loop control schema seems to be a helpful paradigm in intelligent traffic management and control.

Further research and simulated tests on a control strategy, based on intelligent autonomous agents, is necessary to provide appropriate evidence on the usability of agent-based control systems.

REFERENCES

Ambrosino, G., Bielli, M. and Boero, M. ,1994. Artificial intelligence approach to road traffic control. In: artificial intelligence applications to traffic engineering, Bielli, M., Ambrosino, G., Boero, M.(eds), VSP, Utrecht. pp. 95-116

Hobeika, A.G. and Kim, C.K., 1994. Traffic flow prediction systems based on upstream traffic. In: 1994 vehicle navigation & information systems conference proceedings ; IEEE.

Rogier, J.L.H., 1999. Tomas, TNO-rapport DIS-RPT-990010 (in Dutch), Delft.

Roozemond, D.A., 1998. Self-optimising and self-organising urban traffic control systems. In: Trail Conference proceedings no P98/3, TRAIL Research School, Delft.

Weiss, G., 1999, Multiagent systems, MIT, Massachusetts

Zeigler, B.P.,1990. High autonomy systems: concepts and models. In: proceedings AI, simulation, and planning in high autonomy systems, Zeigler, B., Rozenblit, J (eds.), IEEE, Los Alamos.