Development of an agent structure for a system for operational traffic management

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Abstract

This paper presents an orientating study in the use of agent technology in Dutch operational traffic control. It sets out to answer the main question of: How can agent technology be a useful addition to existing systems, solutions and future visions in operational traffic control in the Netherlands? How can the merits of a traffic control structure using agent technology be compared to those of a nearly equal, but contemporary traffic control structure.

It succeeds in systematically developing a theoretical agent control structure which focuses mainly on short-term operational traffic control and which is presented as being part of a larger envisioned structure combining agents and hierarchical elements.

The agents involved are (1) link agents that monitor the traffic situation on their link and compare the data to local goals, thereby identifying possibilities for improvement. They present these as requests for services to nearby link agents and service agents. The other link agents act upon these requests by evaluating their own situation and deciding if there is room to help. The final response has to come from (2) a (or more) service agent that decides what to do with the requests coming from neighboring link agents and follows through on those decisions by adapting the control of the crude traffic control measure(s) it is built upon. The agents communicate with each other on the level of ‘services’ that can be provided, thereby abstracting that communication from specific technical details in the implementation of the link agents, service agents and the traffic control measures they control.

The implementation of the proposed agent control structure is carried out in the C++ environment provided for by Paramics. While testing this agent traffic controller it showed to have some limitations, mainly in its (very) short-term traffic control strategies. But careful analysis of this first implementation and following tests showed ways of improving on it.

In its advises for further research this paper presents improvements that could be made to the theoretical design as well as to the practical implementation.

Introduction

Traffic management is one of the solutions that provides for a better usage of our traffic network by helping and guiding drivers in making their choices in traffic. However, it is clear that much progress can still be made in traffic management at the moment. Often enough, drivers see ways of improving it, mostly emanating from their local vision: *"If that traffic light only had switched to green a little bit earlier…".* A lot of these possible points of improvement could be dealt with by improving the coordination between the traffic control measures that drivers encounter.

However, it is difficult to pinpoint which traffic control measures need coordination and when that needs to happen. Moreover, in traffic control, lots of systems are in use that are not directly suited for usage within a larger system. It would be an advantage if a flexible solution could be found, that can coordinate different traffic control measures. It should do that from a local perspective, keeping the traffic in the local environment in mind while also paying attention to network wide goals.

Agent technology can be a valuable asset to such a coordinating mechanism. By using intelligent agents that are pursuing network wide goals, but contain enough intelligence and decision making power to localize and make use of local opportunities for improvement and also handle the peculiarities of legacy systems surrounding them.

The main research question

The central question will then be: how can agent technology be an addition to already existing systems, solutions and visions about the future of the (Dutch) operational traffic management system?

Analysis of the current situation shows that there is a need for a control structure within the operational traffic management system. A structure that uses hierarchical and agent elements is presented and a theoretical design of the lowest level of agents within that structure is made that produces a base to construct a practical agent traffic controller on. This design is made following two of these three steps:

1. Choose the agents
2. Choose the knowledge elements, used for communication
3. *Describe all the communication dialogs starting from all the different events that could take place.*

Step three has been left to further research. This question can probably best be answered with some experience of the functioning of the agent control structure. Instead, a practical implementation has been made to get experience with the design of this agent structure and make recommendations for further theoretical and practical development. The results from testing this implementation are not shown here, but the lessons that have been learned can be found in the conclusion.

Proposal for a new agent structure for operational traffic management

The Architecture for Traffic Control (AVB) and then especially the Infrastructure Architecture [5] puts forward a frame of thought that gives direction to thinking about the traffic management system in total. It defines architecture layers that could be found in any traffic management system that is functioning as a whole.

However, the current traffic management system in the Netherlands consists of more or less stand-alone traffic control measures and some regional traffic management centers that have only very limited control over these traffic control measures [4]. A number of inadequacies in current traffic control can be identified:

1. Limited cooperation in the use of traffic control measures to fight larger problems.
2. Random shifting of problem situations over the traffic network.
3. Useless activation of traffic control measures.
4. Contra-productive interaction in between traffic control measures.
5. Missed opportunities for improvement

Using this information, three basic statements that describe the current situation in traffic control in the Netherlands are formulated:

- *Traffic control measures are currently controlled on a local basis*, using local goals and measurements. Because of this, they only partly use their potential or even work contra-productive.
- *The traffic management centers do not have a lot of direct influence on traffic control in the current situation*. It is not likely that they will have that without a large part of the structure being automated. The amount of data and decisions are that big, that a large part of the control cycle will have to be out of the hands of the traffic managers.
- *The Architecture for Traffic Management (AVB) is an architecture that is and can be used to come to an integral design of a Dutch traffic management system*. At the moment, however, it is primarily elaborated upon and worked with at a decision-making level. The part concerning operational traffic management has not been described in sufficient detail until now.
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The main problem in traffic control this theoretical part addresses

Using these statements, the following question is formulated: what is an appropriate structure for an operational traffic management system? This structure should have at least the following characteristics:

- ✓ It makes it possible for the operational traffic management system to make use of as many as possible of the already existing traffic control measures and sensors.
- ✓ It should fit in the frame that is put forward by the AVB for the operational traffic control system.
- ✓ It makes the operational traffic management system scalable from a few crossings within a larger network to a complete traffic network.
- ✓ It makes the operational traffic management system as robust as possible. Might one element (temporarily) stop functioning, it should have as little consequences as possible for the functioning of the whole system.
- ✓ It enables the operational traffic management system to deal with all the goals and restrictions coming from all the different levels and directions in the environment surrounding it.

A solution to the before mentioned problem

These requirements can be met by using a multi-agent and hierarchical structure (see Figure 1) for the operational traffic management system that fits within the architecture already put forward by the AVB. Next to the requirements put forward, it has the following distinct characteristics compared to other possible structures.

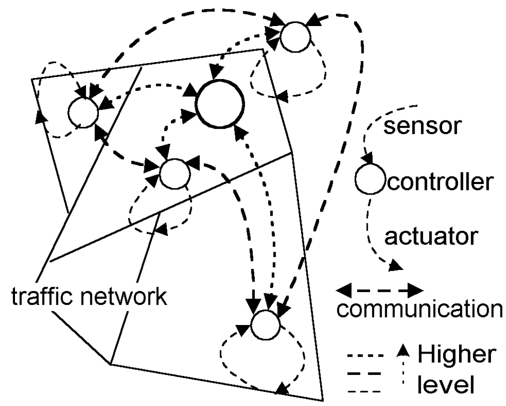

Figure 1: a multi-agent and hierarchical structure for an operational traffic control system. This example has two hierarchical layers.

By combining a multi-agent and hierarchical structure, the final responsibility for attaining the network wide goals lays with limited number of parties, compared to a pure multi-agent structure. The task of dividing that responsibility at every level is a task that needs to be performed at every single level within the hierarchical structure, but it is a limited task at every level.

In opposition to what happens in a hierarchical structure, the agents at the lowest level within the chosen structure coordinate their efforts in between themselves, without the direct interaction of higher levels and without noticing the divisions made at higher levels. This corresponds to the fact that the traffic process is hard to separate at the lowest level(s), but at higher levels of abstraction it can be subdivided.

The agents provide for more flexibility compared to other structures. The agents in the lowest level specifically are uniform over the whole traffic network and their coordination is the product of mutual agreement and not of prescriptions. The quantity of agents has no specific value within the structure, so that can be changed quite easily. Furthermore, the internal structure of the agents themselves and other parallel systems is not prescribed by this structure, because the elements of their communication at a higher level and chosen independently from their internal workings.

A detailed description of the lowest level of agents

Of the chosen multi-agent and hierarchical structure the lowest level has been developed into a more detailed description, which can afterwards be implemented. This level of agents is found just above the level of the already existing traffic control measures and has responsibility for short-term traffic management. For developing the agent structure the following steps have been used:

1. Make appropriate agents that represent certain system parts that follow these criteria:
    - Is a local goal available for the agents?
    - Are there any means for reaching this goal available to the agent?
    - Is the represented system part of the right level?
    - Do the agents have the least differences possible amongst themselves?

2. Choose appropriate communication paths, times and elements in the following manner:
    I. Analyze the current situation in communication
    II. Define the communication paths in between the agents
    III. Define the events upon which communication needs to take place
    IV. Determine the demands that need to be taken into account while choosing the communication elements
    V. Define the communication elements

The Agents

Using this plan[1], two kinds of agents have been defined: link agents and service agents (see also Figure 2).

- *Link agents* represent unidirectional stretches of road without relevant connecting on or off ramps and with a maximum length.
- *Service agents* represent independently controllable traffic control measures.

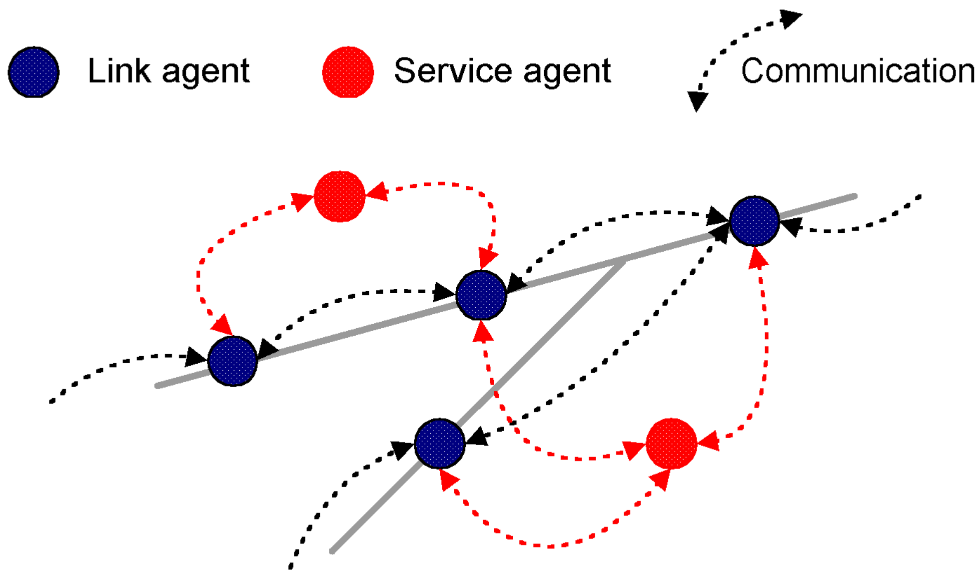

Figure 2: link agents, service agents and communication lines in a simple traffic network.

Link agents – for a link agent the goal is to monitor the traffic situation on the link it represents and to bring or keep it to a preferred status. The means with which it should try to reach that goal is (a) influencing the service agents in its surroundings so that they help in changing the traffic situation in the right way and (b) requesting the surrounding link agents to do the same. The level of scale is chosen so that every traffic network can be subdivided into links and their appropriate link agents. This level also matches the level of service agents, which depends on the level of scale of the independently controllable traffic control measures. These link agents will only differ in between themselves on parameters and goals.

Service agents – a service agent has the goal to weigh the wishes of the link agents in its neighborhood and, keeping in mind any restrictions, come to a certain control plan for the traffic control measures it represents. The manner in which a service agent can reach its goal is by requesting the wishes of the link agents and weighing these against the restrictions and each other to decide upon a control plan. The level of scale of these agents matches that of the link agents and the communication involved will be limited. Differences between service agents exist, because of the differences in the traffic control measures they represent. But they will also have a lot of similarities because the communication is based on abstract elements, not related to the inner workings of the service agents nor the link agents.

Communication - the communication flows are between the link agents themselves and between link agents and service agents. During non-congested conditions on the traffic network, communication is not needed. The operation of the traffic control measures can then be based upon local measurements and will not have to be altered by the service agents that control these measures. However, during congested or near-congested situations, communication is the way in which the agents coordinate their efforts. The link agents try to find common interests as much as possible and request the service agents to change their controls to match those interests. In case of conflict between the link agents, the service agents will have to make the final decision.

The selected Knowledge Elements for communication

The knowledge elements that are used for communication are chosen with the following criteria in mind:

A. All relevant effects of traffic control measures and neighboring links on the traffic situation of a link should be covered. (Completeness).
B. Different elements in the language should also represent different effects (Straightforwardness).
C. Wishes of link agents should be easily compared by service agents and other link agents (Uniformity)
D. The link agents should be able to describe the quantity in which they would like or would not like a certain effect to occur or change. (Quantifiable).

Using services as the basic knowledge elements takes these criteria into account. Services[2] is used as a term to describe the ‘services that are provided to the traffic network by traffic control measures’. These services have been defined in a general sence, based upon the effect that they have on (parts of) the traffic network instead of the specific functioning of the traffic control measure used to produce it.

Time is also an imported element in the communication between the agents, because traffic control is only effective when the timing is right. Time is now explicitily presented as part of the communication elements, because the communication and agreements between agents in the proposed structure are not prescribed to be time-dependent, meaning that it is not known when certain communication is going to take place.

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[1] And earlier work on this kind of agent traffic control, see [2].

[2] Also defined in the Architecture for Traffic Control.

The communication between link agents should be based upon the following elements, which are the basic services that link agents can provide to each other supplemented by the element of time:

- Change in the inflow into a link
- Change in the outflow out of a link
- Time

The communication between link agents and service agents should be based upon the following elements, which are the services that service-agents can provide to link agents[3], supplemented by the element of time:

- Change in the in and outflow of a link.
- Change in the internal flow in a link.
- Change in the average speed on a link.
- Time

Validation of the proposed agent structure by implementation

An implementation in Paramics has been made that follows the main idea of the proposed agent control structure. Some elements have not been implemented, however. Mainly, the time element is missing in the communication between the agents. Furthermore, the following combination of choices made the implementation unsuited for a real comparison between the agent control structure and contemporary control structure:

- In the behavioral rules of the link agents has primarily been made use of time-smoothed measurements that also have been averaged over the whole of the link.
- Within the service-agents a 'replacing' agent control structure has been chosen. This means that the local controller, like one using the ALINEA algorithm, is completely replaced by the agent control structure. Therefore, the agent control structure is also responsible for short-term and local behavior of the traffic control measures.

However, lessons about these choices have been learned [1], which makes it possible to improve upon this implementation. Furthermore, the experience with implementing the theoretical design also helps in improving this design later on.

Conclusions

The use of a multi-agent and hierarchical structure within the Dutch operational traffic management system has certain advantages over the use of other structures and fits the existing ideas about the development of a coherent Dutch operational traffic management system, set by the Architecture for Traffic Management (AVB).

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[3] This list is not complete, but some of the most well-known services are presented in it.

The existing methodology for agent development has been advanced in a structural manner. Criteria and a logical order of steps have been incorporated in this extension to the methodology to make it possible to re-use it during future design.

Using this extended methodology, a well-founded choice has been made for the use of link and service agents and the communication paths and elements to be used between them. Further elaboration on this, combined with a further elaboration on the internal structure of the link and service agents, will be needed in future research. This should be done in a structured and general way, so the methodology that is used can be added to an expanding set of design tools for agent design.

The existence of future traffic control measures should be taken into account while extending the theoretical design of the agent control structure proposed. The design will then better match future demands and possibilities.

Using the results of the implementation, recommendations can be made for future implementation. The main recommendations are:

- Do not incorporate the local and short-term behavior of the traffic control measures, but keep the focus of agent design and implementation on intra local and longer-term behavior, thereby improving upon the current behavior of traffic control measures without replacing it.
- Incorporate time in the communication between the agents. This should be done in concert with improving the internal design of the link and service agents.

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