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Multi-agent fuzzy signal control based on real-time simulation

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Abstract

In this paper a traffic signal control system based on real-time simulation, multi-agent control scheme, and fuzzy inference is presented. This system called HUTSIG is closely related to the microscopic traffic simulator HUTSIM, both have been developed by the Helsinki University of Technology. The HUTSIM simulation model is used both for off-line evaluation of the signal control scheme and for on-line modeling of traffic situations during actual control. Indicators are derived from the simulation model as input to the control scheme. In the presented control technique, each signal operates individually as an agent, negotiating with other signals about the control strategy. Here the decision making of the agents is based on fuzzy inference that allows a combination of various aspects like fluency, economy, environment and safety. The fuzzy implementation of the HUTSIG signal control system is developed under the FUSICO-project at Helsinki University of Technology.

Keywords: Traffic signal control; Real-time simulation; Multi-agent control; Fuzzy logic

1. Introduction

Traffic signal control has come a long way since fixed-time control (FT) with well-defined criteria and analytical theory for optimal timing (Webster and Cobbe, 1966). For isolated intersections, traffic signal control has been replaced with vehicle or traffic actuated control (VA). However, this has a disadvantage in that the extension of green is determined without consideration to the overall efficiency of the intersection. Miller (1963) proposed a method for real-time optimisation of signal control based on frequent calculations of the impacts on delay for the whole intersection by using an extension or termination of the current green phase. Bång (1976) implemented Miller's concept for isolated signal control, and showed by means of simulation and

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field studies that it had the potential for very significant reductions in delay. A further development in this area was undertaken by Vincent et al. (1988), who used it as a basis for the commercially available MOVA-controller. The SPOT/UTOPIA system integrates the self-optimising functions with public transport priority and other considerations at the network level (Cunningham and Kronborg, 2000). The complexity of signal control is growing rapidly, leading to the need for new ideas concerning how to control signals in relation to multiple aspects.

In this paper, the principles of a new traffic signal control methodology are presented. The new system methodically combines three principles namely: real-time simulation, multi-agent control and fuzzy inference. The signal control concept is called HUTSIG, which is derived from the underlying simulation model HUTSIM (Kosonen, 1999). Both systems have been developed by Helsinki University of Technology (HUT) Laboratory of Transportation Engineering.

2. On-line simulation

In this paper on-line or real-time simulation means that a microscopic simulation system is connected to real-time detector data where the objective is to model the prevailing traffic situation as realistically as possible. The on-line simulation can be used for monitoring the overall status of the traffic system despite incomplete detector input. The use of on-line simulation is described in detail for traffic information purposes in an earlier report by the author (Kosonen and Bargiela, 2000). Here, the same principles are used to improve traffic control system. The simulation system used (HUTSIM), is a high-fidelity microscopic model that has been developed for a wide range of applications and is well-calibrated against field measurements. HUTSIM is an object-oriented simulation system with rule-based vehicle dynamics (Kosonen, 1999).

The basic data obtained through the detector system consists of lane occupancy data extracted from detectors that are usually embedded in the road surface. Each detector provides information about the presence or absence of a vehicle at a discrete location. The rest of the information about the traffic situation must be derived from general knowledge related to the system layout, statistics for traffic patterns, and general vehicle dynamics. In on-line simulation all these factors are methodically combined with the real-time detector data.

The real-time simulation approach postulated here significantly extends the monitoring capabilities of the control system by extrapolating the traffic occurrences in discrete locations through the simulation of realistic traffic flows in the whole network. From the detailed micro simulation model, all kinds of higher-order measures can be computed and used to indicate traffic fluency, emissions, economy, and safety. These comprehensive indicators can be used as input for traffic management and control systems (Fig. 1).

To facilitate on-line simulation, detector data must be received and processed. Therefore, the simulation system must be supplemented with additional functions that adjust the simulation model to maintain consistency between simulated and measured traffic. The use of detector data includes the generation and removal of vehicles, adjusting their speed and position, and fine-tuning turning percentages. More details concerning the use of micro-simulators for state estimation of traffic are given in Kosonen (1999) and Kosonen and Bargiela (2000).

The advantage of using on-line simulation is that it provides indicators that can be used for both traffic control and traffic information purposes. The queues, delays, travel times etc. can be

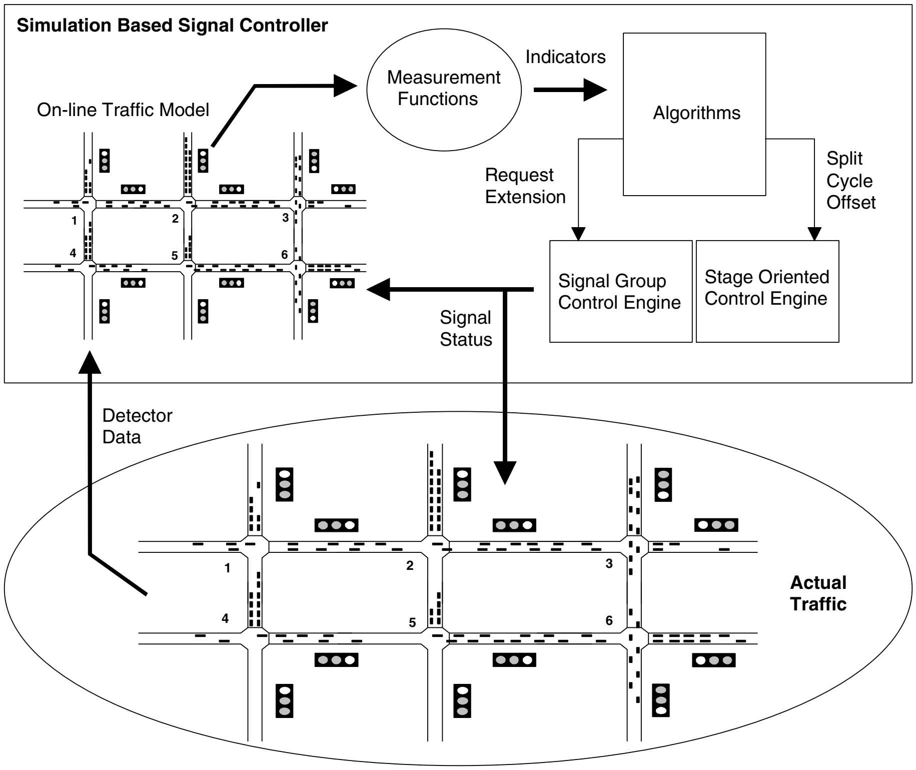

Fig. 1. On-line simulation based traffic signal control (HUTSIG).

monitored continuously and delivered to road users with stationary or mobile terminal devices. The performance of the signal control system can also be monitored in a traffic control center.

3. Multi-agent signal control

In a multi-agent control scheme the control process is handled by a number of individual agents that interact with each other. This interaction can also be called negotiation as each agent, while pursuing its own goals, can also take into account the situation of other agents. Consequently, the final decision is usually a trade-off between the agent's own preferences against those of others.

Multi-agent control is decentralized, meaning that there is not necessarily any central level of control, and that each agent operates individually and locally. The interaction and negotiation with other agents is usually limited to those belonging to the agent's neighborhood. The neighborhood is often defined by physical distance, but can also depend on other things.

In the Scandinavian countries, what is termed a "signal group control method" is in common use (Fig. 2). This method applies the multi-agent control strategy. In this traffic signal control scheme, a set of signal-heads that always show the same signal is defined as a signal group. These signal groups operate as individual agents and can be changed to green when requested by traffic and when permitted by other signal groups. Hence there is a need for negotiation between the

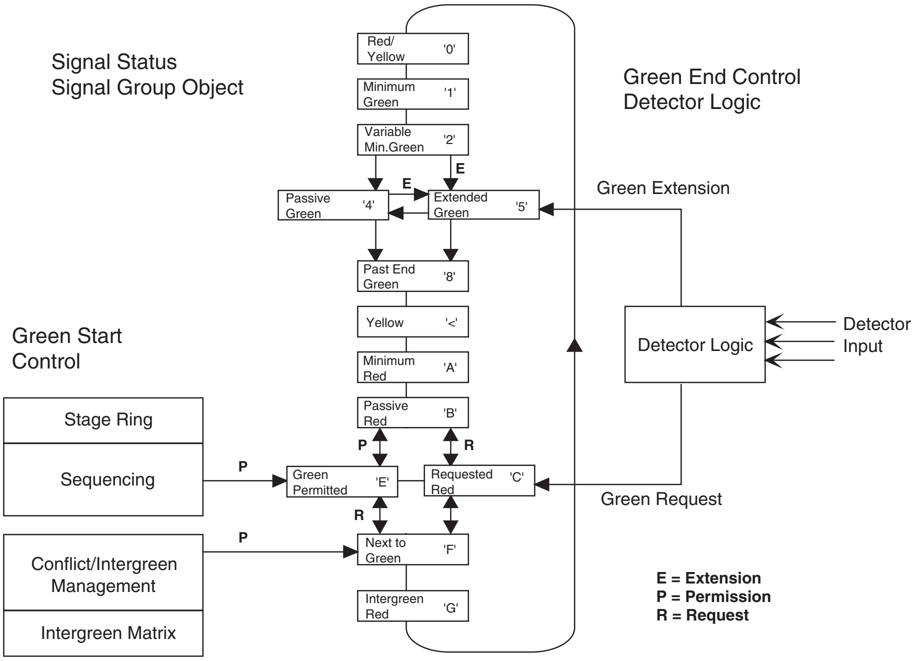

Fig. 2. A diagram of "Scandinavian" signal group control.

signal groups about how to operate together to produce reasonable phase pictures. The advantage of the multi-agent approach is that there are no fixed stages, and any reasonable phase picture can be formed as needed.

The drawback of the Scandinavian signal group control technique is that it combines the multi-agent approach with a rather simple timing (detector logic) and sequencing technique (phase ring), which does not consider the overall traffic situation and performance. The basic objective here is to generalize the existing signal group technique to the multi-agent control scheme and to make it use more intelligent decision-making based on comprehensive traffic input from the on-line simulation model.

The signal group agents have a basic "tendency" to pursue the green state whenever requested by the incoming traffic. Whether it is possible to go green depends on the status of the other signal groups. Having changed to green, a signal group agent is allowed to decide its own green time. Given these basic conditions, the signal group agents have to compose a mutual control strategy that takes care of the following objectives, listed in priority order:

1. Safety (inter-green management)
2. Equality (assuring each direction has a possibility to get green)
3. Timing objectives (several contradictory objectives: efficiency, safety, etc.)
4. Minimizing transitions (find an optimal rest state when there is no traffic).

The priority order means that lower-priority objectives can be pursued only within the limits of higher-priority objectives. This means, for example, that signal timing is subject to limitations set

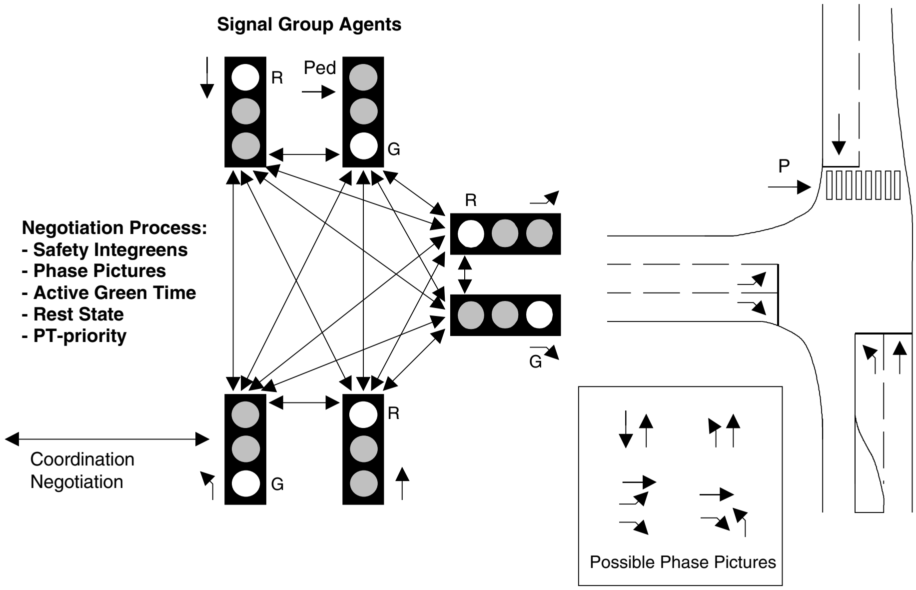

Fig. 3. The multi-agent control principle in a simple intersection.

by the minimum inter-green times between conflicting signals. In Fig. 3 the idea of generic multi-agent control is demonstrated with a simple intersection. In more complex intersections with plenty of dedicated lane signals, pedestrian crossings and public transport priorities, the advantages of flexible multi-agent control become clearer.

Inter-green management is basically a negotiation process between signal groups to guarantee the minimum traffic safety requirements. The usual implementation involves an inter-green matrix that is used to define minimum safety margins between conflicting signal groups. A more intelligent negotiation could involve assessing the traffic situation and reducing the inter-green times when possible, but without compromising safety.

The next problem to be solved by negotiation is to guarantee the chances for each signal group to get green. This is not automatically guaranteed, and there must be a mechanism for this (sequencing). The prevalent technique is called a phase ring. The phase ring rotates the highest priority of green permission (phase) from one set of signal groups to the next. The phase ring guarantees equal chances for getting green within a "cycle". At very high traffic volumes the phase ring produces fixed stages, but at lower traffic volumes it allows more flexible phase patterns. A more advanced system could apply intelligent negotiation between signal group agents to produce more flexible phase patterns. Obviously a negotiation is always needed between conflicting signal groups, but there is also a need for non-conflicting signal groups to coordinate their mutual operation.

Once a signal group has received a green permission from inter-green and sequencing negotiation, it can start its active green time. Usually there are minimum and maximum time limitations, but otherwise the signal group decides its own active (extended) green time and no other signal group can terminate it. However, without any demand for an active green extension, a signal group can still remain passive green, which is terminated as soon as a conflicting signal group demands green.

In the Scandinavian signal group technique "detector logic" is used. The detector logic delivers extension pulses whenever a vehicle is passing over a detector. These pulses extend the green time until there is a sufficient gap between vehicles, or the maximum green time is achieved. This gap-seeking method is not "intelligent" and therefore does not involve any negotiation with conflicting signal groups. For example, the queue behind conflicting signal groups has no effect on the green extension. However, with proper parameter setting and special functionality, this type of timing mechanism can also perform surprisingly well. The Swedish LHOVRA-control is a good example of such a method (Kronborg, 1992).

A more intelligent multi-agent approach in green timing would allow the current green signal group to negotiate with other (primarily conflicting) groups about whether to extend or terminate its active green time as explained in the introductory chapter. The basic idea is to combine the flexible phase pictures with more intelligent and holistic timing decisions. The negotiation mechanism involves weighing-up the pros against cons. For example, the flow during a three second green extension can be weighed against a simultaneous queue build-up behind all conflicting signal groups, as in stage oriented MOVA and SPOT-systems.

Finally, there are decisions to be made about the rest state when no traffic is present. Normally, the rest state is given to each signal group as a fixed input (go red, remain unchanged, go green). However, it has been shown that the optimal rest state depends on a number of factors. An intelligent mechanism for selecting the right rest state can therefore be quite valuable.

4. Fuzzy signal control

So far, two of the three main principles have been presented, i.e. the on-line simulation and the multi-agent control. The third principle in the system is the algorithm chosen to provide the control agents with a decision-making capability. Generally this is a mapping problem from one input space to another output space, i.e. from traffic situation variables to output decision variables. Any mapping problem can be solved with algorithms. The selection of algorithms is, however, very dependent on how the target behavior is to be defined.

If a mathematical model is available, mathematical optimization becomes plausible as suggested by Miller (1963) and Bång (1976). If a good collection of examples can be identified and demonstrated, then neural-networks can be used to generalize the inherent mapping needed for control operation. A rule-based approach is suitable if a human expert can describe the control task as set of rules. In some cases such rules can be found, but often the conditions for activating a certain rule are vague. In these cases, fuzzy rule-based inference can be suitable. Fuzzy inference is used for decision-making in the control system, but in principle other algorithms could be applied instead.

Traffic in general is controlled by rules, which makes rule-based signal control a plausible choice. A rule-based approach gives better control related to how the system should behave, although it does not search for, or guarantee, an optimal solution. A traffic signal expert can describe roughly how signals should operate, and this can then be interpreted into a rule-base.

The rules and conditions in signal control are typically vague and it is difficult to say when a queue is, for example, "long". In fuzzy logic, membership functions can be used to define such terms like "short-queue" and "long-queue". These vague arguments can then be used in the rule-base using expressions such as: "if queue = long then extend green". The details of the fuzzy logic algorithm are not explained here owing to the fact that there are plenty of references about the theory of fuzzy sets.

In binary logic, decision trees can be formed where only one branch is followed in accordance with different parts of the rules. In fuzzy inference, all rules are considered every time the rule set is used. Fuzzy inference allows smoother transitions from one state to another compared to a binary logic based rule set. Fuzzy inference can be seen more as rule-based calculation rather that rule-based reasoning. The output of such calculation is a fuzzy membership function. Therefore, a defuzzification method must be applied to get a crisp output value from a fuzzy algorithm.

In a way, fuzzy inference resembles human reasoning. The rule-base allows the use of vague arguments that do not need to be unit compatible. Therefore, very different aspects can be taken into account in the decision-making.

The new approach proposed here, is to combine the multi-agent control scheme with a comprehensive reasoning mechanism, i.e. with fuzzy inference. The target of combining fuzzy inference with signal group techniques is to maintain the flexibility of signal group oriented control, but also to improve its capabilities in signal control decisions such as those related to timing, phasing, priorities, and coordination.

In Fig. 4 the idea of multi-agent control with fuzzy inference is applied to signal timing, i.e. the extension of active green time. The signal group agents negotiate through fuzzy inference. concerning whether to extend or terminate the active green signal Signal group agents supply their own traffic data that they collect from the on-line simulation model. In the simplest case, there are only two type of inputs, i.e. the flow passing the green signal and the total queue behind the conflicting red signals.

In this example (Fig. 4) fuzzy inference is applied to green extension only. It is also possible to apply fuzzy inference to other signal control functions like phasing, PT-priorities etc. The phase ring can, for example, be replaced by a fuzzy phase selector. This demonstrates that the actual control strategies in the multi-agent system can be implemented in many different ways.

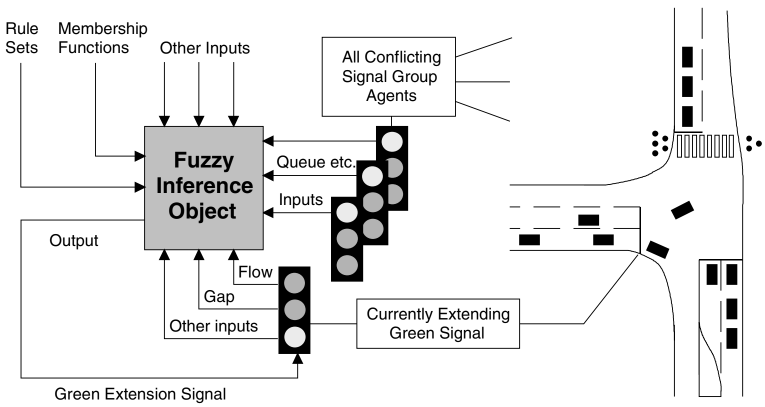

Fig. 4. The negotiation of active green time (extension) using fuzzy inference.

Generally any number and type of traffic indicators can be included into the control system. The basic flow and queue inputs can be made time dependent, i.e. their value depends on a particular extension output candidate. The elapsed green time is an important input as the decision should depend on how much green time has already been used. The car-following gap (or discharge flow) can be useful to recognize the end of a platoon. For environmental objectives, speed levels, speed changes (accelerations) and the number of stops are meaningful inputs. Traffic safety aspects can be measured by the number of vehicles in the option zone, or in terms of required deceleration power or time to collision. For pedestrians the main input variable is the waiting time from detection to green start. Special inputs are needed in order to favor public transport vehicles.

During the simulation and control operation the signal group agent updates the fuzzy extender object only at the time of intervention. An intervention takes place whenever the last extension is to be ended (typically every 1–10 s). Upon intervention the inputs are collected and the inference process launched. The fuzzy output is defuzzified and the duration of the next extension signal is determined. In meantime, the extender only maintains the active extension signal until next intervention, or until the extension time expires. If the intervention time is one second, the decision has only two options: extend green or terminate.

In the HUTSIG system the fuzzy inference is encapsulated into a generic object type (Fig. 4) that can be used by any other object such as, for example, the signal group agent that has to submit the input, launch the inference, and read the output. The user can give all membership functions and rules as an input file.

5. Area signal control

Efficient area signal control is one of the main problems in traffic signal control. The coordination of all signals in a given region is a much more complicated task than the control of a single intersection. In area control there are far more variables and contradicting objectives to take into consideration. The main objective of area control is often to minimize the overall delay, or to avoid stops on the main street (green waves) or favor public transport. Minimizing emissions or maximizing safety can also be important objectives. Regardless of the particular objectives, the key issue has to do with the fact that improved co-operation is needed between controllers to achieve better performance.

The traditional coordination method is to force the signals into a common cycle time and apply offset times between green stages. An example of this kind of system is SCOOT, which optimizes the split, cycle and offset parameters of the coordinated system. In principle, this method was implemented using fuzzy logic by Chiu (1992). The Italian SPOT-system is not based on common cycle time but it uses fixed stages. In this system some stages can, for example, be optional for public transport vehicles only.

The use of fixed stages and/or fixed cycle time simplifies the optimization task but reduces the overall flexibility. The basic approach here is to extend the presented multi-agent control scheme to area control, and to exploit the flexibility of signal group control in coordinated systems. This can be achieved by widening the negotiation area (local neighborhood) from a single intersection to those in a surrounding area. In other words, each signal group agent can negotiate not only with signal groups within the same intersection, but also with other signal groups in the neighboring intersections, both upstream and downstream.

In coordinated control the main task is to solve signal timing, i.e. to decide the green extensions so that the traffic flows smoothly from one intersection to another. Generally this cannot be done for all directions simultaneously, but with the multi-agent approach the signal control agents could compose the green waves for different directions in a flexible manner as and when they are needed. The system can also be improved if the coordination is applied to the negotiation of phase pictures and public transport priorities.

To allow signal group agents to negotiate regarding control decisions, they must be able to exchange their local traffic and control data. It is also important that the control agents can share a common and consistent view of the prevailing traffic situation. Hence in coordinated area control the on-line simulation modeling of the traffic situation is even more important than in isolated control.

There are plenty of possibilities related to how the signal group agents could compose a common area control strategy. One possible approach is proposed in Fig. 5. In this example, the signal group agents in each intersection negotiate regarding the green extensions, as in Fig. 4. In coordinated operation this negotiation process is affected by external signals from the neighboring intersections. Each signal group generates two additional outputs by using fuzzy inference, i.e. one output for extending the green signal and one output for requesting the green signal in the downstream intersection.

In Fig. 5 the idea of coordinated multi-agent signal control is demonstrated. The signals are supposed to operate on a one-second basis, hence the fuzzy decision has only two options: extend or terminate green. The output of the fuzzy control is demonstrated by two bars, and the defuzzification simply involves choosing the tallest. When the green bar is much higher than the red, the fuzzy decision is clearly favoring green extension and is therefore unlikely to be terminated

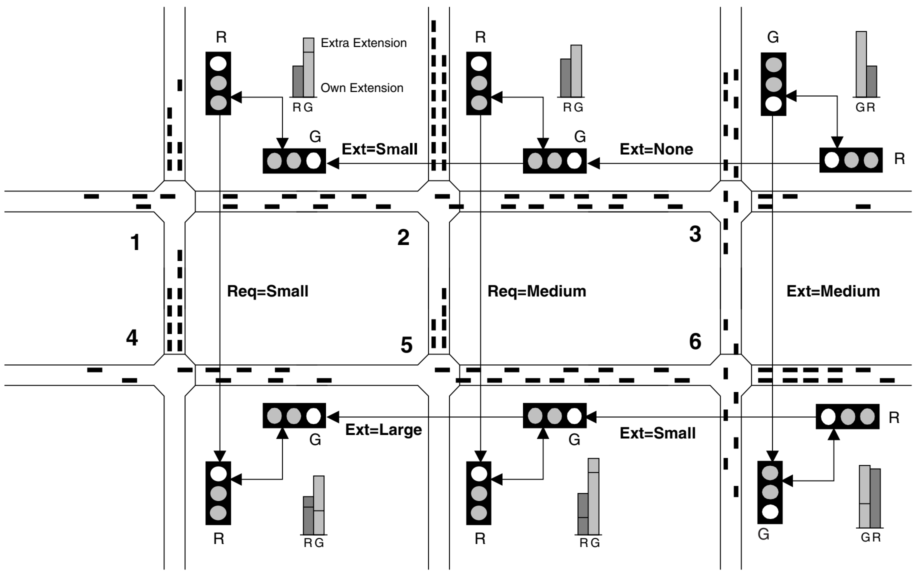

Fig. 5. Negotiation network of signal group agents in coordinated operation.

very soon. When the green bar is only slightly higher, the decision is no so clear-cut and the green is likely to be terminated sooner.

In intersection 4 (Fig. 5) the green is extended because a platoon is crossing and the queue is not too long. From upstream intersection 5 another platoon is approaching, which gives an extra fuzzy extension to intersection 4. Because the queue in 5 is short the green is likely to be continued for some time and hence the extra extension is large. In intersections 1 and 2 the situation is similar, however the queue in 2 is long and is therefore more likely to terminate the green sooner. For this reason, intersection 2 only gives a small extra extension. Similarly, intersection 6 gives only a small extension to 5 because of the fact that the long queue in 6 is behind red, and therefore not likely to reach 5 soon. The extra extension from intersection 3 to 2 is zero since the conflicting queue has just started discharge. Fuzzy request signals can also be generated from one intersection to another. The strength of the extra request signal depends on the length of the queue.

In this example, the external green extension is caused by the upstream intersection only. A downstream intersection could have the opposite effect. For example, if the downstream link is blocked, it could send a "negative extension" to reduce the traffic to that link. The creation of green waves can be reinforced by adjusting weighting factors that can favor the main street, public transport, or platoons of vehicles.

The multi-agent control method can also be adapted to operate under a centralized system. A centralized level of control delivers guidelines for the local operation of signal group controllers. This centralized mode of operation can be used as a supplement to the normal operation, and gives more specific control over the green waves. Centralized operation can be useful especially during very heavy traffic conditions.

For centralized operation, the negotiation of signal group agents does not have to be changed as such, but changes need to be made to signals in the given time frames. In the local operation there are no cycle times at all, however, in centralized operation a common cycle time is set. Each signal group receives the earliest and latest moment of green start within the cycle. If a request is detected during this time frame the signal goes green, otherwise the next phase gets the turn. A green signal gets the earliest and latest termination time within the cycle. All operations of the

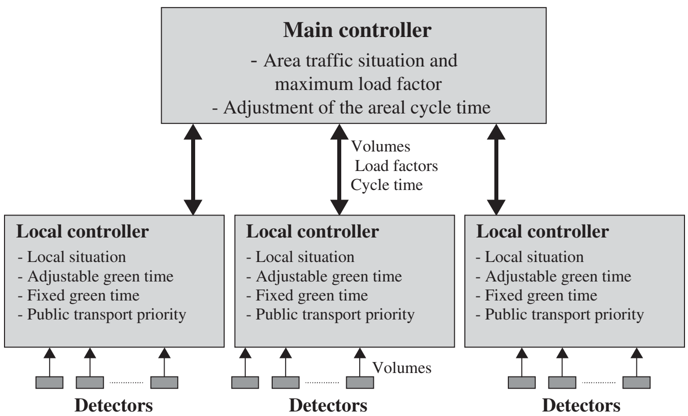

Fig. 6. Multi-agent fuzzy control with central level coordination.

multi-agent control take place within the given central time frame. To create green waves the local cycle counters must be synchronized and certain offset values must be applied.

During autumn 2001 a centralized version of the multi-agent fuzzy control was implemented into the HUTSIM-simulation system (Fig. 6). The main controller sets the common cycle time by looking for the critical intersection with the maximum load factor. After each cycle, a new cycle time is set by fuzzy rules and delivered to all local controllers. Currently, fixed offset times are used. The local controllers set a minimum (fixed) green for each cycle according to the load factors. The minimum green is extended depending on the fluctuations of actual traffic, and the maximum green time is limited by the central level.

6. Simulation results and field experiences

The presented HUTSIG control system has been tested at Helsinki University of Technology by laboratory simulations and field experiments. So far the focus has been mainly on signal timing in isolated intersections using fuzzy logic. The research and development of area signal control started in 2001 and preliminary simulation results are available. A more comprehensive description of the simulation tests using fuzzy logic can be found from the articles of Niittymäki (2002).

A number of simulations have been carried out to evaluate the system, and also to find the most efficient rule sets and membership functions. Several controller versions were developed in various research projects. In the very first version, the experiment formulated by Pappis and Mamdani (1977) was repeated. In the second phase the original rule sets were adjusted and also pedestrian signals included. Later a multi-objective version was developed to take into account emissions and safety aspects. The main result was that the ordinary VA-controller performed better with low traffic volumes and fuzzy control was better with medium and high traffic volumes.

The HUTSIG concept has also been applied to decide the phase pictures in a more flexible way than the phase ring. At low demand the phase ring offers a good level of flexibility in the phase pictures, but at higher traffic volumes it starts producing fixed stages. A negotiation process with fuzzy inference can be applied to give more freedom in choosing the next phase. The reduced delay when using the fuzzy phase selector varied from 0–20% depending on traffic flows and the selected defuzzification method. The best results were obtained using the maximal fuzzy similarity method (Könönen, 1999).

The HUTSIG signal control system has been enhanced with public transport priorities. The basic flow and queue input were supplemented with bus arrival inputs. The fuzzy rule basis was adjusted to either extend active green, terminate the conflicting greens, or to use an extra phase to give priority to the bus. The performance of the control was studied by simulations and by field measurements. According to the field measurements, the delays for buses could be reduced by up to 20% if compared with the normal VA-control without bus priorities. The average delay for private vehicles decreased in 1/3 of the cases and increased in 2/3 of the cases. However, the changes in average delays were small, typically less than 5 s (Mäenpää, 2000).

Signal control of major arterials is a challenging task due to the potential safety hazards. In these types of intersections, the main objectives are to favor the main road, giving priority to trucks and clearing the dilemma zone at the end of the green signal. The Swedish LHOVRA technique implements these objectives by means of detector logic. The HUTSIG signal control was also enhanced with additional functions for high-speed environment. The simulations and field studies indicated that fuzzy control performed better than LHOVRA when the load factor was 0.55 or more (Kosonen, 2002). The risk for rear-end collisions could be handled more effectively with the HUTSIG-model. This model allowed the detection of two vehicles in the option zone (instead of one), giving extra green time only when it really necessary for safety reasons.

The HUTSIG-fuzzy control was compared with ordinary detector logic (VA) control and with mathematical optimization (SOS). Each method has its own timing principle, but uses similar signal group (multi-agent) control engine. In the morning rush hour traffic the fuzzy control seems to perform better than VA-control. However, the mathematical optimization seems produce less delays especially with high traffic volumes (Fig. 7). During the daytime traffic fuzzy control generally performs at the same level as the VA and SOS (Fig. 8). The results concerning the SOS-algorithm are preliminary since there were some differences in the test environment used in Sweden (Niittymäki and Nevala, 2000).

Preliminary simulation studies of area signal control have also been done by Ronkainen (2002). A test network and traffic input defined by Chiu (1992) was constructed with HUTSIM. This network has nine intersections in square (3×3). Four control methods were compared, namely the detector logic based vehicle actuation (VA), coordinated VA-control, fixed time coordination and fuzzy control. The very preliminary simulation results for area signal control indicate the same

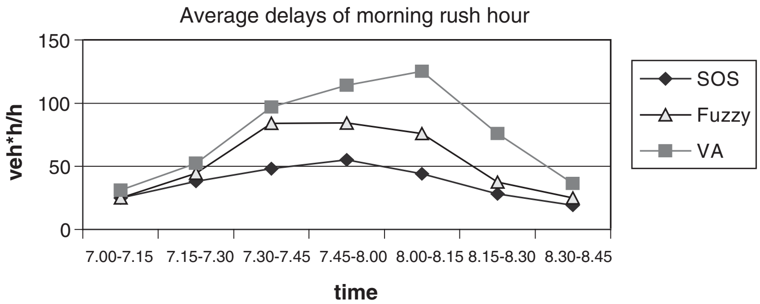

Fig. 7. Comparison of signal control performance based on detector logic (VA), fuzzy logic, and mathematical optimization (SOS) during morning rush hour (Niittymäki and Nevala, 2000).

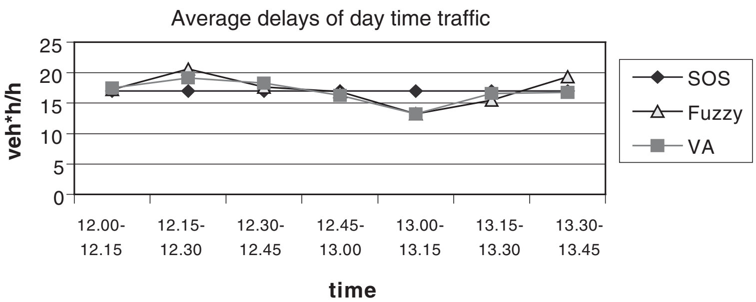

Fig. 8. Delays of signal control based on detector logic (VA), fuzzy logic, and mathematical optimization (SOS) during morning rush hour (Niittymäki and Nevala, 2000).

tendencies as those found in isolated signal control. Fuzzy control performs better with medium or high traffic flows. With low traffic volumes other methods still perform better in terms of delay and stopping probability.

7. Conclusions

The simulation tests and field experiments with isolated signal control have generally shown good results compared to the prevailing detector logic (gap seeking) control system in Scandinavia. To date, mathematical optimization seems to be more efficient than the present version fuzzy control algorithm. However, a Swedish research has proven that the detector logic control can be as efficient as mathematical optimization in terms of delay (Kosonen, 1999). Because there still seems to be some discrepancy in the results, more systematic studies are needed to compare the different control methods. This can be done by implementing also the mathematical algorithm into HUTSIG-system, and by making sure that the parameters of each control method are as optimal as possible.

However, the main benefit of HUTSIG-fuzzy control is likely to be achieved with regard to other objectives. Fuzzy logic combined with a simulated traffic model provides the essential framework for multi-objective traffic signal control. Extensive research is needed to determine the size of the effects the presented signal control system has on traffic safety, efficiency and environmental effects. One particular problem concerns defining a commonly accepted measure of effectiveness for multi-objective control.

The experience and knowledge gained from this work have brought about the start of a new project in which the HUTSIG fuzzy signal controller can be developed from research tool into an actual signal controller product (in the first stages for isolated intersections only). This work involves generalizing the rule sets, integrating the software and improving the user interfaces. The primary objective is to offer a signal control system that is representative of human decision-making, therefore making it an attractive choice for traffic signal engineering.

In area control, the preliminary simulation studies demonstrate the potential of HUTSIG and fuzzy control in general. However, there is still a lot of work remaining in order to improve the performance for a wider range of traffic demand. There are several alternatives for the main control principles of area control. The multi-agent approach can be implemented in full, or it can be used to fit into the common cycle time framework. Future research will disclose more about the alternatives that are actually feasible. A test site for area signal control with fuzzy logic will be started in Finland in the summer of 2002 in the city of Tampere.

The presented HUTSIG traffic signal control concept has proven a successful and comprehensive method for traffic signal control. The on-line simulation forms the necessary foundation for a control system to get comprehensive access to the many different aspects of traffic situations. The multi-agent type of control maintains a maximal level of freedom in control while also searching for a mutually optimal solution for any given traffic situation. Fuzzy logic provides a method to take into consideration the various aspects of decision-making that can be used to achieve a balance between efficiency, safety and environmental objectives in traffic control.

Especially in area control, it is important to develop a single solid and consistent system with generic operation principles that can be adapted to various scenarios. The system should be able to handle all situations that may involve isolated/coordinated intersections, pedestrian crossings, public transport priorities etc. In the future it is possible that the HUTSIG concept can be extended to control variable speed-signs, lane-signs, route- signs and parking signs.

The advantage of on-line simulation is that it provides a continuous flow of indicators that can be used to monitor the traffic system and to maintain statistics related to system performance. In future versions of HUTSIG, this feedback can be used to develop self-learning control algorithms that adjust their control parameters in accordance with earlier results.

As a secondary product, the on-line simulation results can be used to benefit road users through various information services using, for example, the Internet, mobile phones and vehicle terminals. An interesting possibility is also to make short-term predictions by running an additional copy of the simulation that runs faster than real-time. The predicted traffic indicators are very useful for road-users in terms of the information they can provide. These indicators could also be used by the traffic control system to keep it a step ahead of the emerging traffic situations.

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