# The role of fuzzy logic public transport priority in traffic signal control

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This paper proposes the structure and the tested rule bases for fuzzy public transport priorities. A number of before and after studies from three intersections in Finland, are presented which have shown promising results and in which fuzzy controllers operated well without problems. The authors conclude that fuzzy control is a competitive method for use in traffic signal control.

## INTRODUCTION

Traffic signals are now a common feature of urban areas throughout the world, controlling millions of vehicles. Careful planning of these signals is important for various reasons; it increases the efficiency of the road network, which yields both economic and environmental benefits. Signal control has a direct bearing on safety aspects of road and pedestrian transport. To manage the complex task of adaptive traffic signal control design, simple methods, like the extension principle, are usually used in actual control in isolated intersections. The mathematical optimisation (e.g. MOVA- or SOS-control) has become a feasible alternative for the extension principle in these locations (Kronborg et al.1997). In addition to traditional real-time optimisation, new methods, like fuzzy control, genetic algorithms and neural networks are coming into the field of adaptive traffic signal control. The published applications are mainly theoretical but there is active research going on in this area, and the first real installations have been presented in 1990s.

The fuzzy control has also proved to be superior in problems of engineering judgement, and the traffic signal control is a typical control process subject to 'rule of thumb' decisions. The systematics, targets and discrepancies of traffic signal control have to be known before good modeling can be achieved. For that reason, we have to know the principles of signal control before commencing the fuzzy modeling.

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## MOTIVATION

The main reason why fuzzy-set theory is a suitable approach to traffic signal control is the nature of uncertainties in signal control; decisions are made based on imprecise information, the consequences of decisions are not well-known, and the objectives have no clear priorities. It has been known through various experiments and applications that fuzzy control is well suited when the control involves these kinds of uncertainties and human perception, like traffic signal control.

In practice, the use of traditional optimisation methods (like Miller, 1968) can be problematic or too complex to develop. The aim of fuzzy logic-based control is to soften the decision making process by accepting human-like acquisition of information and executing soft decision rules. Such control will be robust and adaptive in terms of handling various objectives at the same time, and choosing the parameters should be rather simple.

In the case of public transport priorities, there are reasons to believe that the fuzzy public transport priorities can be better than the traditional binary-logic priorities (Niittymäki, 1998):

- Public transport priorities add to the complexity of the control policy, and the control policy has at least one additional objective.
- Consequences of activated public transport priority function are not known.
- Binary-logic calls public transport priority regardless of traffic situation.
- There can be large variations in travel time (uncertainty), especially during the peak hours. Travel time can be even longer than the maximum phase extension time.
- Infrastructure (simple detector configuration with traffic situation modeling) and control rules (not many) can be quite simple.
- The rule base can easily be modified for all kinds of isolated intersections, and the rule structure can be extended to coordinated signals.

## CONVENTIONAL PRIORITIES FOR PUBLIC TRANSPORT AND DETECTION

### Detection

The ideal bus detection system must be able to distinguish single buses and their line numbers. It should be possible to use the bus detection equipment in other public transport telematics such as passenger information systems or fleet control. However, the number of roadside detectors should be kept as small as possible to avoid high maintenance costs. There are basically two different ways of achieving bus-detection; using roadside equipment or on-board computers. Inductive loops, microwave antennas and infrared communication systems are the most common detection types.

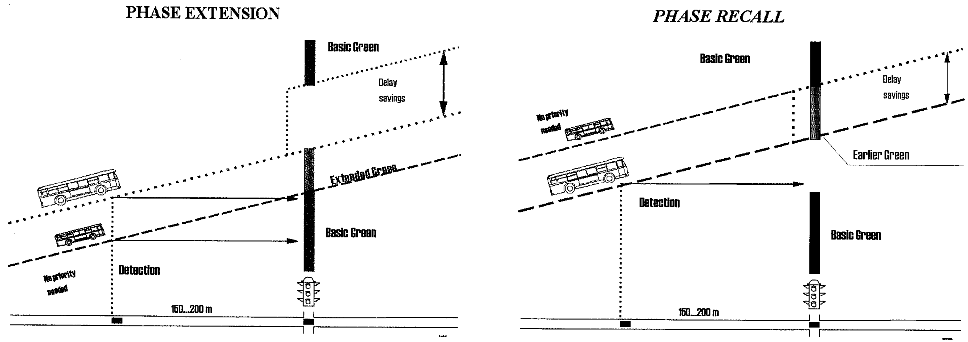



**Figure 1. Public transport priority functions (Sane, 1995).**

The radio transmission communication concept will be the new detection method for public transport priorities. With this method, buses are equipped with an onboard computer and a speedometer. The computer sends messages to the roadside antennas located at intersections. This concept works in the same way as in tram priority detection.

### Control Algorithms

Priority systems can be classified as either passive or active. Normally, public transport priorities are tailor-made using some special algorithms. The most important of these algorithms are phase extension, phase recall, extra phase and rapid cycle. Public transport priority is given when a public transport vehicle is detected.

Phase extension is the function, which continues the green phase if the public transport vehicle is approaching the intersection. The priority lasts until the public transport vehicle has passed the intersection or to some maximum value programmed to the controller. If the exit detector at the stop line of the bus approach is used, the extension can be stopped exactly at the right moment. Otherwise, some reprogrammed settings for the extension period during peak and off-peak should be used.

Phase recall is the function which cancels the conflicting green phases and starts the green phase of the public transport vehicle approach. This function should pay attention to some minimum green restrictions to avoid too short green times. The minimum green time should be traffic-actuated. If there is traffic demand in those approaches where the green time is to be cancelled, the minimum green time should always be longer than normal minimum green time to avoid excessive delays of those approaches.

Extra phase is the function, which is used only in multiphase intersections. If the normal order is A-B-C (A is the phase of the public transport vehicle), then the priority call during B forces the phase sequence to an extra phase. After that phase the order is A-B-A-C. Extra phase is very effective, especially when it is very short (4 - 6 s). The extra phase-function can always be used in isolated signals. In the coordinated signals, especially with shorter cycles, rapid cycle-function is more useful. It keeps the length of all conflicting phases as short as possible until the priority phase has green again.

## FUZZY APPROACH FOR TRAFFIC SIGNAL CONTROL

### Structure of Fuzzy Rule Base

The preliminary plan is that traffic signals will work using the multilevel fuzzy decision making algorithms (Niittymäki and Pursula, 1997). In general, the fuzzy rules work at three levels; traffic situation level, phase and sequence level, and green ending or extension level. The extension level can also be a multi-objective. The fuzzy public transport priority function has to be connected to the green extension level and the phase and sequence levels.

The basic idea of fuzzy approach to public transport priorities is that PT-requesting (the first approach detection, PT(time) > 0) starts rule combinations. In this case, PT is the general term for public transport. PT(time) is the most important fuzzy variable for time of public transport requesting, and it means the time a public transport vehicle remains between the priority detectors or first detector and stop line. It starts when requested in call detector and it stops (PT(time)=zero) when requested in the exit detector. If two or more PT-vehicles are coming, the fuzzy variable is the smaller value.

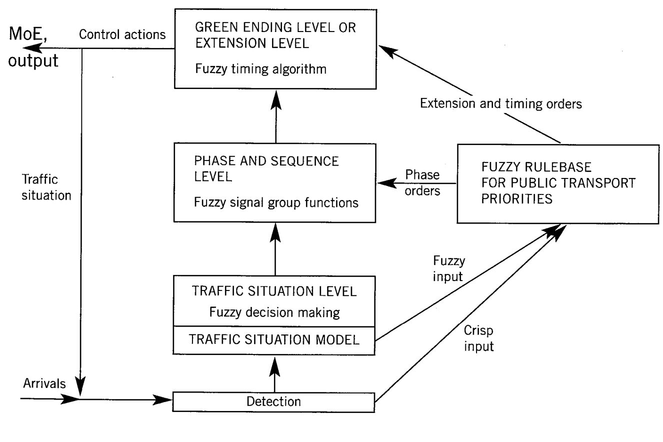
### Fuzzy Rule Base for Public Transport Priority

The main goals of the fuzzy rule base of public transport priority are:

- to give a correct priority function as a function of request moment,
- to make a correct priority decision, based on the current traffic situation at the intersection.

In our suggested application, a request-exit detector-system is used and two detectors are located per approach. The locations of the request and the first detector define the used membership functions. The recommended distances are 100 – 150 meters. The public transport detection (crisp input) and the use of the traffic situation model give an input to fuzzy algorithms. The recommended priority functions are phase extension and phase recall for two-phase control, and phase extension, phase recall, rapid cycle and extra phase for multi-phase control. The two-phase control is a simple con-

**Figure 2. Multilevel fuzzy control algorithm with public transport priorities.**



**Multi-phase control rules**

trol case because the conclusion of the rule base is either to continue current phase or terminate it. If the public transport request is detected in the approach of a green signal group, the phase extension rules evaluate the current traffic situation based on two fuzzy parameters:

- detection time of public transport (PT(time); zero, short, medium, long);
- weight of red signal group (W(red); short, medium, long).

The W(red) or W(next) is the fuzzy factor for the importance of the next phase, for example the estimated green time needed in the next phase or just the number of stopped vehicles (Q = queue). The rules are typical if-then-rules, for example:

- If PT(time) is zero and W(red) is short then use basic rules or;
- if PT(time) is medium and W(red) is medium then extend phase or;
- if PT(time) is long and W(red) is high then use basic rules.

If the public transport request is detected in the approach of a red signal group, the phase recall rules evaluate the current traffic situation, based on two fuzzy parameters:

- detection time of public transport (PT(time); zero, short, medium, long);
- weight of green signal group (W(green); short, medium, long).

Figure 3. The test intersection in Vantaa.

The W(green) or W(next) is the fuzzy factor for the importance of the next phase, for example, in the estimated green time needed current phase or just the number of approaching vehicles (A = arrivals). The phase recall order means that the green signal group is ready to be terminated. For example:

- if PT(time) is zero and W(green) is short then use basic rules or;
- if PT(time) is medium and W(green) is medium then recall phase or
- if PT(time) is long and W(green) is high then use basic rules.

The multi-phase control is more complicated because there exists the opportunity to affect the phase and sequence order too. The decision rules for priority algorithms are based on the moment (phase) of public transport detection (crisp) and the fuzzy parameter of next phase (W(next)).

| W(next) | PHASE WHILE PT-REQUEST (crisp input) | | |
|---|---|---|---|
| | A | B | C |
| low | extension | extra phase | recall |
| medium | extension | rapid cycle | recall |
| high | extra phase | rapid cycle | basic |

If the selected control algorithm is phase extension or phase recall, then we can evaluate the traffic situation using the phase extension and phase recall rules. If extra phase or rapid cycle as in selected, then the control algorithm works as in the conventional control.

## TEST CASES (MÄENPÄÄ, 2000)

### Vantaa

The test intersection in Vantaa is a four-leg intersection. There are three phases, and all phases include bus traffic. If no buses are detected, the fuzzy controller makes the decisions concerning green extensions according to fuzzy rule base and membership functions. The bus detected first gets the priority first. All three ways to give the priority are available: phase extension, phase recall and extra phase.

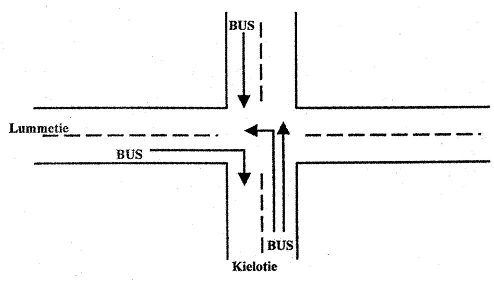
In Vantaa the travel times of buses were measured with video cameras on two directions: buses approaching from major street and either driving straight or turning left in their own phase. Before the fuzzy system the average travel times were 29.7s (straight) and 41.4s (turning left). After the installation they were 27.1s and 31.3s. In particular the average travel time of left turning buses decreased considerably by 10s.

### Lahti

The test case in Lahti is a four-leg intersection with three phases. The intersection is located in the center of the city. Buses approach the intersection from two directions, and their routes cross each other's. The constant cycle time, 100 s, is used as a part of coordination in the intersection.

When a bus is detected, the fuzzy signal controller decides according to the fuzzy rule base, whether a priority is given or not. Phase extension, phase recall and extra phase are the alternatives to give the priority. In situations where two or more buses are approaching from different directions, the priority is first given to the bus first detected.

The travel times of buses were measured with video cameras before and after the installation of fuzzy system. Cameras were located before and after the intersection, so the travel times could be measured exactly. In Lahti the average travel times of both approaching directions were before installation 34.4s (major street) and 38.3 (minor street). After the installation they were 36.6s (major) and 35.7s (minor). The average time for buses approaching from the major street has increased 2.2s. That is, because some buses do not have time to pass the intersection within the green exten-



sion or extra phase and they have to wait the whole cycle time again. The other reason for some fairly high travel times is that some buses were not detected due to their low speeds at the inductive loop. The same happened in the other direction too, but not so often. If we leave those buses out of the measurement material, the average travel time for major street buses was 32.1s. Some changes to the membership functions and the traffic situation model have been done after measurements.

### Jyväskylä

In Jyväskylä, the test intersection is a T-intersection with three phases. The traffic volume arriving from the minor street is quite small. Buses approach the intersection from both major street directions and they drive straight through. The fuzzy signal controller gives priorities to buses if the current traffic situation allows it. The fuzzy signal controller makes the decisions concerning green lengths also if there are no buses detected, like in Vantaa. The bus priority can be phase extension, phase recall and extra phase. The travel times for buses were measured the same way as in Lahti. The average travel time of buses was before the installation 22.7s and after it 20.1s.

## DISCUSSION AND CONCLUSIONS

This paper proposes the structure and the tested rule bases for fuzzy public transport priorities. The purpose of the before-and-after-study was to measure and to simulate the impacts on bus and vehicle traffic operations on an isolated intersection of using the bus priority algorithm. The testing of fuzzy rule base was done and will be done using the simulation and the field tests. The results of field tests are presented in this paper. The results have been at least promising, and the fuzzy controllers have operated well without problems. As a summary of this paper, we believe that fuzzy control is a competitive method in traffic signal control.

Our project continues by developing new systems for fuzzy urban traffic control (Fuzzy-UTC). The first pilot-area for simulations and field tests will be in Tampere.

### References

**Brase M. and Rutherford D. (1978). Fuzzy Relations in a Control Settings. Kybernetics, vol. 7, no. 3, pp. 185 – 188.**
**Kronborg P., Davidsson F. and Edholm J. (1997). SOS – Self Optimising Signal Control. Tfk –Transport Research Institute, Report 1997:2E. 62 p.**
**Miller A. J. (1968). The Capacity of Signalized Intersections in Australia. Australian Road Research Board. Bulletin No. 3, Kew. 95 p.**
**Mäenpää M. (2000). Joukkoliikenne-etuuksien toteuttaminen sumealla logiikalla(Public Transport Priorities Using Fuzzy Logic). Teknillinen Korkeakoulu, Liikennelaboratorio. Draft version of Master's thesis. In Finnish.**
**Niittymäki J. (1998). Fuzzy Logic Application to Public Transport Priorities at Signalized Intersections. Mathematics in Transport Planning and Control. Pergamon, 1998. pp. 47 – 57.**
**Niittymäki J. and Pursula M. (1997). Signal-Group Control Using Fuzzy Logic. Paper presented at the 9th Mini-EURO Conference, and accepted for publication in the Journal of Fuzzy Sets in Traffic and Transport Systems, EURO Working Group on Transportation. Budva, Yugoslavia. September 15 – 19, 1997. 17 p.**
**Sane K. (1995). Public Transport Priorities in Traffic Signals. – Theory and Practice from the City of Helsinki. Paper presented in European Workshop (DG XVIII), 16.3.1995, Barcelona, Spain. 9 p.**
**Zhou W-W., Wu J., Lee A., Fu L. and Miska E. (1997). Fuzzy Flows. ITS: Intelligent Transport Systems, May/June 1997. pp. 43 – 45.**