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## Installation and experiences of field testing a fuzzy signal controller

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### Abstract

This paper describes the installation of a fuzzy signal controller (FSC) at a real intersection. The results of a vehicle-actuated control system with a fuzzy-control system using microscopic simulation and field measurements have been compared. The results indicate that the fuzzy control is very competitive against traditional vehicle-actuated control, if traffic volumes are higher than low-demand. The benefit of fuzzy logic lies in its ability to handle linguistic information by representing it as a fuzzy set. The simple algorithm structure, the savings of material costs and the low installation and maintenance costs are important advantages. The results of this paper prove that the FSC can be installed in real infrastructure and that fuzzy algorithms can be more effective than traditional vehicle-actuated control. © 2001 Elsevier Science B.V. All rights reserved.

*Keywords:* Adaptive traffic signal controller; Fuzzy logic; Fuzzy signal controller; Measures of effectiveness

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### 1. Introduction

The aim of this paper is to describe the installation of a fuzzy signal controller (FSC) at a real intersection, and to compare the results of a vehicle-actuated control system with a fuzzy-control system using microscopic simulation and field measurements. The results are based on the FUSICO-research project at Helsinki University of Technology in Finland.

An isolated traffic signal control system is one where the intersection operates independently

from other intersections. This means that the system controlling the intersection can be designed with a wide choice of control strategies. Fuzzy control has been successfully applied to a wide range of automatic control tasks. Based on recent research work, fuzzy-control technology appears particularly well suited to traffic signal control situations involving multiple approaches and vehicle movements (Sayers et al., 1998; Niittymäki, 1997).

Some attempts to apply fuzzy logic to traffic signal control have been made in the past two decades. Despite this, the application of fuzzy logic to traffic signals has only been known within limited circles. The main problem of previous work was that the problem environment assumed was not realistic, and the measures used to compare a fuzzy-control system

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with a traditional-control system were not adequate. However, one of the most important tasks of the transportation engineer is to determine how well a transportation system is functioning. This paper presents a comparison of a traditional adaptive-signal control and fuzzy-signal control on the basis of simulations and before-and-after field studies.

## 2. Test site – infrastructure and hardware

The test intersection in Oulunkylä, Helsinki (Fig. 1), was chosen based on the following criteria:

- isolated intersection;
- high volumes of traffic during peak hours;
- four approaches;
- bus traffic;
- pedestrian crossings;
- suburban location;
- two-phase controlled.

The intersection is located quite near the railway station and the shopping centre in Oulunkylä.

The pedestrian volumes are quite high, and three bus lines cross at the intersection. The traffic volumes were calculated using the signal control inductive loops and the intersection movement analysis during the measurements. We found three different peak hours (7.30–8.30, 15–16 and 16–17). Especially, the morning peak hour is complicated because half of the traffic is coming from east to the south and west, and has a turning conflict with the opposite traffic flow in the two-phase control system.

The detectors in the fuzzy-control system were located 40 and 60 m before stop line (only four detectors). The stop-line detectors and pedestrian push buttons are not in use in the fuzzy-control system as in the vehicle-actuated control. The controller is a FC-2000. A normal PC computer with the FUSICO-software was installed beside the controller. A simple parallel interface is used for detector pulses from the controller to FUSICO, and for control orders from FUSICO to the controller. The system structure is shown in Fig. 2. In this arrangement, the real controller is a “slave” of the FUSICO-control algorithm.

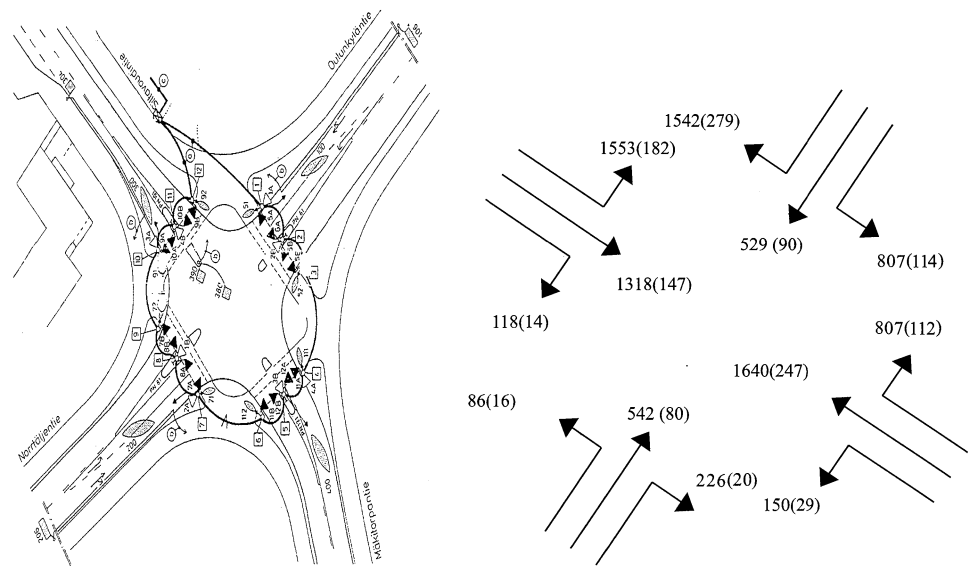


Fig. 1. Intersection layout, traffic volumes in the measurement period (7.30–16.00) and in parentheses, peak-hour traffic volumes.

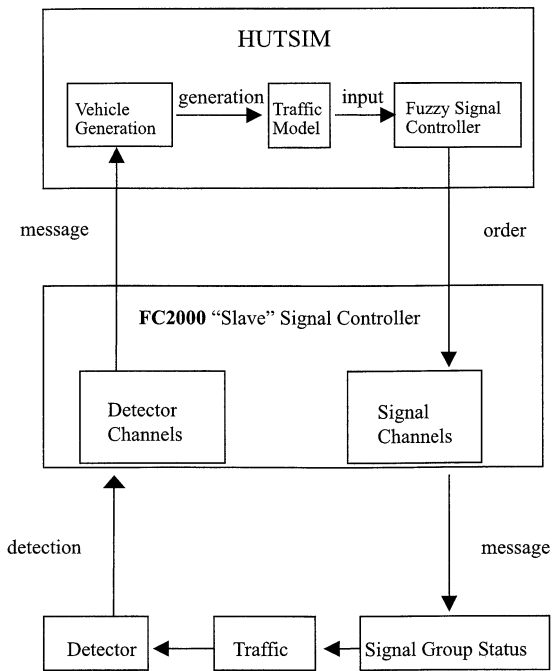


Fig. 2. The systematics of the FSC.

### 3. Control algorithms in comparison – vehicle actuated vs. fuzzy

#### 3.1. Vehicle-actuated control

Two-phase control system is the most common control strategy in the world. The traffic or vehicle-actuated signals (VA) function so that the green signal group gives at least a minimum green time. If demand is sufficient, then the green time can be extended stepwise according to the lengths of time between vehicles passing to a maximum green time. After the green extension for that signal group can go to red or remain as a passive green, which means that signal group is ready to terminate. The passive green can be terminated by the demands of conflicting signal groups. In our VA-application, the first detectors are located 40–60 m before the intersection. This means that we know how many vehicles are approaching the stop line within the next 4–6 seconds. The vehicle minimum green time is 5 seconds and the extension period is 4 seconds (Fig. 3).

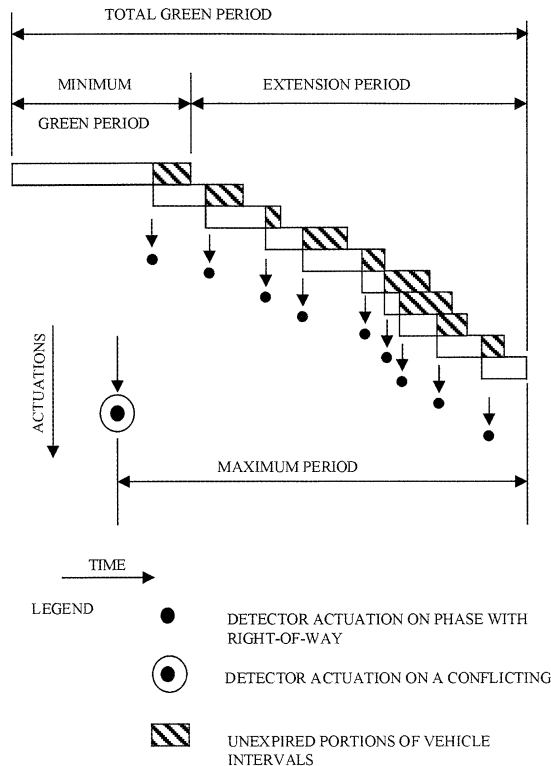


Fig. 3. Extension principle in traditional vehicle-actuated traffic signal control (FHWA, 1996).

#### 3.2. Fuzzy control

Basically, our fuzzy-control algorithm works on two levels. The upper level classifies the traffic situation (TS); oversaturated normal or low-demand conditions. The lower level adjusts the green and cycle times. The decision of the upper level is based on two-input parameters:

$VOL$  = traffic volume of previous 5 minutes (vph).

$OCC$  = occupancy of the first detectors ( $D_{xx}$ ) during last 5 minutes (%).

The fuzzy rules for the upper level are

if  $VOL$  is any and  $min(OCC)$  is high then  $TS$  is oversaturated or;

if  $VOL$  is low and  $max(OCC)$  is low then  $TS$  is low or;

if *VOL* is any and *max(OCC)* is intermediate then *TS* is normal,

where

*min(OCC)* = minimum occupancy of detectors;  
*max(OCC)* = maximum occupancy of detectors.

The main goals of lower level rules are

- to adjust the cycle time;
- to divide the cycle into the green times of phases (split).

There are only two input variables for the fuzzy rule base:

*A* = approaching vehicles at the moment in the green directions *t*; a few, medium, many.

*Q* = queuing vehicles at the moment in the red directions *t*; a few, medium, many.

The fuzzy rules for the lower level are

After minimum green (5 seconds)

if *A* is zero then terminate immediately  
 (0 seconds)

or if *A* is a few and *Q* is *lt*(medium) then *EXT* is short (3 seconds)

or if *A* is *mt*(a few) and *Q* is any then *EXT* is medium (6 seconds)

if *A* is many and *Q* is any then *EXT* is long (9 seconds).

After the first extension ( $ext_1 + \min$  green 5 seconds)

if *A* is zero then terminate immediately  
 (0 seconds)

or if *A* is a few and *Q* is *lt*(medium) then *EXT* is short (3 seconds)

or if *A* is medium and *Q* is any then *EXT* is medium (6 seconds)

or if *A* is many and *Q* is any then *EXT* is long (9 seconds).

After the second extension ( $ext_1 + ext_2 + 5$  seconds)

if *A* is zero then terminate immediately  
 (0 seconds)

or if *A* is a few and *Q* is *lt*(medium) then *EXT* is short (3 seconds)

or if *A* is medium and *Q* is *lt*(medium) then *EXT* is medium (6 seconds)

or if *A* is many and if *Q* is *lt*(medium) then *EXT* is long (9 seconds).

After the third extension ( $ext_1 + ext_2 + ext_3 + 5$  seconds)

if *A* is zero then terminate immediately  
 (0 seconds)

or if *A* is *mt*(a few) and *Q* is *lt*(medium) then *EXT* is short (3 seconds)

or if *A* is medium and *Q* is *lt*(medium) then *EXT* is medium (6 seconds)

or if *A* is many and *Q* is *lt*(a few) then *EXT* is long (9 seconds).

After the fourth extension ( $ext_1 + ext_2 + ext_3 + ext_4 + 5$  seconds)

if *A* is zero then terminate immediately  
 (0 seconds)

or if *A* is *mt*(a few) and *Q* is a few then *EXT* is short (3 seconds)

or if *A* is medium and *Q* is *lt*(a few) then *EXT* is medium (6 seconds)

or if *A* is many and *Q* is *lt*(a few) then *EXT* is long (9 seconds).

NOTE: that if *ext* is 0 then the signal group will be terminated immediately.

The parallel additional rule for a two-phase control is “if *Q*(length) is too long terminate immediately”. It is possible to use specific safety rules together with these delay rules, but the main goals of the delay rules are to adjust the cycle time and to divide the cycle into the green times of phases. The basic idea of this rule base is that the emphasizing of the main traffic flow can be done using the different membership functions for minor and major streets. An additional reason for the different membership functions is the different detector locations. The membership functions are available (Niittymäki, 1997) and the fuzzy inference of two-phase control is shown in Fig. 4.

## 4. Experimental results

### 4.1. Introduction

The experimental tests were done in three phases. The first phase was a pure simulation test,

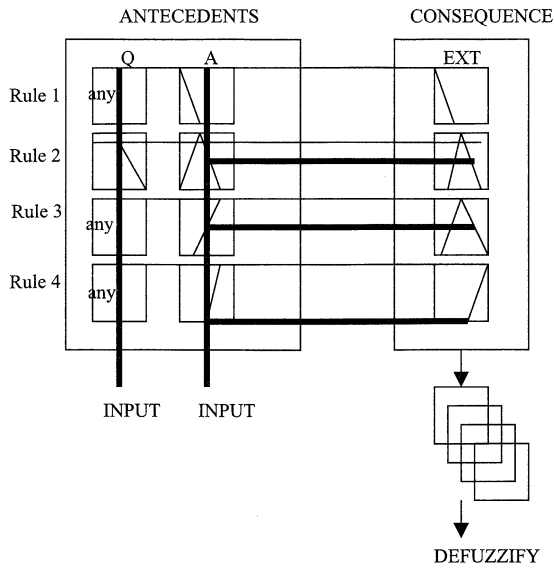


Fig. 4. Fuzzy inference for field-test control.

whose objective was to test that the fuzzy-control algorithm works well in all kinds of traffic before the field installation. The second phase was the field measurements for data collection. The main goal was to measure traffic volumes, delays, queue lengths and percentage of stops for vehicles, and cycle and green times of traffic signal control. In the third phase, the measured data was used as input. The main objective of the third phase was to simulate more traffic situations than was measured, and to estimate emissions and fuel consumption for measurement periods. The multi-objective fuzzy-control algorithm was also tested.

4.2. Simulation

In the area of traffic signal control, microscopic computer simulation can be used both in practice, for the comparison of actual planning and design alternatives, and in theoretical work, for the research and development of new control methods and strategies. In both cases, the main advantages of simulation are the possibility of testing different alternatives in exactly the same traffic situations in the office, and the great amount of detailed data

about vehicle movements and detector and signal functions that can be collected from the model output for thorough analysis (Pursula and Niittymäki, 1996).

One of the basic problems in signal control design is the measure of performance that is used in its evaluation. In addition to the traditional measure of effectiveness, the average delay of vehicles, there are many others, like the length of the queues, the amount of emissions, the fuel consumption, and the percentage of stopped vehicles. All these can be calculated by microscopic simulation. Simulation also makes it possible to analyse the signal controller functions, such the lengths of the green phases, the phase sequence, and so on.

A simulation model of the intersection was built using the HUTSIM-simulator, which is a micro-simulation model developed by Helsinki University of Technology (Kosonen, 1996, 1999). Simulations can be divided into three main components: intersection geometry; traffic flow and signal control. In our case, the intersection geometry and the traffic in the two-control strategies

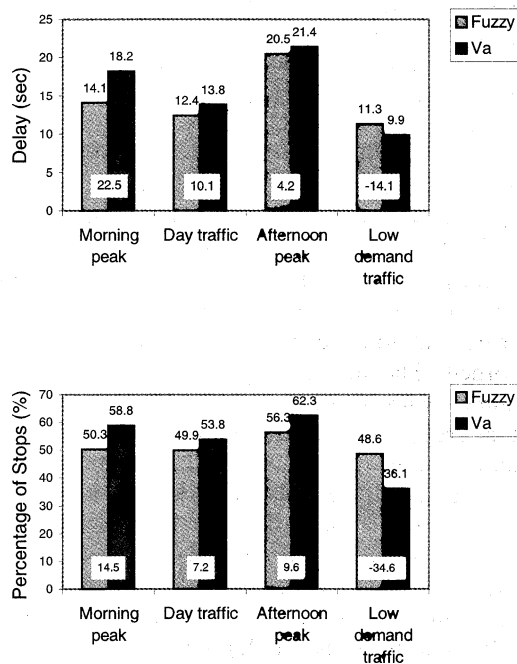


Fig. 5. Comparison of delays in different control programs.

were the same, and the signal control algorithms to be compared were the vehicle-actuated with gap-seeking ones against fuzzy ones. In reality, there are four VA-control algorithms for different times of day and only one fuzzy algorithm. The simulation comparison was made from the results of each control program in four typical traffic volumes (Fig. 5). The traffic volumes were calculated automatically by inductive loops.

The results indicate that the fuzzy control is very competitive against traditional vehicle-actuated control, if traffic volumes are higher than low-demand. To summarize, the simulations indicate much better efficiency for fuzzy control than for traditional vehicle-actuated control. Maximum delay savings were in excess of 20%. However, the main aim of the simulation tests was to be sure that the fuzzy control algorithm used worked well in all kinds of traffic before the real installation.

#### 4.3. Field measurements

The main idea was to compare a well-tuned vehicle-actuated control with the fuzzy-control algorithm in the same intersection. A special emphasis was put on traffic fluency, i.e., the delays to vehicles, the number of vehicle stops and the travel times of buses.

Measurements were carried out during three time periods (each period being 2–3 days) between June and August, 1998. The measurement time period was 7:30–17:00, but the traffic volume was also measured until 21:00. The measurements were made mainly by video recording with six video cameras. In total, over 170 hours videotape was recorded. The measured parameters were traffic volumes with turning movements, cycle times, signal-group times, queue lengths (measured manually during the measurements), percentage of stops and travel times between cross-sections (250 m before – 250 m after the intersection).

The first period was the before-measurement period for vehicle-actuated traffic signals (VA). The second period was the first after-measurement for fuzzy traffic signals (FU), and the third period was the second after-measurement for fine-tuned fuzzy traffic signals (FU2). Fine-tuning means that

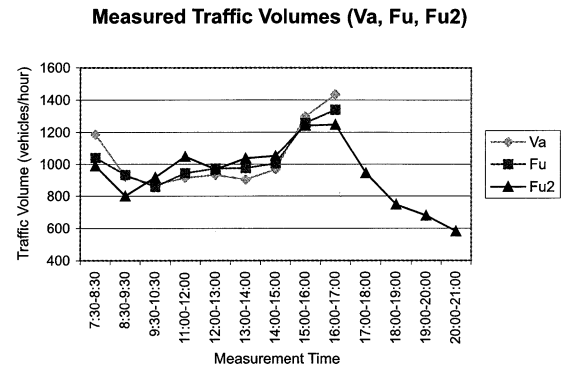


Fig. 6. Measured traffic volumes in Oulunkylä in summer 1998.

the speed levels and the turning movements in the traffic situation model were calibrated. The measured traffic volumes are shown in Fig. 6. They are sufficiently high for the fuzzy control to work all the time at the intersection.

#### 4.4. Simulation comparison based on measured traffic volumes

The measured traffic volumes were put into the HUTSIM-simulator, and the test simulations were repeated. The environmental measures, like emissions (CO, HS, NO<sub>x</sub>) and fuel consumption, were simulated in this phase. After that, three different control algorithms were compared; vehicle-actuated (Va), normal fuzzy (Fu) and multi-objective fuzzy (Fm). The Fm algorithm was designed for safety and environmental aspects as well as efficient flow, and whereas the Fu algorithm only considered the traffic fluency (Niittymäki and Pursula, 1997). The results are shown in Fig. 7.

The results indicate that both fuzzy algorithms are working well. The fuzzy algorithm gives the smallest delays and the Fm algorithm gives the smallest percentage of stops. This result is to be expected given the goals of algorithms. One important result is that the fuzzy algorithm cycle times are shorter than the cycle times of traditional vehicle-actuated control algorithm. Basically, this means that the fuzzy-control algorithm works in an effective way because the saturation ratio is higher and there are no extensions in the fuzzy-

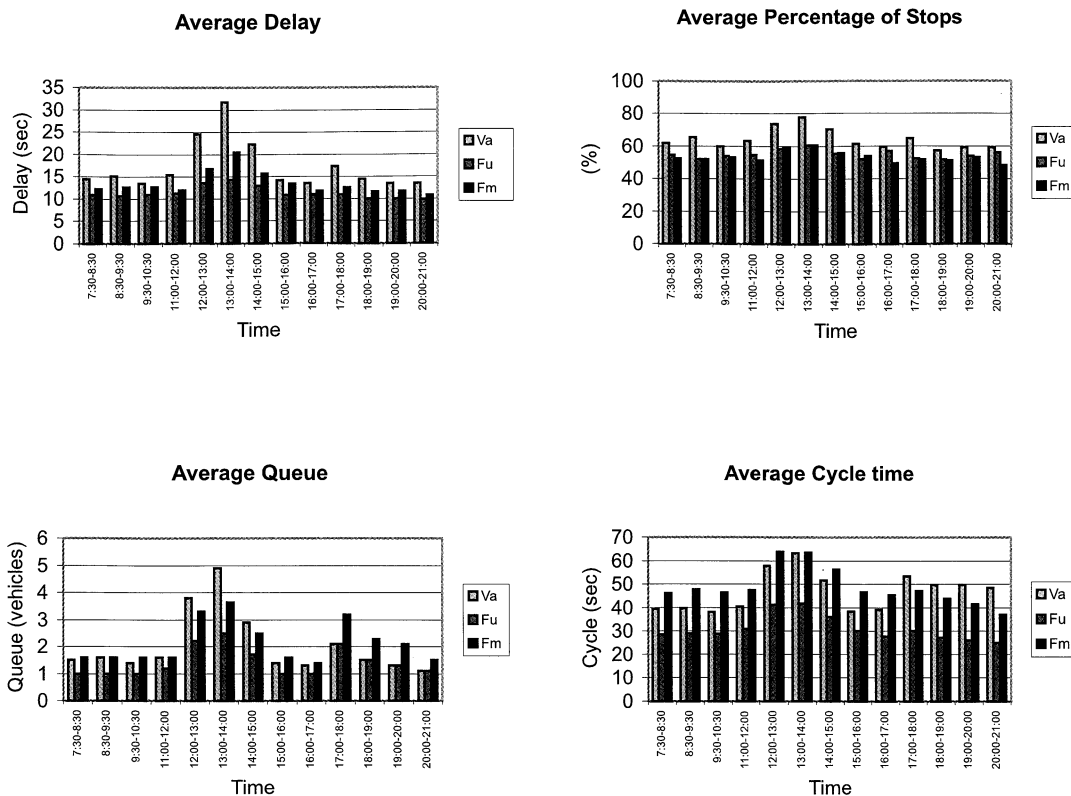


Fig. 7. Simulated comparisons of three different control algorithms using real traffic volumes.

control system for an individual approaching vehicle if the number of queuing vehicles is high.

#### 4.5. Summary of results

A summary of field measurement results is shown in Fig. 8. The difference in results between FU and FU2 is not significant, but the termination of each signal group works better in the fine-tuned algorithm (FU2).

The measurement results correspond to the simulated results quite well. Average cycle times and queue lengths are shorter for fuzzy-control systems. The results for the percentage of stops are good. The main difference is the measure of time. We have used delay in simulation and travel time in field measurements. However, we can assume that the differences (VA–FU) in travel time and the

difference (VA–FU) in delay time are approximately the same measure, called control delay difference. The differences for some important measures are shown in Fig. 9.

The results from field measurements show that the fuzzy-control algorithm works better than vehicle-actuated control in most cases. The average delays are approximately 3–8 seconds shorter, the percentages of stops are 2–12% lower, the bus delays are smaller in 8/9 cases, and there are good savings in fuel and emissions. All these results prove that the fuzzy-control algorithm can be successfully used to control traffic in real intersections. However, the better traffic fluency is only one advantage. Pedestrians can also benefit, because the cycle times are on average 8 seconds shorter, which means shorter waiting times for based on shorter green times of conflicting signal groups. The pedestrian signal groups were secondary

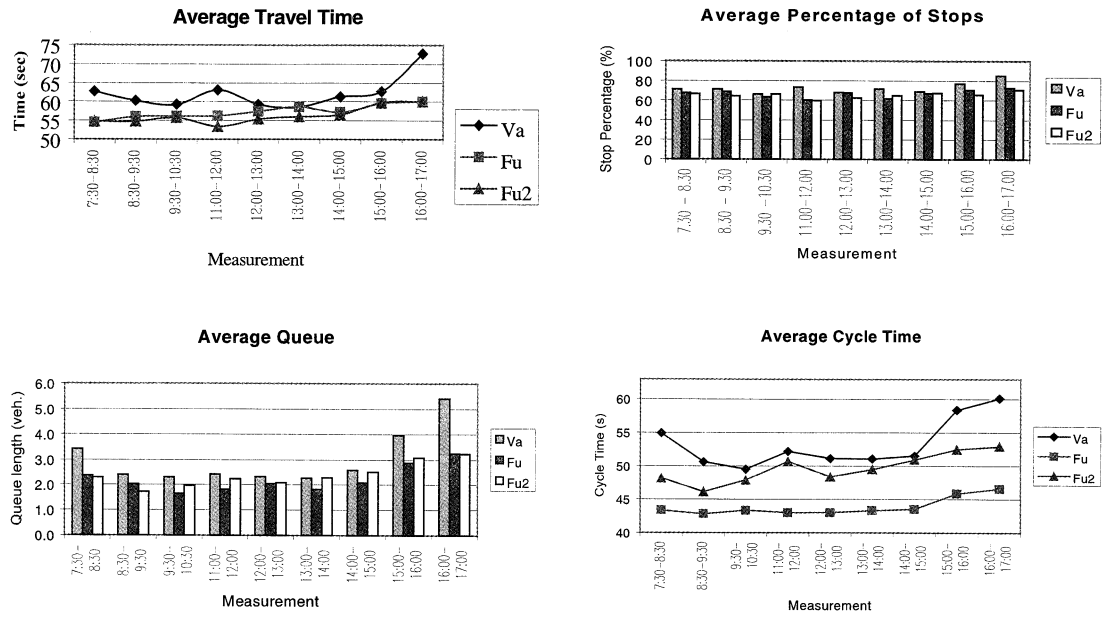


Fig. 8. Comparison of field measurements for vehicle-actuated and fuzzy-control algorithms in Oulunkylä.

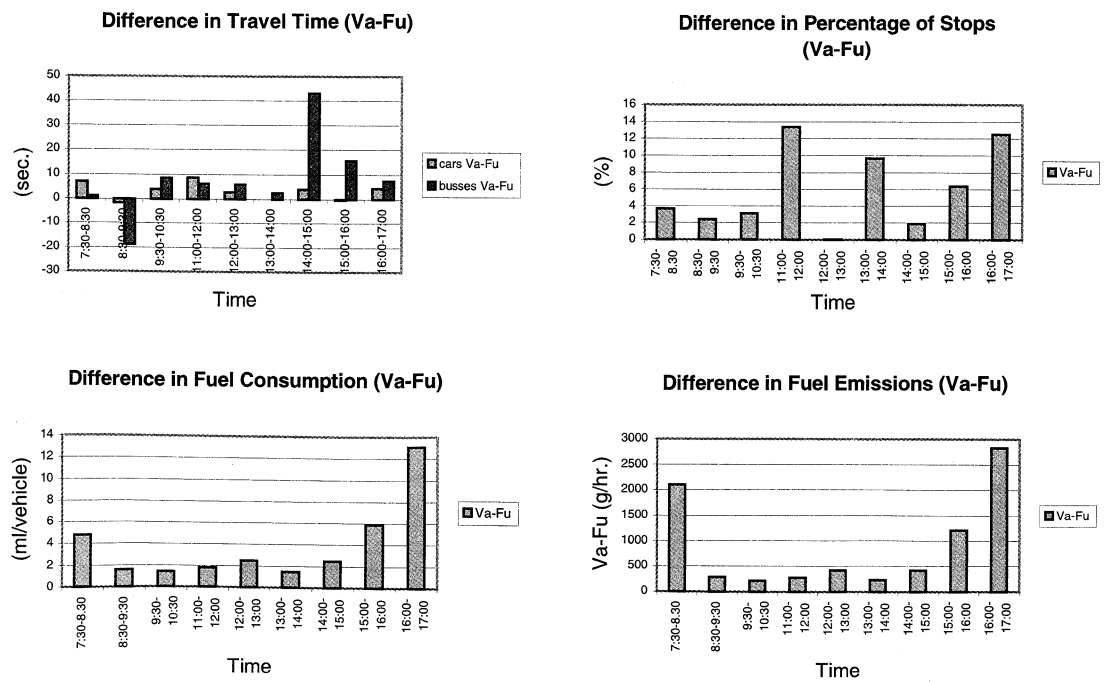


Fig. 9. Comparison of measurement from the field test in Oulunkylä.



requested in our experiment, but we have also developed a specific rule-base for pedestrian signal group control in isolated signal control.

## 5. Conclusions

The opportunities offered by fuzzy logic for controlling real signalized intersection have been shown in this paper. The hardware installation was carried out in June 1998. The FSC has worked from that time without any problems. Some fine-tuning has been made twice concerning the traffic model for the first time period and the extension sensitivity for the second time period. The feedback has been extremely encouraging.

The experimental results of this paper prove the excellence of fuzzy control in real signalized intersection. The results are based on simulations and field measurements. This combination of simulation and measurement is a highly recommended method for this kind of before-and-after-study in transportation engineering.

The main difference and one of the main advantages of fuzzy control in comparison to the vehicle-actuated control can be seen in the extension of signal-groups. In the vehicle-actuated case, each individual vehicle can extend the green of signal group and this can result in individual vehicles keeping on the move in the intersection area. In fuzzy control, each extension is some kind of compromise between queuing and approaching vehicles and one individual vehicle cannot obtain an extension if a queue is waiting the green signal. However, two consecutive approaching vehicles can trigger an extension because there is a risk for rear end collision, and in fuzzy control two is much greater than one. Basically, we believe that this means better traffic safety in fuzzy control.

The benefit of fuzzy logic lies in its ability to handle linguistic information by representing it as a fuzzy set. The simple algorithm structure, the savings of material costs (we needed only four detectors in our field test), and the low installa-

tion and maintenance costs are important advantages. The results of this paper prove that the fuzzy signal controller can be installed in real infrastructure and that fuzzy algorithms can be more effective than traditional vehicle-actuated control. The comparison of fuzzy control and mathematical optimized control, like Miller-algorithm or MOVA, would be important step in near future.

We believe that fuzzy control has more to offer when applied to more complicated intersections involving public transport priorities and multiple approaches, or to area traffic signal control (UTC).

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