The advantages of fuzzy logic for traffic signal control

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Outline of presentation

- **Background**
  - Changing objectives for traffic signal control

- **Prototype signal controller**
  - Fuzzy logic modules
  - Optimisation using Multi-Objective Genetic Algorithm (MOGA)

- **Some results**
Background

- UTMC programme
- Delphi study done by TORG

New objectives include
- priority to public transport
- improving conditions for vulnerable road users
- reducing traffic impact on air quality
3 generations of vehicle actuated signal control

- Crisp logic
  - “Gapping out”
- Single objective network control
  - SCOOT, SCATS
- Multi-objective network control
  - SCOOT+, SCATS+
  - Fuzzy Logic
Multi-objective network control

- Different junctions, different priorities
  - pedestrians
  - public transport
  - private transport

- Road space reallocation
  - pedestrianisation
  - bus lanes
  - “red routes” (no parking)
Road space reallocation
What is fuzzy logic?

- Quantification of linguistic information while allowing for imprecision
- Invented by Zadeh (1965), now used widely for inference and control problems
- “non-linear mapping of an input data (feature) vector into a scalar output” (Mendel, 1995)
Fuzzy logic system

Input quantities

Fuzzifier

Sets and levels of belief

Inference engine

If-Then statements

Defuzzifier

Sets and levels of belief

Output quantity

Rules
Past work in the field

- Pappis and Mamdani (1977) – seminal work
- Nakatsuyama et al (1983) – two junctions
- Chui (1992) - network
- Sayers, Bell, Mieden and Busch (1996) - urgency
- Niitymaki and Pursula (1997) – group-based control
- Landenfeld and Cremer (1997) – junction with spill back
- Niitymaki and Kikuchi (1997) – pedestrian crossing
- Niitymaki (1998) – bus priority
Advantages of fuzzy logic

- Uses linguistic variables
- Allows imprecise/contradictory inputs
- Permits fuzzy thresholds
- Reconciles conflicting objectives
- Rule base or fuzzy sets easily modified
Simulation Environment: Dynamic Data Exchange on PC

- Raw data from vehicle, bus and pedestrian detectors plus signals
- Derived data, such as estimated number of vehicles in queue
- Fuzzy modules
  - Urgency value for each signal group
- Microscopic simulator (VISSIM, from PTV)
- Signal control program
  - Signal instructions
  - Signal control logic
Input data for signal controller

**Vehicle**
- Smoothed gap at stop line detector
- Smoothed gap at upstream detector
- Estimated queue
- Number of seconds since first vehicle arrived at stop line

**Pedestrian**
- Time since pedestrian request was received
- Time since last pedestrian green

**Public Transport**
- Deviation from scheduled arrival time
- Deviation from desired headway between buses
Fuzzy sets for input variables

- Simple triangular membership functions (3 or 4)
- 19 configurations defined
- Goal of optimisation is to find optimal configurations of fuzzy sets for all input variables

[Diagram showing universe of discourse and membership degrees]
### Rulebase for urgency when vehicle signal is red

<table>
<thead>
<tr>
<th>Upstream Arrival Rate</th>
<th>Low</th>
<th>Med</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>M</td>
<td>L</td>
<td>VL</td>
</tr>
<tr>
<td>Med</td>
<td>H</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>High</td>
<td>VH</td>
<td>VH</td>
<td>VH</td>
</tr>
</tbody>
</table>

- **Vehicle waiting time**
- **Urgency value**
Sample fuzzy module

- Upstream arrival rate
- Vehicle waiting time
- Interim Urgency
- Queue
- Rulebase 1
- Rulebase 2
- Urgency
The MOGA process

- **Initial pool of random solutions**
- **Evaluate each solution**
- **Pool of solutions with fitness for each criterion**
- **Choose best parents and reproduce**
- **Pool of new solutions**
Evaluation of each solution

Each candidate solution in turn

Create new version of signal control program

Evaluate signal control program using simulation

Derive measures of performance for candidate solution

Output from simulation

New parameters for fuzzy sets

Fitness measures for this solution
Generating new solutions

Pool of solutions with fitness for each criterion

- Use Pareto rank and niching to select pair of parents
- Create new pair of solutions from parents by crossover and mutation

Repeated until the new pool is the same size as the old pool

Pool of new solutions
Evaluation criteria

- Vehicle-related criteria
  - Average vehicle delay
- Pedestrian-related criterion
  - Average pedestrian delay
- Bus-related criteria
  - Deviation from timetabled arrival (+/-)
  - Deviation from desired headway (+/-)
Typical result of optimisation

Average pedestrian delay [s]

Average vehicle delay [s]

- Before optimisation
- After optimisation
Each point shows performance of the controller with a certain configuration of input variable fuzzy sets.

The optimal sets cover a range of policy options, from vehicle-friendly (A) to pedestrian-friendly (D).
Optimal membership functions

- Fuzzy sets for Queue input variable for 4 points on preceding graph
- X-axis is the estimated number of vehicles on the approach
Conclusions and further research

- Urgency approach to fuzzy control promising
- MOGA plus simulation can optimise membership functions
- Conflicting objectives (pedestrian, car, public transport) reconciled
- Network control with differing local priorities
- On-going PhD research:
  - Fuzzy control for mixed traffic
  - Fuzzy control with incident detection
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Thanks for listening!
“Gapping out” logic

If GAP > 3s then END GREEN
SCOOT
Cyclic flow profile model

Detector data → Simulator → Optimiser

Performance Index

Signal times

Signal times
SCOOT
DS + equi-saturation + offset optimisation

Cumulative arrivals and departures
Stops
Delay
Flow
DS
Accept-profile

Flow
Cycle
Dispersion
In-profile
Platoon

Flow
Cycle
Arrive-profile
Platoon
SCATS
DS + equi-saturation + offset selection