MOSCUE

Multiobjective Signal Control in an Urban Environment

Bellmann-Zadeh Control of A Major Intersection Considering Vehicles and Pedestrians

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Overview of presentation

- Background and Motivation:
  - Why multiple objective signal control?
  - Pedestrian-friendly signal control
- Methodology:
  - The MOSCUE framework
  - Bellmann-Zadeh optimisation
- Case Study Site: Marylebone Corridor in Central London
- Results and Conclusions

Background and Motivation: Why multiple objective signal control?

- Signal control aims to balance several conflicting objectives
  - Minimise delays for vehicles from different approaches
  - Public transport priority
  - Consideration of pedestrian delays
  - Safety of traffic and vulnerable road users
  - Environmental considerations (minimise stops)

- **To which of these objectives more priority should be given is ultimately a political decision.**

Background and Motivation: Why multiple objective signal control?

- **Several Modes**
  - Car, Goods Vehicles
  - Bus
  - Train, LRT
  - Cyclists
  - Pedestrians

- **Objectives of Integration**
  - Streamline Journeys
  - Make travel, safer, faster and reliable
  - Interconnectivity

Background and Motivation: Why multiple objective signal control? (3)

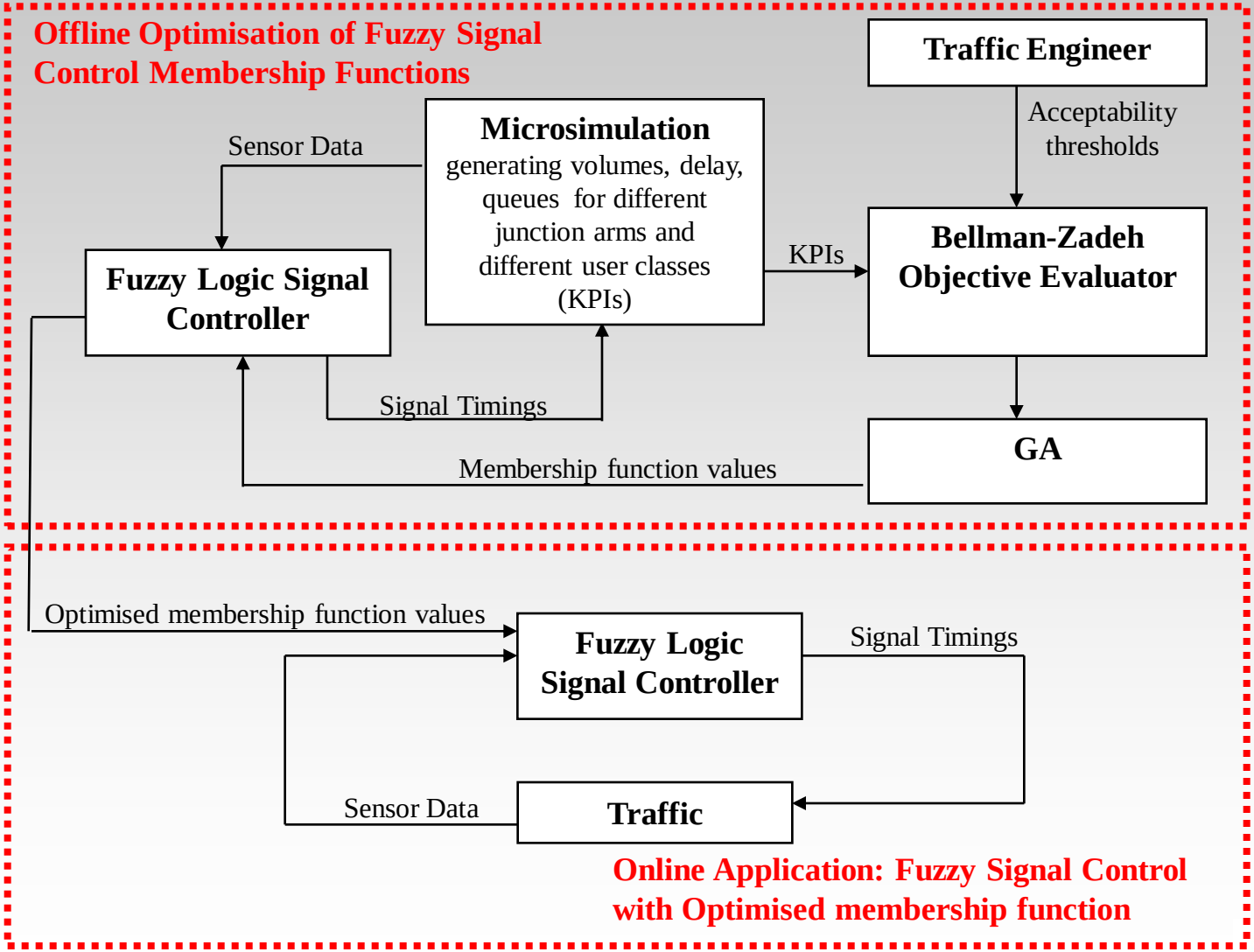
- Consensus over which objectives are of higher importance difficult to achieve (Sayers et al, 1998).
- Objectives might change depending on
  - Time of the day
  - Weather conditions
  - Changes in transport policy

- **Therefore a flexible multi-objective signal controller is needed which allows transportation planners to adjust the priorities easily**

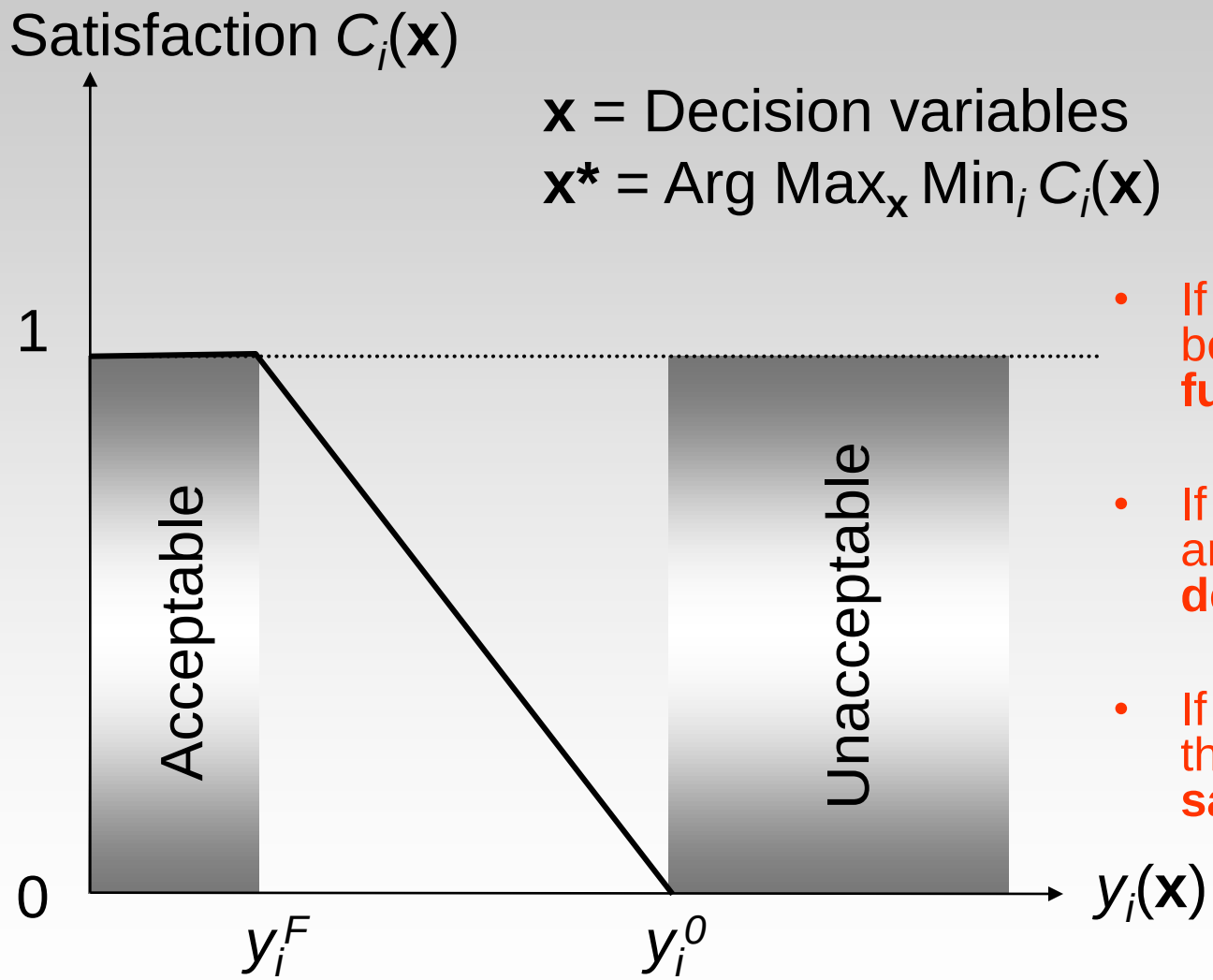
Pedestrian-friendly signal control

- Better consideration of pedestrian concerns is important:
  - Current signal settings focus on vehicle delays (e.g. SCOOT)
  - Ishaque and Noland (2006) point out that extending pedestrian green times can reduce total person-delay at a junction.
  - Carsten et al (1998) note that often pedestrian safety but not pedestrian delays are considered
  - Through video and microwave technology, control strategies can be "**pedestrian-actuated**" as well as "vehicle-actuated".

MOSCUE framework



MOSCUE framework: Mapping on satisfaction scale



$\mathbf{x}$ = Decision variables

$\mathbf{x^*} = \text{Arg Max}_{\mathbf{x}} \text{Min}_i \, C_i(\mathbf{x})$

- If objective value (e.g. delay) is below y^F then traffic engineer is **fully satisfied**
- If objective value is between y^F and y^0 then satisfaction $C_i(x)$ **decreases linearly** with y
- If objective value is above y^0 then traffic engineer is **not satisfied**

MOSCUE framework: Bellmann-Zadeh optimisation

Maximise the minimum satisfaction among all objectives:

x: Vector of decision variables

$y_i(\mathbf{x})$: Value of objective *i*

$C_i(\mathbf{x})$: Degree of satisfaction with respect to objective *i*

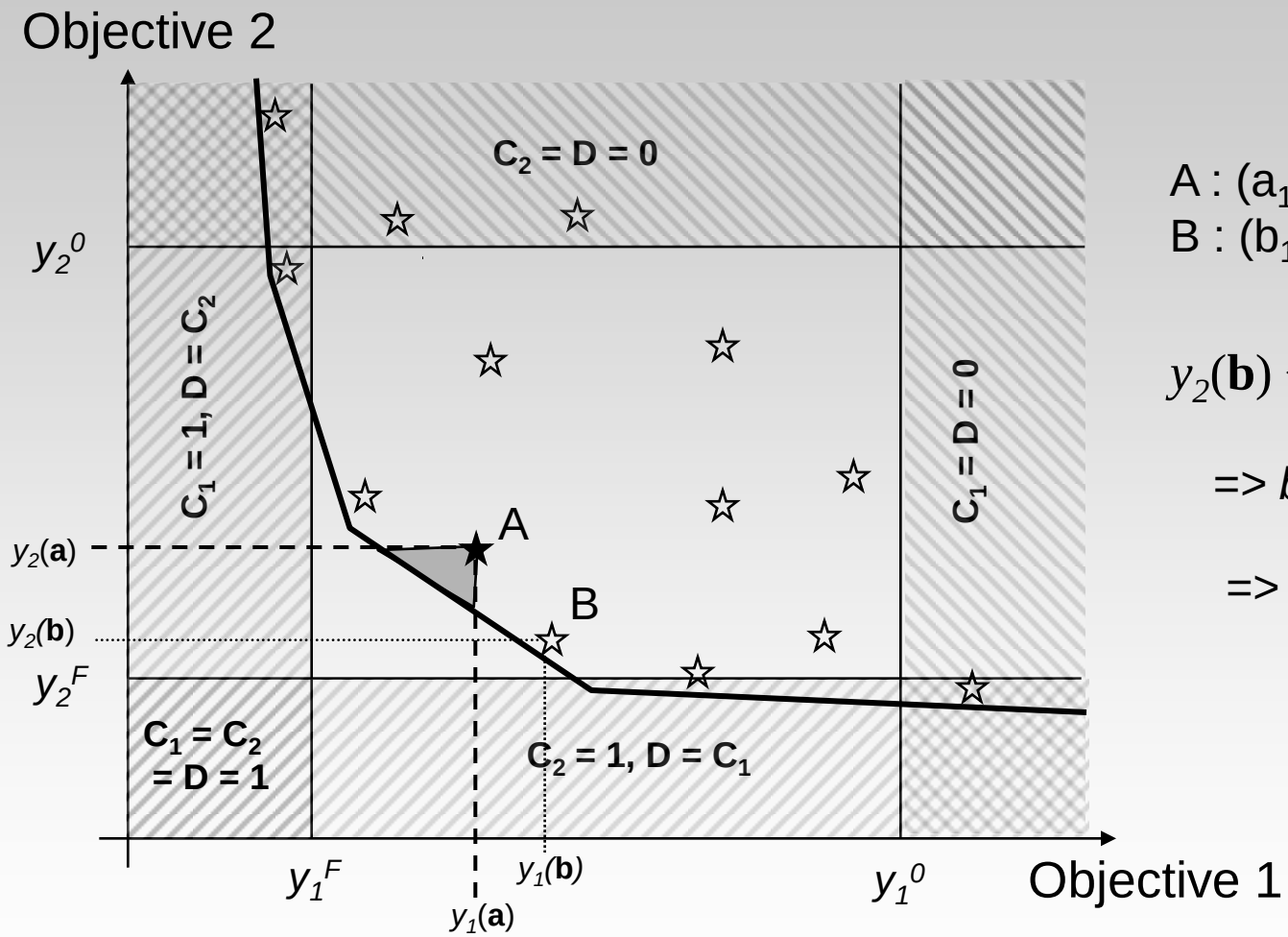
$D(\mathbf{x})$: Fitness of alternative **x**

$$C_i(\mathbf{x}) = \max\left\{0, \min\left\{1, \left(\frac{y_i^0 - y_i(\mathbf{x})}{y_i^0 - y_i^F}\right)\right\}\right\}$$

$$D(\mathbf{x}) = \min\left\{C_1(\mathbf{x}), \ldots, C_n(\mathbf{x})\right\}$$

$$\mathbf{x}^* = \underset{\mathbf{x} \in X}{Arg\ \max}\ D(\mathbf{x})$$

MOSCUE framework: Pareto optimality



A : (a_1, a_2)
B : (b_1, b_2)

$$y_2(\mathbf{b}) < y_2(\mathbf{a}) = y_1(\mathbf{a}) < y_1(\mathbf{b})$$

$$\Rightarrow b_2 > a_1 = a_2 > b_1$$

$$\Rightarrow D(\mathbf{a}) = a_1 = a_2 > D(\mathbf{b}) = b_1$$

MOSCUE framework: Fuzzy Logic

- Use of Fuzzy Logic for signal control has been found to be advantageous in numerous studies since Pappis and Mamdani (1977)

- Fuzzy Logic includes three main stages:
  - Fuzzyfication of crisp input
  - Application of Fuzzy Rule Base
  - Defuzzyfication of output-variable

- Finding a suitable set of fuzzy rules as well as determining the membership function values for these rules is a complex problem. In this study:
  - Fuzzy membership function values are optimised
  - Fuzzy rule base is fixed

MOSCUE framework: Fuzzy Rule Base

Fuzzyfication of Input (example membership values, values to be optimised)

a) Vehicle Queue	Min	Mid	Max
Short	0	50	100
Med	45	60	135
Long	80	100	∞

b) Av Ped. Delay	Min	Mid	Max
Short	0	25	40
Med	30	40	50
Long	45	60	∞

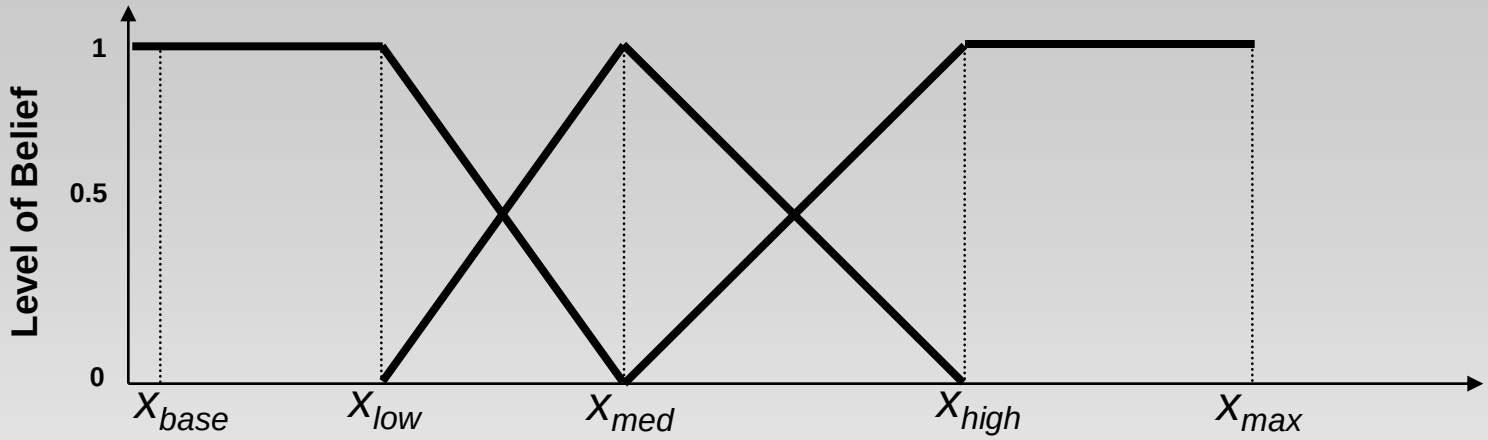
Fuzzy Rule Base (fixed)

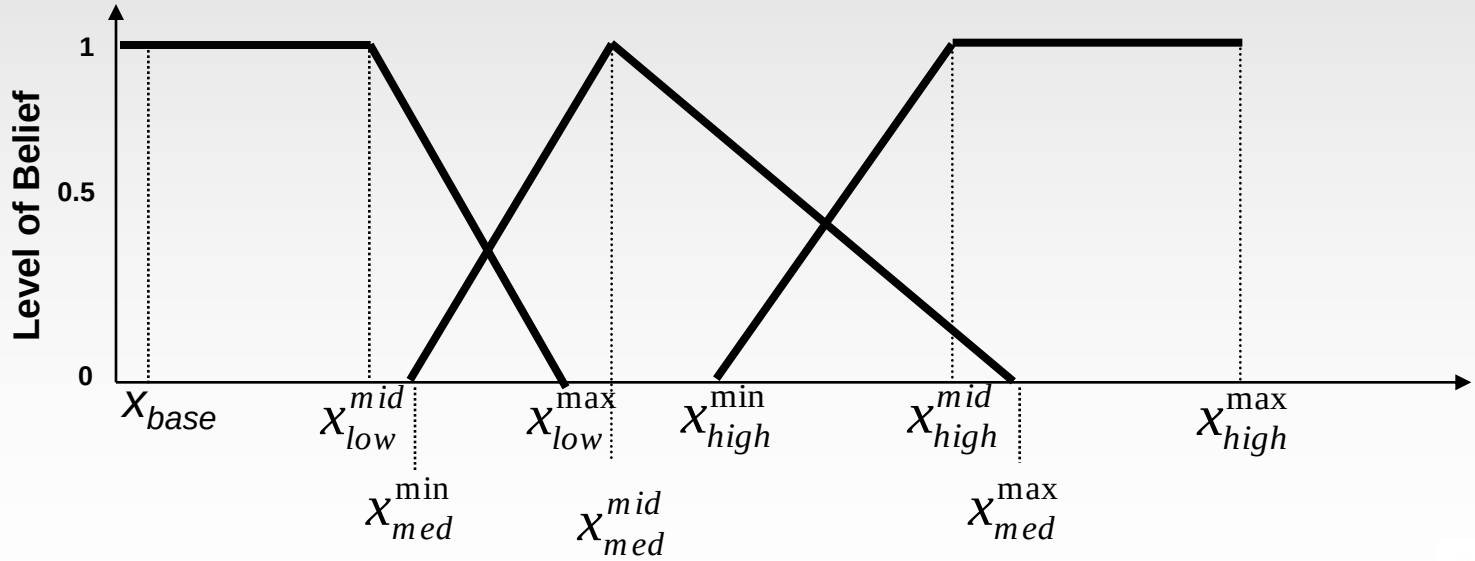
Veh. Queue + Av. Ped Delay → Ped. Stage Duration		Av. Pedestrian Delay		
		Low	Med	High
Vehicle Queue	Low	*Medium*	*Long*	*Very Long*
	Med	*Medium*	*Medium*	*Long*
	High	*Short*	*Medium*	*Long*

Defuzzyfication of Output (example membership values, values to be optimised)

Pedestrian Stage Duration	Min	Mid	Max
Short	0	4	6
Medium	5	8	10
Long	6	9	11
Very Long	7	10	15

MOSCUE framework: Membership functions

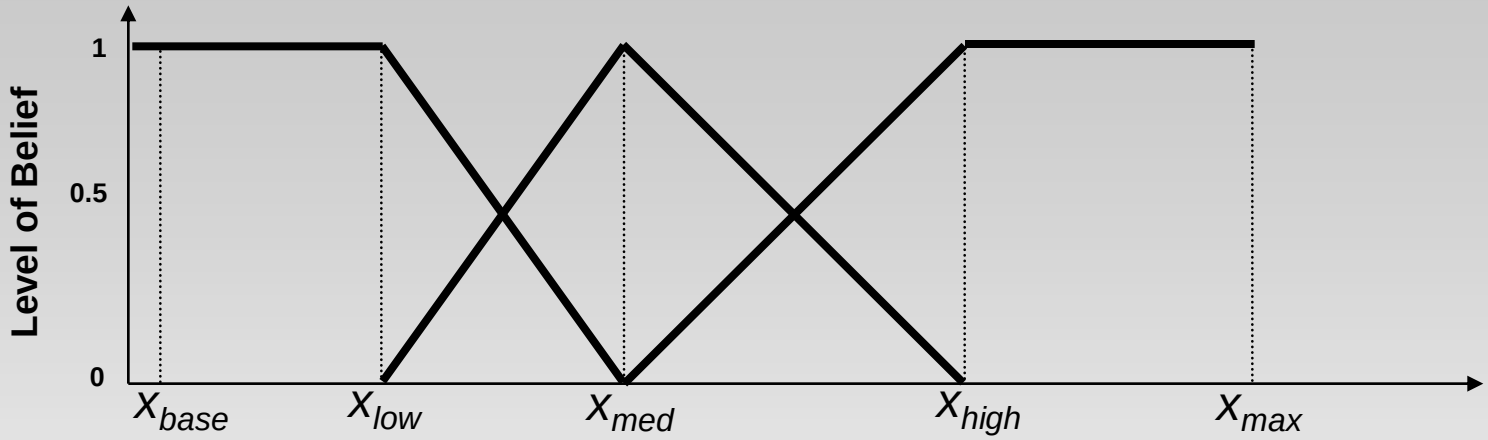




MOSCUE framework: Genetic Algorithms

- A common method to optimise fuzzy logic membership functions is by a Genetic Algorithm (GA)
- Yuan and Zhuang (1996) first showed that a GA can find improved membership functions, though it was found to be an inefficient method
- Anderson et al (1998) note that for multiple objective optimisation GA is likely to be superior to hill-climbing methods as there might be local optima in the solution space

MOSCUE framework: Coding of thresholds



$$x^r_{base} < x^r_{low} < x^r_{med} < \ldots < x^r_{\max}$$

Let $g^r_{k,i}$ denote gene *i* which is used to describe *k* of variable *r*. Then x^r_k is defined as

$$x^r_k = x^r_{k-1} + c_k\left(g^r_{k,0} + 2g^r_{k,1} + 4g^r_{k,2} + 8g^r_{k,3}\right) + 1$$

with $c_k = 2$:

$$x^r_{base} = 0 \qquad x^r_{low} = 1 \qquad x^r_{med} = 2 \qquad x^r_{high} = 3$$

$$x^r_{base} = 30 \qquad x^r_{base} = 61 \qquad x^r_{base} = 92 \qquad x^r_{base} = 123$$

MOSCUE framework: Reproduction, cross-over and mutation

Creation of a new generation:

Step1: Sort all **x** of generation *t* according to their fitness $D(\mathbf{x})$.

Step2: <u>Reproduction:</u> Reproduce the $N\alpha_r$ chromosomes with the best fit

Step 3: <u>Crossover:</u> Repeat Steps3a-3c $N\alpha_c$ times

Step3a: From the reproduced chromosomes randomly choose two chromosomes **x1** and **x2** with genes *g1* and *g2*

Step3b: Define two random crossover points $0 < m < n < L$

Step3c: Create $\mathbf{x}^{t+1} = \{g1_0, g1_1, \ldots, g1_m\} + \{g2_{m+1}, \ldots, g2_n\} + \{g1_{n+1}, \ldots, g1_L\}$

Step 4: <u>Mutation:</u> Repeat Steps4a-4c $N(1-\alpha_r-\alpha_c)$ times

Step4a: From the reproduced chromosomes randomly choose a chromosome **x**

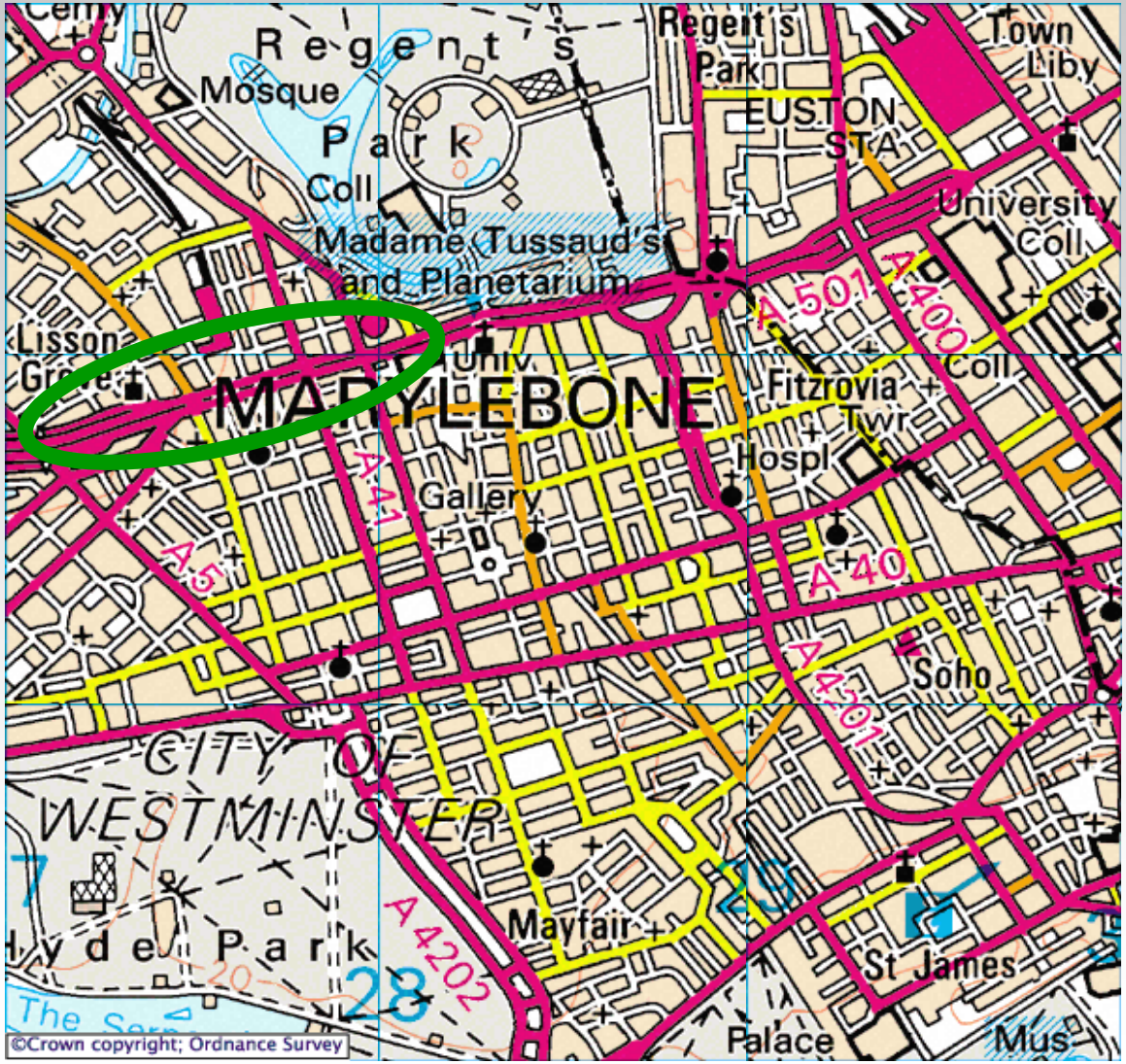
Step4b: Set $\mathbf{x}^{t+1} = \mathbf{x}$

Step4c: $\forall\ g \in \mathbf{x}^{t+1}$ define random number $0 \leq r \leq 1$ and set g = (1-g) if $r > (1-\beta)$

MOSCUE framework: VISSIM microsimulation model

- Each scenario (chromosome) tested with VISSIM microscopic traffic simulation model
- GA + microsimulation is slow! Therefore Chiou (2005) propose to use macroscopic simulation.
- However using VISSIM has following advantages:
  - Test with different random seeds possible
  - Detailed simulation of different road users
  - In particular detailed simulation of pedestrians: Non-compliance to signals and gap-acceptance and queue formation at traffic lights

Marylebone Rd Corridor – Location of Case Study Area

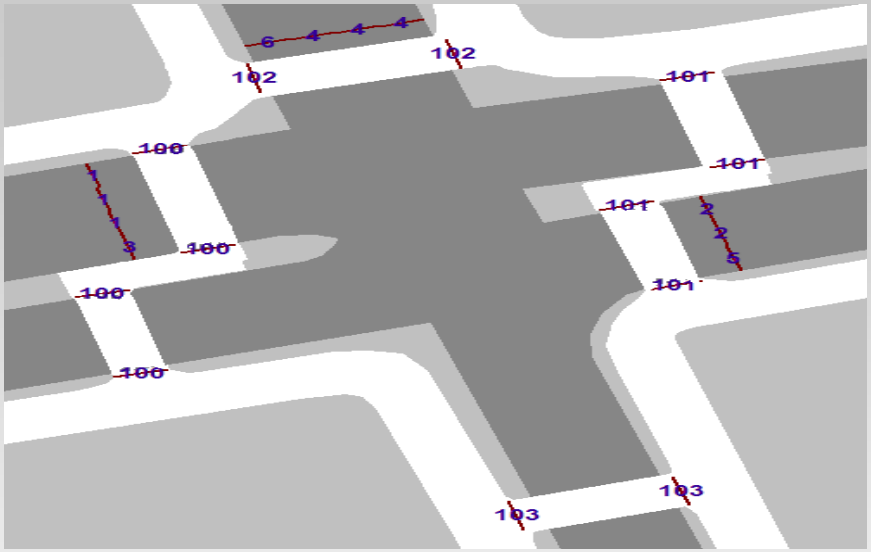


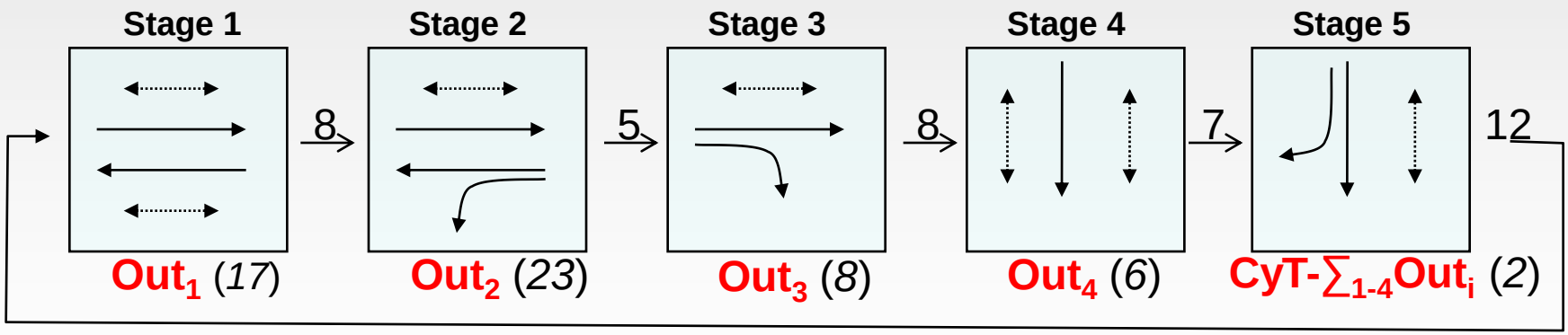
Marylebone Rd Corridor – Junctions modelled with VISSIM

Marylebone Rd Corridor – Vehicles and pedestrians entering the corridor

Categories	Number of vehicles	Vehicle type	Number of vehicles
Vehicles	5,203	Articulated Buses	18
		Bicycles	196
		Buses	81
		Cars	2,834
		HGVs	266
		LGVs	588
		Motorcycles	556
		Taxis	665
Pedestrians	4,071		

Optimisation of Baker Street Intersection: Stage order and stage durations





Optimisation of Baker St Intersection
KPIs and definition of 3 scenarios

Key Performance Indictors	"Balanced policy"		"Policy minimising queues"		"Pedestrian Friendly Policy"	
	Fully Satisfied (y^F)	Not satisfied (y^0)	Fully Satisfied (y^F)	Not satisfied (y^0)	Fully Satisfied (y^F)	Not satisfied (y^0)
Obj1: Av. Delay Cars (in network)	50	200	50	200	50	200
Obj2: Av. Delay Buses (in network)	50	200	50	200	50	200
Obj3: Av. Delay Ped (at optimised junction)	40	70	40	70	20	40
Obj4: Queue EW (at optimised junction)	50	250	30	100	50	300
Obj5: Queue NS (at optimised junction)	50	250	30	100	50	300

Optimisation of Baker St Intersection: Fuzzy Rule Base

Queue East + Ped Delay 100 → **Stage 1 Duration**		Av. Pedestrian Delay 100		
		Low	Med	High
Queue East (Marylebone Rd)	Low	*long*	*medium*	*short*
	Med	*long*	*medium*	*medium*
	High	*very long*	*long*	*medium*

Queue East + Ped Delay 103 → **S2 Duration**		Av. Pedestrian Delay 103		
		Low	Med	High
Queue East (Marylebone Rd)	Low	*long*	*medium*	*short*
	Med	*long*	*medium*	*medium*
	High	*very long*	*long*	*medium*

Queue East +Queue West → **S3 Duration**		Queue West (Marylebone Rd)		
		Low	Med	High
Queue East (Marylebone Rd)	Low	*medium*	*long*	*very long*
	Med	*medium*	*medium*	*long*
	High	*short*	*medium*	*long*

Queue North + Ped Delay 100 → **S4 Duration**		Av. Pedestrian Delay 100		
		Low	Med	High
Queue North (Baker St)	Low	*medium*	*long*	*very long*
	Med	*medium*	*medium*	*long*
	High	*short*	*medium*	*long*

Results – Fuzzy Membership Functions
Input Variables

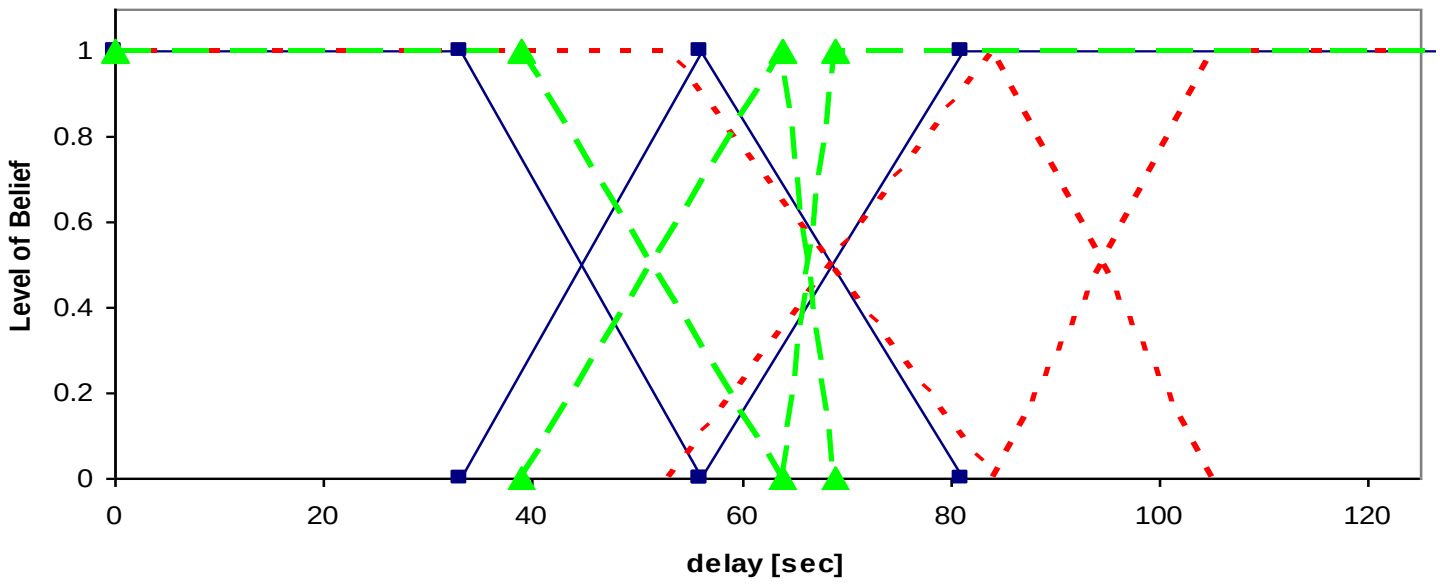
Input1: Queue EW (Marylebone Rd)

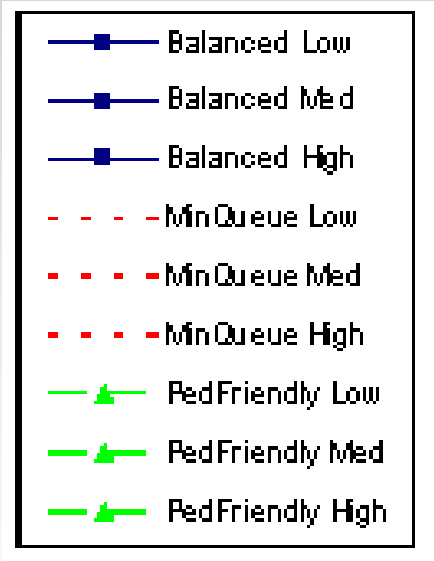
Input2: Queue WE (Marylebone Rd)

Input3: Queue North (Baker St)

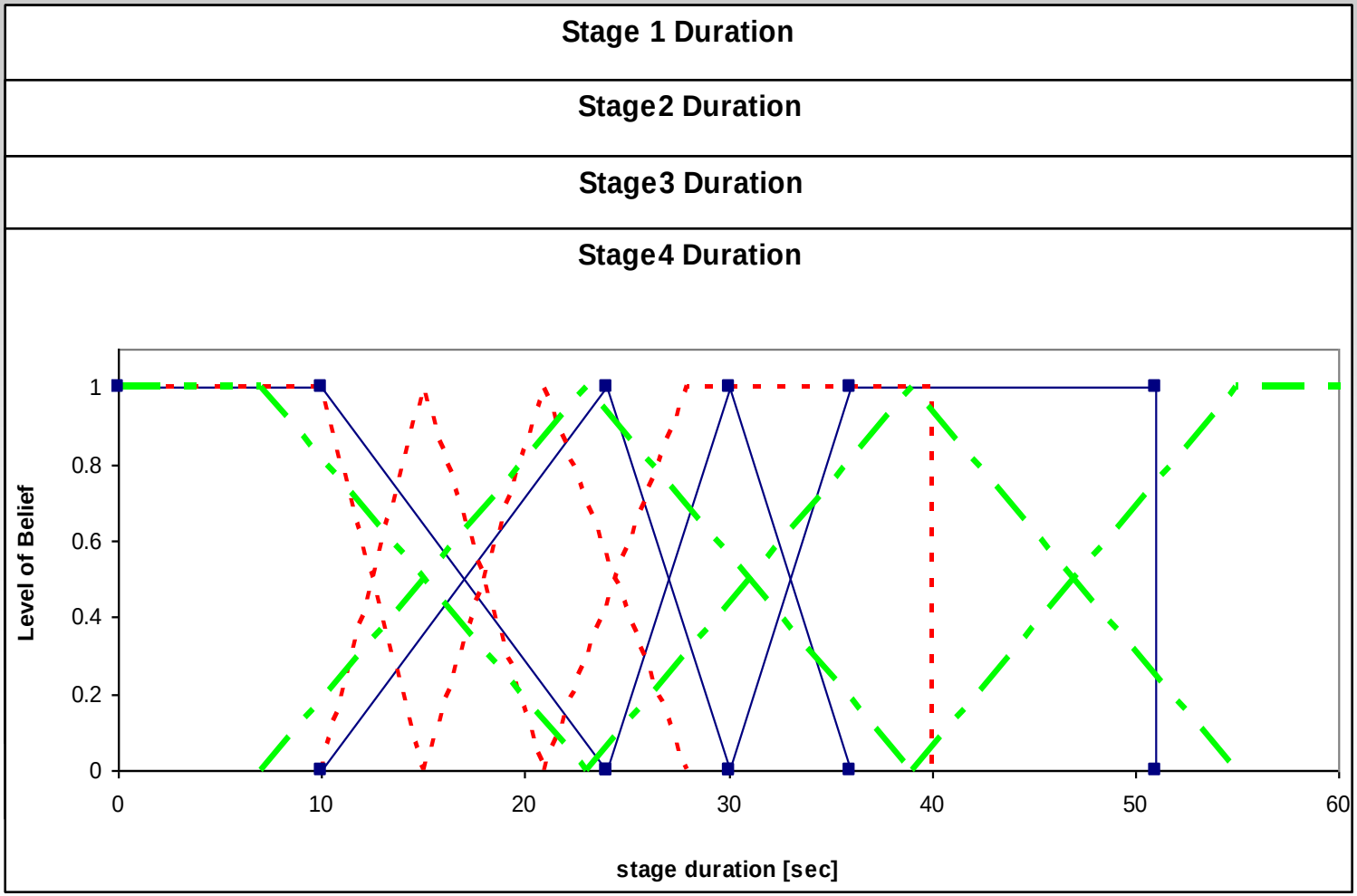
Input4: Ped Delay (crossing Marylebone Rd)

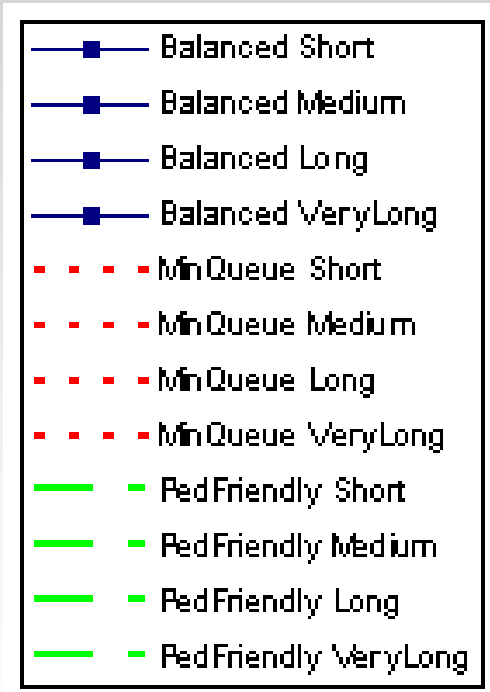
Input5: Ped Delay (crossing Baker Street)





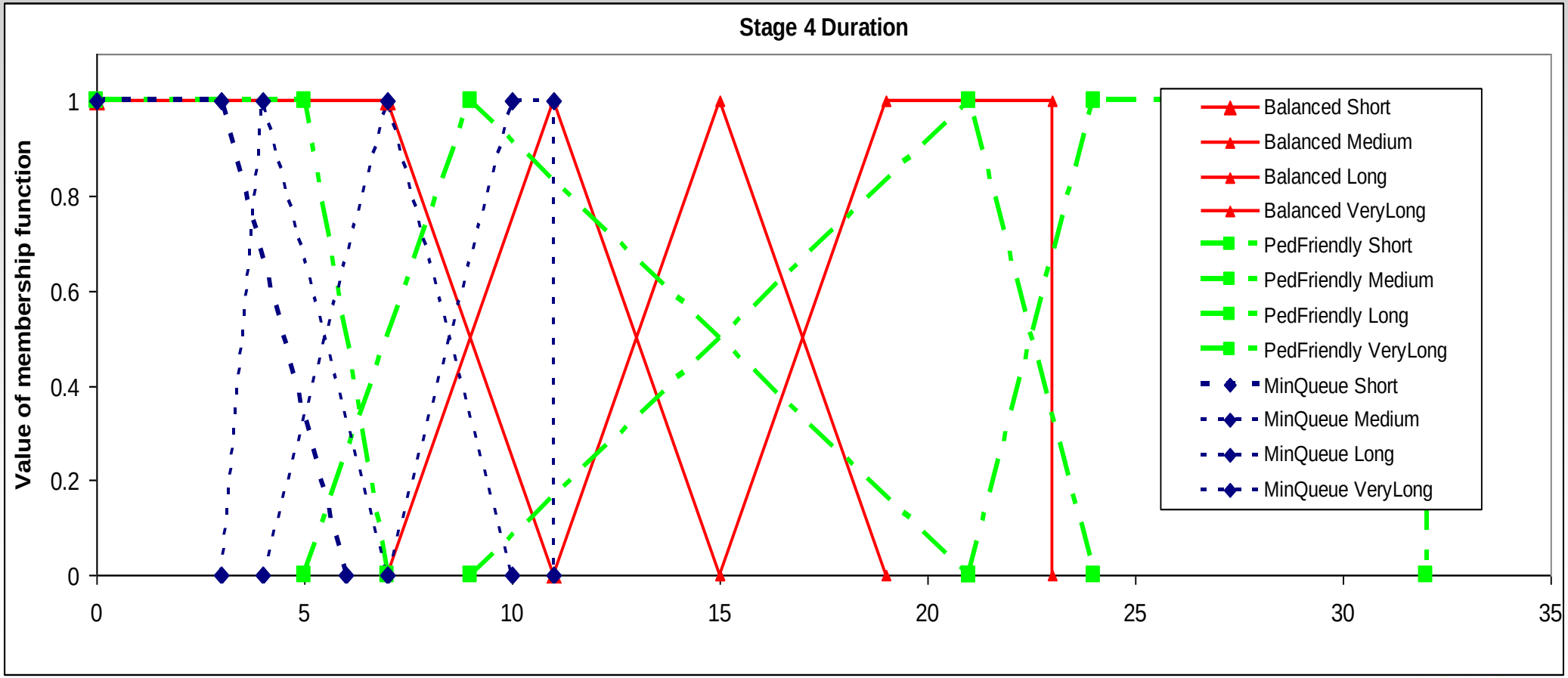
Results – Fuzzy Membership Functions
Stage Durations (Output)



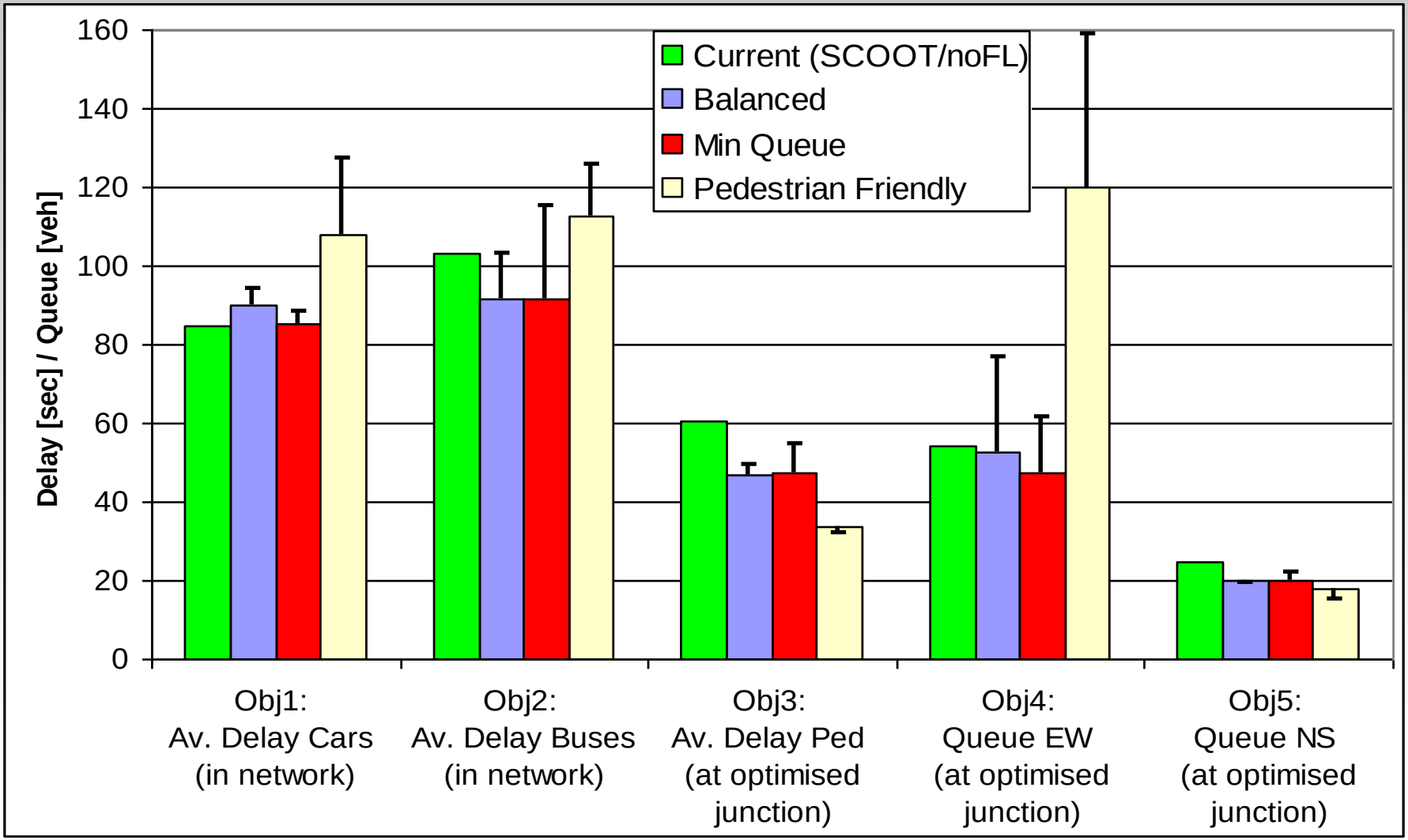


Results – Fuzzy Membership Functions
Stage Durations (Output)

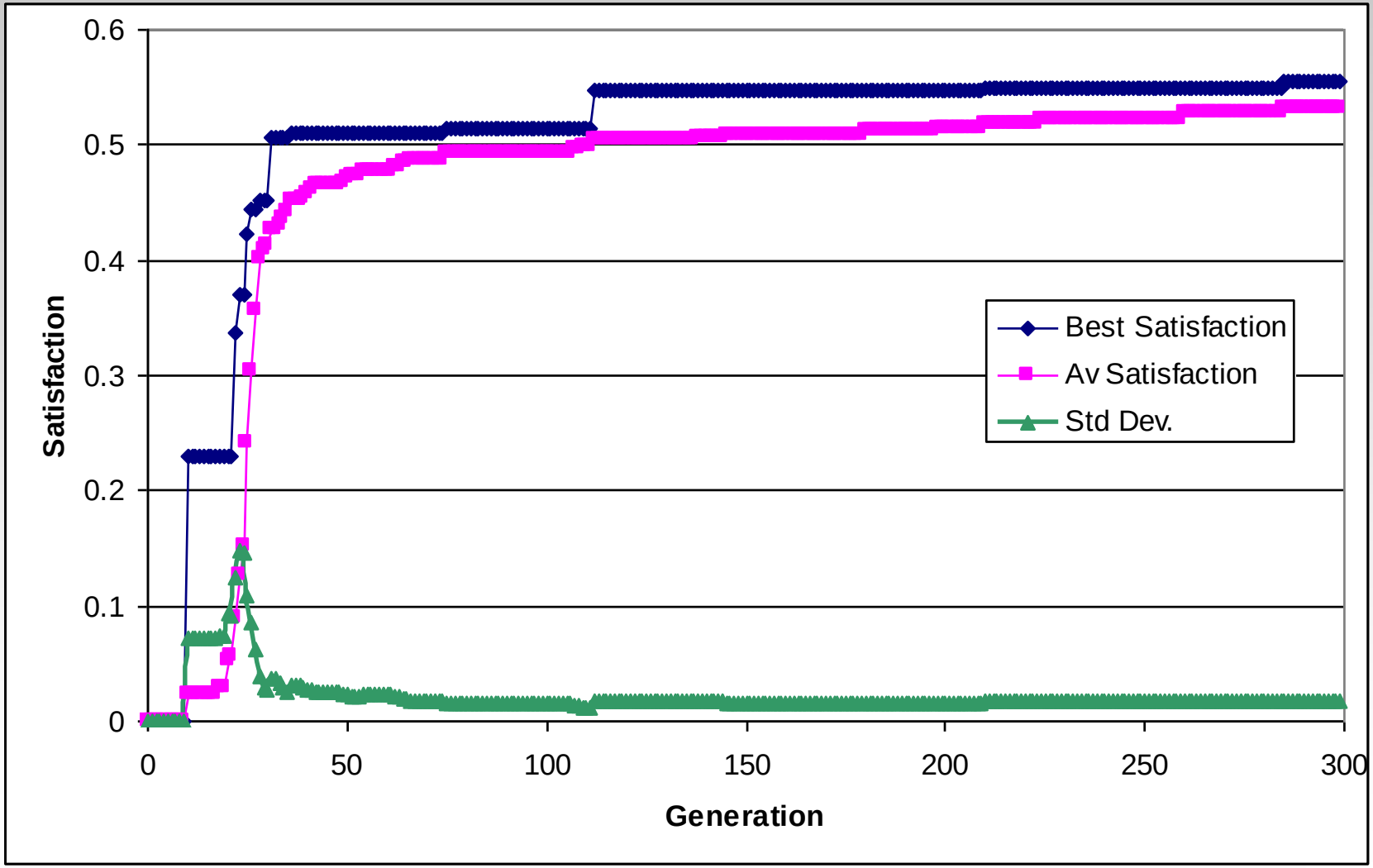
For comparison: Optimisation of Stage4 duration only (interpretation is much simpler!)



Results – KPIs



Results – “Convergence”



Conclusions

- Approach to multi-objective signal control presented
  - Using Fuzzy Logic
  - Optimisation of Fuzzy Membership Functions with GA
- Evaluation of alternatives according to Bellmann-Zadeh decision making
  - Offers the traffic engineer flexibility
  - Chooses one solution from a Pareto-optimal front of solutions
- Case Study mainly as proof of concept. Results show conflicts between
  - Different road users
  - Traffic from different junction arms
  - Local and network wide optimisation (SCOOT focus is on car traffic delay)

Further work

- Implementation – Field trials
- Control of several junctions / area wide MOSCUE control
  - Include further modes (inclusion of cycles, trams)
  - “green waves”
- Inclusion of environmental objectives
- Computation time too long? Obtaining a result for a single policy takes around 24h (100 generations, 20 chromosomes) – but maybe not important.
- Research on behaviour of pedestrians around junctions - compliance level and route choice of different user groups (*recently DfT project*)