Fuzzy Automated Braking System For Collision Prevention

by

Piero P. Bonissone & Kareem Aggour

Agenda

- Problem Description (Objective,Assumptions)
- Related Work
- System Design
  - Dynamic Simulator
  - Fuzzy Controller Design
  - Genetic Algorithm Tuning
- Tuning Results
- Analysis & Conclusion

Motivation

- Driver reaction time often delays identification of potentially hazardous situations

- Many such accidents could be prevented

Objective

- Use an embedded Fuzzy Logic controller

- To automatically identify and react to potentially hazardous driving situations

Related Work on FC for Braking

- US Patent 5634698 (Cao et al. of Germany):
  - "*System for Controlling Brake Pressure Based on Fuzzy Logic Using Steering Angle and Yaw Speed*"
  - This system is focused more on reducing vehicle skidding than on reducing the vehicle speed to prevent collisions
- US Patent 5416709 (Yeh et al. of Taiwan):
  - "*Fuzzy Controller for Anti-Skid Brake Systems*"
  - This system is similar to Cao's system and is also only vaguely similar to the goal of the second fuzzy controller designed.

Model Assumptions

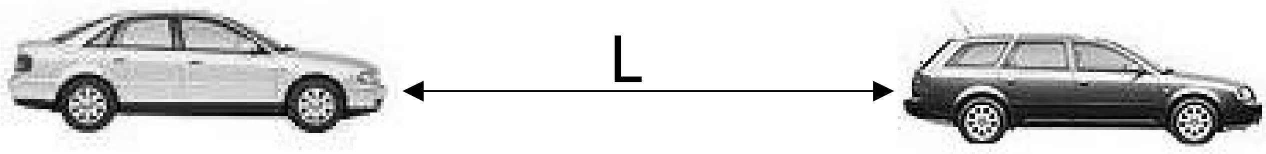
- Straight line on a surface with no gradient
- Controlled vehicle's wheels do not slip
  - Limits the simulation to consider only static friction, disregarding the kinetic friction generated by wheel slip
- Linear correlation between the application of brake pressure and the deceleration the vehicle experiences.
  - If 25% of the maximum possible brake pressure is applied, then the vehicle will decelerate by 25% of its maximum possible deceleration.

Sensor & Actuator Assumptions

- The sensor technology required to measure the state variables used by the proposed system (range, relative velocity, and friction coefficient) is readily available.
  - Laser range finders, and Doppler radars could provide the first two measurements,
  - Wheel-slip sensors currently used for automobile Traction Control Systems or Anti-lock Breaking Systems (ABS) could estimate the third state variable.
- The required actuators are already installed in all automobiles equipped with ABS.

Variables of Interest

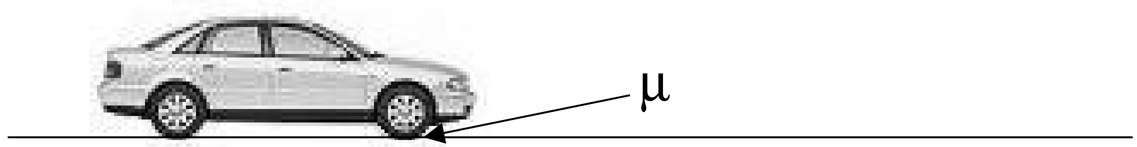
- Separation between the two vehicles



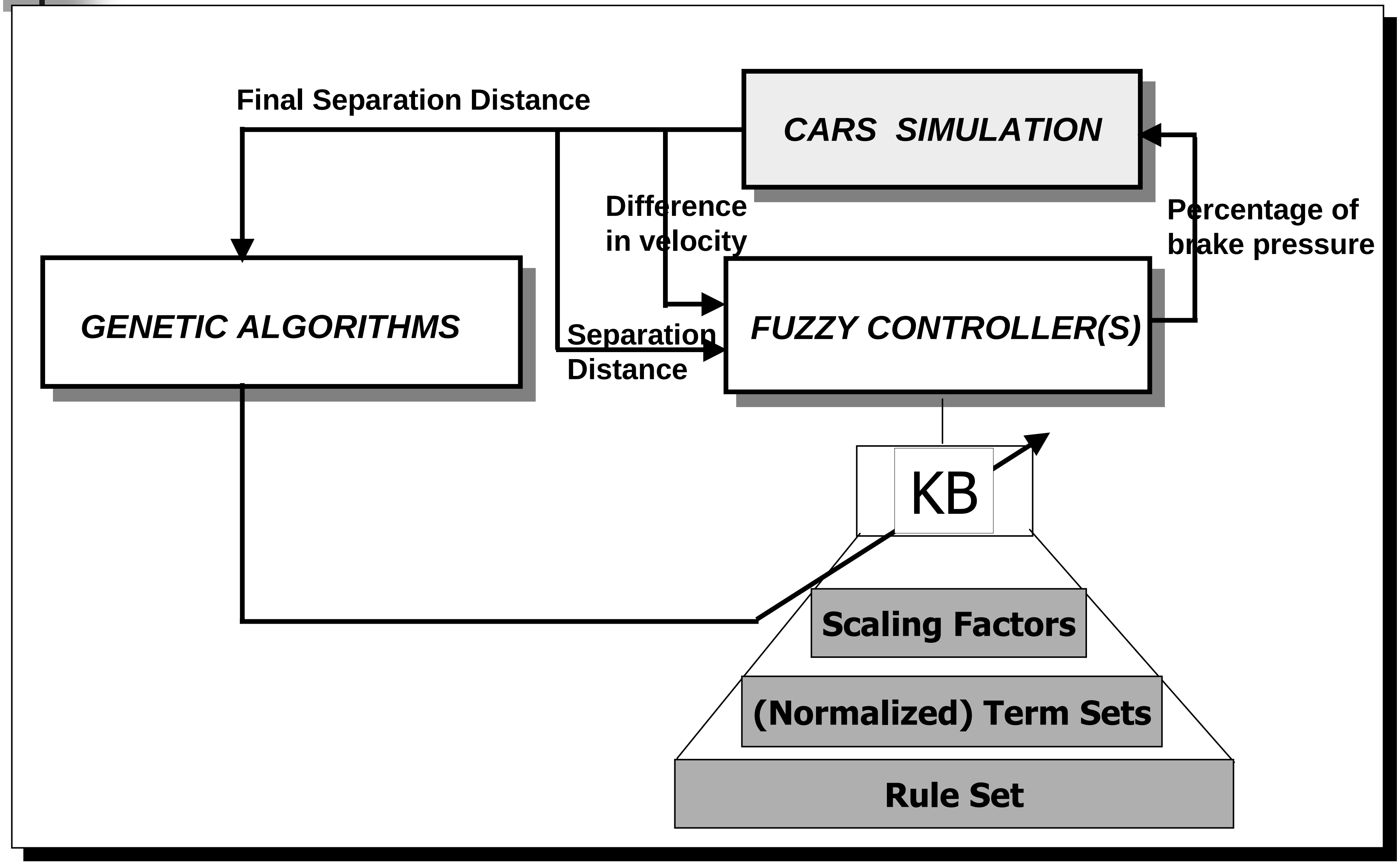
- Differences in their velocities

$$\Delta V = V_{tracked}(t) - V_{tracking}(t)$$

- Surface conditions (i.e., friction coefficient μ between the vehicle tires and the road)



Simulator-FC-GA Architecture



Tuning FC Knowledge Base with GA

- A Mamdani- type FLC approximates a relationship between a state *X* and an output *Y* by using a KB and a reasoning mechanism (interpreter) implemented by the *generalized modus-ponens*.
- The Knowledge Base (KB) is defined by:

Parameters	▪ *Scaling Factors (SF):* ▪ Ranges of values of state and output variables ▪ *(Normalized) Term Set (TS):* ▪ Membership functions of values, normalized by SF
Structure	▪ *Rule Set (RS):* ▪ Syntactic mapping of symbols from X to Y

FC Sensitivity to Parameter and Structure Changes

Changing a Scaling Factor

X1			X2		
	Very Low	*Low*	*Medium*	*High*	*Very High*
Very Low	PH	PH	PM	PL	ZE
Low	PH	PM	PL	ZE	NL
Medium	PM	PL	ZE	NL	NM
High	PL	ZE	NL	NM	NH
Very High	ZE	NL	NM	NH	NH

Changing a Term in X1

X1			X2		
	Very Low	*Low*	*Medium*	*High*	*Very High*
Very Low	PH	PH	PM	PL	ZE
Low	PH	PM	PL	ZE	NL
Medium	PM	PL	ZE	NL	NM
High	PL	ZE	NL	NM	NH
Very High	ZE	NL	NM	NH	NH

Changing a Rule

X1			X2		
	Very Low	*Low*	*Medium*	*High*	*Very High*
Very Low	PH	PH	PM	PL	ZE
Low	PH	PM	PL	ZE	NL
Medium	PM	PL	ZE	NL	NM
High	PL	ZE	NL	NM	NH
Very High	ZE	NL	NM	NH	NH

FC Sensitivity to Parameter and Structure Changes

Changing a SF

X1			X2		
	Very Low	*Low*	*Medium*	*High*	*Very High*
Very Low	PH	PH	PM	PL	ZE
Low	PH	PM	PL	ZE	NL
Medium	PM	PL	ZE	NL	NM
High	PL	ZE	NL	NM	NH
Very High	ZE	NL	NM	NH	NH

Changing a Term in a TS (e.g. X1)

X1			X2		
	Very Low	*Low*	*Medium*	*High*	*Very High*
Very Low	PH	PH	PM	PL	ZE
Low	PH	PM	PL	ZE	NL
Medium	PM	PL	ZE	NL	NM
High	PL	ZE	NL	NM	NH
Very High	ZE	NL	NM	NH	NH

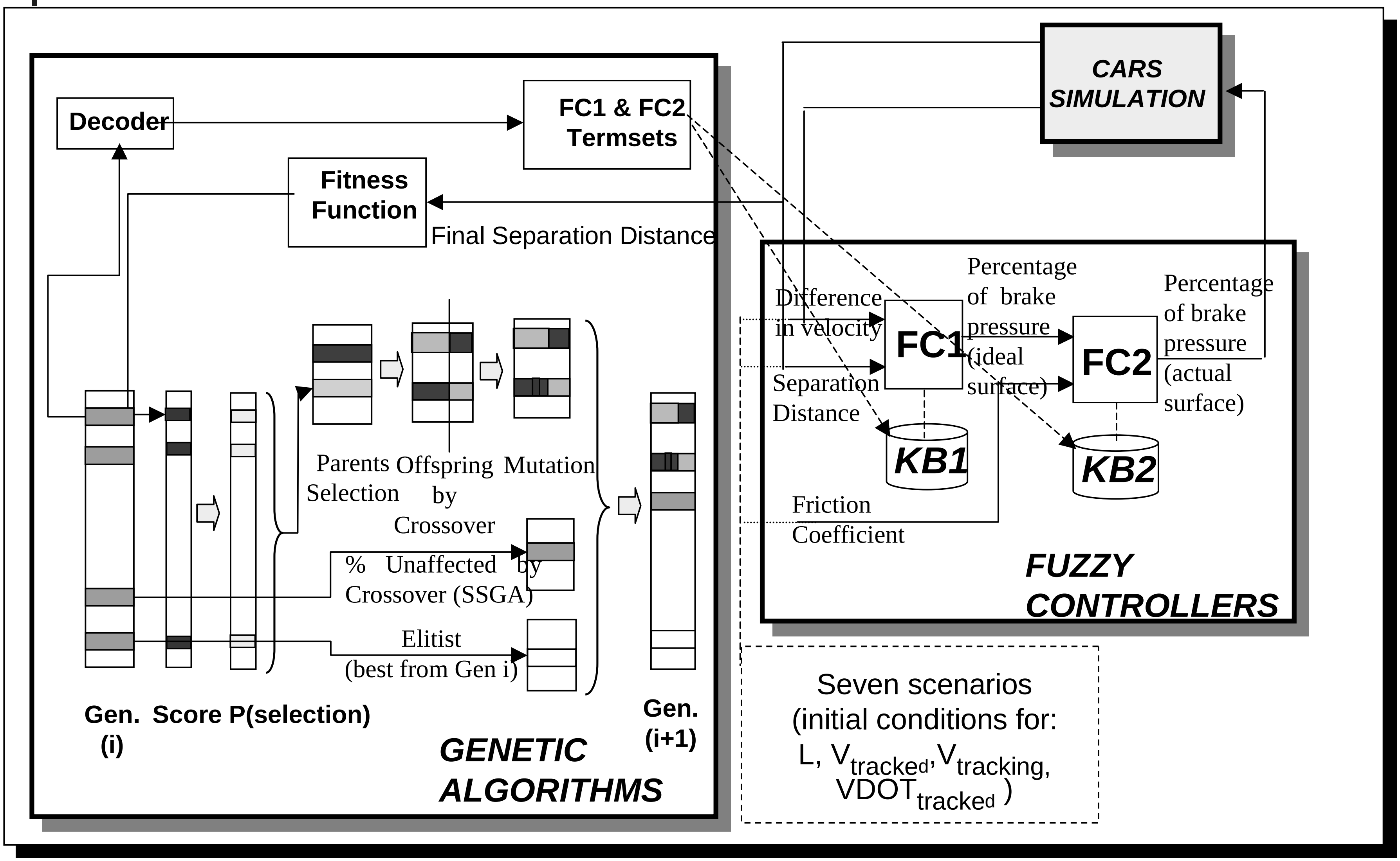
Changing a Rule in RS

X1			X2		
	Very Low	*Low*	*Medium*	*High*	*Very High*
Very Low	PH	PH	PM	PL	ZE
Low	PH	PM	PL	ZE	NL
Medium	PM	PL	ZE	NL	NM
High	PL	ZE	NL	NM	NH
Very High	ZE	NL	NM	NH	NH

We use Non-normalized Term Sets, e,g, the SF are incorporated into the Term Sets.

So we will Focus our tuning to the Term Sets

Simulator-FC-GA Architecture



Simulator Design Equations

$$d = \frac{V_o + V_f}{2} t$$

$$V_f = V_o + a\Delta t$$

$$momentum = \frac{1}{2} mV^2$$

$$Work_{friction} = -\mu mgd$$

$$Work_{net} = \Delta\ Momentum$$

$$Work_{friction} = \frac{1}{2} mV_f^2 - \frac{1}{2} mV_o^2$$

$$-\mu mgd = -\frac{1}{2} mV_o^2$$

Simulator Design Equations

$$d_{stopping} = \frac{V_o^2}{2\mu g}$$

$$a = \frac{-V_o^2}{2d}$$

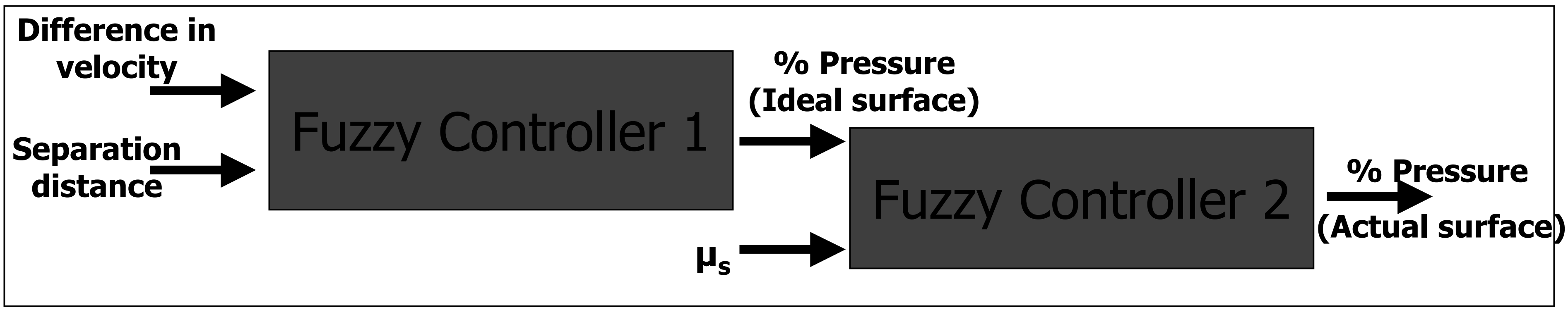
$$a_{maximum} = -\mu g$$

$$V(t+1) = V(t) + (a_{maximum} * \%_{Braking})\Delta t$$

$$d_{separation}(t+1) = d_{separation}(t) + (V_{tracked}(t+1) - V_{tracking}(t+1))\Delta t$$

Fuzzy Controller(s) Design

- Designed system containing two fuzzy controllers (FC) connected in series



- Each FC Interpreter uses:
  - LHS evaluation and rule Firing: Minimum Operator
  - Rule Aggregation: Maximum Operator
  - Defuzzification Method: Center of Gravity
- Each KB defined by:
  - (Non-normalized) Term Sets & Rule Set

Rule Sets – FC 1

	VL_L	L_L	M_L	H_L	VH_L
$VL_{\Delta V}$	$M_{\%P}$	$L_{\%P}$	$VL_{\%P}$	$Z_{\%P}$	$Z_{\%P}$
$L_{\Delta V}$	$H_{\%P}$	$M_{\%P}$	$L_{\%P}$	$VL_{\%P}$	$Z_{\%P}$
$M_{\Delta V}$	$VH_{\%P}$	$H_{\%P}$	$M_{\%P}$	$L_{\%P}$	$VL_{\%P}$
$H_{\Delta V}$	$F_{\%P}$	$VH_{\%P}$	$H_{\%P}$	$M_{\%P}$	$L_{\%P}$
$VH_{\Delta V}$	$F_{\%P}$	$F_{\%P}$	$VH_{\%P}$	$H_{\%P}$	$M_{\%P}$

Term Sets

Control Output: $\%P_{Ideal}$

- F = Full
- VH = Very High
- H = High
- M = Medium
- VL = Very Low
- Z = Zero

State Variables: ΔV, L

- VL = Very Low
- L = Low
- M = Medium
- H = High
- VH = Very High

Rule Sets – FC 2

	VL_{μ}	L_{μ}	M_{μ}	H_{μ}	VH_{μ}
$Z_{\%P}$	$Z_{\%P}$	$Z_{\%P}$	$Z_{\%P}$	$Z_{\%P}$	$Z_{\%P}$
$VL_{\%P}$	$H_{\%P}$	$M_{\%P}$	$L_{\%P}$	$VL_{\%P}$	$VL_{\%P}$
$L_{\%P}$	$VH_{\%P}$	$H_{\%P}$	$M_{\%P}$	$L_{\%P}$	$L_{\%P}$
$M_{\%P}$	$F_{\%P}$	$VH_{\%P}$	$H_{\%P}$	$M_{\%P}$	$M_{\%P}$
$H_{\%P}$	$F_{\%P}$	$F_{\%P}$	$VH_{\%P}$	$H_{\%P}$	$H_{\%P}$
$VH_{\%P}$	$F_{\%P}$	$F_{\%P}$	$F_{\%P}$	$VH_{\%P}$	$VH_{\%P}$
$F_{\%P}$	$F_{\%P}$	$F_{\%P}$	$F_{\%P}$	$F_{\%P}$	$F_{\%P}$

Term Sets

Control Output $\%P_{Actual}$

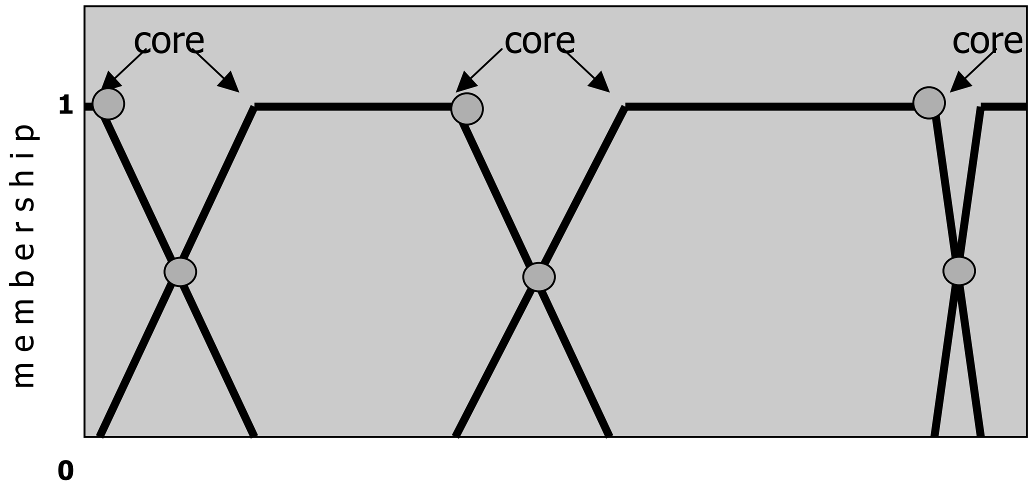
F = Full
VH = Very High
H = High
M = Medium
VL = Very Low
Z = Zero

State Variables:

$\% P_{Ideal}$	μ
F = Full	VL = Very Low
VH = Very High	L = Low
H = High	M = Medium
M = Medium	H = High
VL = Very Low	VH = Very High
Z = Zero	

Genetic Algorithm – Tuning Term Sets

- Chromosome Design:
  - Parametric representation of the term sets:
    - Slopes intersection at 0.5, and core (1 side)



(Generic Term Set)

- Guarantee that for each point in the universe of discourse the sum of its associated membership values equal one
  - Reduces degrees of freedom (by ½)
  - Preserved a good property of the term set, which usually provides good interpolation behavior

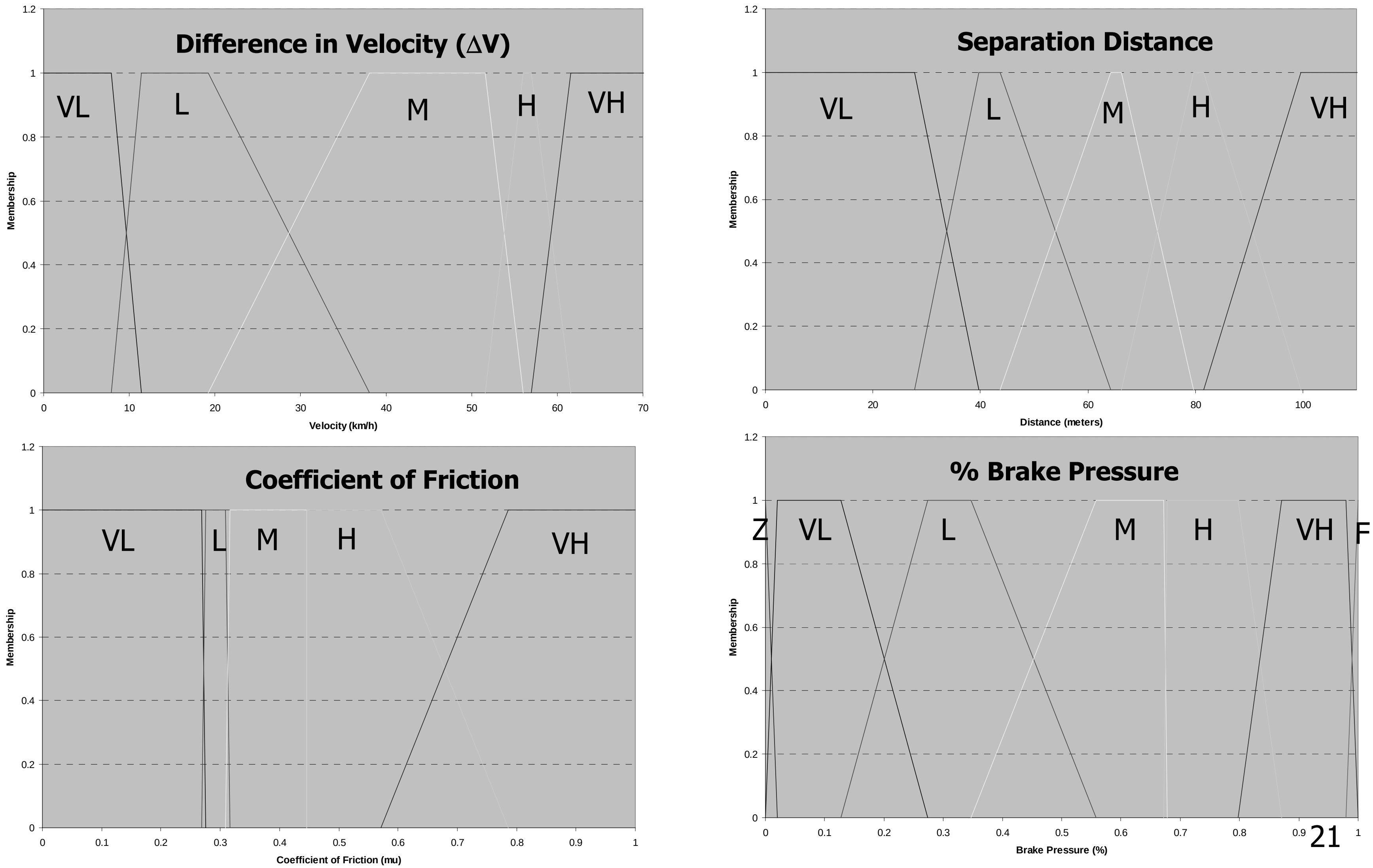
GA Parameters

- Encoding = real-valued
- Population size = 200
- Probability Mutation = 0.5%
- Probability Crossover = 30%
- Fitness Scenarios = 15
- Elitist strategy = YES
- Crossover type = single cut
- Maximum number generations = 2,000
- Selection type = Rank

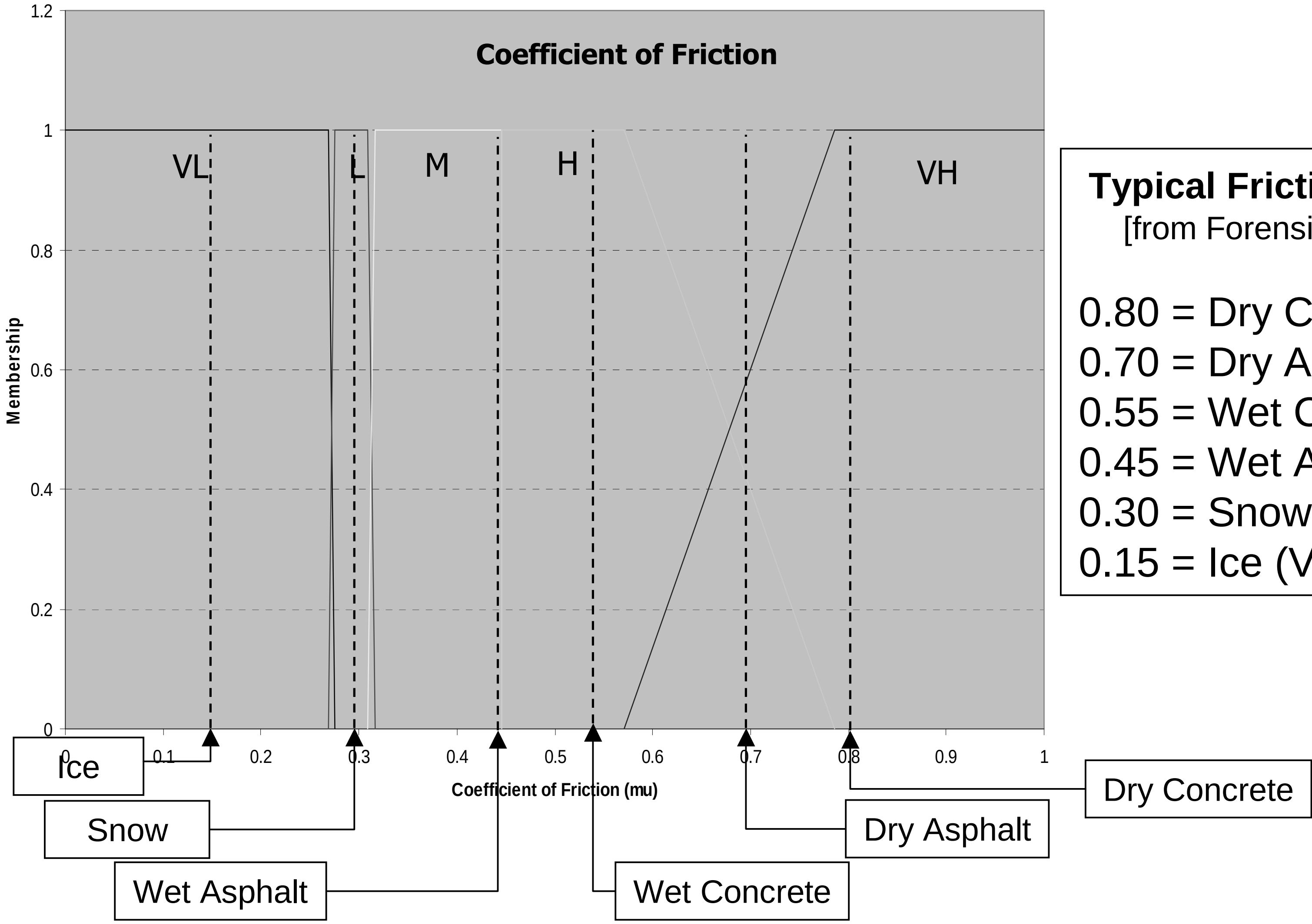
Fitness Function:

Final Separation	<= -10	(-10, -7.5]	(-7.5, -5]	(-5, -2]	(-2, 0]	(0, 1]	(1, 2.5]	(2.5, 3.5]	(3.5, 5]	(5, 7]	(7, 10]	(10, 12]	12 <=
Reward	**-25**	**-20**	**-15**	**-10**	**-5**	**5**	**8**	**15**	**10**	**5**	**2**	**-2**	**-5**

Tuned Term Sets



Tuned Term Sets (Friction Coefficients)



Typical Friction Coefficients
[from Forensic Dynamics, Inc]

0.80 = Dry Concrete (VH)
0.70 = Dry Asphalt (VH)
0.55 = Wet Concrete (H)
0.45 = Wet Asphalt (M)
0.30 = Snow (L)
0.15 = Ice (VL)

Analysis & Conclusion

- Performance:
  - Tested against hundreds of random scenarios with wide range of initial distances, velocity and friction coefficients
    - Consistently stopped within 3m (± 0.5m) of the tracked vehicle (when physically possible)
    - Occasional accidents were possible only when tracked vehicle defied laws of physics due to unrealistic random initial conditions
  - Two controllers in series worked well
    - Reduced size of rule sets by ~ 50%
      - # Rules in cascading controllers: 5X5 + 7x5 = 60
      - # Rules in a 3-input controller: 5X5X5 = 125
  - The GA tuning of the Term Sets was very successful and considerably improved performance of the manually designed FCs

Comments for future Work

- L could be a function of Delta V
- We could add a second goal of tracking vehicle at safe distance