SOME APPLICATIONS OF FUZZY LOGIC IN TRANSPORTATION ENGINEERING

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Fuzzy Logic

"*The power (in a set–theoretic sense) of our thinking and feeling is much higher than the power of living language. If in turn we compare the power of a living language with the logical language, then we will find that logic is even poorer.*" — **Zimmermann**

- Expressing any natural phenomenon by mathematical expressions does not always guarantee exact capturing of the phenomenon itself.
- If any phenomenon, especially related to human decision making can be expressed linguistically chance of proper capturing of the phenomenon increases.
- Fuzzy logic is a logic based on approximate reasoning and can be expressed linguistically to capture the inherent vagueness of human mind; thus, it can be applied to the areas which involve human decision making like supervision, monitoring, planning, scheduling etc.

Set and Fuzzy set

Set

$$A = \{x \mid x \in X\}$$

x: an element of the set and X is the common property of the set

Fuzzy set

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) \mid x \in X\}$$

$\mu_{\tilde{A}}$: membership function/grade of membership/degree of compatibility/degree of truth of x in $\tilde{A}$ that maps X to the membership space M $(0 \leq M \leq 1)$

Fuzzy Set Operations

For sets $\widetilde{A}$ and $\widetilde{B}$

Union ($\widetilde{C}$)

$$\mu_{\widetilde{C}}(x) = Max\{\mu_{\widetilde{A}}(x), \mu_{\widetilde{B}}(x)\}$$

Intersection ($\widetilde{D}$)

$$\mu_{\widetilde{D}}(x) = Min\{\mu_{\widetilde{A}}(x), \mu_{\widetilde{B}}(x)\}$$

Complement ($\overline{\widetilde{A}}$)

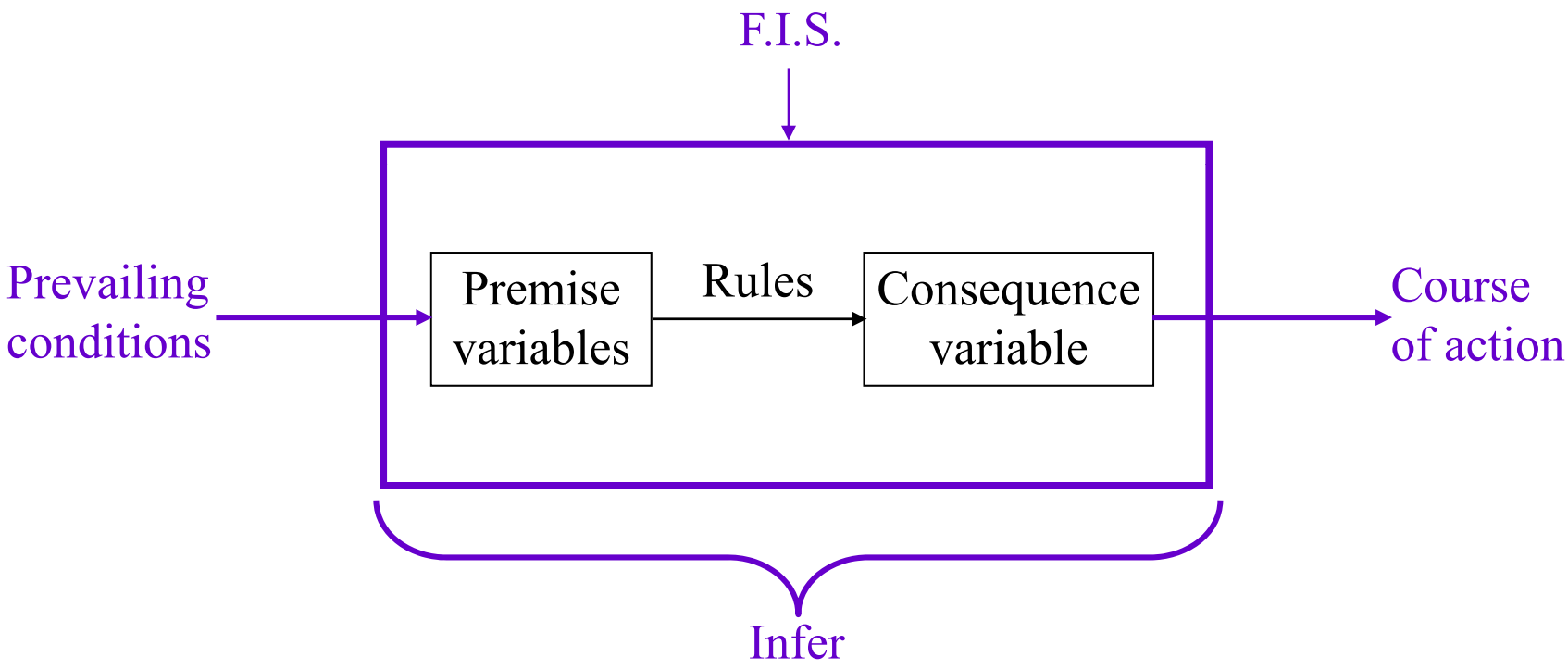
$$\mu_{\overline{\widetilde{A}}}(x) = 1 - \mu_{\widetilde{A}}(x)$$

$$\widetilde{A} \cap \overline{\widetilde{A}} = \phi$$

Fuzzy Inference

Proposition and Truth Value	⟺	Statement and its degree of truthfulness
Logical Connectives	⟺	A & B; A || B
Premise Variable	⟺	Prevailing condition/s
Consequence Variable	⟺	Course of action
Implication and Reasoning		

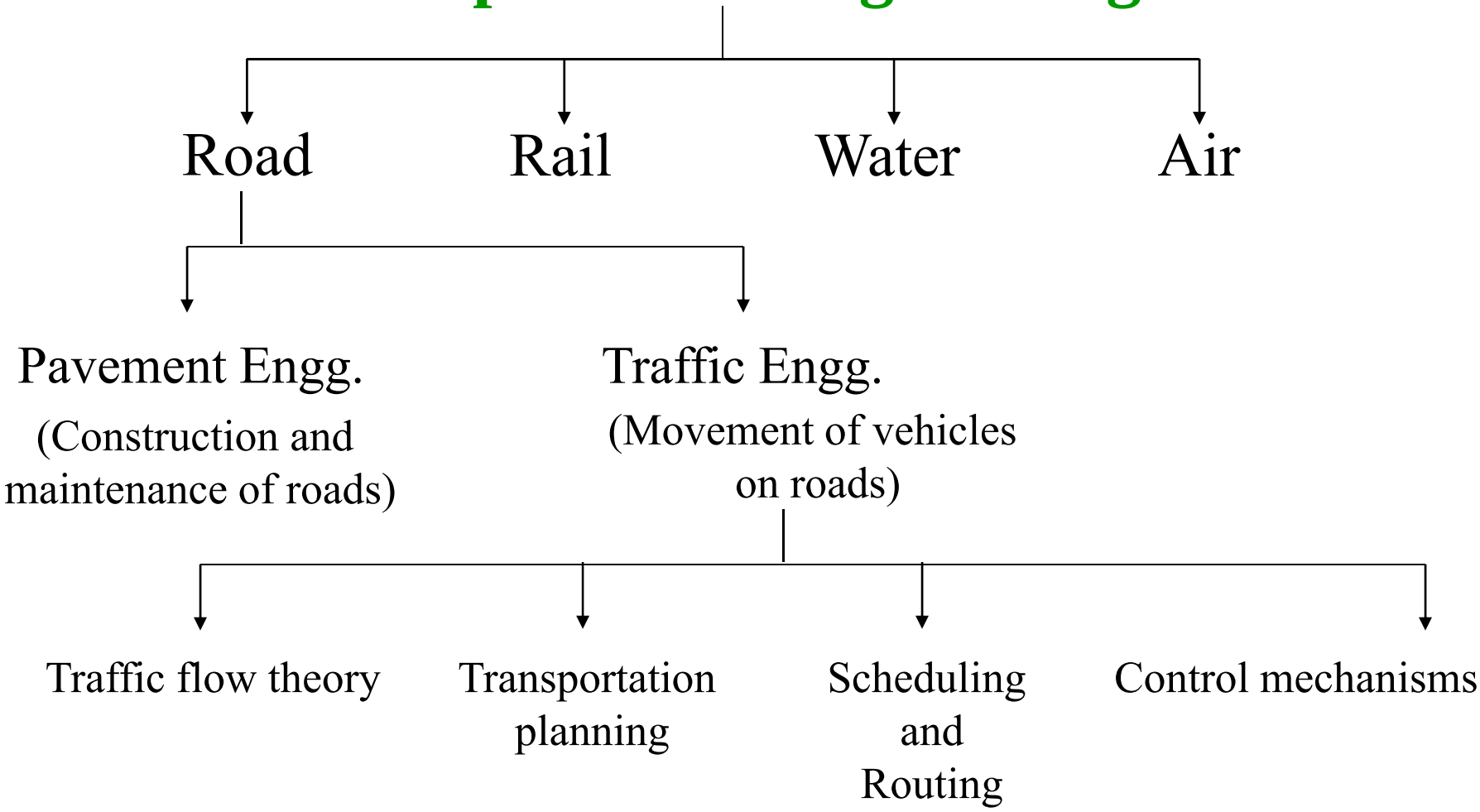
Implication and Reasoning



Fuzzy inference system

Applications of Fuzzy Logic in Transportation Engineering

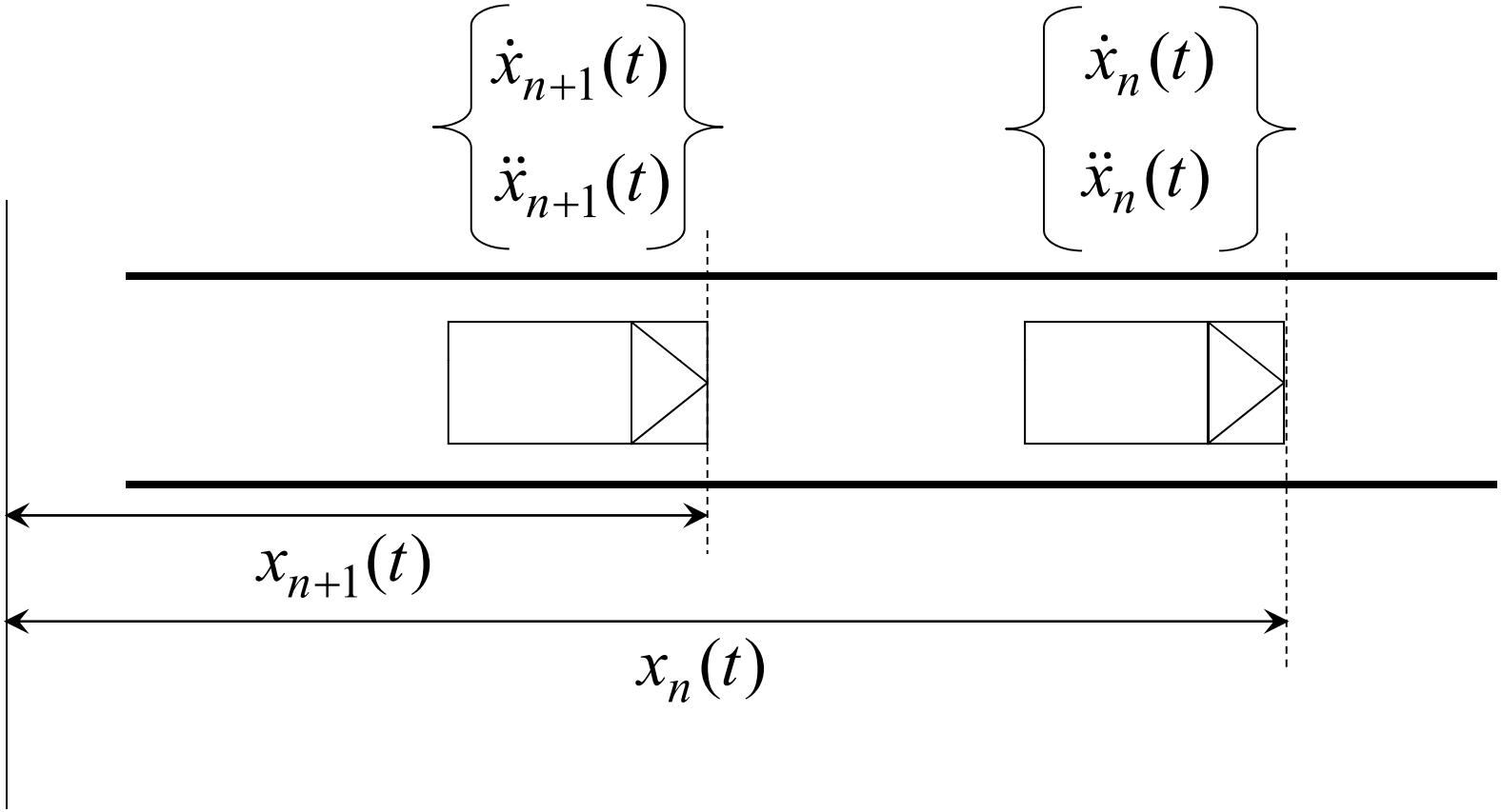
Transportation Engineering



Applications of Fuzzy Logic in Transportation Engineering

- Traffic Flow Modelling: Car Following Behaviour
- Transportation Planning
- Traffic Control at Signalized Intersection
- Ramp–metering
- Parking Garage
- Traffic Monitoring and State Estimation

Traffic Flow Modelling: Car Following Behaviour



u/s
benchmark

Traffic Flow Modelling: Car Following Behaviour

General Motors (GM) model (Gazis et al., 1961)

$$\ddot{x}_{n+1}(t+\Delta t) = \{\frac{\alpha(l,m)(\dot{x}_{n+1}(t+\Delta t))^m}{(x_n(t)-x_{n+1}(t))^l}\}[\dot{x}_n(t)-\dot{x}_{n+1}(t)]$$

$x_i(t)$: distance (from some arbitrary upstream point),

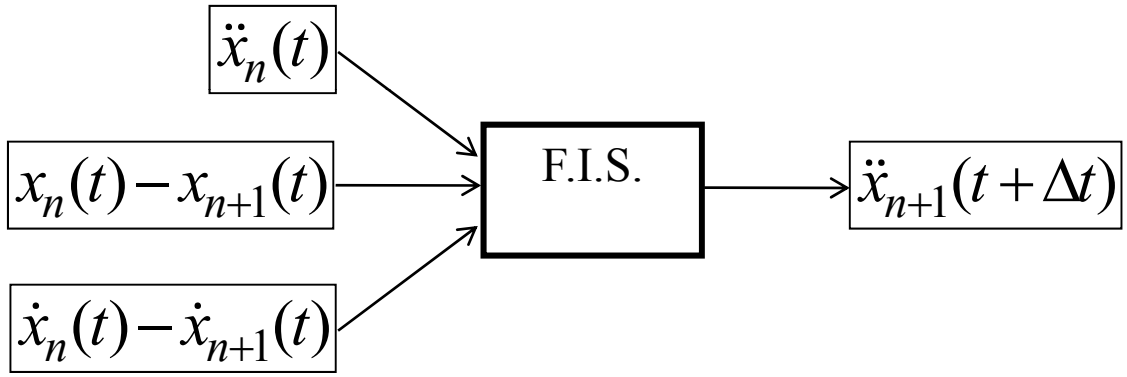
$\dot{x}_i(t)$: speed and

$\ddot{x}_i(t)$: acceleration/deceleration of the i^{th} vehicle at time t.

Δt: perception reaction time;
l and m: constants;
$\alpha(l, m)$: constant dependent on l and m.

Traffic Flow Modelling: Car Following Behaviour

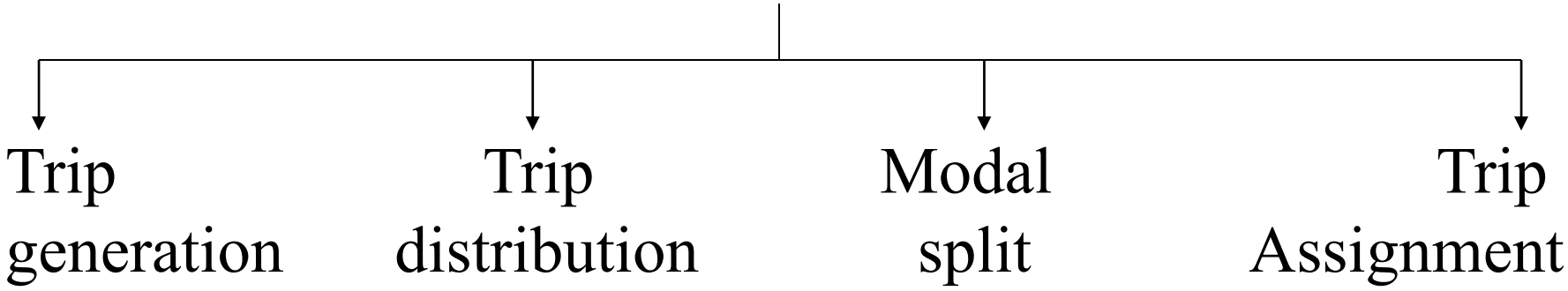
Car following model based on fuzzy inference system (Chakroborty and Kikuchi, 1999)



Schematic of the fuzzy inference based car following model

This model because of being based on imprecise decision making process of drivers can explain all the properties of car following behaviour, i.e., can overcome the lacunae of the GM model.

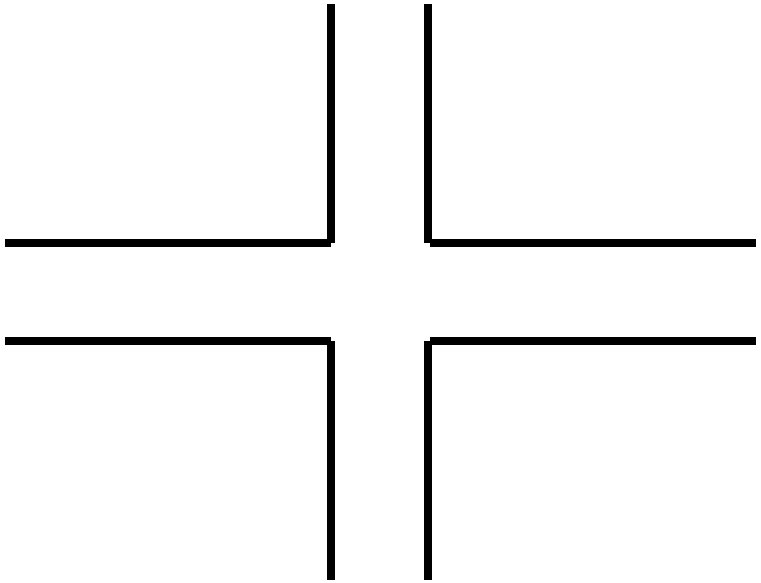
Transportation Planning



Hoogendoorn et al. (1998): multi–modal *modal split* model based on fuzzy logic

Vincent (2000): fuzzy rule based *trip assignment* model considering the imprecisions and the uncertainties lying in the dynamic route choice

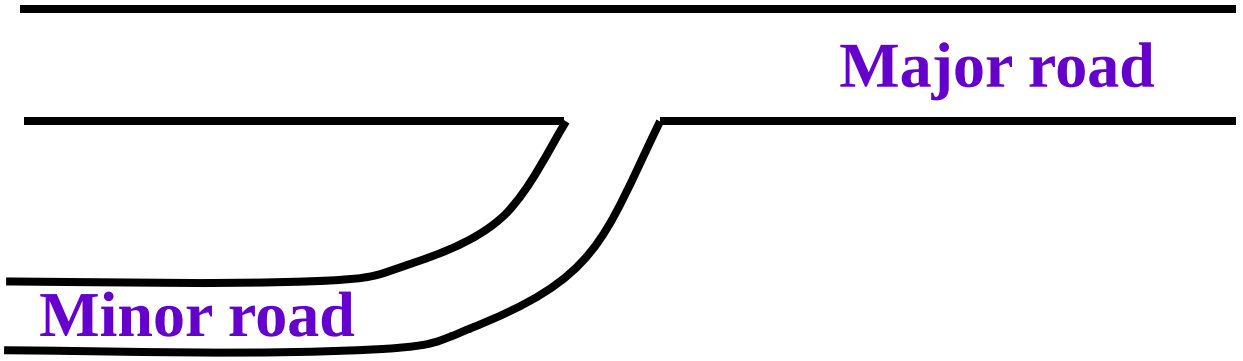
Traffic Control at Signalized Intersection



Wei et al. (2001): used fuzzy logic for signal timing at four–approach intersection to ascertain whether the existing signal phasing is okay or to change it

Niittymaeki and Maeenpaeae (2001): proposed a structure of fuzzy inference based signal control system and tested its rule bases

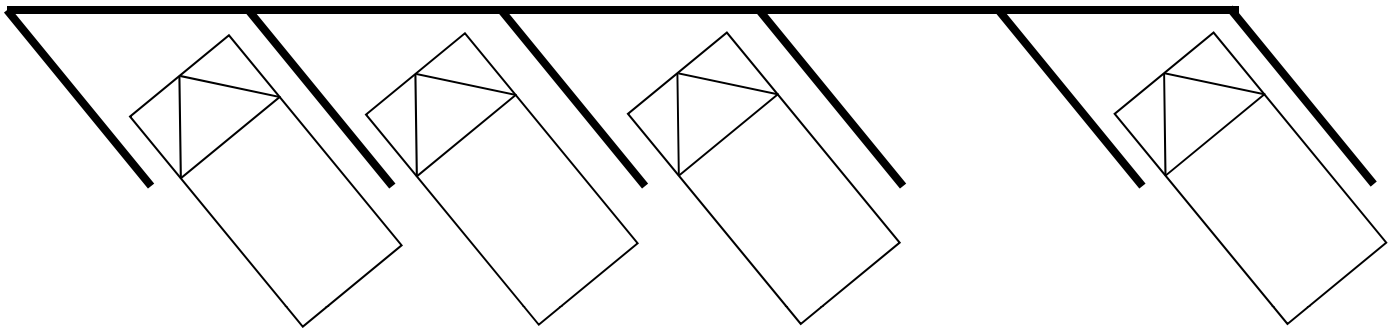
Ramp–metering



Hoogendoorn (1998): observed that fuzzy controller performed better than the existing controllers

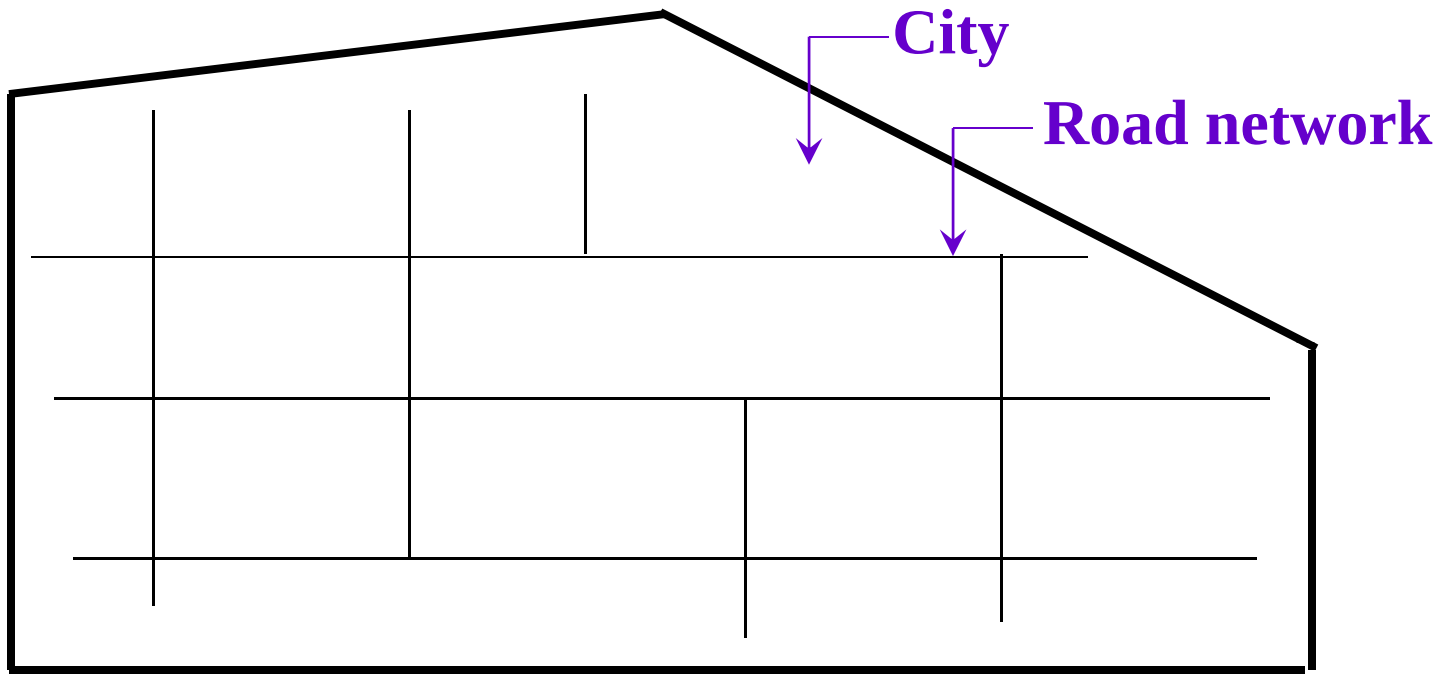
Chen et al. (1990): developed a fuzzy ramp–metering control algorithm using procedural knowledge of traffic operators

Parking Garage



Hellendoorn and Baudrexl (1995): developed a fuzzy–inference based forecasting system to predict the available space in a parking garage

Traffic Monitoring and State Estimation



Kirschfink *et al*. (1997): developed a traffic network data analysis system using fuzzy logic

Busch *et al*. (1994): used fuzzy logic to detect an incident related to traffic flow

Conclusions

- Fuzzy logic uses linguistic variables to draw imprecise conclusions from imprecise input conditions.
- It is suitable to capture the inherent vagueness of human mind and determine the course of action, when the prevailing conditions are not clear and the consequence of the course of action is not known.
- Fuzzy logic has been applied into various areas including transportation engineering. In the area of transportation engineering it has been applied to model traffic flow, transportation planning, and traffic control and so on. In all of these applications fuzzy logic has proved to be successful in overcoming the drawbacks of other methods in the respective areas.

References I

1. Zimmermann, H.J. (2001), “Fuzzy set theory and its applications”, Fourth edition, Kluwer Academic Publishers, Boston/Dordrecht/London.
2. Zadeh, L.A. (1965), “Fuzzy sets”, *Information and Control* , vol. 8, pp 338–353.
3. Bellman, R.F. and Zadeh, L.A. (1970), “Decision making in a fuzzy environment” *Management Science*, vol. 17, pp 14–164.
4. Kaufmann, A. and Gupta, M.M. (1985), “Introduction to fuzzy arithmetic theory and its applications”, Van Nostrand Reinhold Company, New York.
5. Klir, G.J. and Folger, T.A. (1988), “Fuzzy sets, uncertainty, and information”, Prentice Hall, Englewood Cliffs, New Jersey.
6. Zadeh, L.A. (1979), “A theory of approximate reasoning” *Machine Intelligence*, vol. 9, pp 149–194.
7. Gazis, D.C., Herman, R. and Rothery, R.W. (1961), “Nonlinear follow–the–leader models of traffic flow” *Operations Research*, vol. 9, pp 545–567.
8. Chakroborty, P. and Kikuchi, S. (1999). “Evaluation of the General Motors based car-following models and a proposed fuzzy inference model”, *Transportation Research Part C*, vol. 7, pp. 209–235.
9. Chakroborty, P. and Kikuchi, S. (2003), “Calibrating the membership functions of fuzzy inference system: Instantiated by Car–following Data” *Transportation Research Part C*, vol. 11, pp. 91–119.

References II

10. Henn, V. (2000), “Fuzzy route choice model for traffic assignment”, *Fuzzy Sets and Systems*, vol. 116, pp 77–101.
11. Hoogendoorn–Lanser, S. (1998), “Structured modelling of multi – modal urban travel choice behaviour”, 4th TRAIL PhD Congress.
12. Wei, W., Zhang, Y., Mbede, J.B., Zhang, Z. and Song, J. (2001), “Traffic signal control using fuzzy logic and moga”, *IEEE*, vol. 2, pp 1335–1340.
13. Niittymaeki, J. and Maeenpaeae, M. (2001), “The role of fuzzy logic public transport priority in traffic signal control” *Traffic engineering & control, vol. 42, pp* 22–26.
14. Hoogendoorn, S., Hoogendoorn–Lanser, S. and Schuurman, H. (1998), “Fuzzy perspectives in traffic engineering”, Research Report, TRAIL Research School, Delft, report on behalf of Dutch Ministry of Transport.
15. Chen, L.C., May, A.D. and Auslander, D.M. (1990), “Freeway ramp control using fuzzy set theory for inexact reasoning”, *Transportation Research*, vol. 24A, pp 15–25.
16. Hellendoorn, H., and Baudrexl, R. (1995), “Fuzzy neural traffic control and forecasting”. *International Joint Conference Of The 4th IEEE International Conference On Fuzzy Systems and The 2nd International Fuzzy Engineering Symposium IEEE International Conference On Fuzzy Systems*, vol. 4, IEEE, Piscataway, pp 2187–2194.

References III

17. Kirschfink, H., Lange, R. and Jansen, B. (1997), “Monitoring, control and management on the motorway network in Hessen using intelligent traffic modeling”, *Proceedings of the ’97 ITS Word Conference*, Berlin.
18. Busch, F., Cremer, M., Ghio, A. and Henninger, T. (1994), “A multi-model approach for traffic state estimation and incident detection on motorways”, *Proceedings Of The First World Congress On Applications Of Transport Telematics And Intelligent Vehicle-Highway Systems*, Paris, vol. 3, pp 1245–1252.

Thank you!