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

\[ A = \{ x \mid x \in X \} \]

\( x \): 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 $\tilde{A}$ and $\tilde{B}$

Union ( $\tilde{C}$ )

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

Intersection ( $\tilde{D}$ )

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

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

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

$\tilde{A} \cap \overline{\tilde{A}} = \phi$
Fuzzy Inference

- Proposition and Truth Value
- Logical Connectives
- Premise Variable
- Consequence Variable
- Implication and Reasoning

Statement and its degree of truthfulness
A & B; A || B
Prevailing condition/s
Course of action
Implication and Reasoning

Fuzzy inference system

Prevailing conditions \rightarrow \text{Premise variables} \xrightarrow{\text{Rules}} \text{Consequence variable} \rightarrow \text{Course of action}

F.I.S.

Infer
Applications of Fuzzy Logic in Transportation Engineering
Transportation Engineering

Road
- Pavement Engg.
  (Construction and maintenance of roads)
- Traffic flow theory

Rail
- Traffic Engg.
  (Movement of vehicles on roads)
- Transportation planning

Water
- Scheduling and Routing

Air
- Control mechanisms
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

\[
\begin{align*}
\begin{cases}
\dot{x}_{n+1}(t) \\
\ddot{x}_{n+1}(t)
\end{cases}
& \quad \begin{cases}
\dot{x}_n(t) \\
\ddot{x}_n(t)
\end{cases}
\end{align*}
\]

\[x_{n+1}(t) \quad x_n(t)\]

u/s benchmark
Traffic Flow Modelling: Car Following Behaviour

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

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

\(x_i(t)\): 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 \(t\).

\(\Delta t\): 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)

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

- Trip generation
- Trip distribution
- Modal split
- Trip Assignment

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 Maeenpaeeae (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 Baudrexel (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

References II

References III


Thank you