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Title: Mamdani vs. Takagi-Sugeno Fuzzy Inference Systems in the Calibration of Continuous-Time Car-Following Models

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Abstract: The transition to intelligent transportation systems (ITSs) is necessary to improve traffic flow in urban areas and reduce traffic congestion. Traffic modeling simplifies the understanding of the traffic paradigm and helps researchers to estimate traffic behavior and identify appropriate solutions for traffic control. One of the most used traffic models is the car-following model, which aims to control the movement of a vehicle based on the behavior of the vehicle ahead while ensuring collision avoidance. Differences between the simulated and observed model are present because the modeling process is affected by uncertainties. Furthermore, the measurement of traffic parameters also introduces uncertainties through measurement errors. To ensure that a simulation model fully replicates the observed model, it is necessary to have a calibration process that applies the appropriate compensation values to the simulation model parameters to reduce the differences compared to the observed model parameters. Fuzzy inference techniques proved their ability to solve uncertainties in continuous-time models. This article aims to provide a comparative analysis of the application of Mamdani and Takagi-Sugeno fuzzy inference systems (FISs) in the calibration of a continuous-time car-following model by proposing a methodology that allows for parallel data processing and the determination of the simulated model output resulting from the application of both fuzzy techniques. Evaluation of their impact on the follower vehicle considers the running distance and the dynamic safety distance based on the observed behavior of the leader vehicle. In this way, the identification of the appropriate compensation values to be applied to the input of the simulated model has a great impact on the development of autonomous driving solutions, where the real-time processing of sensor data has a crucial impact on establishing the car-following strategy while ensuring collision avoidance. This research performs a simulation experiment in Simulink (MATLAB R2023a, Natick, MA, USA: The MathWorks Inc.) and considers traffic data collected by inductive loops as parameters of the observed model. To emphasize the role of Mamdani and Takagi-Sugeno FISs, a noise injection is applied to the model parameters with the help of a band-limited white-noise Simulink block to simulate sensor measurement errors and errors introduced by the simulation process. A discussion based on performance evaluation follows the simulation experiment, and even though both techniques can be successfully applied in the calibration of the car-following models, the Takagi-Sugeno FIS provides more accurate compensation values, which leads to a closer behavior to the observed model.

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