Literature review on traffic simulation and data assimilation

Traffic simulation can be grouped into macro- meso- and micro-level models, with focus on different levels of abstraction of the system. Ma

Macro level simulations consider the traffic as a continuum of vehicles [1], attempting to classify the average behavior of a system instead of individual vehicles. With traffic flow model which consists of equations for spatial densities, average velocities, macro level simulations study the traffic flow both into and out of the system, in order to help control the traffic or improve the existing traffic management system. The British TRANSYT-program [39] is an example of macroscopic simulation of urban arterial signal control coordination and the American FREQ- and FREFLO-programs [40] plus the corresponding German analysis tool [41] are related to motorway applications. In [42], using a macro-level simulation, INTEGRATION, a set of case studies has been developed to evaluate the proposed architectures for Intelligent Vehicle Highway System (IVHS) program. INTEGRATION is also used in [43] to simulate a 35-km section of Highway 401 in Toronto for better understanding the traffic dynamic behavior.

Micro level simulations regard the traffic as the composition of individual vehicles, focusing on modeling the behaviors of individual vehicles. Compared to macro level models, micro model is more suitable for complex traffic problems, such as intelligent transportation system, congestions and accidents. In addition, it shows more details in the lower level such as driver decision in lane changing and decelerating to avoid accidents, while the macro level model only demonstrates the spatial-temporal dynamics which needs further evaluation for behavior recognition. VISSIM[[1]](#footnote-1) and CORSIM[[2]](#footnote-2) are the most frequently used traffic simulation packages for analysis of traffic and many researchers have made use of them to simulate and validate their models. To name a few, [45] implements a psycho-physical car following model and validate the possibilities of VISSIM on measurement data taken from a German freeway and from a US freeway. In [46], a procedure for simulation model calibration and validation is proposed for microscopic simulation model calibration and validation and an example case study is presented with real-world traffic data from Route 50 on Lee Jackson Highway in Fairfax, Virginia. Similar to [46], a procedure for constructing and calibrating a detailed model of a freeway using VISSIM is presented and applied to a 15-mile stretch of I-210 West in Pasadena, California in [47]. In a more recent research [48], an accurate estimation of traffic states of transportation system has been by using real-time roadway data aggregated at various update intervals. Same as VISSIM, the use of CORSIM can also be found in many literatures. For instance, [49] discuss the test and assess procedure of adaptive traffic signal control algorithm with CORSIM. In addition, with the help of microscopic simulation model CORSIM, the results of simulating the proposed driver distribution generator which determines the desired speed factor and adjusts the driver distribution indicates the need of better model of driver behavior distribution [50]. Other applications of evaluating microscopic models or roadway designs have been proposed in [51-53]. Apart from these two models, INTEGRATION [54, 55], MITSIM [56, 57], WATSIM, PARAMICS [60, 61] and TRANSIMS [62, 63] have also been proposed in many related works so far and the comparison of some of the models can be found in [58, 59].

The compromise will be the meso model, which maintains individual vehicle representation but more aggregated than traffic dynamics [10]. For example, CONTRAM [11] uses nodes and links to represent road network, and the vehicles are grouped into packets that traveling through the links. In [12], DYNAMIT is introduced based on speed-density relationship and queuing model. In this model, lanes are represented in detail only when congestion or queue builds up. It also considers the operation at intersections. DYNASMART [13] extends the model by introducing signalized intersections to model delays at facilities. Other similar models are discussed in [14-17]. Furthermore, the combinations of the models have also been proposed for large-scale simulations in order to balance the efficiency and details. To be specific, hybrid models usually apply the lower level models to model specific areas of interest with details, while simulating the remaining areas in lesser detail on higher level models. Hybrid meso-micro models can be found in [9][18-21] while macro-micro models have been proposed in [22-24]. The open problem of hybrid models is the consistency of different representations of vehicles, road networks and traffic dynamics, and the performance of both sub-models should synchronize with all the parameters such as travel time, road density.

The MovSim, also known as Multi-model open-source vehicular-traffic Simulator[[3]](#footnote-3) [25], we will use in this project is a microscopic traffic simulator. It implements various car-following models such as time continuous models, iterated maps and cellular automata. Some demo applets have been shown on the German computer exhibition CeBIT 2009 and 2010, and also in Wallstreet Journal (July 1, 2005) as well as some TV and Radio broadcasts [25]. This simulator has been released as an open source project, and applied for traffic dynamic research in many existing literatures works. For example, the builder of MovSim, Martin Treiber has utilized this simulator to simulate enhanced Intelligent Driver Model in [26]. In addition, in order to show the consistency between their experimental findings with the proposed theoretical phase diagram they simulate on-ramp, lane closing situations using Intelligent Driver Model in [27]. Other researchers in [28][29] study the intelligent vehicle control strategy based on an multi-objective algorithm. Thanks to the open-source feature of MovSim they can modify the models and employ extra layers for decision making process without much effort.

Much work has been carried out on traffic data assimilation. This is due to the fact that simulation models are commonly used in traffic management, and the fact that a lot of sensor data exist. Various data assimilation methods, also known as filtering algorithms, have been proposed in existing works. Extended Kalman filter (EKF), for instance, has been applied in [2-5] for better estimation of traffic states (vehicle velocity and density). In [2, 3, 5], real-time freeway traffic states are estimated based on a stochastic macro traffic flow model, Lighthill-Whitham-Richards (LWR) partial differential equation (PDE) model [30,31] which has been widely used in traffic flow dynamic analysis. [4] presents traffic states estimation and prediction based on a cell transmission model which is transcribed in a closed analytical state-space form. Unscented Kalman Filter (UKF) as another deterministic filter algorithm has also been applied for traffic state estimation based on a compositional traffic model [6]. Different from EKF, UKF uses weighted samples to represent the target distribution deterministically. Additionally, [7] proposes ensemble Kalman Filter in which a Markov chain Monte Carlo method is applied, using randomly drown samples as the representation of target distribution. All these works use modified Kalman filters which is originally designed for linear behavior. However, the studied traffic flow model, LWR model for instance, is well known as non-linear [1] non-Gaussian [32] behavior. To deal with the non-linear non-gaussian behavior, several works have applied particle filters on data assimilation. These works include [33-38]. In [37, 38] Lyudmila et al, proposes particle filter framework based on a speed extended cell transmission model. To validate the model and verify the performance of Particle Filter (PF), they compare the estimation results between PF and UKF with respect to accuracy and complexity. In [34], particle filter is applied to conduct a muti-step speed prediction using speed measurements based on a combination model of both LWR model and Van Aerde traffic stream model. Similar strategy has been developed in [35], but with a different second-order macroscopic traffic flow model which is derived from microscopic equations [8]. [36] employs cellphone handoff data as measurement of the estimated models to conduct the PF framework. In all these works, the simulation models are models with analytical forms such as LWR LDE, Gas-Kinetic Equation. On the other hand, micro-simulation models gain more and more attention in traffic simulation. Data assimilation using these micro-simulation models makes it possible to have more accurate state estimation for the micro-level traffic phenomenon of interest. (e.g., more accurate simulation of congestion areas). There are some works on data assimilation using micro-simulation models. In [64], a estimation process is proposed which initiates employing the non-analytical microscopic traffic model for particle filter to estimate the number, positions and speeds of unequipped vehicles between an equipped one and another equipped one or a specified point in front. Nevertheless, real world application is very limited due to the fact that micro simulation models do not have analytical form, and that the high dimension state space problem. In previous work, we applied PF to traffic simulation based on the MovSim model [65]. In this paper [65], the dynamic data driven event reconstruction for traffic flow simulation is presented, in which the sequential Monte Carlo methods to assimilate real time sensor data into the simulation model is applied to estimate the traffic states, such as slow vehicles or accidents.

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