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Modeling the impacts of mandatory and discretionary lane-changing maneuvers

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A B S T R A C T

In this paper, a novel mesoscopic multilane model is proposed to enable simultaneous simulation of mandatory and discretionary lane-changing behaviors to realistically capture multilane traffic dynamics. The model considers lane specific fundamental diagrams to simulate dynamic heterogeneous lane flow distributions on expressways. Moreover, different priority levels are identified according to different lane-changing motivations and the corresponding levels of urgency. Then, an algorithm is proposed to estimate the dynamic mandatory and discretionary lane-changing demands. Finally, the lane flow propagation is defined by the reaction law of the demand–supply functions, which can be regarded as an extension of the Incremental-Transfer and/or Priority Incremental-Transfer principles. The proposed mesoscopic multilane cell transmission model is calibrated and validated on a complex weaving section of the State Route 241 freeway in Orange County, California, showing both the positive and negative impact of lane changing maneuvers, e.g., balancing effect and capacity drop, respectively. Moreover, the empirical study verifies that the model requires no additional data other than the cell transmission model does. Thus, the proposed model can be deployed as a simple simulation tool for accessing dynamic mesoscopic multilane traffic state from data available to most management centers, and also the potential application in predicting the impact of traffic incident or lane control strategy.

1. Introduction

The kinematic wave (LWR-KW) model (Lighthill and Whitham, 1955; Richards, 1956) and its discretized version the cell transmission model (CTM) (Daganzo, 1994; Szeto, 2008; Sumalee et al., 2011), which adopt the triangular fundamental diagram (Newell, 1993), is recognized as the simplest means to explain the evolution of traffic dynamics and features. However, these macroscopic models simply assume that traffic flow is uniformly distributed over lanes by integrating traffic streams traveling on different lanes into a single flow stream with uniform lateral distribution (Munjal and Pipes, 1971). This uniform assumption may not be appropriate in the sense that heterogeneous traffic flow distribution, such as lane specific flow, density, speed and vehicle type, can be easily observed on multilane expressways (Carter et al., 1999; Cassidy and Rudjanakanoknad, 2005; Gunay, 2007; Duret et al., 2012). Therefore, single lane traffic models may fail to capture more

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Nomenclature

Calibrated parameters

$v_{f,m}$	free-flow speed of lane m
$w_{c,m}$	wave-back speed of congestion of lane m
$\rho_{c,m}$	critical density of lane m
$\rho_{J,m}$	jam-density of lane m
Q_m	capacity of lane m
$\alpha_0,\ \alpha_1,\ \alpha_2$	parameters of the cumulative distribution function of MLC demand on longitudinal dimension
$c_l,\ c_f$	coefficients associated with the speed difference for evaluating extra leading gap and extra lag gap
$x_c,\ x_r$	remaining distances by which the test section is partitioned as remote, median, and close sections, respectively, with each section corresponds to a specific level of MLC urgency and minimum acceptance criterion
$\bar{g}_{min}$	the minimal safe gap for the subject vehicle provided by the target lane
τ	the average reaction time of lane changing

Variables for dynamics propagation and LC acceptance/rejection assessment

$\rho_{i,m}(k)$	traffic density of *cell* (i, m) at time step k
$v_{i,m}(k)$	traffic speed of *cell* (i, m) at time step k
$s_{i,m}^{i+1}(k)$	the sending function that determines the flow intended to leave *cell* (i, m) and towards downstream *cell package* ($i+1$) involving all possible lanes (e.g. the adjacent lanes $m-1$, $m+1$ and the current lane m), during time interval $[kT_s,(k+1)T_s)$
$R_{i-1}^{i,m}(k)$	the receiving function of *cell* (i, m) towards which traffic flows sent by the upstream *cell package* ($i-1$) are intended to merge during time interval $[kT_s,(k+1)T_s)$
$U_{i-1}^{i,m}(k)$	the total sending function that determines the amount of flow intended to merge to *cell* (i, m) from upstream *cell package* ($i-1$) during time interval $[kT_s,(k+1)T_s)$
$s_{lc,i,m}^{i+1,\beta}(k)$	the sending function of lane-changing flow that intends to leave *cell* (i, m) and towards downstream *cell* ($i+1$, β) during time interval $[kT_s,(k+1)T_s)$ with $\beta=m\pm1$, and the lane-changing intention is of *lc* type, where *lc* = 1, 2 represent the MLC and DLC, respectively
$s_{st,i,m}^{i+1,m}(k)$	the sending function that determines the flow intended to leave *cell* (i, m) and move straightly to the downstream *cell* ($i+1$, m) during time interval $[kT_s,(k+1)T_s)$
$q_{lc,i-1,\alpha}^{i,m}(k)$	the lane-changing flow that left *cell* ($i-1$, α) and received by the downstream target *cell* (i, m) during time interval $[kT_s,(k+1)T_s)$ with $\alpha=m\pm1$ and the lane-changing intention is of *lc* type
$q_{st,i-1,m}^{i,m}(k)$	the flow that left *cell* $(i-1,m)$ and received by the downstream target *cell* (i, m) during time interval $[kT_s,(k+1)T_s)$
$x(k)$	remaining distance from the current position of the subject vehicle to its target turning point
$\tilde{g}_{lc,i-1,\alpha}^{i,m}(k)$	the minimum gap acceptance criterion required by the sending flow of *cell* $(i-1,\alpha)$ towards the target *cell* $(i-1,m)$ during time interval $[kT_s,(k+1)T_s)$ with $\alpha=m\pm1$ and the lane-changing intention is of *lc* type
$\tilde{\phi}_{lc,i-1,\alpha}^{i,m}(k)$	the minimum acceptance criterion factor normalized from $\tilde{g}_{lc,i-1,\alpha}^{i,m}(k)$
$\bar{G}_{i,m}(k)$	the average space gap between the successive vehicles on the *cell* (i,m) at time step k

Variables for determining LC demand and execution

$\tilde{S}_{lc,m}^{tm(r)}(t)$	the estimated total *lc* type lane changing demand from lane m to the terminal lane *tm* at time t at the rth iteration
$L_{1,m}^{\beta(r)}(t,x)$	the estimated cumulative MLC demand at location x of lane m to the target lane β at time t at the rth iteration
$\sigma_m^{\beta}(t)$	traffic state dependent parameter of the cumulative distribution function of MLC demand on longitudinal dimension
$I_{1,m}^{\beta(r)}(k\cdot T_s,x_n-i\cdot l_i)$	the estimated cumulative MLC demand (originally proposed at time step k and position x_n) actually executed at the downstream boundary of cell i at the rth iteration
N_m^{tm}	the number of lanes to be crossed from current lane m to the terminal target lane *tm*

Abbreviation list

DLC	discretionary lane-changing
IT	Incremental-Transfer
LFD	lane flow distribution
MFD	macroscopic fundamental diagram
MLC	mandatory lane-changing
PCE	Passenger Car Equivalent