阪神高速道路 Zen traffic data を用いた合流挙動に関する研究

Analysis of merging behavior at Hanshin Expressway using Zen Traffic Data

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1. Introduction

Lane-changing behavior is an important topic in traffic flow modeling. Drivers need to select an appropriate gap and interact with surrounding vehicles to make lane-changing decisions. This study developed a game theory-based merging model considering car-following behaviors during merging, the decision model was incorporated with car-following models to predict behavior during the entire merging process. Trajectory data from Zen Traffic Data at Hanshin Expressway Ikeda Line was utilized to calibrate and validate the proposed model. The proposed model is expected to be implied in microscopic simulation to evaluate the traffic conditions at merging sections.

2. Methodology

2.1. Game-theory based merging model

The typical merging scene is shown in Fig. 1, with a merging vehicle (MV) on the ramp lane, a preceding vehicle (PV) on the mainline target lane, and an lag vehicle (LV) on the mainline target lane. Lane changing is prohibited on the mainline and LV will not change to another lane.

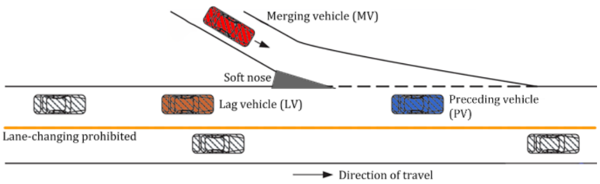

Figure 1 Typical merging scenario

This study considers a simultaneous, two-player, non-zero-sum, non-cooperative game. Player 1 (MV) has 2 strategies: *merge*/*wait*, while Player 2 (LV) has 3 strategies: *yield*/*keep following*/*block*. Thus, there are 6 strategy sets: {*merge-yield, merge-keep following, merge-block, wait-yield, yield-keep following, wait-block*}.

It is assumed that the objective of MV is to avoid collision and to complete merging, a risk indicator derived from time-to-collision is adopted. The objective of LV is to avoid collision and to keep following the mainline PV with as little interruption as possible. The speed difference, risk indicator based on Time-to-collision, as well as MAPE against the predicted trajectories of following MV and PV are adopted to formulate the payoff functions of players.

Table 1 Game formulation

			LV		
			Yield (L_1)	Keep following (L_2)	Block (L_3)
		Probability	p^1_{LV}	p^2_{LV}	p^3_{LV}
MV	Merge (M_1)	p^1_{MV}	(P_{11}, Q_{11})	(P_{12}, Q_{12})	(P_{13}, Q_{13})
	Wait (M_2)	p^2_{MV}	(P_{21}, Q_{21})	(P_{22}, Q_{22})	(P_{23}, Q_{23})

2.2. Car following model for different strategies

It is also assumed that MV and LV that are engaged in a merging interaction will follow different car-following strategies to continuously adjust their acceleration and thus speed to achieve the desired gap in merging. In this study a modified IDM model is adopted. Besides, to reflect the impact of MV on the adjacent lane, a combination of the spacing to both MV and PV is adopted for LV.

3. Model calibration and validation using Zen Traffic Data

Zen Traffic Data (ZTD) of Hanshin Expressway was utilized for model calibration and validation. The data was collected along a section of Hanshin Expressway Ikeda Line (阪神高速池田線), in Osaka City, Osaka Prefecture, during September 2018. The observation site is a ~2.1 km two-lane expressway section with an on-ramp entrance (塚本料金所) in the middle. The eastward direction (bound for Osaka) was observed. The morning peak-hour datasets, 7:00-8:00 am and 7:30-8:30 am, were utilized to calibrate the model.

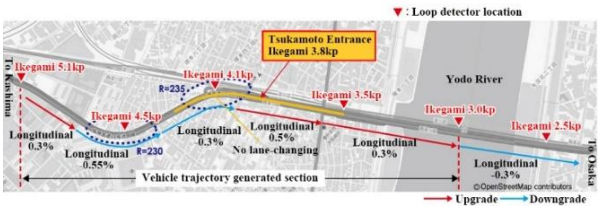

Figure 2 Site map of the study area

First, IDM models are calibrated with mainline outer lane trajectories to reflect the regular behavior, i.e., *keep* *following* strategy of LV.

Then, 363 merging trajectories containing MV, LV and PV are extracted from the dataset. The action of MV can be directly observed from the relative position of MV and surrounding vehicles. And a rule-based method incorporating car-following behavior was adopted to identify the action of LV. We compared the deviation from expected car-following trajectory of LV with the observed data.

a)　If the MAPE against observed speed and IDM-predicted speed were under 10% threshold (indicating that the observed trajectory was similar enough to ideal car-following behavior), it was identified as keep following.
b)　If the MAPE was over 10% threshold, and the observed spacing between LV and PV was smaller than IDM-predicted gap at the end of merging process (indicating that there is a reduced gap compared to regular following), it was identified as block.
c)　If the MAPE was over 10% threshold, and the observed spacing was larger than the IDM-predicted gap (indicating an increased gap compared to regular following), it was identified as yield.

Among 363 trajectories, 319 MV-merge, 44 MV-wait, 206 LV-yield, 144 LV keep following, and 13 LV-block are identified. It can be found that in most cases ramp cars can successfully merge into mainline in a single merging attempt, and few mainline cars tend to refuse the merging.

Table 3 Summary of vehicle actions

Action type	N of observations	Percentage
Merge-Yield	188	51.8%
Merge-Keep following	125	34.4%
Merge-Block	6	1.7%
Wait-Yield	18	5.0%
Wait-Keep following	19	5.2%
Wait-Block	7	1.9%
MV Merge	319	87.9%
MV Wait	44	12.1%
LV Yield	206	56.7%
LV Keep following	144	39.7%
LV Block	13	3.6%

Utilizing the identification result, car following parameters under different strategies are also calibrated. It can be found that:

a)　Drivers on Hanshin Expressway tended to drive over the speed limit and showed a more aggressive behavior with shorter headway and higher acceptable braking rate. compared with IDM typical value
b)　During the merging process, drivers under all three strategies tended to keep a shorter standstill distance. *Yield* LV tends to keep a longer headway to give a spacing, while MV and *block* LV or tends to keep a much shorter headway to reduce the spacing.

Table 2 Car following parameters for different strategies.

Parameter	Mainline	LV-yield	LV-block	MV-merge	MV-wait
desired speed v_0 [m/s]			22.52		
standstill distance s_0 [m]	2.55	1.63	1.51	1.19	
minimum headway t_0 [s]	1.15	2.09	0.41	0.62	
maximum acceleration a [m/s^2]			0.74		
comfortable brake rate b [m/s^2]			2.33		
weight of spacing k	-	0.34	0.37	-	
waiting brake rate [m/s^2]					-0.4

A bi-level programming method proposed by Liu (2007) was adopted to estimate the game model parameters. The upper-level programming was a non-linear programming problem, to minimize the error between the observed and the predicted actions. The lower-level programming seeks the solution for the Nash equilibrium. 254 out of 363 (70%) observations were randomly selected for calibration, and the remaining data was used for cross validation.

We found that the model could successfully predict 95.5% of MV behavior and performed well for the *merge* strategy. The model could also predict 75.2% of LV behavior, the performance for *yield* and *keep following* was acceptable while performance for *block* was not so good due to the small sample size.

Besides, Sobol sensitivity analysis is also conducted. The constant term in MV's payoff under *merge-keep following* strategy, coefficients of risk factor in LV's payoff under *merge-yield* and *merge-block* strategy are the 3 parameters with highest sensitivity score. It means that these factors in drivers' mind contribute most to the change in drivers' decisions.

4.　Conclusion

This paper describes a game-theory-based model incorporating car-following behavior for merging-section modelling. Models were calibrated with ZTD data. The validation indicated that the proposed model has reasonable capability in both decision-making prediction and trajectory prediction.

Since the sample size was not large enough, the block strategy of LV was rarely observed, resulting in a relatively lower prediction rate for LV in the model. In future, more observation data will be required.

Reference

1)　阪神高速道路（株）:Zen Traffic Data，http://zen-trafficdata.net/
2)　Liu et al., A game theoretical approach for modelling merging and yielding behaviour at freeway on-ramp sections, 2007.