Australasian Transport Research Forum 2021 Proceedings
8-10 December, Brisbane, Australia
Publication website: http://www.atrf.info

Crash risks during mandatory lane-changing manoeuvres in a connected environment

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1. Introduction

A connected environment offers 360º awareness of hazards and situations that drivers cannot foresee. Such information (or awareness) will substantially change how humans drive and can help in solving massive road transport issues in traffic congestion, road safety, energy consumption, and greenhouse gas emissions. More specifically, driving aids provided by a connected environment are expected to assist during the lane-changing decision-making process, which affects traffic flow characteristics and traffic safety. For instance, sideswipe crashes accounted for about 3% of the Fatal crashes in 2018 in Queensland, Australia (DTMR, 2019). Besides, lane-changing has been frequently reported to link with capacity drops (Cassidy and Rudjanakanoknad, 2005). Recognising such profound effects of lane-changing on both traffic flow characteristics and traffic safety, there is a growing interest from researchers in understanding, analysing, and modelling lane-changing behaviour.

Lane-changing is often classified as mandatory lane-changing and discretionary lane-changing. While the former refers to the compulsory nature of lane-changing that must be performed to reach a planned destination (e.g., entering and exiting a motorway, etc.), the latter is mainly performed to gain better driving conditions (e.g., speed gain, avoiding a slow-moving truck, etc.). Mandatory lane-changing generally poses a greater risk on traffic, and thus, this study focusses on mandatory lane-changing.

A mandatory lane-changing manoeuvre requires a driver to maintain a safe gap in the current lane, properly judge the positions and speeds of surrounding vehicles in the target lane, and efficiently communicate the lane-changing intention with other drivers. These altogether elevate mental pressure and make the lane-changing decision-making process more error-prone, thereby increasing crash risk. To this end, driving aids provided by a connected vehicle environment could be beneficial in reducing mental workload and uncertainty associated with mandatory lane-changing. More specifically, a driver would be assisted with information about driving conditions in the current lane and surrounding traffic information in the target lane, which can minimise crash risk during mandatory lane-changing.

Many studies have shown the effectiveness of a connected environment at an individual driver level and at a network level, evidence of the efficacy of a connected environment in minimising crash risk during mandatory lane-changing is scant, primarily because unavailability of crash data (which accrue slowly) in a connected environment. Given the paucity of crash data in a connected environment, this study aims to evaluate the safety benefits in terms of quantifying the crash risk by utilising more frequent (or observable) events and applying traffic conflict techniques that can provide information on the likelihood of crash occurrence, as elaborated below. In particular, a Block Maxima (BM) approach, corresponding to Generalised Extreme Value distribution, is adopted herein (to estimate and compare crash risk during mandatory lane-changing manoeuvres using the trajectory data obtained from an advanced driving simulator experiment. The BM approach is often preferred because of its ability to account for serial-dependency during its parameter estimation procedure automatically.

2. Experimental Design and Data Collection

A mandatory lane-changing scenario was designed in the driving simulator experiment where participants were asked to perform a mandatory lane-changing manoeuvre and exposed to lane-changing crash risk. Participants drove in three randomised driving conditions: (i) baseline driving condition, reflecting a traditional environment; (ii) a connected environment with perfect communication (PC); and (iii) a connected environment with communication delay (CD).

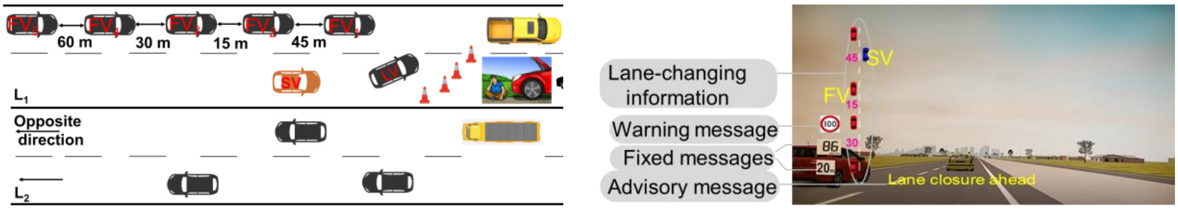
The high-quality vehicle trajectory data were collected using the Centre for Accident Research and Road Safety-Queensland (CARRS-Q) advanced driving simulator. More details of driving simulator can be found in Ali et al. (2020).

Seventy-eight participants were recruited to participate in the experiment. The mean age of the participants was 30.8 years (standard deviation [SD] 11.70 years), and 64% of the participants were male. As a mandatory requirement, all the participants possessed a valid Australian driving licence at the time of the experiment, and their mean driving experience was 12.2 (SD 11.5) years.

2.1 Scenario design

This study designed a hypothetical 3.2 km long four-lane motorway with two lanes in each direction with the posted speed limit of 100 km/h. Following the standard road design in Australia, roadway geometric features, lane markings, and road signs along the motorway were carefully designed in the simulator experiment.

About 500 m away from the start of the scenario, a lane closure was placed (that is, lane closure due to a broken vehicle or work zone) in the current lane (see Figure 1(a)). As a result, drivers were forced to perform a mandatory lane-changing manoeuvre and faced five opportunities in the target (or adjacent) lane. The following vehicles in the target lane were scripted to mimic a real driver response to a lane-changing request: accelerate to avoid a lane-changing action, decelerate to show courtesy, and remain unaffected to a lane-changing request.



(a) Design of a mandatory lane-changing event (b) Design of the connected environment

Figure 1: Schematic of experiment design

Note that the design of mandatory lane-changing in the experiment remained the same for all driving scenarios (i.e., baseline, connected environment with perfect communication and communication delay), whereas the only difference is the dissemination of information in connected environment driving conditions, as elaborated below.

To assist during mandatory lane-changing manoeuvres, the connected environment provided four types of driving aids, namely, fixed messages, advisory messages, warning messages, and lane-changing gap messages (see Figure 1(b)). Finally, a lane-changing message on the left side of the windscreen appeared with a beep sound, providing information on the available gaps in the target lane.

The driving aids described above remained the same in both connected environment driving conditions, i.e., perfect communication (PC) and communication delay (CD). However, the driving aids in the CD scenario were delayed by 1.5 s, reflecting an impaired communication system. This delay of 1.5 s was selected based on a pilot testing where different delays were tested ranging from 0.5 s to 2.5 s, and the minimum delay was selected when the participants started to notice a delay in the supply of driving aids. Of note, the delay of 1.5 s is also found to be concurrent with a previous study that reported that any delay of 1.5 s or more in the supply of information negatively affects traffic safety (Talebpour et al., 2016).

2.2 Dataset

Recall that most previous studies do not use driving behavioural factors while developing Extreme Value Theory (EVT) models except Farah and Azevedo (Farah and Azevedo, 2017), rather using aggregated traffic information. To this end, this study utilises driving behavioural factors as an input to EVT models, and they include speed, spacing, remaining distance, and lag gap. In this study, 78 participants performed mandatory lane-changing manoeuvres in three conditions (i.e., baseline, PC, and CD), which resulted in 234 trajectories. However, four participants were unable to perform the third drive, and as such, 230 trajectories were used for analysis.

2.3 Block Maxima model development

The Block Maxima (BM) approach, corresponding to Generalised Extreme Value (GEV) distribution, is selected in this study. While applying the BM approach, a necessary step is to aggregate observations into fixed intervals maintained in time and space, forming a block. The maxima (or minima) of a specified block are often selected and treated as extremes. Let $X_1, X_2, .., X_n$ be a set of independent and identically distributed random observations having a common distribution function $F(x) = Pr\ (X_i \leq x)$, the maximum $M_n = max\ (X_1, X_2, .., X_n)$ converges to a GEV distribution given that $n\ \rightarrow \infty$ (Zheng et al., 2014). Mathematically, the GEV function can be written as

$$G(x) = exp\left\{-\left[1 + \xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\} \tag{1}$$

where, $-\infty < \mu < \infty$ indicates the location parameter, $\sigma > 0$ denotes the scale parameter, and $-\infty < \xi < \infty$ represents the shape parameter of a GEV distribution.

To develop a conflict–crash relationship using the EV approach, a conflict needs to be identified by applying traffic conflict techniques. This study adopts gap time for lane-changing (GT_{LC})—a variant of time-to-collision—that is described as "*the elapsed time between the expected completion time of mandatory lane-changing for the subject vehicle (t_1) and the expected time for the following vehicle to arrive at the mandatory lane-changing point (t_2)* (Gettman and Head, 2003, Ali et al., 2019)". GT_{LC} can be calculated as the difference of two times, $GT_{LC} = t_2 - t_1$.

To overcome the non-stationarity issue, covariates can be included in either the location parameter or the scale parameter of a GEV model using the identity link function. In this study, however, we found that models with covariates included in the location parameter of the GEV model outperformed its counterpart in terms of goodness-of-fit measures, and this is also in line with findings of earlier studies (e.g., (Songchitruksa and Tarko, 2006) and Zheng et al. (2014)).

More specifically, the location parameter can be written as

$$\mu_i = \mu_0 + \boldsymbol{\beta}_1 \boldsymbol{\gamma}_1 \tag{2}$$

where, μ_i is the location parameter of a GEV distribution of driving condition i, $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ respectively indicate the vectors of estimated parameters and covariates. The list of covariates included in the model is presented in the previous section.

To develop a crash–conflict relationship, a GEV distribution is fitted to more observable levels or conflicts (commonly identified by a suitable conflict measure). To examine the crash risk in different scenarios, $\mathrm{GT_{LC}}$ is selected as a conflict measure. If $\mathrm{GT_{LC}} \leq 0$, the trajectory of the subject vehicle in the current lane will overlap with the trajectory of the following vehicle in the target lane, representing a collision. For the sake of convenience and to be concurrent with the literature (Zheng et al., 2014), negated $\mathrm{GT_{LC}}$ values are modelled using a GEV distribution, and a potential collision is identified when negated $\mathrm{GT_{LC}} \geq 0$. This risk of collision, in case of mandatory lane-changing, can be obtained from the tail region of a GEV distribution as follows (Songchitruksa and Tarko, 2006)

$$R = Pr(Z \ \geq 0) = 1 - G(0) \tag{3}$$

where, R and Z denote the risk of collision and the maximum negated $\mathrm{GT_{LC}}$ respectively, and $G(\cdot)$ is the GEV distribution.

3. Results

3.1 GEV model development

Table 1 presents the best selected (and parsimonious) model for each driving condition. The AIC (BIC) values of the baseline, perfect communication (PC) and communication delay (CD) models are 1704 (1732), 1738 (1765) and 1775 (1803), respectively. Using the estimated GEV distributions for different driving conditions, the crash risk during the mandatory lane-changing manoeuvre has been computed. Note that crash risk in the context of this study can be defined as the probability of a driver engaging in a mandatory lane-changing crash with the immediate follower in the target lane. As shown in Figure 2, the GEV estimated crash risk for the baseline condition is 0.457 (calculated using Equation 3), whereas the corresponding crash risks for perfect communicaiton and communication delay driving conditions are 0.201 and 0.328, respectively. While the crash risk in the communication delay driving condition is lower than the baseline condition, it is found to be higher than that of the perfect communication condition. Overall, the presence of driving aids (either working perfectly or impaired) has been found to reduce the crash risk significantly compared to no driving aids, with a 2.3 times reduction in crash risk in the perfect communication condition than the baseline. This finding suggests the efficacy and potential of the connected environment in minimising mandatory lane-changing crash risk.

Table 1. GEV model estimation results

Model	Location (μ)					Scale (σ)	Shape (ξ)	AIC	BIC
	μ_0	$\mu_{Spacing}$	μ_{RD}	μ_{Speed}	$\mu_{Lag\ gap}$				
Baseline	-7.718	-0.057	-0.007	0.091	-0.018	2.635	-0.766	1704	1732
PC	-10.661	-0.097	-0.004	0.008	-0.021	3.408	-0.919	1738	1765
CD	-6.170	-0.031	-0.011	0.013	-0.030	2.759	-0.855	1775	1803

PC: perfect communication; CD: communication delay; RD: remaining distance; AIC: Akaike information criterion; BIC: Bayesian information criterion

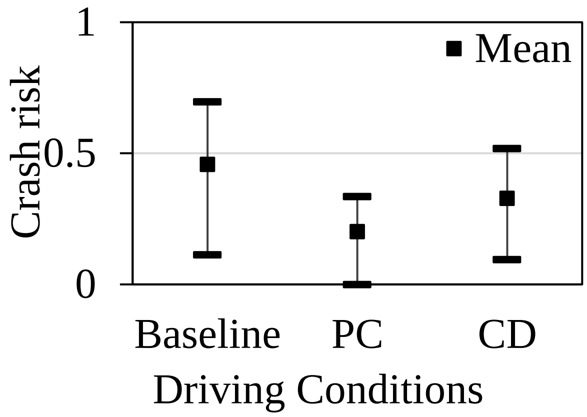


Figure 2. Crash risk during a mandatory lane-changing manoeuvre; PC: perfect communication; CD: communication delay

4. Conclusions

This study developed crash–conflict relationships and quantified the mandatory lane-changing crash risk in a connected environment by using the Extreme Value Theory approach. By utilising the high-quality trajectory data of 78 participants collected through the advanced driving simulator experiment, three separate models for each driving condition (i.e., baseline, perfect communication, and communication delay) were developed and compared by incorporating driving behavioural factors. More specifically, speed, spacing, lag gap in the target lane, and remaining distance were used as covariates, reflecting the mandatory lane-changing decision-making process. The concept of crash risk was employed to quantify the crash risks. Results reveal that in the connected environment driving conditions, the mandatory lane-changing crash risk is significantly reduced compared to the baseline, with the highest reduction observed in the perfect communication condition. The crash risk is found to be higher in the communication delay condition compared with the perfect communication condition. This study analyses lane-changing crashes on motorways; however, lane-changing crashes in Queensland are prevalent on roads with speed limits of 60 or 70 km/h, which should be investigated. Note that this study did not analyse the crash risk associated with different age groups. Such work is ongoing.

References

Ali, Y., Bliemer, M. C., Zheng, Z. and Haque, M. M. 2020. Comparing the usefulness of real-time driving aids in a connected environment during mandatory and discretionary lane-changing manoeuvres. *Transportation research part C: emerging technologies,* 121**,** 102871.

Ali, Y., Haque, M. M., Zheng, Z., Washington, S. and Yildirimoglu, M. 2019. A hazard-based duration model to quantify the impact of connected driving environment on safety during mandatory lane-changing. *Transportation Research Part C: Emerging Technologies,* 106**,** 113-131.

Cassidy, M. J. and Rudjanakanoknad, J. 2005. Increasing the capacity of an isolated merge by metering its on-ramp. *Transportation Research Part B: Methodological,* 39 (10)**,** 896-913.

Dtmr 2019. 2019 Summary Road Crash Report, Queensland Road Fatalities. Customer Services, Safety & Regulation Division, Department of Transport and Main Roads, Brisbane, Australia: Queensland Transport.

Gettman, D. and Head, L. 2003. Surrogate safety measures from traffic simulation models. *Transportation Research Record,* 1840 (1)**,** 104-115.

Songchitruksa, P. and Tarko, A. P. 2006. The extreme value theory approach to safety estimation. *Accident Analysis & Prevention,* 38 (4)**,** 811-822.

Talebpour, A., Mahmassani, H. S. and Bustamante, F. E. 2016. Modeling driver behavior in a connected environment: Integrated microscopic simulation of traffic and mobile wireless telecommunication systems. *Transportation Research Record,* 2560 (1)**,** 75-86.

Zheng, L., Ismail, K. and Meng, X. 2014. Freeway safety estimation using extreme value theory approaches: A comparative study. *Accident Analysis & Prevention,* 62**,** 32-41.