Examination of Lane Changing Duration Time on Expressway

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Abstract. Lane changing (LC) manoeuvre has been regarded as an essential characteristic of driving behaviour, which mostly influences traffic efficiency and safety. Thus, a wrongful performance of LC could lead to accident occurrence in the form of rear-end, sideswipe, or angled crash. Consequently, to develop countermeasures to minimize events associated with LC, an understanding of drivers' behaviours during LC manoeuvres and its duration are essential. This study explores into characteristics of drivers’ LC duration time along Kuala Lumpur – Seremban expressway. Data were collected along a selected segment using an instrumented vehicle. A passenger car was instrumented with a Video Velocity Box (VBox), which used video recording of field traffic event. Hence, VBox attached to the test vehicle was used for recording LC manoeuvres in the field after which the video records were played back in a computer to estimate the LC duration times. A total of 174 LC manoeuvre incidences were observed in this study, the LC duration times of the observed motorists' LC events ranged from 0.90 to 10.52 seconds with mean and standard deviation values of 3.02 and 1.32 seconds, respectively. Out of 174 sampled drivers, an approximate of 162 representing 93% performed LC manoeuvre in less than 5.0 seconds with most of them executed in less than 3.0 seconds. This implies that more than 90% of the drivers observed are characterized by an aggressive LC driving behaviour. It was also found that the LC duration times data obtained in this study fits a Lognormal distribution reasonably.

1. Introduction
Lane changing manoeuvre (LC) is referred to as a driving manoeuvre in which a vehicle moves from one lane to another where both lanes have the same travel direction [1-2]. However, the term LC does not involve lateral movement onto the roadway’s shoulder or into an oncoming travel lane. It is an event that is commonly associated with multilane highways or expressways. Lane changing is classified as mandatory or discretionary. The mandatory lane changing is performed when the driver must leave the current lane (to use an off-ramp or avoid a lane blockage) while the discretionary lane changing is performed when the driver perceives driving conditions are better in the target lane [3]. The discretionary LC is deemed essential when the speed of the leader is below the desired speed of the follower. Thus, the following driver then checks the opportunity to increase speed by moving to a neighboring lane in an attempt to acquire speed or queue advantage as adjacent lane allows for faster travel speed or having a shorter queue. Generally, LC allows the driver to change lane to pass a slower lead vehicle to maintain the current speed [4].
The choice of lane changing performance may be affected by set factors; these include the emergence of the following vehicle, the surrounding traffic impact, and the driver's behaviour [5]. Lane changing is one of the most sensible characteristics of driving behavior, which mostly impacts on traffic efficiency and safety [6]. Hence, performance of LC in an unsafe manner could lead to a rear-end, sideswipe, or angled crash [7]. Therefore, to develop countermeasures to minimize events associated with LC, an understanding of drivers' behaviors and their timing are essential [1]. Earlier transportation studies estimated that LC crashes account for 4 to 10% of all crashes [8–10].

Recently, researchers have shown an increased interest in lane changing behavior and with more attention to lane changing safety. More recently, concerns were raised by several researchers through models’ development for the determination of the LC duration time. These models depend on many factors; which include drivers' behavior, relative speed and so forth. Among these factors, the driver’s behavior is regarded as the most important, which directly affects the lane changing parameters [11]. Despite the existing models’ accuracy, there is a difference between the European and Asian drivers’ behavior; hence, the models specific could be considerably affected by the drivers’ disparity. This paper examines the characteristics of LC duration time for Malaysian drivers.

While a variety of definitions for the term lane changing duration-time were suggested; for the purpose of this study, the definition based on Toledo and Zohar, would be utilized [12]. These authors defined LC duration time as the interval between the instance of initiation of lane changing and the moment when a vehicle completely crossed the lane marks and entered into the target lane. This time is significant for the understanding of driver’s behavior during lane changing event. Driver’s initiation of steering input with the intention of changing the direction of the vehicle relative to the lane has been the criterion that was predominantly used to establish lane changing initiation [13].

The execution of LC is an essential process utilized to identify the influencing factors leading to the different durations of lane changing manoeuvre. However, the difference in duration time of LC indicates that the oversight of the event’s execution may have a significant influence on traffic process and safety [14] and related to the drivers' behavior. An earlier study showed that LC duration time is longer when the movement is to avoid a dangerous situation or when the task is complicated by the interrelationship between the subject vehicle and the surrounding vehicles. Such a situation can be quantified by traffic conflict [14]. Globally, several studies were conducted on the estimation of LC duration time using different techniques. A brief review and findings of some previous studies relating to the measurement of LC duration time are as follows.

Among the earlier studies was conducted by [15]. They evaluated drivers’ LC duration time on the multilane highway using an aerial imaging technique. Finding from this study revealed that the LC duration time of the sampled drivers ranged from 1.25 to 1.95 second (s). Finnegan and Green reviewed articles on tasks associated with LC and estimates on LC duration time conducted in the USA. The results obtained from the reviewed articles were subsequently incorporated into a model that was utilized for prediction time required for completion of LC [16]. This research discovered that LC duration time ranged between 4.9 and 7.6 s. In another research on LC crashes to guide the development of Intelligent Vehicle Highway System (IVHS) crash avoidance system, Chovan examined LC crashes as well as LC duration. A model was then developed and exercised under various conditions of LC scenarios. It was found that LC duration time ranged from 2.0 to 16 s [17].

Moreover, Shannon, examined driver’s lane changing behavior as well as the potential effectiveness of five warning onset rules for lane changing or side crash avoidance system (SCAS) technologies for the evaluation of potential warning onset rules or algorithms of driver’s intent to change lanes. Data for this study were collected through the use of a field observer. The study discovered that LC duration time ranged between 3.4 and 13.6 s [18].

Hanowski, who examined the impact of local/short haul operations on driver’s fatigue with regard to lane changing. This study found that LC duration time ranged from 1.1 to 16.5 s [19]. In another investigation [20], a time course of lane changing in terms of driver’s control and eye movement behaviour was evaluated with the aid of a simulator. The average lane changing duration time of the tested samples was found as 5.14 s. In an examination of naturalistic lane-changes, Lee, provide a useful insight on the nature and severity of lane changes in a real driving environment using an instrumented vehicle approach. In this study, 16 sampled commuters drove two vehicles, after which a concept of safety envelope for lane changes was developed using forward and rearward area analyses. Find from this revealed a LC duration time of 6.3 s. in an attempt to examine lane changing decision among
drivers, a study on eye glance behavior of van and passenger car was conducted. Each of the sampled
drivers used an instrumented vehicle and was accompanied by a ride-along observer during a daylight
period and dry pavement conditions. The study was conducted on both urban streets and highways. This
study discovered that LC duration time for urban streets and highways ranged from 3.5 to 6.5 s and 3.5
to 8.5 s, respectively [13].

In an investigation on lane changing execution under heavy traffic condition, Moridpour et al
examined the LC execution process of heavy vehicles on freeways. They related it to LC duration, speed
and acceleration. Further, an analysis of lane-change execution characteristics of heavy vehicles and
passenger cars was made with an emphasis on the acceleration and deceleration behaviors during the
lane-change execution process and proposed specific acceleration and deceleration models for heavy
vehicles and passenger cars. This study established a lane change duration in the range of 1.1 to 8.9 s
for passenger cars [21]. In an exploration of lane changing duration, Cao, attempted to find the relation
and interaction between the subject and surrounding vehicles during lane changing process from an
arterial road in Melbourne through a video recording technique. Subsequently, a model was developed
and applied for examining passenger cars and heavy vehicles. Results from this study indicated that the
LC duration time for passenger cars and heavy vehicles ranged from 1.0 to 6.8 s and 2.0 to 9.8 s,
respectively [14].

The earlier studies on LC duration time reported herein varied widely as they ranged from as low as
1.0 s to as high as 16.5 s. This relatively wide variation could be attributed to the fact that some of the
studies were conducted on different vehicles’ categories, roads’ types, as well as under different drivers’
behavior. Most of the earlier studies on lane changing duration presented here were carried out in
Europe and the United States of America with very rare ones focusing on Asian drivers. For the fact
that motorists’ behavior varies in many parts of the world, a vital issue of concern is that there is scanty
literature on lane changing duration time on Malaysian traffic condition since drivers’ behavior varies
from one part of the worth to another. Hence, this study attempts to examine drivers’ lane changing
duration time using a representative Malaysian multilane highway using an instrumented vehicle. This
could provide invaluable information as well as more insight on lane changing duration time
characteristics as related to the Malaysian traffic condition and motorists’ behavior.

2. Methodology

2.1. Study area

For the fact that lane changing (LC) manoeuvre is associated with multilane highways, this study
utilized a representative segment along Kuala Lumpur – Seremban expressway, Malaysia. Figure 1
depicts the location of the study site used in work as extracted from Google map. The expressway
comprises of three lanes (having a lane width of 3.70 m for each) in each traffic direction along which
the posted speed is mostly 110 km/h. The basis for the choice of the study segment along Kuala Lumpur
– Seremban expressway is that the facility is mainly in good condition with considerable traffic volume
as it links many parts of Malaysia to the capital city. Further, the traffic volume on the route comprises
of varying vehicles categories with reasonable incidences of LC manoeuvres due to the presence of on-
and off-ramps within the chosen study segment. This would allow for observing a reasonable sample
of LC events sufficient for analysis.
2.2. Estimation of lane changing duration time

Estimation of LC duration time depends on the event’s initiation. It is, however challenging to
distinguish the actual LC initiation point accurately. This study used the vehicle's lane cross shift, which
can be observed because of the lateral distance of the vehicle's tire relative to the longitudinal lane
marking. Specifically, once a lane-changer initiates an LC manoeuvre, the lane lateral shift value will
increase drastically, and as soon as the vehicle entirely crosses the lane marking, the LC is deemed
accomplished [22]. Gurupackiam, refers to LC duration as the time required for a vehicle to execute an
LC manoeuvre safely (wholly transiting from the origin lane to the target lane) [23].

For the purpose of this study, LC duration starts when the front tire of the following vehicle crosses
the lane marking and finishes when the following vehicle completely crossed to the target lane. Thus,
the LC duration time is estimated using equation (1).

\[ t = t_{fe} - t_{fs} \]  

where, \( t \) is the lane changing duration time (sec), \( t_{fs} \) is the elapsed time at the start of lane changing
(sec), and \( t_{fe} \) is the elapsed time at the end of lane changing (sec).

2.3. Data Collection and Processing

As stated in the preceding section, data for this study were collected on segment situated along Kuala
Lumpur – Seremban expressway. Data for the study were collected during the daylight period under
varying traffic conditions and good weather. The data on LC duration time was collected with the aid
of an instrumented vehicle. A typical passenger car instrumented with a Video Velocity Box (VBox)
was used for the data sampling. A VBox is an on-board data recording system used for measuring
traffic event, speed of the instrumented vehicle, acceleration, and lap timing, among other things. It
consists of a VBox video recorder, 10Hz GPS data logger (with an external antenna), two video cameras
(used for recording desired direction events), SD card, and a microphone. For the purpose of this
research, the VBox camera (being fixed on the instrumented vehicle and facing backwards) was used
for the recording of LC events as the test vehicle traverses the road study segment. The VBox version
(RLVBVD10LT) used in this research recorded the traffic events and logged the recorded data onto the
SD card inserted into the system at 10 Hz [24]. Equally, a previous study [25] utilized the VBox system
for collection of traffic data on platooning on two-lane highways, and the system was found promising
in traffic data sampling. Figure 2 shows the VBox system and its accessories being connected to the
test car.
In the course of the data collection, the instrumented vehicle traversed the study segment for approximately 35 minutes (depending on the traffic situation) over a distance of 50.2 km. As mentioned earlier, the chosen segment has three lanes on which mostly the posted speed being 110 km/h including a reasonable number of on and off-ramps with frequent lane changing manoeuvres. To collect the required data, the instrumented vehicle was drove on the selected segment with VBox system’s video camera being fixed on the vehicle’s rear windscreen to capture the following vehicles’ LC events. The VBox video camera having a resolution of 720 x 576 pixels was fixed on the vehicle such that it covered the entire trajectory of vehicles involved in LC manoeuvre. It is essential to mention that the video recording camera fixed on the instrumented vehicle was mounted in a hidden place from the view of other drivers in order not to influence their driving behaviour. Each time the instrumented vehicle traversed the study segment, the traffic events within was recorded by the video camera attached to the VBox system. During the video recording process, the GPS data logger registered the position and speed of the instrumented vehicle at any instant.

During the data collection for this study, a total number of 188 LC manoeuvres were observed. It was however noted that out of this number, 14 LC manoeuvres were executed at on- and off-ramp sections while some others were carried in succession, as such these were excluded. Therefore, a total of 174 LC manoeuvres were used for the analysis. This data refinement process is consistent with the approach adopted by [26]. These authors suggested the exclusion of vehicles creating multiple lane changes for analysis so as to exclude likely mandatory LC manoeuvres. It is worthy to mention that only passenger cars involved in LC manoeuvres were considered in this study. Heavy vehicles and motorcycles were excluded as they are completely characterized by different LC manoeuvres behaviour. Significantly, heavy vehicles being associated with low travel speed commonly used the outermost lanes; hence, their LC behaviour would certainly be different from those of passenger cars. Likewise, the proportion of motorcycles on intercity expressways is usually very small relative to that on urban roads. In the current study, the combined proportion of both heavy vehicles and motorcycles were found to be trivial in the traffic stream as they only constitute 3.5 per cent. All data collection processes were made using the instrumented vehicle with the aid of video camera fixed to the VBox system, which was utilized for the video recording of field traffic events.

After the completion of the field recorded traffic events, the video was subsequently uploaded and played back in a computer to extract the required data. During the playback of the recorded video, information extracted via visual observation include; LC manoeuvres, speed of the instrumented vehicle (displayed during the playback), and following vehicle’s LC duration time. The LC duration time ($t$) for the following vehicle was estimated as the interval between the elapsed time at the start of lane changing ($t_{fs}$) and the elapsed time at the end of lane changing ($t_{fe}$) based on equation (1). The terms $t_{fs}$ and $t_{fe}$ were determined through the extraction of relevant information from the field video recorded traffic events on LC manoeuvres as soon as the subject vehicle started to change lane and completed, respectively. Information on the LC duration time was determined with the aid of
longitudinal lane markings as captured in the field video recorded traffic events. Further, for better accuracy, automatic screenshot programme was used to capture all incidences of vehicle’s lateral movements within an interval of 0.5 sec.

3. Results and discussions
As stated earlier, a total number of 174 LC manoeuvre incidences were observed in this work. To have more insights into the characteristics of LC duration times associated with observed samples, the data was segregated into intervals to establish the drivers’ proportion within each interval. Table 1 presents the LC duration times and drivers’ proportion corresponding to each duration time’s interval.

| LC Duration Time (sec) | Number of Vehicles | Proportion (%) |
|------------------------|--------------------|----------------|
| ≤ 1.0                  | 1                  | 0.57           |
| 1.1 – 3.0              | 96                 | 55.17          |
| 3.1 – 5.0              | 65                 | 37.36          |
| 5.1 – 7.0              | 9                  | 5.17           |
| 7.1 – 9.0              | 2                  | 1.15           |
| 9.1 – 11.0             | 1                  | 0.57           |
| Total                  | 174                | 100            |

The results in table 1 indicated that an approximate 55% and 37% of the sampled drivers performed LC manoeuvres within duration times of 1.1 to 3.0 seconds and 3.1 to 5.0 seconds, respectively. Likewise, about 93% performed LC manoeuvres within duration times of less than 5.0 seconds. This finding indicates that a substantial proportion of the sampled motorists executed LC manoeuvres within a short duration. This indicates level of aggressive LC driving behaviour which could be attributed to high speed during the LC manoeuvre. The aggressive LC driving behaviour recorded with the sampled motorists is not surprising as it was earlier demonstrated that Malaysian drivers are associated with level of aggressiveness driving behaviour [27].

A simple statistical analysis revealed that the LC duration times of all sampled vehicles in this study ranged from 0.90 to 10.52 seconds. Whereas, the mean and standard deviation were estimated at 3.02 and 1.32 seconds, respectively. The range of the LC duration time recorded in this research was found to be with those reported in the existing pieces of literature [12,19, 21, 28]. However, most proportion of the LC duration times recorded in this work was executed within a short time interval, which is an indication level of aggressive LC driving behaviour as stated in [27]. Moreover, Figure 3 illustrates the variation of LC duration time with the frequency of the observed motorists as well as the statistical trend. Shorter LC durations are suspected to be associated with high speed drivers as against longer durations associated with low speed drivers. However, this claim requires more data to draw a reliable inference. Based on the computed mean (3.02 sec) and standard deviation (1.32 sec) of the LC duration times, it was found that the data fit a Lognormal reasonably distribution defined by equation (2). Thus, the fitness of the data to the Lognormal distribution suggests that LC duration times are non-negative.

\[
n(x, \mu, \sigma) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}
\]  

Where, \( \mu \) is the mean and \( \sigma \) is the standard deviation of the observed samples.
4. Conclusions
This study examined the characteristics of lane changing (LC) duration time on one representative segments along Kuala Lumpur – Seremban expressway in Malaysia using an instrumented test vehicle approach. Based on the study conducted and results obtained, the key findings from the investigation are summarized as follows:

(i) The LC duration times of the sampled motorists ranged from 0.90 to 10.52 seconds with mean and standard deviation values of 3.02 and 1.32 seconds, respectively.

(ii) Out of the total of 174 sampled drivers, an approximate of 162 corresponding to 93% performed LC manoeuvre in less than 5.0 seconds with most of them executed within a duration shorter than 3.0 seconds. This implies that more than 90% of the drivers observed are characterized by level of aggressiveness LC driving behaviour.

(iii) It was also found that the LC duration time data obtained in this study have reasonably fitted a Lognormal distribution, suggesting that LC duration times are non-negative.

5. References
[1] Fitch G M, Lee S E, Klauser S, Hankey J, Sudweeks J and Dingus T 2009 Analysis of Lane-Change Crashes and Near-Crashes Final Rep. DOT HS 811 147 (U.S.A: National Highway Traffic Safety Administration) pp 1–88
[2] Zhao D, Peng H, Nobukawa K, Bao S, LeBlanc D J and Pan C S 2014 Analysis of mandatory and discretionary lane change behaviors for heavy trucks 14th Int. Symp. Adv. Veh. Control, Mlc, 1–6
[3] Halati A, Lieu H and Walker S 1997 CORSIM-corridor traffic simulation model Proc. of Traff. Congest. and Traff. Safety in the 21st Century: Challenges, Innovations, and Opportunities (Illinois)
[4] Sanik M E, Hamid N B, Mat Nor A H, Prasetijo J, Che Ani M S and Mustakim F 2016 Drivers lane changing behavior at urban intersection by using Gap Acceptance approach, ARPN Jour. of Eng. and App. Sci. 11(24) 14070–14074
[5] Cao X, Young W and Sarvi M 2015 A study of traffic conflict with surrounding traffic during mandatory lane-changing execution Proc. of Australasian Transp. Res. Forum (Sydney)
[6] Chang G L and Kao Y M 1991 An empirical investigation of macroscopic lane-changing characteristics on uncongested multiline freeways, *Transp. Res. Part A: Gen.* **25**(6) 375–389

[7] Vechione M, Balal E and Cheu R L 2018 Comparisons of mandatory and discretionary lane changing behavior on freeways, *Int. J. of Transp. Sci. and Technol.* **7**(2) 124-136

[8] Young S K, Eberhard C A and Moffa P J 1995 Development of Performance Specifications for Collision Avoidance Systems for Lane Change Merging and Backing Task 2 Interim Report: Functional Goals Establishment (U.S.A.: National Highway Traffic Safety Administration) pp 1-36

[9] Wang J S and Knipling R R 1994 *Lane Change / Merge Crashes : Problem Size Assessment and Statistical Description Technical Report* Final Report HS-808 075 (Washington D.C.: Transportation Research Board) pp 1-61

[10] Barr L and Najm W 2001 Crash problem characteristics for the intelligent vehicle initiative *Transportation Research Board 80th Annual Meeting* 01-2471

[11] Wåhlberg A A 2009 *Driver Behavior and Accident Research methodology* (London: CRC Press) pp 1-322

[12] Toledo T and Zohar D 2007 Modeling duration of lane changes, *Transp. Res. Rec.* **1999**(1) 71–78.

[13] Lee S E, Olsen E C B and Wierwille W W 2004 *A Comprehensive Examination of Naturalistic Lane-Changes* Final Report HS-809 702 (Washington D.C.: National Highway Traffic Safety Administration) pp 1-236

[14] Cao X, Young W and Sarvi M 2013 Exploring duration of lane change execution *36th Australasian Transp. Res. Forum* (Brisbane)

[15] Cook A R and Donald E 1974 The detection of freeway capacity reducing incidents by traffic stream measurements, *Transp. Res. Rec.* **495** 1-11

[16] Finnegarn P and Green P 1990 *The Time to Change Lanes : A Literature Review*, IVHS Technical Report -90-13 (Michigan: University of Michigan Transportation Research Institute) pp 1-23

[17] Chovan J D, Tijerina L, Alexander G and Hendricks D L 1994 *Examination of Lane Change Crashes and Potential IVHS Countermeasures* Final Report HS-808 071, DOT-VNTSC-NHTSA-93-2 (Washington D.C.: National Highway Traffic Safety Administration) pp 1-56

[18] Hetrick S 1997 *Examination of Driver Lane Change Behavior and the Potential Effectiveness of Warning Onset Rules for Lane Change or 'Side' Crash Avoidance Systems* Master Thesis (Virginia: Virginia Polytechnic Institute & State University) pp 1-82

[19] Hanowski R J 2000 *The Impact of Local/Short Haul Operation on Driver Fatigue* PhD Thesis (Virginia: Virginia Polytechnic Institute and State University) pp 1-146

[20] Salvestrucci D D and Liu A 2002 The time course of a lane change: Driver control and eye-movement behavior, *Transp. Res. Part F: Traffic Psychol. and Behav.* **5**(2) 123–132

[21] Moridpour S, Sarvi M and Rose G 2010 Modeling the lane changing execution of multiclass vehicles under heavy traffic conditions, *Transp. Res. Rec.* **2161**(1) 11-19

[22] Ali Y, Zheng Z and Haque M M 2018 Connectivity’s impact on mandatory lane-changing behaviour: Evidences from a driving simulator study, *Transp. Res. Part C: Emerg. Technol.* **93** 292–309

[23] Gurupackiam S and Jones Jr S L 2012 Empirical study of accepted gap and lane change duration within arterial traffic under recurrent and non-recurrent congestion, *Int. Jour. for Traff. and Transp. Eng.* **2**(4) 306–322

[24] RACELOGIC 2009 *Video VBOX Lite Hardware and Software Manual* www.racelogic.co.uk 1, (United Kingdom) pp 1–87

[25] Ibrahim M N, Puan O C and Mustaffar M 2019 Measurement of percent time spent following on two-lane highways: an exploration of spot and space-based methodologies *IOP Conf. Series: Mat. Sci. and Eng.* **527** 012069.

[26] Balal E, Cheu R L, Gyan-Sarkodie T and Miramontes J 2014 Analysis of discretionary lane changing parameters on freeways, *Int. Jour. of Transp. Sci. Technol.* **3**(3) 277–296

[27] Puan O C 2004 Drivers’s car following headway on single carriageway roads, *Jur. Kej. Awam* **16**(2) 15–27

[28] Tijerina L, Garrott W R, Stoltzfus D and Parmer E 2005 Eye glance behavior of van and passenger car drivers during lane change decision phase *Transp. Res. Rec.* **1937**(1) 37-43