Modeling Drivers’ Lateral Movement Behavior under Weak-Lane-Disciplined Traffic Conditions

by

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BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

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I hereby declare that the research work presented in this thesis has been performed by me and this thesis or any part of it has not been submitted elsewhere for any other purposes except for publication.

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ABSTRACT

In recent years the use of microscopic traffic simulation tools are increasing worldwide for selecting the most effective transport planning scheme and evaluate its economic feasibility as it can be used in laboratories for testing effectiveness of candidate traffic improvement initiatives before their actual field implementation. So, now a microscopic traffic simulator considering the traffic of Dhaka is a basic need for the transportation planner here. Development of the lateral movement model regarding the Dhaka traffic which is actually known as lane changing model worldwide carries a major importance as one of the base of the simulator.

The lane changing is an important maneuver which defines the lateral movement on the road. As an effective component of the microscopic traffic simulator, a number of lane changing models have been developed so far in all over the world. But the models have been developed mainly for the homogeneous lane based traffic. The research has focused on developing a lateral movement model considering the weak lane based heterogeneous traffic of Dhaka where the vehicle can occupy any part of the road without strictly following the lane marking.

The lateral movement model proposed in this research uses an econometrics based approach bearing in mind that the road consists of several number of small strips rather than lane. On the basis of the movement characteristics, Discretionary Lateral Movement Model and Mandatory Lateral Movement Model have been formulated then. The data used for developing these models have been collected from two locations of Dhaka City; Kalabagan and Shukrabad to represent two types of movement respectively using video cameras mounted on over-bridges. GPS equipped vehicles were run as well in a pre-specified route including these locations in order to supplement the video data. The recorded videos have been processed using software ‘TRAZER’ which provides vehicle trajectory data. The data have been fed into ‘MATLAB’ code then and the input variables for the model have been generated. Ultimately, two best models on the basis of physical and statistical significance for two different types of lateral movement have been considered as the final models out of various generated models. All the models have been generated using the statistical estimation software GAUSS. At last, the final models have been verified with different sets of trajectory data obtained from the same locations at different time.

As the final models have been selected taking into account the most influential variables in case of lateral movement on the road and found significant, these models could be an effective components for the formation of the microscopic traffic simulator for the developing countries like Bangladesh.
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CHAPTER ONE
INTRODUCTION

1.1 Background

Traffic simulation or the simulation of transportation systems is the mathematical modeling of transportation systems (e.g., freeway junctions, arterial routes, roundabouts, downtown grid systems, etc.) through the application of computer software to better help plan, design and operate transportation systems. It is an important area of discipline in traffic engineering and transportation planning today. In transportation planning the simulation models evaluate the impacts of regional urban development patterns on the performance of the transportation infrastructure. Various national and local transportation agencies, academic institutions and consulting firms use simulation to aid in their management of transportation networks. Simulation in transportation is important because it can study models too complicated for analytical or numerical treatment, can be used for experimental studies, can study detailed relations that might be lost in analytical or numerical treatment and can produce attractive visual demonstrations of present and future scenarios.

Traffic simulation models are useful from a microscopic, macroscopic and sometimes mesoscopic perspectives. Microsimulation models track individual vehicle movements on a second or subsecond basis. Microscopic traffic simulation tools actually models individual driver maneuvers and deduce network condition from those. It can be used as laboratories for testing the effectiveness of candidate traffic initiatives before their actual field implementation. These tools are therefore increasingly being popular worldwide for selecting the most effective transportation planning scheme and evaluate its economic feasibility.

As excessive traffic is one of the major problems of Dhaka, a microscopic traffic simulator developed for the traffic of this city is required for the transportation planner to evaluate the impact of considered measures and building infrastructures to reduce the congestion problem before their actual activation. But, such kind of dedicated simulator considering the traffic of Dhaka city is not available now. So, the development of the different part of a simulation tool like lateral movement model,
acceleration movement etc. and ultimately developing a microscopic traffic simulator for Dhaka is one of the most important need of time in Bangladesh.

Lateral movement model may be defined as the modeling of the behavior of the driver for changing the position on the road laterally. The urgency of the change of position may arise from various circumstances. The drier may need to take right turn or left turn ahead in the intersection, but it may stay in such a position where most of the vehicle moves straight. So the driver must have to consider the lateral movement to reach its destined way. Moreover the driving satisfaction is not found the same in all position on the road. A car driver may not feel comfortable to drive behind a heavy vehicle like Truck or Bus or a slow moving vehicle like Rickshaw. So the requirement of lateral changes arises here. The lateral movement model will capture every detail of the decision for the change and ultimately incorporate the entire responsible variable in the model equation.

The lateral movement model is mainly familiar as lane changing model all over the world. A number of models have been developed so far (e.g. Rorbech, 1976; Halati et al, 1997; Yang and Koutsopoulos, 1996; Ahmed, 1999; Toledo, 2003; etc.) for various countries considering various situations. With the passage of time, more detailed model has been introduced to predict the lane changing behavior with great reliability. Some of the models have also been implemented in some microscopic traffic simulator. But the lane changing models follows some criteria which do not matches with the requirement for the traffic of the developing countries like Bangladesh. The models and the simulator are mainly focused on the traffic of the developed countries (CORSIM, MITSIM, SITRAS etc.). The homogeneity of the traffic is one of the main features in the developed countries. All the vehicles are motorized with common operating system. The special type of vehicle is also found to have special lane with an intention to ensure uninterrupted movement. Moreover, the traffic follows the lane strictly in these countries. So a vehicle will always stay on any of the designated lane in the road. If it consider the lateral movement, it will occupy another lane if available leaving the current position. The lane based traffic behavior may be termed as discrete change. Because, either it will take the adjacent lane or stay in the current lane. So, the position on the road is not a concern for the researcher but the number of lane a vehicle occupies.
But, the traffic is heterogeneous in nature here. Various type of vehicle shares the same road at a time. Moreover, the traffic does not follow the lane discipline strictly. It can stay anywhere on the road. So, the most important setback is that as the previous models are developed for homogeneous lane-based traffic (Figure 1.1a), they cannot be directly applied to heterogeneous traffic stream which are characterized by the following (Figure 1.1b).

1. Presence of various non-motorized traffic and motorized traffic on the same road and therefore difference in speed among the vehicles
2. Weak lane discipline

To incorporate these special features of the traffic movement, lane changing model customized for the Dhaka traffic is required to proceed further for development of a microscopic traffic simulator for this country which may eventually represent all the developing countries with similar traffic. As the lane discipline is not in operation, it is more meaningful to name the sidewise movement model as lateral movement model other than lane changing model. The successful development of the model could be a base for the simulator which would be a useful tool for the traffic planner.
Figure 1.1: (a) Homogeneous lane based traffic (b) Heterogeneous weak lane based traffic of Dhaka

1.2 Objective

The specific aim of the research is to develop models to capture the driving behavior in weak lane based scenarios considering non-collision criteria on the road using detailed data collected from selected locations of Dhaka city. Specific objectives of this study include:

- Formulating proposed models to represent the decision of the driver on the road during lateral movement in various situations
- Collection and processing of comprehensive disaggregate (e.g. second by second trajectory data) and aggregate data (e.g. traffic counts and speeds) to calibrate the proposed model structure
- Calibration of the proposed models
The main outcome of the research is to developing a model taking into account all the detailed factors on the road for lateral movement for both mandatory and discretionary situations. This model can be run into the simulator to represent the lateral movement behavior of individual driver in heterogeneous traffic and reasonably predict the regarding decisions.

1.3 Scope of the Study

The scope of the study is to develop a lateral movement model for heterogeneous weak lane based traffic of Dhaka. The model will be based on econometric model. The estimated parameters of the model will be statistically significant and meaningful in nature. The model will consider a very small time step which will be essential in capturing the detailed movement of the vehicle. It will ultimately results in a reliable model for this kind of movement.

Two models will be formed to represent the two scenario of the lateral movement. One is the mandatory lateral movement and other is the discretionary lateral movement. When a vehicle must have to take the lateral change to follow its planned way, the movement related to it will be regarded as mandatory. But, if the lateral movement mainly depends on the drivers’ choice with a view to obtain a better driving condition, it will be considered as discretionary lateral movement.

The latest technology will be used in case of data collection. The location for capturing the mandatory and discretionary movement will be different. Disaggregate and aggregate data will be collected from different location of Dhaka city. The disaggregate data will be the trajectory data. The trajectory data will be available from the video data and high precision GPS data. As the data obtained from the field will be very detailed and microscopic, the formulated model will incorporate the entire influencing variable for lateral change. A calibrated model will be presented with those data. Ultimately the model will be verified with different set of data to check its effectiveness. The model can be combined with the car following model for mixed traffic of Dhaka. The combination of these two models along with other required input can be a strong base to form a microscopic traffic simulator for the developing countries having the similar type of traffic like Dhaka.
1.4 Organization

This thesis comprises of six chapters to illustrate the methodology for achieving the aforementioned objectives. The thesis is organized as below.

- Chapter 1 gives the context of the study in a nutshell
- Chapter 2 focuses on the review of the previous thesis papers and other sources related to this topic by comparison of different approaches
- Chapter 3 describes the model structure developed for thesis and also the challenges for modeling lateral movement behavior of heterogeneous traffic streams
- Chapter 4 highlights on data collection prior to model development
- Chapter 5 illustrates the analysis of data and subsequent model development using this data
- Chapter 6 presents the conclusion of the entire study, identifies potential applications and provides suggestions and recommendations for further development of the work
2.1 General

Driving behavior models represent the maneuver of drivers in roads while driving in different roadway and traffic condition. There are a number of such models to represent the behavior of drivers which have been developed for more than half a century. Though there are models for almost all types of driving operations, acceleration models for longitudinal movement are predominant followed by lane-changing models and other models (e.g. models for merging and crossing). In the following subsections a detailed description of the lane changing model for homogeneous and heterogeneous traffic will be presented.

2.2 Lane Changing Models for Homogeneous Traffic

Homogeneous traffic mainly represents the traffic of the developed countries where there have operational and functional similarities in between the vehicles sharing the same right of way. In most of the cases the vehicle follows the lane based discipline. Actually, lane changing behavior has not been studied as extensively as acceleration behavior. But interest in this field has grown with the development of micro-simulation tools which predominantly represents the homogeneous lane based traffic.

2.2.1 General Models

Gipps (1986) presented the first lane changing decision model intended for microscopic traffic simulation tools. The model covers various urban driving situations, in which traffic signals, transit lanes, obstructions and presence of heavy vehicles affect drivers’ lane selection. The model considers three major factors: necessity, desirability and safety of lane changes. Drivers’ behavior is governed by two basic considerations: attaining the desired speed and being in the correct lane to perform turning maneuvers. The relative importance of these considerations varies with the distance to the intended turn. Gipps defines three zones: when the turn is far away it has no effect on the behavior and the driver concentrates on attaining the
desired speed. In the middle zone, lane changes will only be considered to the turning lanes or lanes that are adjacent to them. In the last zone, close to the turn, the driver focuses on keeping the correct lane and ignores speed considerations. Zones are defined deterministically, ignoring variability between drivers and inconsistencies in the behavior of a driver over time. When more than one lane is acceptable the conflict is resolved deterministically by a priority system considering, in order of importance, locations of obstructions, presence of heavy vehicles and potential speed gain. No framework for rigor estimation of the model parameters was proposed.

Rorbech (1976) developed a model of lane changing behavior in two-lane motorways. A vehicle may be in one of four states based on two characteristics: the lane it is in (right or left) and traffic conditions (free-flow or constrained). A stochastic Markov process is used to model transitions between the states. An important observation he made is that lane changing behaviors from the right lane and from the left lane are different.

CORSIM (Halati et al 1997, FHWA 1998) is a microscopic traffic simulation model developed by FHWA. In CORSIM, lane changes are classified as either mandatory (MLC) or discretionary (DLC). An MLC is performed when the driver must leave the current lane (e.g. in order to exit to an off-ramp, avoid a lane blockage). A DLC is performed when the driver perceives that driving conditions in the target lane are better, but a lane change is not required. A risk factor is computed for each potential lane change. This factor is defined in terms of the deceleration a driver would have to apply if its leader brakes to a stop. The risk is calculated for the subject with respect to its intended leader and for the intended follower with respect to the subject. The risk is compared to an acceptable risk factor, which depends on the type of lane change and its urgency. Variability in gap acceptance behavior is ignored.

Yang and Koutsopoulos (1996) implemented in MITSIM a rule based lane changing model. Lane changes are classified as mandatory (MLC) or discretionary (DLC). Drivers perform MLC in order to connect to the next link on their path, bypass a downstream lane blockage, avoid entering a restricted-use lane and comply with lane use signs and variable message signs. Conflicting goals are resolved probabilistically based on utility theory models. DLC are considered when the speed of the leader is below a desired speed. The driver then checks the opportunity to increase speed by moving to another lane.
Hidas and Behbahanizadeh (1999) implemented a similar model in the microsimulator SITRAS. Downstream turning movements and lane blockages may trigger MLC or DLC, depending on the distance to the point where the lane change must be completed. MLC are also taken in order to obey lane use regulations. DLC are performed in an attempt to obtain speed advantage or queue advantage, which are defined as the adjacent lane allowing faster traveling speed and having a shorter queue, respectively. In addition they introduced a cooperative lane changing model. A vehicle in an MLC situation under heavily congested traffic conditions may change lanes through cooperation with the intended follower. The willingness of the follower to allow the subject vehicle to change lanes is a function of his aggressiveness. A cooperative follower will start following the subject vehicle and the subject will start following the intended leader in the target lane. As a result a gap will open in the target lane and the subject vehicle will be able to change lanes.

Ahmed et al (1996) and Ahmed (1999) developed and estimated the parameters of a lane-changing model that captures both MLC and DLC situations. A discrete choice framework is used to model three lane-changing steps: decision to consider a lane-change, choice of a target lane and acceptance of gaps in the target lane. The model framework is presented in Figure 2.1. When an MLC situation applies, the decision whether or not to respond to it depends on the time delay since the MLC situation arose. DLC is considered when MLC conditions do not apply or the driver chooses not to respond to them. The driver’s satisfaction with conditions in the current lane depends on the difference between the current and desired speeds. The model also captures differences in the behavior of heavy vehicles and the effect of the presence of a tailgating vehicle. If the driver is not satisfied with driving conditions in the current lane, neighboring lanes are compared to the current one and the driver selects a target lane. Lane utilities are affected by the speeds of the lead and lag vehicles in these lanes relative to the current and desired speeds of the subject vehicle. A gap acceptance model is used to represent the execution of lane-changes.
Figure 2.1: Structure of the lane changing model proposed by Ahmed (1999)
Ahmed estimated the parameters of this model using second-by-second vehicle trajectory data. The model however does not explain the conditions that trigger MLC situations. The parameters of the MLC and DLC components of the model were estimated separately. The MLC model was estimated for the special case of vehicles merging to a freeway, under the assumption that all vehicles are in MLC state. Gap acceptance models were estimated jointly with the target lane model in each case. The estimation results for DLC and MLC models are summarized in Table 2.1 and Table 2.2 respectively.

Table 2.1: Estimation results for the DLC model proposed by Ahmed (1999)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility of unsatisfactory driving conditions</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.225</td>
</tr>
<tr>
<td>(Subject speed - desired speed), m/sec.</td>
<td>-0.066</td>
</tr>
<tr>
<td>Heavy vehicle dummy</td>
<td>-3.15</td>
</tr>
<tr>
<td>Tailgate dummy</td>
<td>0.423</td>
</tr>
<tr>
<td>Utility of left lane</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-2.08</td>
</tr>
<tr>
<td>(Lead speed - desired speed), m/sec.</td>
<td>0.034</td>
</tr>
<tr>
<td>(Front speed - desired speed), m/sec.</td>
<td>-0.152</td>
</tr>
<tr>
<td>(Lag speed - subject speed), m/sec.</td>
<td>-0.097</td>
</tr>
<tr>
<td>Desired speed model</td>
<td></td>
</tr>
<tr>
<td>Average speed, m/sec.</td>
<td>0.768</td>
</tr>
<tr>
<td>Lead critical gap</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.508</td>
</tr>
<tr>
<td>Min (0, lead speed - subject speed), m/sec.</td>
<td>-0.420</td>
</tr>
<tr>
<td>$\sigma_{e_{\text{lead},DLC}}$</td>
<td>0.488</td>
</tr>
<tr>
<td>Lag critical gap</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.508</td>
</tr>
<tr>
<td>Min (0, lag speed - subject speed), m/sec.</td>
<td>0.153</td>
</tr>
<tr>
<td>$\sigma_{e_{\text{lag},DLC}}$</td>
<td>0.188</td>
</tr>
<tr>
<td>Max (0, lag speed - subject speed), m/sec.</td>
<td>0.526</td>
</tr>
</tbody>
</table>
Ahmed (1999) also developed and estimated a forced merging model. This model captures drivers’ lane-changing behavior in heavily congested traffic, where acceptable gaps are not available. In this situation, drivers are assumed to change lanes either through courtesy yielding of the lag vehicle in the target lane or by forcing the lag vehicle to slow down. Important factors affecting this behavior include lead relative speed, the remaining distance to the point the lane change must be completed and existence of a total clear gap in excess of the subject vehicle length.

Zhang et al (1998) developed a multi-regime traffic simulation model (MRS). Their definitions of MLC and DLC and the gap acceptance logic are similar to Ahmed et al (1996). MLC critical gaps are randomly distributed across the population. The mean critical gap is a function of the remaining distance to the point where the lane change must be completed and existence of a total clear gap in excess of the subject vehicle length.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Utility of mandatory lane change</strong></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-0.654</td>
</tr>
<tr>
<td>First gap dummy</td>
<td>-0.874</td>
</tr>
<tr>
<td>Delay (sec.)</td>
<td>0.577</td>
</tr>
<tr>
<td><strong>Lead critical gap</strong></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.384</td>
</tr>
<tr>
<td>$\sigma \varepsilon_{lead,MLC}$</td>
<td>0.859</td>
</tr>
<tr>
<td><strong>Lag critical gap</strong></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.587</td>
</tr>
<tr>
<td>Min (0, lag speed - subject speed), m/sec.</td>
<td>0.048</td>
</tr>
<tr>
<td>Max (0, lag speed - subject speed), m/sec.</td>
<td>0.356</td>
</tr>
<tr>
<td>$\sigma \varepsilon_{lag,MLC}$</td>
<td>1.073</td>
</tr>
</tbody>
</table>

Ahmed (1999) also developed and estimated a forced merging model. This model captures drivers’ lane-changing behavior in heavily congested traffic, where acceptable gaps are not available. In this situation, drivers are assumed to change lanes either through courtesy yielding of the lag vehicle in the target lane or by forcing the lag vehicle to slow down. Important factors affecting this behavior include lead relative speed, the remaining distance to the point the lane change must be completed and existence of a total clear gap in excess of the subject vehicle length.

Zhang et al (1998) developed a multi-regime traffic simulation model (MRS). Their definitions of MLC and DLC and the gap acceptance logic are similar to Ahmed et al (1996). MLC critical gaps are randomly distributed across the population. The mean critical gap is a function of the remaining distance to the point where the lane change must be completed and existence of a total clear gap in excess of the subject vehicle length.

- No change in acceleration: The adjacent gap is acceptable as is.
- The subject needs to accelerate: Either the total length of the adjacent gap is sufficient but the lag gap is too small or the total length of the adjacent gap is unacceptable but the gap between the lead vehicle and its leader is acceptable.
- The subject needs to decelerate: Either the total length of the adjacent gap is sufficient but the lead gap is too small or the total length of the adjacent gap is
The model also considers courtesy yielding. The authors performed a validation study but did not suggest a framework for calibration of the model. Wei et al (2000) developed a model of drivers' lane selection process when turning into two-lane urban arterials and their subsequent lane changing behavior. Depending on the driver’s path plan the arterial lanes are classified according to three criteria:

- **Target (non-target) lane:** a lane (not) connecting to the intended turn at the next intersection.
- **Preemptive (non-preemptive) lane:** a lane (not) connecting to the intended turn at a downstream intersection.
- **Closest (farther) lane:** the lane closest to (farther away from) the curb on the side the driver is turning onto the arterial from.

A set of deterministic lane selection rules were developed using observations from Kansas City, Missouri:

- Drivers that intend to turn at the next intersection choose the target lane.
- Drivers that intend to turn farther downstream choose the preemptive lane if it is the closest. If the preemptive lane is the farthest, the lane choice is based on the aggressiveness of the driver.
- Drivers that are already traveling in the arterial remain in their lanes.

The lane changing behavior of drivers in the arterial is influenced by the lane classification (e.g. target, preemptive) and is governed by another set of rules. Analysis of the field observations showed that passing is an important behavior that needs to be modeled. Vehicles in the target lane may perform a passing maneuver (double lane change to a non-target lane and back) in order to gain speed. The model requires that both the adjacent gap in the non-target lane and the gap in the target lane between the subject’s leader and its leader be acceptable for passing to take place. Most of the decision rules do not account for variability in the driver population.
Toledo (2003) developed an integrated lane-changing or lane shift model that allows joint evaluation of mandatory and discretionary considerations. In this model, the relative importance of MLC and DLC considerations vary depending on explanatory variables such as the distance to the off-ramp. This way the awareness to the MLC situation is more realistically represented as a continuously increasing function rather than a step function. The model consists of two levels: choice of a lane shift and gap acceptance decisions. The structure of the model is shown in Figure 2.2.

![Figure 2.2: Structure of the lane-changing model proposed by Toledo (2003)](image)

The first step in the decision process is latent since the target lane choice is unobservable and only the driver's lane-changing actions are observed. Latent choices are shown as ovals, observed ones are shown as rectangles. At any particular instance, the driver has the option of selecting to stay in the current lane or opting to move to an adjacent lane. The CURRENT branch corresponds to a situation in which the driver decides not to pursue a lane-change. In the RIGHT and LEFT branches, the driver perceives that moving to these lanes, respectively, would improve his condition in terms of speed and path plan. In these cases, the driver evaluates the adjacent gap in the target lane and decides whether the lane-change can be executed or not. The lane-change is executed (CHANGE RIGHT or CHANGE LEFT) only if the driver perceives that the gap is acceptable, otherwise the driver does not execute the lane-change (NO CHANGE). This decision process is repeated at every time step.

Explanatory variables in Toledo’s model include neighborhood variables, path plan variables, network knowledge and experience, and driving style and capabilities.
Information about the driver’s style and characteristics is however not available and is captured by introducing individual specific error terms.

The parameters of the model were estimated jointly using second by second trajectory data collected in a section of I-395 Southbound in Arlington, VA. The estimation results of the integrated lane-changing model (lane shift model) are summarized in Table 2.3.

**Table 2.3: Estimation results for the lane shift model by Toledo (2003)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter value</th>
<th>t-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL constant</td>
<td>2.490</td>
<td>3.74</td>
</tr>
<tr>
<td>RL constant</td>
<td>-0.173</td>
<td>-0.51</td>
</tr>
<tr>
<td>Right-most lane dummy</td>
<td>-1.230</td>
<td>-3.89</td>
</tr>
<tr>
<td>Subject speed, m/sec.</td>
<td>0.062</td>
<td>1.59</td>
</tr>
<tr>
<td>Relative front vehicle speed, m/sec.</td>
<td>0.163</td>
<td>3.02</td>
</tr>
<tr>
<td>Relative Lag speed, m/sec.</td>
<td>-0.074</td>
<td>-1.30</td>
</tr>
<tr>
<td>Front vehicle spacing, m.</td>
<td>0.019</td>
<td>3.42</td>
</tr>
<tr>
<td>Tailgate dummy</td>
<td>-3.162</td>
<td>-1.68</td>
</tr>
<tr>
<td>Path plan impact, 1 lane change required</td>
<td>-2.573</td>
<td>-4.86</td>
</tr>
<tr>
<td>Path plan impact, 2 lane changes required</td>
<td>-5.358</td>
<td>-5.94</td>
</tr>
<tr>
<td>Path plan impact, 3 lane changes required</td>
<td>-8.372</td>
<td>-5.70</td>
</tr>
<tr>
<td>Next exit dummy, lane change(s) required</td>
<td>-1.473</td>
<td>-2.30</td>
</tr>
<tr>
<td>$\theta_{MLC}$</td>
<td>-0.378</td>
<td>-2.29</td>
</tr>
<tr>
<td>$\pi_1$</td>
<td>0.004</td>
<td>0.46</td>
</tr>
<tr>
<td>$\pi_2$</td>
<td>0.009</td>
<td>0.77</td>
</tr>
<tr>
<td>$\alpha_{CL}$</td>
<td>0.734</td>
<td>4.66</td>
</tr>
<tr>
<td>$\alpha_{RL}$</td>
<td>2.010</td>
<td>2.73</td>
</tr>
<tr>
<td>Lead Critical Gap</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.353</td>
<td>2.48</td>
</tr>
<tr>
<td>$Max(\Delta V_{n,lead}^{lead}(t),0),m/sec.$</td>
<td>-2.700</td>
<td>-2.25</td>
</tr>
<tr>
<td>$Min(\Delta V_{n,lead}^{lead}(t),0),m/sec.$</td>
<td>-0.231</td>
<td>-2.42</td>
</tr>
<tr>
<td>$\alpha_{lead}$</td>
<td>1.270</td>
<td>2.86</td>
</tr>
<tr>
<td>$\sigma_{lead}$</td>
<td>1.112</td>
<td>2.23</td>
</tr>
<tr>
<td>Lag Critical Gap</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.429</td>
<td>6.72</td>
</tr>
<tr>
<td>$Max(\Delta V_{n,lag}^{lag}(t),0),m/sec.$</td>
<td>0.471</td>
<td>3.89</td>
</tr>
<tr>
<td>$\alpha_{lag}$</td>
<td>0.131</td>
<td>0.64</td>
</tr>
<tr>
<td>$\sigma_{lag}$</td>
<td>0.742</td>
<td>3.68</td>
</tr>
</tbody>
</table>

Choudhury (2005) has worked on modeling lane changing behavior in presence of exclusive lanes. The objective of her thesis was to develop an improved lane-changing model that has a generalized structure and is flexible enough to capture the lane-changing behavior in all situations including the presence of unlimited access exclusive lane. As per this research the direction of the immediate lane change is
based on the choice of this target lane rather than myopic evaluation of adjacent lanes. A lane change occurs in the direction implied by the chosen target lane depending upon gap availability. The parameters of the model are jointly estimated with detailed vehicle trajectory data and calibrated for a situation with unlimited access High Occupancy Vehicle (HOV) lane. Estimation results show that the target lane choice is affected by lane-specific attributes, such as average speed and density, variables that relate to the path plan and the interactions of the vehicle with other vehicles surrounding it.

The proposed lane-changing model structure is summarized in Figure 2.3 with examples of a four-lane road.

The model hypothesizes two levels of decision-making: the target lane choice and the gap acceptance. The direction of the driver’s immediate lane change is implied by the selected target lane. The driver therefore evaluates the available gaps in that direction. The lane-changing decision process is thus latent, and only the driver’s actions (lane changes) are observed. Latent choices are shown as ovals and observed choices are represented as rectangles.

In Figure 2.3, the decision structure shown on the top is for a vehicle that is currently in the second lane to the right (Lane 2) in a four-lane road. Therefore, Lane 3 and Lane 4 are on its left, and Lane 1 is on its right. At the highest level, the driver chooses the target lane. In contrast with existing models the choice set constitutes of all available lanes in the road (Lane 1, Lane 2, Lane 3, and Lane 4 in this example). The driver chooses the lane with the highest utility as the target lane. If the target lane is the same as the current lane (Lane 2 in this case), no lane change is required (No Change). Otherwise, the direction of change is to the right (Right Lane) if the target lane is Lane 1, and to the left (Left Lane) if the target lane is either Lane 3 or Lane 4. If the target lane choice dictates a lane change, the driver evaluates the gaps in the adjacent lane corresponding to the direction of change and either accepts the available gap and moves to the adjacent lane (Change Right or Change Left) or rejects the available gap and stays in the current lane (No Change). The bottom decision structure in Figure 2.3 is for the subject vehicle in Lane 1 in a similar situation.
Figure 2.3: Example of the structure of the proposed lane changing model by Choudhury (2005)

a. For a four-lane road with subject vehicle in lane 2
b. For a four-lane road with subject vehicle in lane 1

The disaggregate data was collected in 1983 by FHWA in a section of I-395 Southbound in Arlington VA. The data for aggregate calibration and validation consists of sensor data and aggregate trajectory data. The data collection site includes
approximately 1.5 miles of highly congested section of I-80, in Emeryville and Berkeley California.

A random utility approach has been adopted to model both components. The estimation results of the proposed lane-changing model with the data from I-395 section are presented below.

**Table 2.4:** Estimation results of the target lane model by Choudhury (2005)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter value</th>
<th>t-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target Lane Model</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 1 constant</td>
<td>-1.696</td>
<td>-3.03</td>
</tr>
<tr>
<td>Lane 2 constant</td>
<td>-0.571</td>
<td>-1.68</td>
</tr>
<tr>
<td>Lane 3 constant</td>
<td>0.059</td>
<td>1.16</td>
</tr>
<tr>
<td>Lane density, vehicle/km</td>
<td>-0.013</td>
<td>-1.21</td>
</tr>
<tr>
<td>Average speed in lane, m/sec</td>
<td>0.176</td>
<td>1.59</td>
</tr>
<tr>
<td>Front vehicle spacing, m.</td>
<td>0.024</td>
<td>3.86</td>
</tr>
<tr>
<td>Relative front vehicle speed, m/sec.</td>
<td>0.115</td>
<td>1.46</td>
</tr>
<tr>
<td>Tailgate dummy</td>
<td>-4.935</td>
<td>-1.96</td>
</tr>
<tr>
<td>CL dummy</td>
<td>2.686</td>
<td>1.55</td>
</tr>
<tr>
<td>1 lane-change from the CL</td>
<td>-0.845</td>
<td>-1.15</td>
</tr>
<tr>
<td>Each additional lane-change from the CL</td>
<td>-3.338</td>
<td>-1.91</td>
</tr>
<tr>
<td>Path plan impact, 1 lane change required</td>
<td>-2.549</td>
<td>-4.57</td>
</tr>
<tr>
<td>Path plan impact, 2 lane changes required</td>
<td>-4.953</td>
<td>-2.19</td>
</tr>
<tr>
<td>Path plan impact, 3 lane changes required</td>
<td>-6.955</td>
<td>-1.65</td>
</tr>
<tr>
<td>Next exit dummy, lane change(s)</td>
<td>-0.872</td>
<td>-1.35</td>
</tr>
<tr>
<td>$\theta_{\text{MLC}}$</td>
<td>-0.417</td>
<td>-2.48</td>
</tr>
<tr>
<td>$\pi_1$</td>
<td>0.001</td>
<td>0.68</td>
</tr>
<tr>
<td>$\pi_2$</td>
<td>0.086</td>
<td>1.38</td>
</tr>
<tr>
<td>$\alpha_{\text{lane}1}$</td>
<td>-1.412</td>
<td>-2.29</td>
</tr>
<tr>
<td>$\alpha_{\text{lane}2}$</td>
<td>-1.072</td>
<td>-0.50</td>
</tr>
<tr>
<td>$\alpha_{\text{lane}3}$</td>
<td>-0.071</td>
<td>-3.61</td>
</tr>
<tr>
<td>$\alpha_{\text{lane}4}$</td>
<td>-0.089</td>
<td>-1.56</td>
</tr>
</tbody>
</table>
In summary, the target lane utility can be given by:

\[
U_{nt}^i = \beta^i - 0.013D_{nt}^i + 0.176S_{nt}^i + 0.024\Delta X_{nt}^{i,\text{front}}\delta_{nt}^{i,\text{CL}} + 0.115\Delta S_{nt}^{i,\text{front}}\epsilon_{nt}^{i,\text{adj}/\text{CL}}
- 4.935\delta_{nt}^{\text{tailgate}}\delta_{nt}^{i,\text{CL}} + 2.686\delta_{nt}^{i,\text{CL}} - 0.845\delta_{nt}^{i,\Delta CL=1} - 3.338(\Delta CL_{nt} - 1)\delta_{nt}^{i,\Delta CL>1}
+ \left[ d_{nt}^{\text{exit}} \right]^{-0.417} \left( -2.549\delta_{n}^{\text{tailgate}} - 4.953\delta_{n}^{\text{L1}} - 6.955\delta_{n}^{\text{L2}} - 0.872\delta_{nt}^{\text{next exit}} \Delta Exit^i \right)
- \alpha^i v_n + \epsilon_{nt}^i
\]

Where, \(\beta^i\) is the lane \(i\) constant. \(D_{nt}^i\) and \(S_{nt}^i\) are the lane-specific densities and speeds, respectively. \(\Delta X_{nt}^{i,\text{front}}\) and \(\Delta S_{nt}^{i,\text{front}}\) are the spacing and relative speed of the front vehicle in lane \(i\), respectively. \(\delta_{nt}^{i,\text{adj}}\) is an indicator with value 1 if \(i\) is the current or an adjacent lane, and 0 otherwise. Similarly, \(\delta_{nt}^{i,\text{CL}}\) has value 1 if \(i\) is the current lane, and 0 otherwise. \(\delta_{nt}^{\text{tailgate}}\) is an indicator with value 1, if vehicle \(n\) is being tailgated at time \(t\) and 0 otherwise. are the number of lane changes required to get from the current lane to lane \(i\). \(\delta_{nt}^{i,\Delta CL=1}\) and \(\delta_{nt}^{i,\Delta CL>1}\) are indicators that have values 1 if the lane \(i\) involves one lane change from the current lane and more than one lane changes from the current lane respectively and 0 otherwise. \(\beta^{\text{path}}\) is the path plan impact coefficient for lane \(i\). \(d_{nt}^{\text{exit}}\) is the distance to the exit driver \(n\) intends to use. \(\delta_{n}^{i,1}\) is an indicator with value 1 if lane \(i\) is 1 lane away from the desired exit of individual \(n\), 0 otherwise. Similarly, \(\delta_{n}^{i,2}\) and \(\delta_{n}^{i,3}\) are indicators with value 1 if lane \(i\) is two and three lanes away from the desired exit of individual \(n\) respectively. \(\delta_{nt}^{\text{next exit}}\) is an indicator with value 1 if the driver intends to take the next exit and 0 otherwise. \(\Delta Exit^i\) is the number of lane changes required to get from lane \(i\) to the exit lane.

The model is validated and compared with an existing lane-changing model using a microscopic traffic simulator in an HOV lane situation. The results indicate that the proposed model is significantly better than the previous model.
2.2.2 Gap acceptance models

Gap acceptance is an important element in most lane-changing models. In order to execute a lane-change, the driver assesses the positions and speeds of the lead and lags vehicles in the chosen lane and decides whether the gap between them is sufficient to execute the lane-change.

Gap acceptance models are formulated as binary choice problems, in which drivers decide whether to accept or reject the available gap by comparing it to the critical gap (minimum acceptable gap). Critical gaps are modeled as random variables to capture the variation in the behaviors of different drivers and for the same driver over time. In CORSIM, critical gaps are defined through risk factors. The risk factor is defined by the deceleration a driver will have to apply if his leader brakes to a stop. The risk factors to the subject vehicle with respect to the intended leader and to the intended follower with respect to the subject vehicle are calculated for every lane-change. The risk is compared to an acceptable risk factor, which depends on the type of lane-change to be performed and its urgency.

Kita (1993) used a logit model to estimate a gap acceptance model for the case of vehicles merging from a freeway ramp. He found that important factors are the length of the available gap, the relative speed of the subject with respect to mainline vehicles and the remaining distance to the end of the acceleration lane.

Ahmed (1999), within the framework of the lane-changing model described above, assumed that the driver considers the lead gap and the lag gap separately and in order to execute the lane-change, both gaps must be acceptable. Critical gaps are assumed to follow a lognormal distribution in order to guarantee that they are non-negative. Ahmed jointly estimated the parameters of the target lane and gap acceptance models. It was found that lead and lag critical gaps in MLC situations are smaller than those in DLC situations. A similar critical gap approach was used by Toledo in the lane-shift model.

Choudhury (2005) as a part of the modeling lane changing behavior in presence of exclusive lanes developed a gap acceptance model using the data of I-395 Southbound in Arlington VA as stated earlier. The estimation result is presented in the table below.
Table 2.5: Estimation result of the gap acceptance model by Choudhury (2005)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter value</th>
<th>t-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.541</td>
<td>5.59</td>
</tr>
<tr>
<td>$Max(\Delta S_{nt}^{\text{lead}}, 0)$, m/sec</td>
<td>-6.210</td>
<td>-3.60</td>
</tr>
<tr>
<td>$Min(\Delta S_{nt}^{\text{lead}}, 0)$, m/sec.</td>
<td>-0.130</td>
<td>-2.09</td>
</tr>
<tr>
<td>$\alpha_{\text{lead}}$</td>
<td>-0.008</td>
<td>-3.17</td>
</tr>
<tr>
<td>$\sigma_{\text{lead}}$</td>
<td>0.854</td>
<td>1.29</td>
</tr>
<tr>
<td>Constant</td>
<td>1.426</td>
<td>5.35</td>
</tr>
<tr>
<td>$Max(\Delta S_{nt}^{\text{lag}}, 0)$, m/sec</td>
<td>0.640</td>
<td>3.36</td>
</tr>
<tr>
<td>$\alpha_{\text{lag}}$</td>
<td>-0.205</td>
<td>-0.48</td>
</tr>
<tr>
<td>$\sigma_{\text{lag}}$</td>
<td>0.954</td>
<td>4.80</td>
</tr>
</tbody>
</table>

Number of drivers = 442  
Number of observations = 15632  
Number of parameters = 31  
$L(0) = -1434.76$  
$L(\beta)= -875.81$  
$\rho^2 = 0.368$

The summary the estimated lead and lag gaps are given by

$$G_n^{\text{lead}}(t) = \exp \left( 1.541 - 6.210 \max \left( 0, \Delta V_n^{\text{lead}}, TL \right) (t) \right) - 0.130 \min \left( 0, \Delta V_n^{\text{lead}}, TL \right) (t) - 0.008 \nu_n + \epsilon_n^{\text{lead}} (t)$$

$$G_n^{\text{lag}}(t) = \exp \left( 1.426 + 0.640 \max \left( 0, \Delta V_n^{\text{lag}}, TL \right) (t) - 0.240 \nu_n + \epsilon_n^{\text{lag}} (t) \right)$$

$\epsilon_n^{\text{lead}} (t) \sim N \left( 0, 0.854^2 \right)$ and $\epsilon_n^{\text{lag}} (t) \sim N \left( 0, 0.954^2 \right)$
2.3 Heterogeneous Traffic Microscopic Simulation Models

Since the early 1980’s there has been considerable interest in the development of the microscopic heterogeneous traffic models. Initially Indo-Swedish Road Traffic Simulation Model (INSWERTS) (Palaniswamy, Gynnerstedt et al. 1988) and MORTAB (Model for Depicting Road Traffic Behavior) (Ramanayya 1988) were developed for the uninterrupted flow behavior. Between these two, the INSWERTS considered only the inter-city roadways. The unique characteristics associated with overtaking on two-lane roads were represented in the model. Both these initial models were developed for the Indian traffic condition.

Subsequently, models were developed to represent traffic in an urban environment. These models developed at two universities in the U.K representing the traffic condition of the Bangladesh and Indonesia.

INSWERTS is the first model developed for the mixed traffic flow was for two-lane and multi-lane highways (Palaniswamy, Gynnerstedt et al. 1988). This stochastic discrete-event based simulation model was based on modifications made to the Swedish Road Traffic Simulation Model (SWERTS) (Brodin and Carlsson 1979), designed for motorized traffic. This model was modified to simulate Indian roadway and traffic conditions including narrower, bidirectional roads with widths varying from 3.75m to 7m, different shoulder types, alignments, terrain, desired speed and power-to-mass ratio. The modified model in referred as INSWERTS.

Nine different vehicles were modeled and these were grouped in four similar categories. The slow moving NMV and their effects were considered as the noise in the system and the calibration was adjusted to account for this noise.

The behavior of mixed flow traffic on single-lane bi-directional roads was modeled appropriately. The model was validated for 28 flows for four different configurations. The result of the validation was found well comparing with the main model.

Another micro-simulation model MORTAB (Model for Depicting Road Traffic Behavior) was developed for the uninterrupted traffic flow of India (Ramanayya 1988). The paper detailing this effort listed the various factors included in the models, but provided few details.

Eight vehicle types were modeled. There were some components sub models. The different heuristics included in the models are vehicle tracking, car-following models,
overtaking criteria, lateral gap adequacy and merging logic. An interesting approach
adopted here was the formulation of macroscopic speed, flow and density
relationships based on the results obtained from the microscopic simulation model.
This approach shows promise if the microscopic simulation is well calibrated and
validated.

Urban Uninterrupted flow traffic simulation model is the first detailed microscopic
simulation model for the heterogeneous traffic developed by Singh (1999). It a model
for the urban uninterrupted divided facilities in India where data was collected from
the two locations. Eight different vehicles types were modeled. More than 50 percent
of the traffic was non-motorized vehicle. A simple car following algorithm, the first
algorithm developed by the GM researchers was adopted in this model. The values of
the different parameters in the force equation are based on the results of an exhaustive
study of different vehicle type in India (Central Road Research Institute 1994).

Three different checks were applied to ensure that an appropriate acceleration rate is
applied by the following vehicle. The first check ensures the acceleration is neither
greater than the maximum acceleration rate nor less than the maximum deceleration
rate. The second check is to ensure that the vehicle speed does not exceed its free flow
speed nor goes below zero. The third check is made to ensure that the following
vehicle does not collide with the lead vehicle. The overtaking behavior was modeled
by considering the difference in the free flow speeds of the two interacting vehicles
and the lateral gap between the vehicles. The yielding behavior of the slower moving
traffic to give way to faster moving following vehicles was also modeled as a function
of the difference in the free flow speed and the lateral gap between the vehicles. Then
the model was validated for a flow rate (2,332 vehicles per hour) that was different
from the flow rate used in the calibration stage. Simulated and field data were
compared for various measures of effectiveness which were found well.

The TRANSMIC ( TRAffic Simulation for Mixed Condition) model (Sutomo 1992)
has been developed for an intersection approach for Indonesian traffic conditions.
Recognizing the basic distinguishing element for mixed traffic being non-lane based
movements, each approach (road width) of the intersection was considered to be
composed of 1m wide strips. Each vehicle type occupies a certain number of strips
based on their width. A total of 10 vehicle types were considered in this study. The
NMV was insignificant in the data collection locations.
The generalized GM car-following model with one modification was implemented in TRANSMIC. The modification considered was the headway between the two vehicles was replaced by the gap between the vehicles. Additionally, a perception threshold gap was considered, beyond which the following vehicle did not necessarily apply the acceleration determined from the vehicle-following heuristics. The perception threshold considered in the Singh (Singh 1999) model is similar to that considered in TRANSMIC. The model was validated for four intersection approaches with the flow ranging from 1520 to 2405 vph. The primary MOE’s used were queue length, travel time and discharge profile. Although the model was able to replicate the queue length and the discharge profile reasonably well, the model estimates for the travel time were significantly lower.

To overcome the shortcomings in TRANSMIC, MIXSIM-SIMulation of MIXed Traffic Stream (Hoque 1994) was developed to model isolated signalized intersections for mixed traffic flow conditions. The unique elements considered in this effort included

- More than one lead vehicle impacts the behavior of following vehicles
- Queue formation is based on making maximum use of available roadway space
- Queue discharge characteristics is a function of police enforcement and/or red violation

Nine types of the vehicles were included in the study. The types of the vehicle were

- Motorcycle
- Auto-rickshaw
- Car/Jeep/Microbus/Taxi/Pick-up/Van
- Mini-bus/Truck
- Bus
- Truck
- Bicycle
- Tricycle
- Rickshaw van
- Push-cart

The static parameter for which data were collected included the stopped lateral and longitudinal gaps. Moreover, data were collected for free speed (at low flow conditions), free turning speed, free flow acceleration rate, free flow deceleration rate
and maximum deceleration rate. It was observed that there was a little interaction between motorized and NMV’s upstream of the intersection and separate distributions were considered for representing the arrival pattern of vehicles. For motorized vehicle a log normal distribution was used at four of the five locations with the shifted negative exponential distribution being considered for non-motorized vehicles and for motorized vehicle in the fifth location.

The approach of using strips to model the traffic flow is used here as TRANSMIC. For the betterment of the model 0.5m strip width is used. The narrowest vehicle which is a bicycle occupies one strip, a motorcycle occupies two strips, a tricycle, pushcart and auto-rickshaw occupy three strips, cars and mini-buses five strips and buses and trucks occupy six strips. The non-collision vehicle-following developed as part of CARSIM was adopted as the basic vehicle-following model. The constraint of maintaining a safe distance results in the following vehicle always considering the speed and the maximum deceleration rate of the preceding vehicle and keeping track of the target position of the stopping vehicles. Because of the mix of vehicles of widely varying operating characteristics it was determined that this approach provided better result than the stimulus-based approach. The acceleration and deceleration rates considered were based on the data collected in Bangladesh. In a departure from step wise acceleration rate considered in CARSIM, a linear acceleration model based on a constant rate of acceleration jerk was considered. The acceleration rate, $a$, at any speed, $v$, was determined as,

$$a = a_0 \sqrt{1 - \frac{v}{v_{max}}}$$

Where,

$a_0$ = initial acceleration rate, m/s$^2$
$v_{max}$ = maximum speed, m/s

Various lane changing heuristics are described here in the study. Right-turning motorized vehicles were introduced into the model on the right side of the road. Left turning motorized vehicles considered turn intention 75m before reaching the last queued vehicle in the left turn lane. Similarly, right turning NMV’s considered the turn intention 50m prior to reaching the last queued vehicle in the right turn lane.

The model was calibrated using the data collected from the four intersections with a wide range of traffic situations- 400 vehicles per hour to 3400 vehicles per hour on
9m to 13m wide approaches. Queue length was measured at the end of the red interval and travel times were measured between specific control points. The MOE’s used were saturation flow rates, queue lengths and travel time. Most of the comparisons made between observed and simulated runs were significant at the 5% or 1% level of significance.

Considering MIXSIM as a starting point the MIXNETSIM (Hossain, 1996) was developed for simulating mixed traffic flow conditions within a road network. The different intersection configurations modeled included un-signalized intersections, signalized intersections and roundabout.

As the development of the model was preceded by the development of MIXSIM, various characteristics such as vehicle sizes, lateral gaps maintained by different vehicles, stopped gaps and free flow speed distribution were assumed to be the same. However, the additional data were collected on gap acceptance, approaching speed at the intersections, free flow deceleration distance and free flow circulating speed around roundabouts. Vehicle arrival were represented by separate shifted negative exponential distributions for motorized (shift 0.5 seconds) and non-motorized (shift 1.5 seconds) vehicles. However, it was noted that as the negative exponential model performed poorly for high flow conditions, multiple generators were used for representing such conditions.

The same non-collision based vehicle-following model and the linear acceleration model used in MIXSIM were adopted for this study also. The manner of referencing the vehicle is the major difference here from the MIXSIM model. Recognizing the limitations associated with strip based approach, a new coordinate based representation of vehicle position is adopted in this simulation.

A common phenomenon considered in the modeling of turn movements at both signalized and un-signalized intersections was that the vehicle decelerated to either the turn speed or a stop condition depending in the availability or non-availability if the acceptable gap. This approach was also considered in the modeling of roundabout approaches as they are considered to operate on the yield on entry rule. Moreover, though gap acceptance data were collected due to lack of disciplined driving behavior, no specific gap acceptance characteristics could be determined. Rather it was found that often enough drivers would take extremely small gaps and this would result in delays to vehicles that had the right-of-way. Observations of this behavior further
reinforced the applicability of the non-collision based vehicle-following algorithm adopted.

The results of the simulation runs were validated by comparing it with observed values in the field for two corridors. Travel time was a common measure used for all the individual intersection types modeled (un-signalized, signalized and roundabout). Additionally, queue length and saturation flow rates at signalized intersections and entry flow versus major road/circulating flow relationships were compared for roundabouts and un-signalized intersections. The validation efforts were encouraging in that barring a few exceptions with all of the comparison was significant at the 5% level of significance.

Maini (2001) developed a Vehicle-Following Model (VEHFOL) and a Heterogeneous Traffic Simulation Model (HETSIM) for controlled intersection considering the traffic of the India (data was collected from Delhi and Baroda) for representing the non-lane based heterogeneous traffic. After developing the VEHFOL, it was implemented in the comprehensive simulation model HETSIM which represents the flow at controlled intersection in India.

VEHFOL considers the longer term goal of a following vehicle achieving a steady-state with the lead vehicle. The steady state was characterized by a minimum time gap and equal velocity of the lead and following vehicles. The reaction time of drivers was considered explicitly. It was a constant value of 0.5 seconds. A new non-collision constraint that ensured a safe gap from a lead vehicle is formulated. Additionally, a perception threshold heuristics ensured that following vehicle decelerate at an acceptable rate. VEHFOL is based on three basic premises as follows:

- A following vehicle reacts to the stimulus provided by a lead vehicle only if the following vehicle can perceive the stimulus.
- A following vehicle attempts to achieve a steady state where its velocity is equal to that of the lead vehicle and a minimum time gap is maintained.
- After the following vehicle reaches steady state, the following vehicle attempts to maintain the minimum distance gap (based on the minimum time gap) with the lead vehicle. The constraint of equal velocity is no longer applied specifically.

VEHFOL was validated by comparing model estimates of headway, velocity and acceleration at every simulation time step (0.5 seconds) with observed data. A total of 31 vehicle-following cases with different combinations of lead and following vehicle
types and modes of operation (accelerating, decelerating, flow during green were considered. The validation result was found satisfactorily.

The comprehensive model for simulating heterogeneous traffic through controlled intersections, HETSIM, included ten vehicle types (seven motorized and three non-motorized). Video data were reduced and used to model the stochastic variation of driver-vehicle characteristics such as acceleration and deceleration rates and stopped and moving longitudinal and lateral gaps. The unique aspects of lateral movement of heterogeneous traffic which typically does not travel in lanes were considered. The four primary vehicle movement sub models included in HETSIM were (a) vehicle generation and introduction (b) overtaking (c) response to turn intention and (d) response to intersection control.

HETSIM was validated for a wide range of traffic and roadway conditions observed at six intersection approaches in two cities in India. The primary measures of effectiveness considered were the queue length and stopped delay. The observed and simulated average delays were compared for both the queue length and stopped delay by performing a 5% level of significance. In most of the cases the result was positive and the modeled and the simulated data were not significantly different.

2.4 Limitations of the Heterogeneous Traffic Model in Bangladesh

The consideration of the heterogeneous traffic for estimation a lane changing model is always a challenge for the transportation engineer. Actually, the road traffic here does not follow the lane exactly. It is a benefit for the case of formation of the model for the homogeneous lane based traffic because the position of the vehicle is specific on the basis of lane. But, this is one of the main limitations for the model of heterogeneous traffic of weak lane based traffic where the position of the vehicle cannot be specified by designating the lane. The vehicle can stay anywhere on the road. By introducing a compatible way to define the position of the vehicle in case of heterogeneous weak lane based traffic to formulate an effective lateral movement model should be an achievement over the limitation.

Hoque (1994) and Hossain (1996) worked with the data of the Dhaka city to model the intersection behavior. Moreover, Imran (2009) also considered the traffic of the Dhaka city to develop the neuro-fuzzy model for car following behavior in
heterogeneous road traffic condition. Recently, Islam (2013) has formulated a car following model to capture the response of the driver of Dhaka. Though, the study mentioned above has been performed using the data of the Dhaka city, no such model only dedicated to represent the lateral movement of the driver in response to various effect in Dhaka has not been prepared yet. Moreover, the response of the driver varies with the mandatory and discretionary situation faced by the driver depending on the travel plan. But, the other models developed for the heterogeneous traffic do not differentiate these two considerations extensively.

To overcome the above limitations, with the help of latest technology it is intended to develop an independent model for the capturing the lateral movement behavior for the heterogeneous weak lane based traffic. The features of identifying the leader accurately, defining the position of the vehicle along the width precisely etc. should be more obvious and accurate compared to the previous models. The model could be a base along with other model for introducing a simulator for the developing countries like Bangladesh.

2.5 Summary

In this chapter a number of lane changing models developed for homogeneous and heterogeneous traffic have been briefly discussed. It has been seen that the number of lane changing models developed for heterogeneous traffic is significantly less than the models developed for homogeneous lane based traffic. The lane changing model developed for the heterogeneous traffic limitations. The main view of the study is to prepare a model compatible with the traffic movement behavior of the heterogeneous traffic Dhaka city by overcoming the existing limitations.
CHAPTER THREE
MODEL STRUCTURE

3.1 General

This chapter focuses on the basic structure upon which the lateral movement model has been formulated. There have some basic difference in case of the nature of homogeneous and heterogeneous traffic. So the model for the heterogeneous traffic will need some consideration other than usual lane changing model for the homogeneous traffic. The following section of this chapter will demonstrate the main challenges behind the modeling of heterogeneous traffic weak lane discipline of drivers.

3.2 Heterogeneous Traffic Modeling Challenges

The pattern of the movement of the heterogeneous weak lane based traffic is actually not straight forward to formulize. Islam (2013) indicated to some challenges that were faced in case of developing car following model for the heterogeneous traffic of Dhaka. As the data sample has been collected from the same city, the problem of formulating the model of the lateral movement prevails as well. The challenges for the lateral movement model estimation for the heterogeneous weak lane based traffic are described below.

Operational variation of the traffic: Heterogeneous traffic contains both motorized and non motorized vehicle. Due to the operational variation the characteristics of the vehicle varies a lot. So it gets difficult to consider the both vehicle in the same decision frame.

Variation of speed and acceleration: Due to the functional difference among the traffic there has a significant variation in the maneuverability of these vehicles. The dynamic characteristics (e.g. speed, acceleration) are different as well. As a result the complexity is augmented which makes the modeling task challenging.

Size and shape diversity: Heterogeneous traffic does not contain the uniform shape and size of the vehicle as the homogeneous traffic. So the occupancy on the road
varies on vehicle type to type. These diversified physical properties require extra effort to model for heterogeneous traffic.

**Weak lane discipline:** Apart from the heterogeneity in maneuverability and dynamic characteristics, the vehicles maintain poor lane discipline. So it gets difficult to identify some basic requirement for the model formulation like identification of the leader, the change in the lane, position of the vehicle on the road etc. Sometimes the marking of the lane is also found absent. In case of lane based traffic the lane change can be considered as a discrete choice. The concept is that the vehicle will follow any certain lane. So if the exact location of the vehicle is not known on the road it is actually not a problem as the position of the vehicle is restricted by a lane boundary. But in weak lane based situation, the vehicle can stay anywhere on the road without following the lane mark, if any. The lateral movement is a continuous process rather than discretionary here. So, to develop the lateral movement behavior of these traffic in weak lane based condition the exact position on the road is a mandatory which makes the situation more complicated.

**Reliability of data:** In homogeneous traffic the lateral position of traffic may not be a major concern as strict lane discipline is maintained. But in heterogeneous traffic condition where lane discipline is poorly maintained or not maintained at all, it becomes a difficult task for image processing software to maintain accuracy as lateral position also becomes a matter of concern.

These challenges have to be overcome first to develop the lateral movement model for the heterogeneous weak lane based traffic.

### 3.3 Proposed Model Structure

The lateral movement behavior is explained by the explanatory variables that capture the attributes of the current and adjacent lanes to consider the movement in the adjacent lane. So the lateral movement model describes the choice of the adjacent lane in a very short time step. The estimation data is likely to include the repeated observations of drivers’ lane-changing choices over a period of time. It is therefore important to capture the correlations among the choices made by a given driver over time and choice dimensions. It is also necessary to introduce individual-specific latent
variables in the various utilities to capture the correlations due to some unobserved
data like the driver’s aggressiveness, age, level of driving skill etc. It can be assumed
that conditional on the value of this latent variable, the error terms of different utilities
are independent. Considering all of this the model structure for the model estimation
is given by:

\[ U_{int}^c = \beta^c X_{int}^c + \alpha^c_i \theta_n + \varepsilon_{int}^c \]  

(3.1)

Where, \( U_{int}^c \) is the utility of alternative \( i \) in choice dimension \( c \) to individual \( n \) at time
\( t \). \( X_{int}^c \) is a vector of explanatory variables. \( \beta^c \) is a vector of parameters. \( \theta_n \) is an
individual-specific latent variable assumed to follow some distribution in the
population. \( \alpha^c_i \) is the parameter of \( \theta_n \). \( \varepsilon_{int}^c \) is a generic random term with i.i.d.
distribution across choices, time and individuals. \( \varepsilon_{int}^c \) and \( \theta_n \) are independent of
each other.

The resulting error structure (see Heckman 1981, Walker 2001 for a detailed
discussion) is given by:

\[
\text{cov}(U_{int}^c, U_{int'}^{c'}) = \begin{cases} 
(\alpha^c_i)^2 + \sigma^2 & \text{If } n=n', c=c', i=i' \text{ and } t=t' \\
\alpha^c_i \alpha^c_{i'} & \text{If } n=n', c \neq c' \text{ and/or } i \neq i' \text{ and/or } t \neq t' \\
0 & \text{If } n \neq n' 
\end{cases}
\]  

(3.2)

\( \sigma^2 \) is the variance of \( \varepsilon_{int}^c \)

The model is explained in details here. At the highest level of lane-changing, the
driver chooses the lane with the highest utility as the target lane. The target lane
choice set constitutes of all the available lanes in the roadway.

\[ U_{int}^{TL} = V_{int}^{TL} + \varepsilon_{int}^{TL} \quad \text{Vi} \ v_{\text{TL}} = \{\text{current lane, left lane, right lane}\} 
\]  

(3.3)

Where, \( V_{int}^{TL} \) is the systematic component of the utility and \( \varepsilon_{int}^{TL} \) is the random term
associated with the target lane utilities.

The systematic utilities can be expressed as:

\[ V_{int}^{TL} = \beta^{TL} X_{int}^{TL} + \alpha_i^{TL} \theta_n \quad \text{Vi} \ v_{\text{TL}} = \{\text{current lane, left lane, right lane}\} 
\]  

(3.4)
Where, \( X_{\text{int}}^T \) is the vector of explanatory variables that affect the utility of lane \( i \). \( \beta^T \) is the corresponding vector of parameters. \( \epsilon_{\text{int}}^T \) is the random term associated with the target lane utilities. \( \alpha_{i}^T \) is the parameter of individual-specific latent variable \( \vartheta_n \).

Different choice models are obtained depending on the assumption made about the distribution of the random term \( \epsilon_{\text{int}}^T \). Assuming that these random terms are independently and identically Gumbel distributed choice probabilities for target lane \( i \), conditional on the individual specific error term \( (\vartheta_n) \) are given by a Multinomial Logit Model.

\[
P (T_{\text{int}}^L | \vartheta_n) = \frac{\exp (V_{\text{int}}^T | \vartheta_n)}{\sum_{j \in \text{TL}} \exp (V_{\text{int}}^T | \vartheta_n)}
\]  

(3.5)

As the data sample is collected from the Dhaka city where the traffic follows weak lane based traffic and the model is intended to be formed for the heterogeneous traffic, in the proposed model the definition of lane will be changed. Here a lane is subdivided into some number of strips where each strip will be considered as an individual lane for using in the model stated before. So the model for estimating the utility of the strips will be described as:

\[
U_{\text{int}}^T = V_{\text{int}}^T + \epsilon_{\text{int}}^T
\]

(3.6)

\[V_{\text{int}}^T \in \{\text{current strip, left strip, right strip}\}\]

3.4 Proposed Implementation Framework

Lateral movement refers to the movement of the vehicles along the width of the road. Lateral movement occurs on the road to take the vehicle to a position on the road where the utility is assumed to be more than the current position or due to achieve the position to reach in a desired direction. The first one is considered as “Discretionary Lateral Movement” and the second is considered as “Mandatory Lateral Movement”.

In case of discretionary lateral movement the main criteria of the driver is to find out that position on the road for the vehicle for which the current speed, current leader, current follower etc. cases will be improved with respect to the current position. In case of the mandatory lateral movement the vehicle faces a must go condition to take the required path for reaching destination without considering the betterment of the driving environment quality.
The movement of the vehicle along the width of the road for the lane based traffic is known as lane changing. But for weak lane based system of the traffic, the decision making process of the lane changing is continuous rather than discrete where there is no fixed distance to move laterally for changing the lane. So for this type of the road this movement is described as Lateral Movement other than Lane Changing.

3.4.1 Hypothesis

The behavior of the driver for changing the direction on the road is not the same for the mandatory and discretionary situation. In case of mandatory movement, the drivers are forced to consider the movement for the sake of its predefined path plan. So, the flexibility to consider the better driving condition reduces in this case. But when the discretionary movement case arises, it actually defines the choice of the driver. If the driver considers that changing of the current position will increase the driving facilities, the driver may go for the lateral change. It is an optional but most frequently observed scenario on the road. The decision algorithm for the lateral movement for both situations is presented below with the explanation of the term considered.

The flowcharts below are explained in a way that the vehicle is considering the change to a new left or right lane. But actually the model is prepared on the basis of strip consideration instead of lane which is smaller than lane in width. In fact a lane is consisting of more than one strip. The principle of the model regarding the road divided in strips will be described in the later part of the chapter. So the flowchart state about the strip which is nothing but a smaller lane.
Figure 3.1: Flowchart for selection of the type of the lateral movement
Figure 3.2: Flowchart for Mandatory Lateral Movement Consideration

1. Has the vehicle crossed the mandatory critical line?
   - No: Discretionary Lateral Movement
   - Yes: Next step

2. Is there right /left lane available?
   - No: Next step
   - Yes: Occupy the lane

3. Has the vehicle reached the intersection?
   - No: Next step
   - Yes: Stop the vehicle and execute forced merging

4. Has the vehicle reached the mandatory safe zone?
   - No: Next step
   - Yes: End of mandatory consideration
Figure 3.3: Flowchart for Discretionary Lateral Movement
3.4.1.1 Strip and Time Step Consideration

When the lane based system is followed strictly on the road, the vehicle always stays within a boundary of lane. So it is obvious for this type of discipline on the road that if there is n number of lanes, a vehicle will stay anyone of the n lanes. But this movement and the position of the vehicle on the road is not that obvious for the weak lane based traffic. In this situation the vehicle can take any distance laterally to reach its desired position. So the boundary of the lane is not applicable here. Because if the lane system is well thought-out for this system then the movement of the vehicle will be obtained as fraction of a lane for most of the time which may not be effective to replicate in the model for heterogeneous traffic.

Being concerned of this usual lateral movement, a strip based system has been considered here in this research. Observing the most natural lateral movement of the vehicle, the minimum width of a strip has been regarded as 0.5m. If the road is 12m wide, then the road is divided as 24 strip road. The system mimics the most common lane changing models with a difference in the width of the lane only. As the width of the vehicle is known, each vehicle occupies a certain number of strips depending on the position of the vehicle which is rounded up to an integer value. So, the occupied strips actually consider the width of the vehicle including the safe lateral gap to avoid the sidewise collision. Depending on the width of the vehicle and the safe lateral gap in both side of the vehicle, the usual occupancy of each type on the basis of the strip (11 types of the vehicle are available in Dhaka) is listed as below.

Time step is another consideration for the development of the model. Time step is the time interval of the surrounding driving behavior being updated. The surrounding behavior consist of the current speed and acceleration of the subject vehicle, current position on the road, the leader vehicle and the follower vehicle and their speed, acceleration at that moment etc. So according to the time step, these properties for the subject vehicle will be updated following the time interval.

The main objective of this research is to estimate a lateral movement model focusing on every details of the movement using the latest technology. To develop the behavior in a microscopic manner the time step should be less. It will represent the movement obvious. Considering all of this and for the sake of a reliable model the time step has
been considered as 0.2sec. So the position of the subject vehicle along with its surrounding environment will be updated after 0.2sec continuously. As the time step is very small, so the possibility of capturing every details of the lateral movement on the road increases.

Table 3.1: Vehicle wise strip occupancy

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Usually occupied strip</th>
</tr>
</thead>
<tbody>
<tr>
<td>passenger car</td>
<td>4</td>
</tr>
<tr>
<td>microbus</td>
<td>4</td>
</tr>
<tr>
<td>suv (jeep, pajero)</td>
<td>5</td>
</tr>
<tr>
<td>pickup</td>
<td>5</td>
</tr>
<tr>
<td>utility vehicle</td>
<td>4</td>
</tr>
<tr>
<td>cng auto rickshaw</td>
<td>3</td>
</tr>
<tr>
<td>cycle rickshaw (pedal)</td>
<td>3</td>
</tr>
<tr>
<td>motorcycle</td>
<td>2</td>
</tr>
<tr>
<td>bicycle</td>
<td>2</td>
</tr>
<tr>
<td>bus</td>
<td>5</td>
</tr>
<tr>
<td>truck</td>
<td>5</td>
</tr>
</tbody>
</table>

3.4.1.2 Leader Identification

The identification of the leader refers to the finding of the most obstructing vehicle for the subject vehicle on the road. The leader will be identified with in a search area in front of the vehicle. The vehicles of the Dhaka have been classified in 11 classes here. All types of vehicles have unique dimension. Each vehicle occupies a certain amount of strips on the road. The usually occupied strips for each vehicle type are presented in Table 3.1.

The width of the search area for a subject vehicle will be expanded up to the half width of the widest vehicle in the network from the side of the subject vehicle in both left and right. The longitudinal distance up to which the leader will be searched for is considered as 20 m from the front of the vehicle.

To identify the leader of a vehicle let’s consider a subject vehicle, SV occupying 3 strips on the road as shown in the figure 3.4. The SV is shown as CAR. If the widest vehicle in the network occupies 4 strips then the lateral search zone, $SZ_x$ is stated in the figure where,
$$SZ_x = \text{Width of the subject vehicle (W) + Half-width of the widest vehicle in the network} \times 2$$

$$= 3 \text{ strips} + 2 \text{ strips} \times 2 = 7 \text{ strips for this case.}$$

The longitudinal search zone, $SZ_y$ is considered 20 m here which is fixed. So, the search zone for the SV is $SZ_x \times SZ_y$. If the widest vehicle contains odd number of strips, then the half of the width will provide a fraction number which will be upper rounded to have an integer value to fix the search zone in both side of the vehicle.

To find out the exact leader the SV will look within the search area first to find out the vehicles in it. If there is any vehicle found whose half width is within the area then the type of the vehicle will be checked. If the half width reaches the part of the 3 strips occupied by the SV, then that is considered as a potential leader. But, in spite of staying within the search area, if the existence of the vehicle do not conflict with the strips of the SV, that is not stated as potential leader. The figure 3.5 (a) and 3.5 (b) shows the selection of potential and non potential leader.

Whenever the scanning of the SV for the leader is completed in the search area, it will find out the number of the potential leaders there. If the potential leader is only one, then that will be the exact leader for the SV in that time step. But if it is more than one then the vehicle closest to the SV on the basis of space headway within 20 m zone is considered as the exact leader for the SV in that time step. In the figure 3.5 (c) it is shown that the distance $X_2$ is greater than the $X_1$. So in this case the vehicle with 4 strips is the exact leader for this time step though 2 strips vehicles covers more part of the SV.
Figure 3.4: Identification of Search Area
Figure 3.5 (a): (Potential) Leader Identification
Figure 3.5 (b): (Non-Potential) Leader Identification
Figure 3.5 (c): (Exact) Leader Identification
3.4.1.3 Decision Algorithm Explanation

The coordinates \((X, Y)\) of the vehicle after the specified time interval will specify the position of the vehicle on the road. As the coordinate is just a point, it will indicate to an exact strip number on which part of the vehicle stays. Then, from the known width and length of all type of the vehicle, the occupancy of the vehicle on the road can be defined easily. The lateral movement will be considered when there will occur any change in the exact strip number for the change in \(X\) coordinates.

The lateral movement can be observed for two scenarios. They are specified as ‘Mandatory Lateral Movement’ and ‘Discretionary Lateral Movement’. Each vehicle follows a path plan to reach its destination which is supposed to be known to every driver. As per considered path plan, a vehicle may need to take left turn; right turn or U-turn in the intersection or it may need to take the left or right diverged road/ramp to reach the intended location. Whenever these types of movement are found required, then no choice exist other than the lateral movement whether the driver wants it or not. This lateral movement will be regarded as Mandatory Lateral Movement (Figure 3.10). The observed lateral movement other than these will be termed as Discretionary Lateral Movement. In case of discretionary movement the lateral changes occur only to obtain a better or preferred driving condition from the current position. The better driving condition may vary from driver to driver. But the usual conditions for better driving environment in a lane are the attainment of the desired speed, absence of leader especially heavy and slow moving non motorized leader, good driving surface, minimum side friction, better visibility, low density. This is the most frequently observed movement on the road. The Discretionary Lateral Movement is shown in the figure 3.6. Here the presented three vehicles will go straight along the road. The car usually moves faster than the NMV and bus if there is no congestion on the road. So in this figure, if the car wants to occupy the right strips to overtake the NMV provided that the road surface is same everywhere, then the movement will be termed as Discretionary Lateral Movement.
The information about the vehicles is prerequisite for the development of the model. The information of the subject vehicle (SV) will be determined first. The position of the vehicle on the road, the number of the strip it occupies and the change in the number of the strip with time will be identified to observe if there is any lateral movement occurs. Moreover, the current speed and the acceleration of the SV for each time step will be computed from the difference of the coordinate. The type of the SV is another important parameter. It will be categorized as NMV, heavy vehicle or car etc.

After computing the properties of the SV, the properties of the surrounding vehicle will be determined. The identification of the leader is an important task because the movement of a subject vehicle will be governed by the leader vehicle (LV) to a greater extent. The search zone will be fixed to look for the leader vehicle within that. Space headway is the criteria which will be considered here to fix the longitudinal

**Figure 3.6: Discretionary Lateral Movement**
search line. Space headway is a distance from the front bumper of the SV to the back of the front vehicle. The space headway is shown in the figure below.

**Figure 3.7: Space Headway**

The lateral search line will also be needed to find out the search zone. The whole process of the search zone and the leader identification has been discussed in the later part of this chapter.

Follower vehicle is another important criterion for the SV to consider the required lateral movement. The follower vehicle will be identified in the same way as the leader identification. The main difference is that the search area will be extended backward from the SV and the first vehicle in the effective search zone in the back of the vehicle will be considered as effective follower vehicle.

To complete the action the lateral movement a vehicle will need to have acceptable gap in the adjacent strips. A gap in the adjacent strips will only be acceptable if the movement of the Subject Vehicle (SV) to the new position satisfy non collision criteria. It means that if the SV changes from the current position to the left or right, it will not collide with the vehicle that are already moving occupying that strip. So, to maintain this criterion minimum distance has to be ensured for each vehicle in the adjacent strip to consider for the lateral movement.

Ensuring the maximum safety a SV will look at least for the distance ahead up to \((vt + d)\) from its front bumper in a time step to access the feasibility of the movement to the new strip in the next time step. \(d\) defines the perception reaction distance (Wright et. al. 2008) which is found by the following equation:
\[ d = \frac{v^2}{2a} \]  

(3.7)

Here,

- \( v \) = speed of the subject vehicle at the considering time step
- \( a \) = deceleration rate to be taken as 3.4 m/sec\(^2\)
- \( t \) = perception reaction time considered to be different for mandatory and discretionary case

It is the distance required for each vehicle to stop before colliding with a lead vehicle if the lead vehicle suddenly stops on the road. The vehicle will also consider the case of the following vehicle if it moves to the new position. It also has to be ensured that due to the changes of the strip, no vehicle will hit the SV from the back. So the safety distance consideration from the front of the vehicle has to be from the rear side of the vehicle. Ultimately a vehicle will be eligible to move to a new strip if there is available adjacent gap.

Whenever a driver changes its position from the current strip to the left or right, the LV and FV may be changed. The change in the position is an option for the driver. He may take it or not depending on his need. But if there is adjacent gap available to move the vehicle laterally, the vehicle will always check the probable LV and FV whether it moves there or not. If the vehicle can move to the left, it will look for the left LV and left FV. On the other hand, if it can move to the right, it will look for the right LV and right FV. It will be done by assuming that the SV to the new condition as shown in the Figure 3.8. The identification of the leader and the follower is the same as before just only considering the SV is in the new position. If the vehicle actually moves to the left or right strip, the identified leader/follower will be its actual leader/follower. If the vehicle does not take the gap, the identified leader/follower will be considered as probable leader/follower if the movement were completed. The speed, acceleration, type of the actual or probable leader/follower will be computed as before. If no adjacent available gap is found, there will have no scope of finding any actual or probable LV or FV in left or right.

In the figure CAR-1 finds the NMV as the leader at time \( t \). But at time \( t+dt \), if there is adjacent gap available to move left for the vehicle, it will assess its new position by assuming it in the new position as shown by the dotted CAR-1. The CAR-2 will be the probable leader and the BUS will be the probable follower for the CAR-1 then. The identification procedure remains same as before only considering the SV at the
new position. If the vehicle actually moves to the new position at time $t + dt$, the probable leader and the follower will be the exact leader and follower.

![Diagram of vehicle positions](image)

**Figure 3.8: Identification of probable leader and follower**

After being informed regarding the surrounding environment, a driver will now consider for the execution of the lateral movement. In case of discretionary lateral movement, the stimulus of the change actually comes from the intention of achieving better driving condition. It will be termed as utility. The utility is a function of speed, acceleration type of the SV, LV and FV, the properties of the probable leader and follower in the left or right strip etc.

The driver will check for the adjacent available gap in the left and right side of its current position. Depending on the gap, the option of changing appears to the driver. If the gap is acceptable in both sides, the driver will have three option of staying in the current position, lateral change in the right or lateral change in the left. If this case appears, the utility of the three options will be calculated depending on the variable
considered here. The driver will choose the option with greater utility than others. If the gap is acceptable in one side only, the utility will be compared with the current position and that available option. If no gap is available, the vehicle has to stay at its current position with no other option. Before performing the utility comparison, the position of the vehicle on the road is checked whether it stays at the left most or right most strip. If it stays then the option of left or right will not be available to that. The figure 3.9 below shows the consideration for utility calculation. When the car is moving straight staying in the current position, it will consider the black area in front of it to evaluate that position. If the left or right strip is available as shown in the figure, the utility in the right side will be considered by evaluating the blue area, whereas the utility of the left side will be calculated by considering the red area. The car will continue to extend its evaluation with time. If the car does not get the adjacent available gap in the left, the red area will be assessed. Similarly, the blue area will not be taken into account if the right strip is not free to occupy. If the vehicle stays in the left most or the right most zone then the red area or blue area will be disregarded respectively.
Figure 3.9: Utility calculation zone in the current, right and left strips

The mandatory movement is quite different from the discretionary movement. As the driver has the urgency to change the position, the improvement of the driving environment is less likely considered here. To define the mandatory movement, the mandatory zone has to be determined first considering the left turn or right turns in the intersection as that type of movement.

When a vehicle approaches an intersection and needs to take the turn, it considers a line away from the intersection as a starting point to the execution of mandatory move. The line may be defined as mandatory critical line. Moreover, it is a usual scenario in the intersection that, a vehicle can take the left turn or right turn automatically with the traffic flow if it stays in certain left or right zone respectively without any extra effort to change the position. This is because all the drivers becoming aware of their destination try to stay in the require side of the road for the intended turn before reaching the intersection. So, from the mandatory critical line to
the intersection line which is assumed in the starting point of intersection, the area is divided into two zones. The one is the mandatory safe zone and the other one is the mandatory critical zone.

If a turning vehicle reaches the mandatory safe zone, it will be able to complete its maneuvers with the flow. But in case of mandatory critical zone, a vehicle must have to move laterally to reach in the mandatory safe zone to take the turn safely. If that vehicle fails to reach that safe zone and touches the intersection line it will stop there and go for the forced margin to achieve its target. The mandatory lateral movement is shown in the figure 3.10.

The thin red line is the mandatory critical line and the thick red line is the intersection line. The blue area defines the mandatory critical zone for the right turning vehicle and the red zone defines the mandatory safe zone for the right turning vehicle. In the figure the CAR-1 and CAR-2 want to move to the right. Both the vehicles have crossed the mandatory critical line. But the CAR-1 stays in mandatory safe zone where the flow will take it to the right without extra effort. On the other hand, the CAR-2 is in mandatory critical zone where the vehicle has to look for the lateral change to at least touch the mandatory safe zone. So, the mandatory lateral movement is applicable for the CAR-2 only. If it fails to reach the mandatory safe zone before the intersection line, it will stop in the intersection and try for the forced merging.

The other vehicle in the figure is BUS and the NMV. As the BUS will go straight and the NMV has not touched the mandatory critical line yet, they should not be considered for the mandatory movement assessment. The probability of the lateral change for the mandatory moving vehicle will increase from zero to one which is indicated by the thin and thick red line.
Figure 3:10: Mandatory Lateral Movement
3.5 Variable Description

In case of lateral movement model estimation there has some variables to be considered. The considered variables are stated here.

**Vehicle Type:** The type of the vehicle is a major variable for the lateral movement model. The heavy vehicles (e.g. bus, truck) usually less inclined to lateral changes on the road compared to the other vehicles.

**Current Leader:** The current leader of the subject vehicle (SV) is one of the important variables for taking the decision of lateral movement. The type, speed etc. of the current leader affects the decision whether there will have the information of the possible leader in the adjacent strips if any.

**Current Follower:** The presence of the current follower and the possible follower if the strip change occurs is considered as a potential variable for this model.

**Heavy Leader and Follower:** Depending on the type of the subject vehicle the identification of the current leader and follower whether it is heavy or not is a matter of concern for the lateral movement completion. If the subject vehicle itself a heavy vehicle, it may not be concerned for the changes

**NMV:** NMV refers to the non motorized vehicle which includes the cycle and rickshaw in Dhaka city. There is a basic operational and functional difference in motorized and non motorized vehicle. The presence of this kind of vehicle has a strong effect on taking lateral movement decision.

**Current Speed and Speed Limit Ratio:** The speed obtained by the vehicle is compared with the speed limit of the network, which is considered as desired speed here. If the current speed is less than the desired speed, the desire of lateral movement should increase if there is any better position available.

**Position on the Strip:** The position of the vehicle on the strip affects the decision. If the vehicle stays at the right most or left most strips, the decision pattern will be changed from the usual. Generally, the driver prefers the right side of the road compared to the left side due to the more side friction in the left.

**Available Adjacent Gap:** The presence of the available adjacent gap in left or right is a monitoring factor for the driver in case of lateral movement. If the gap is found in both directions, then the gap length, the possible leader and the follower if the gap is accepted etc. are considered as variable in lateral movement model.
**Probable Leader and Follower:** The probable leader and follower are the leader and the follower that will be faced by the vehicle if it move to the new position. A vehicle always consider for this. If the probable leader and the follower is a obstructing one, the vehicle may not consider the lateral change. If the vehicle completes the action of the change, the probable leader and follower will be the actual leader and follower.

**Mandatory Critical Line:** Mandatory critical line is the line before reaching the intersection from where a vehicle starts to think about the mandatory change, if needed. As soon as a vehicle passes the line, the probability of going for the mandatory lateral change begins to increase from zero.

**Intersection Line:** A mandatory turning vehicle will always try to complete the required action of lateral change before reaching the intersection line. It is the line considered in the starting point of the intersection. The probability of the change becomes the maximum one here. If the vehicle cross the line and fails to take the required change, it will stop in the intersection and wait for the perfect opportunity to move by interrupting others.

**Safe Mandatory Zone:** In case of mandatory lateral movement there have some zone on the road from where the vehicle will be able to take the required turn with the flow. It is considered as the safe mandatory zone. If a vehicle needs to take a mandatory change, then its position on the road is a factor to be considered here.

### 3.6 Summary

The tentatively selected model structure is relatively simple in nature. In this chapter a flow chart has been shown to describe the mandatory and discretionary lateral movement for the heterogeneous traffic. The hypothesis considered for the model formation has also been demonstrated. Ultimately the required variable for the estimation of the proposed model has been listed to consider those in case of data collection.
CHAPTER FOUR
DATA COLLECTION

4.1 General

The primary goal of this research is to develop a model for capturing drivers’ lateral movement behavior in case of heterogeneous traffic. To ensure that the model is a reasonably accurate representation of the real world conditions, a significant amount of data is required. The performance of a research work is significantly dependent on the availability of the data. There are various types of data which should be collected for the transportation project. The type, quality and quantity, sensitivity and data collection method entirely depends on the purpose of the research and economic feasibility associated with the research types. So for running a successful output from the research a suitable and efficient data collection plan is a must.

In this thesis data will be collected to develop lateral movement model for the weak lane based traffic of Dhaka and calibration of the developed model. In the following subsections data requirement, data collection methodology and other relevant features related to data collection will be discussed.

4.2 Data Collection Objective

There are several objectives for collecting data as follows:

a. Understanding various driver behavior and vehicle characteristics to construct a model
b. Identifying the elements that represents the behavior of the heterogeneous traffic drivers
c. Ultimately formation and calibration of a lateral movement model for the heterogeneous weak lane based traffic of Dhaka to represent this movement to the best
4.3 Data Collection Method Used in Other Heterogeneous Study

Data in the other recent studies on heterogeneous traffic (TRASMIC, MIXSIM, MIXNETSIM, Singh, HETSIM) were collected with video cameras placed on buildings or structures adjacent to or on the top of the road where the data were being collected. Moreover, field data were collected to facilitate the requirements of the data for the modeling. In a recent study (Khan, Maini et al. 2000) has examined some vehicle following models where two vehicles were instrumented with GPS units with one vehicle following the other. In the recent study, (Imran, 2009) found the video technique as the most effective method to collect the data for development of Neuro-Fuzzy model for car following behavior in heterogeneous road traffic condition.

4.4 Data Requirement for this Study

The traffic of Dhaka follows weak lane based rules. From the real scenario of the road, it is seen that the traffic can stay anywhere on the road depending on its requirements. To formulate the lateral movement model the position of the vehicle is mandatory. So, to satisfy the requirements of the data, the trajectories of the vehicles are also useful which is considered as the primary data for the model formation.

4.4.1 Primary Data

The primary data actually consist of aggregate data and disaggregate data. The video data forms the disaggregate data where as the aggregate data also includes the GPS data along with the video data. For the development of the lateral movement model the disaggregate data will be used. Moreover, it will also be used for calibration. Aggregate data will also be used for aggregate calibration of the developed model.

In the GPS data, second-by-second trajectory of the vehicles will be stored for identifying longitudinal and lateral movement of vehicles as well as 2D movement (combination of longitudinal and lateral movement). The data will later be processed to identify position, speed acceleration, deceleration, strip occupancy etc. of vehicles which are the input of proposed lateral movement model for heterogeneous traffic. On the other hand, the video data, collected by video camera as video recordings, will consist of the actual movement of traffic. As the data itself is realistic, it can be an
excellent source for event identification like lateral movement in terms of overtaking, turning, lane-changing, merging etc. the data can also provide sufficient insight for acceleration decisions like identifying the stimulus for acceleration or deceleration. The data can later be combined with GPS data to supplement the disaggregate data or cross examined with GPS data to check the actual movement with movement found from GPS data.

4.4.1 Methodology for Primary Data Collection

Primary data is the basic input for the estimation of the model. With a view to collect a successful data set from the field a data collection plan is prepared as follows.

4.4.1.2 Data Collection Location Criteria

The purpose of the data always governs to consider the criteria for the selection of the data collection location. Here for primary data (video and GPS data) the locations were chosen in such a way that a perfect synchronization of data collection is possible for future combination or necessary checking. Therefore, both types of data were collected in the same road network at the same time. Also the sites suitable for both type of data had to be considered. As the GPS data had to be collected periodically, a specific route was identified and as the video data was decided to be collected by video camera, a common network was inevitable. The road network was therefore would consist of both the route or road track and the video data collection spot.

4.4.1.3 Data Collection Method

To model the behavior of the driver, the interactions of the subject vehicle with the other vehicles have to be observed for a certain period. So, video data was to be collected continuously and therefore required video recording for specific period. A mounted place would be ideal for video camera and its maneuver. The GPS data was required to be collected continuously along a specific route and therefore some test vehicles equipped with GPS devices was selected as GPS data collection mode.

4.4.1.4 Site Selection for Primary Data Collection

When a location is thought to be selected for the data collection, it is expected to have some properties there. Some criteria for the site selection have been stated below. Upon the attainment of the expected properties, the finally selected site has been described in the later part of this section.
4.4.1.5 Site Selection Criteria

The criteria for selecting locations for primary data collection are as follows,

*Unobstructed view:* the site should be unobstructed as much as possible. If the presence of the trees, post or bill boards etc obstruct the recording of the video, the main purpose of the data collection will be hampered.

*Raised platform for placing camera:* the site should contain a raised space like foot over-bridge to place the video camera.

*Uninterrupted video data collection facility:* the raised platform for the video data collection will be facilitated in such a way that the data collection can be continued neglecting the rainy or sunny weather. Moreover, the vibration in the location should be minimum to capture a good quality video.

*Continuous movement of vehicle:* there should be continuous movement in the site with a reasonable speed.

*Straight portion of road:* the road section should be free from any bend or curve portion so that flow for a reasonably straight road length can be obtained.

*Minimal side friction:* as the side friction hampers the natural movement of traffic the location should be free from it (or the side friction should be minimum if cannot be avoided).

*Absence of major traffic attraction point:* if there is a major traffic attraction zone within the captured area, the obtained movement will not fulfill the real scenario due to the interruption in the traffic flow.

*Avoidance of large commercial vehicles:* image processing software will be used for vehicle counting which works on the basis of only frontal view of traffic and therefore the large vehicle operating road section is not expected (as it obstructs the frontal view of small sized vehicles like private car and auto-rickshaw).

4.4.1.6 Reconnaissance Survey

An extensive video data collection program was executed to facilitate the formation of the OD matrix form the mobile call data (Iqbal, 2013) in thirteen (13) locations in
Dhaka city for both way traffic. From the video data of those locations, some potential video data collection locations have been selected to consider the trajectories of the vehicle for model formation. Then a preliminary field survey has been conducted to find out the possibilities and difficulties to collect the data in those locations. From the video and the survey, some potential locations have been selected initially as the data collection point.

4.4.1.7 Final Selection

Before selecting the data collection location finally, the requirement of the discretionary and the mandatory movement has been considered. To observe both kind of movement, two individual locations are required. The candidate locations identified by the reconnaissance survey were thoroughly checked against each criterion and finally two locations were confirmed for video data collection for the discretionary and mandatory movement. Location one is Kalabagan and location two is Shukrabad. The Kalabagan is a place where the vehicles are captured in a situation when they get the opportunity to move in a straight portion without any interruption from the intersection. So, the Kalabagan is a location to consider the case of Discretionary movement. On, the other hand, the Sukrabad is a location with an intersection where the vehicle has the option to take right turn or U-turn there. This location represents the zone for mandatory turning movement, if required by the vehicle.

The video cameras were mounted on over bridges in these two sites. Figure 4.1 shows the camera location on Kalabagan over bridge with the direction of both camera and traffic. A snapshot of traffic approaching Kalabagan from Asad Gate intersection is presented in figure 4.2. The opposite directional traffic of this location (approaching Kalabagan from New Market) is shown in figure 4.3.

It can be seen from Figure 4.1 that there are two video cameras for capturing two opposite directional traffic. The camera direction is naturally the opposite of traffic direction. Camera 1 captures the traffic coming from Asad Gate and moving towards New Market (though the locations are not in the figure). Camera 2 captures the traffic flowing at opposite direction (from New Market to Asad Gate).
**Figure 4.1**: Kalabagan over bridge (with camera and traffic direction) (Source: Google Earth)
The second data collection site is Shukrabadad only one camera has been used in this location (figure 4.4). The camera is capturing the traffic from Asad Gate to New Market direction. In figure 4.5 the traffic approaching Shukrabad intersection from Asad Gate is exhibited.
Figure 4.4: Shukrabad over bridge (with camera and traffic direction) (Source: Google Earth)
The GPS data were collected along with the video data for disaggregate calibration. Total five vehicles were run along a specified route congruent with video data location site. The route is shown in figure 4.6. Some points on the road are also shown in the picture to mark that the road network coordinates were obtained from GPS data as well.

4.5 Collection of Primary Data

It has been mentioned that the primary data consists of video data and GPS data (disaggregate data).

4.5.1 Video Data

The video data were collected as video recording by video camera placed at two foot over bridges in Mirpur road of Dhaka city. The over bridges are at Kalabagan and Shukrabad as mentioned earlier. The video data were collected for about 1 hour duration continuously and the camera was set at a particular position and specific
viewing angle to capture the front view of all the vehicles passing the site (over bridge).

4.5.2 Auxiliary Data (GPS Data)
There were five test vehicles equipped with high precision GPS devices. Four types of vehicles were used; two private cars, one microbus, one CNG auto-rickshaw and one motorcycle. The vehicles were run along pre-specified tracks of Mirpur road for approximately one hour (figure 4.6). The raw data mainly consists of the position of vehicles and the points are taken with one second interval. Some other information is also present in the data log.

Figure 4.6: Route for GPS Data Collection (with data points)
4.6 Difficulties in Primary Data Collection

There were some obstacles before and during primary data collection. It was difficult to find out the perfect location for data collection as the site selection criteria could not be fully met. The mid-section of the road was not long enough to capture the acceleration of the traffic in full scale by the video camera. There were slight bends also to hinder the longitudinal movement of traffic in some cases. As the over bridges were not too high it was not possible to capture the frontal view of a large platoon of traffic at a particular moment (view obstruction was evident at that moment). There were some inherent weaknesses of the steel over bridge like the vibration while pedestrians were moving using the bridges. Therefore the video was affected as well. Side friction of the road also caused serious problems by reducing the effective width of road and hampering the natural flow of traffic.

4.7 Summary

In this chapter a proper data collection methodology has been explained. Site selection, data collection technique, requirement and use of data have been described as well. It has been found that there are some difficulties associated with data collection which has been resolved later. It is evident that data collection plan is as important as the data itself. Therefore the whole methodology for data collection was devised with proper discretion and data was collected using the appropriate procedure.
CHAPTER FIVE
DATA ANALYSIS AND MODEL DEVELOPMENT

5.1 General

Data analysis is one of the most important parts of this thesis to show the way of how the data has been processed and used to get the ultimate result. Therefore it is necessary to properly demonstrate the process and explain every terms and steps associated with the analysis. In this chapter the whole process starting from data processing to model development will be discussed.

5.2 Data Analysis

5.2.1 Primary Data

The primary video data was collected from the field using the video camera and then processed with video processing software. The location for the mandatory and the discretionary lateral movement consideration was different as stated earlier in the data collection chapter. The location for the mandatory data was the Sukrabad intersection and the location for the discretionary data was the Kalabagan-New Market road. The both sites are situated in the Dhaka city and situated near to each other.

The raw primary GPS data was collected from the five high precision GPS equipped vehicles in the same location as before. The raw primary GPS data contains

- Vehicle ID
- Time
- Latitude
- Longitude
- Mode of GPS device (Autonomous and DGPS)

Some other information is also stored but may not be required for the purpose of the thesis and therefore have not mentioned here. When the latitude and longitude data are given as input in ‘GPS Visualizer’, this software gives the trajectory of the vehicles which were equipped with GPS devices earlier.
The video data was processed using software named ‘TRAZER’. The recorded video is run in the software and the software provides the trajectories of each vehicle in the frame. The trajectories are presented ultimately in the local coordinate which is first fixed on the basis of the width and some portion of the known length of the road. The classified count of the vehicle is an output from the software along with the occupancy, flow and average velocity of the vehicle.

The trajectories were then customized in different forms to make it usable in the utility function for model estimation. The overall process of the modification of the data has been shown in the following figure which is almost same as Islam (2013) used in the acceleration model as follow:

1. Step 1: Read trajectory data file
2. Step 2: Read vehicle type data and group of multiple ids of a vehicle data
3. Step 3: Discard all the invalid vehicle ids from data file
4. Step 4: Group together all the ids of a vehicle (if any)
   (Consider only forward movement)
5. Step 5: Convert frame ids to time and distribute to predefined interval
6. Step 6: Smooth X and Y trajectory data for each vehicle using 5th order polynomial fit
7. Step 7: Place smoothed X and Y trajectory data in the predefined time interval (done in step 5)
Figure 5.1: Steps of variable generation from trajectory data using MATLAB

In TRAZER, the X and Y coordinates of the vehicles were defined as the mid-point of the front bumper line of vehicle, so the spacing was initially obtained as front bumper to front bumper distance. The gap was then converted to clear spacing by using standard dimension of each vehicle class.

The process of identification of the leader and the follower along with the search area determination was presented in the previous part of the thesis. The upper limit of searching the leader in front of the bumper was set to space headway of 20 meter. The width of the road was almost 12 meter which was considered subdivided into 24 equal strips of 0.5 meter each. To define the mandatory safe zone, the video recordings and the field data were assessed. The usual trend of the vehicle movement suggested considering a width of 3 meter as a safe mandatory width and a length of 50 meter from the intersection as a safe mandatory longitudinal distance. The vehicle within this area was free to take the turn in the intersection without considering any mandatory move. Whenever the available adjacent gap has been calculated, the equation 3.7 was used but with a different value for the brake reaction time, t for the mandatory and discretionary movement. The brake-reaction time has been considered as 1.5 seconds for the discretionary movement whereas the time was taken to be 1 seconds for the mandatory movement due to the urgency effect. The acceleration is always considered as 3.4 m/sec².
For formulating the mandatory lateral movement, a data of 50 minutes was analyzed. One hour data was taken in consideration in case of the discretionary lateral movement. After analyzing the data, it is found that most of the vehicles in both locations were private car. The composition of the vehicle is presented below in the figure 5.2.
Figure 5.2: Vehicle Composition
The traffic movement of Dhaka has some special features which have been observed in the data. As it is a congested city, the vehicle cannot speed up as much as wish even though it is operationally fine. In addition to that, the indiscipline on the road, side friction etc. do not allow vehicle to move in desired speed. So, it is observed that the average speed of all type of motorized vehicles do not vary much to each other when they are in a flow. The figure 5.3 below shows the average speed of the vehicles classified by type below in both locations.

**Figure 5.3:** Average speed of all vehicle type

![Average Speed (m/s) of the Vehicle (Discretionary)](image)

![Average Speed (m/s) of the Vehicle (Mandatory)](image)
From the above figure another thing is obvious that the speed difference is negligible in the mandatory site. As there is an intersection in that place and some vehicle are taking the right turning there, so all the vehicles facing that zone is being interrupted and the operating speed is being equal to the speed of the flow.

The location of the mandatory data collection is an important site for Dhaka city. The main road carrying vehicles form Asad Gate toward the New Market and Panthopath. (Figure 5.4). But some vehicles take the right turn in the intersection to reach the Dhanmondi residential area or take U-turn to go toward the Asad gate again. The turning movements are the main concern for observing the mandatory lateral movement. It is found from the final data set that 80 out of 1190 vehicles take the right turn or U-turn there in the intersection. Moreover, 543 updated positions on the basis of time interval out of 10395 moves were found in the mandatory critical zone. So, these are considered primarily for the mandatory model formulation.

![Figure 5.4: Possible movements in the Sukrabad Intersection (Source: Google Earth)](image)

the side friction, speed decrement and movement interruption, the vehicle try to avoid that part. The figure shows that almost ¾ of the vehicle stays in the right mid of the road especially for mandatory case. In case of discretionary movement, most of the
vehicles prefer to stay in the mid part where they get the option of moving in both side.

* The first strip starts from the right side of the road near island and end up in the left side near shoulder

**Figure 5.5: Strip wise vehicle availability**

Though all the vehicles like to move avoiding the left side strips, this is not true for the non motorized vehicles. As the functional deficiency and the difference in the speed, most of the movements from the NMV were found in the left one third side of the road. Out of 3201 time dependent moves from the NMV, 3149 was found in the strips greater than the 16th strip.

The velocity profile varies in quality in the two locations. Where the discretionary movement is observed, the vehicle is found to be increasing. The data collection point is in the mid block of a segment where the vehicle get the chance to speed up if there is no congestion ahead to stop the vehicle. On the other hand, the vehicle in the mandatory zone faces an interruption in the movement due to presence of the intersection where some vehicle may stay to take the turn or some vehicle may merge from the opposite side. So, the velocity reduces as the vehicle reaches the intersection.
The velocity profile of the two sample vehicle in two locations is presented below to observe the real scenario.

**Figure 5.6:** Velocity profile of the sample vehicle in two locations

The most important feature observed during the data analysis is that most of the vehicles prefer to stay at the current position. So, the case of the lateral movement was limited. The figure 5.7 below shows the lateral movement in both left and right along with the current position. As, the traffic of Dhaka is considered here, the difference of the speed among the vehicles is not significant always. Moreover, the road surface quality also does not vary much along the width of the road. If the benefit of the road remains same all over the width, definitely the drivers will change
the lateral position as low as possible. This inertia also may arise from the safety consideration of the drivers. So, the lateral change occurs only when the driver finds it mandatory or when the change will provide a major improvement in the driving condition.

![Lateral Change Frequency (Discretionary)](image)

![Lateral Change Frequency (Mandatory)](image)

**Figure 5.7:** Frequency of the strip change in both conditions

### 5.3 Model Formulation

The estimation results of the proposed lateral movement model using the Kalabagan and Sukrabad dataset are presented here. Both the discretionary and mandatory model has been estimated using a maximum likelihood estimation procedure. Log likelihood function has been used here to estimate the model. The maximum likelihood estimates of the model parameters are found by maximizing this function. In this study, the Broyden-Fletcher-Goldfarb-Shanno (BFGS) optimization algorithm implemented in the statistical estimation software GAUSS (Aptech Systems 1994) has
been used. BFGS is a quasi-Newton method, which maintains and updates an approximation of the Hessian matrix based on first-order derivative information (see, for example, Bertsekas 1999). GAUSS implements a variant of BFGS due to Gill and Murray (1972), which updates the Cholesky decomposition of the Hessian (Aptech Systems 1995). The integrals in the likelihood function were calculated numerically using the Gauss-Legendre quadrature method (Aptech Systems 1994).

Before estimating the parameters, a general casual relationship is assumed based on the practical observation which will indicate the expected response of each variable. The list is given below in the table 5.1.

Table 5.1: Variables and a priori hypothesis

<p>| Vehicle type | There have been eleven (11) types of vehicle considered here including heavy vehicle, non motorized vehicle (NMV) etc. The heavy vehicle (bus, truck) will not move frequently because of the physical characteristics. The car, jeep, microbus (car type vehicle) can move easily on the road but the safety issue of being collided with other will limit its movement. The driver of a car type vehicle will rather prefer to stay in the same position unless they find some safe condition to move laterally. The NMV should always prefer the left side of the road due to functional property. As it will have limited speed, it will not like to interrupt the high speed motorized vehicle by stating at the middle strips or right strips. The motorcycle should change its direction more frequently than others. As the motorcycle occupies a small portion of the road and have the facility to move using the small gap in between the vehicle even in stopped condition, it is expected to be the most unstable vehicle on the road. Moreover, age and experience are another important factor for the weaving movement of the vehicle. |
| Speed       | Speed is one of the most important features to be considered while driving. The vehicles users always want to move with a desired speed to reach the destination in shortest possible time with maintain safety. So, if the speed of the vehicle for staying in a position increases, the utility of that position should be more. If there arises |</p>
<table>
<thead>
<tr>
<th>Speed</th>
<th>any possibility to have better condition in terms of speed in the left strips or right strips with respect to the current speed, the vehicle should have a tendency to move laterally to achieve desired speed.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Vehicle</td>
<td>The presence of lead vehicle should never be appreciated by the drivers. If a road is found in a free flow condition, the driver gets the full freedom to move in its desired speed. But due to the presence of a lead vehicle, a follower vehicle is bound to follow. The operational speed and the movement also been controlled by the lead vehicle as well. So, if there have any lead vehicle in some strips, the utility of those strips will decrease. During the assessment of the feasibility of the left or right lateral movement, the driver will consider the probable leader in those strips. The findings will have some effect on the choice of the driver. In case of urban traffic movement, it is not always easy to obtain the free flow condition. So, the presence of the leader on the road should be a common feature. Though the exact leader for a vehicle cannot be specified but the driver may have option to choose the leader. It should be a common incident for all drivers to avoid the heavy vehicle as much as possible. Moreover, the vehicles that obstruct the speed are not appreciated at all by the vehicle. The obstructing vehicles may be the slow moving non motorized vehicle (cycle, rickshaw etc.) including the heavy vehicle like bus, truck etc. If a vehicle needs to follow a vehicle and if it has option available to choose, it should always go for the option of private car, jeep etc as a lead vehicle. As the movements of these vehicles are perfect according to the safety and law due to the vehicle own safety reasons compared to the other, private car as a leader vehicle will have better utility.</td>
</tr>
<tr>
<td>Follower Vehicle</td>
<td>A driver may not feel comfortable if there is a follower heavy vehicle and itself is private car or non motorized vehicle. If a vehicle consider for the lateral change, it will check in the left or right strips spread up to a backward distance to find out the presence of any follower vehicle. The non collision criterion is always kept in mind</td>
</tr>
</tbody>
</table>
| **Follower Vehicle** | by the drivers. If there have any possibility to be collided by the follower vehicle in the new position, the subject vehicle should not go for it. As the strike from a heavy vehicle should be more vulnerable compared to other vehicle, the utility of the strips with heavy follower will decrease.
A vehicle would not mind if a slow moving NMV type vehicles is found as a follower due to decreased probability of being collided and minimum vulnerability. |
| **Position on the road** | The position where the vehicle stays on the road is an important factor. If the NMVs stay at the left side, the vehicle will go for minimum changes. The other vehicle like car, jeep will prefer to stay at the right part of the road. Moreover, when a mandatory turning vehicle reached closer to the intersection, the frequency of the movement increases with the decrement of the distance. |
| **Type of the movement** | The type of the movement is an important factor to consider. If a vehicle needs to take a discretionary movement, it can complete its movement anywhere on the road. But, a mandatory turning vehicle will not consider the better condition of the road if it found available in the different side of its intended movement. Moreover, smaller the distance to the intersection, greater the probability to change even though the new position is not better than the current position. |
| **Mandatory critical zone** | If a vehicle stays in a mandatory critical zone and need to take the mandatory turn, it will change to the required direction if the minimum gap is found. |

### 5.3.1 Discretionary Lateral Movement Model

The model for the discretionary and the mandatory lateral movement will be estimated following the equation 3.5. The utility of the right strip, current strip and the left strip will be formulated adding the various available variables in the function and their significance will be checked statically and physically. The utility functions are presented below which is followed by the description of the dummy variables in Table 5.2.
\[ U_{\text{right-strip}} = \beta_{\text{right/left-lead-vehicle}} \text{ Right-lead-vehicle dummy} + \beta_{\text{right/left-follower-vehicle}} \text{ Right-follower-vehicle dummy} \]
\[ U_{\text{current-strip}} = \beta_{\text{current-lead-vehicle}} \text{ Lead-vehicle-dummy} + \beta_{\text{speed}} \text{ Speed of the current leader} \]
\[ U_{\text{left-strip}} = \beta_{\text{right/left-lead-vehicle}} \text{ Left-lead-vehicle dummy} + \beta_{\text{right/left-follower-vehicle}} \text{ Left-follower-vehicle dummy} + \beta_{\text{subject-vehicle}} \text{ Subject-vehicle-dummy} \]

**Table 5.2: Description of the dummy variables**

<table>
<thead>
<tr>
<th>Dummy Variable</th>
<th>Description</th>
</tr>
</thead>
</table>
| Right-lead-vehicle dummy        | 1  If the probable lead vehicle in the right strip is obstructing vehicle like heavy vehicle (bus and truck) or slow moving vehicle like cycle and rickshaw  
0  If the probable lead vehicle is other |
| Right-follower-vehicle dummy    | 1  If the probable follower in the right strip is heavy vehicle  
0  If the probable follower is other |
| Subject-vehicle dummy           | 1  If the subject vehicle is itself a heavy vehicle  
0  If the subject vehicle is other |
| Lead-vehicle dummy              | 1  If there have any current lead vehicle which is only car, jeep or microbus  
0  If there is no lead vehicle or the current lead vehicle is other than car, jeep or microbus |
| Left-lead-vehicle dummy         | 1  If the probable lead vehicle in the left strip is obstructing vehicle like heavy vehicle (bus and truck) or slow moving vehicle like cycle and rickshaw  
0  If the probable lead vehicle is other |
| Left-follower-vehicle dummy     | 1  If the probable follower in the left strip is heavy vehicle  
0  If the probable follower is other |
The estimation result of the first model is presented in the table 5.3 below. After that the explanation of the model has been presented.

**Table 5.3: Estimation result of the first model**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated Value</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of the Right/Left-lead-vehicle dummy, $\beta_{\text{right/left-lead-vehicle}}$</td>
<td>-1.476</td>
<td>-5.43</td>
</tr>
<tr>
<td>Coefficient of the Right/Left-follower-vehicle dummy, $\beta_{\text{right/left-follower-vehicle}}$</td>
<td>-1.840</td>
<td>-6.18</td>
</tr>
<tr>
<td>Coefficient of the Subject-vehicle-dummy, $\beta_{\text{subject-vehicle}}$</td>
<td>-2.396</td>
<td>-37.60</td>
</tr>
<tr>
<td>Coefficient of the Lead-vehicle-dummy, $\beta_{\text{current-lead-vehicle}}$</td>
<td>0.341</td>
<td>2.01</td>
</tr>
<tr>
<td>Coefficient of the speed, $\beta_{\text{speed}}$</td>
<td>0.643</td>
<td>15.06</td>
</tr>
</tbody>
</table>

No. of parameters: 5
No. of Vehicles: 1975
Adjusted Rho Square: 0.071

This is the base model for estimating the final model. The obtained parameters are also found statistically significant according to the value of the t-stat. The coefficient $\beta_{\text{right/left-lead-vehicle}}$ states that the utility of the left or right strip will decrease if there found any probable leader which is either heavy vehicle or slow moving non motorized vehicle. $\beta_{\text{right/left-follower-vehicle}}$ depicts that a driver will not be interested to move left or right strip due to the presence of heavy follower vehicle. According to $\beta_{\text{subject-vehicle}}$, if the subject vehicle is a heavy one, it does not like to move a lot to the left or right strip. If there have a lead vehicle, then the subject vehicle would feel comfort to follow that vehicle if it is only car type vehicle. This property is described by the coefficient, $\beta_{\text{current-lead-vehicle}}$. At last, the meaning of the coefficient of the speed is very obvious. If the speed increases, the utility will definitely increase.

After getting the encouraging feedback from the base model, it has been tried to formulate more reliable and effective model by considering other important variables. The next model (model 2) has been developed taking into account the effect of the vehicle specific constant for the current position as follow.
\[ U_{\text{right-strip}} = \beta_{\text{right/left-lead-vehicle}} \text{ Right-lead-vehicle dummy} + \beta_{\text{right/left-follower-vehicle}} \text{ Right-follower-vehicle dummy} \]

\[ U_{\text{current-strip}} = \beta_{\text{current-lead-vehicle}} \text{ Lead-vehicle-dummy} + \beta_{\text{speed}} \text{ Speed of the current leader} + \beta_{\text{subject-vehicle}} \text{ Subject-vehicle(car)-dummy} + \beta_{\text{subject-vehicle}} \text{ Subject-vehicle (heavy vehicle)-dummy} \]

\[ U_{\text{left-strip}} = \beta_{\text{right/left-lead-vehicle}} \text{ Left-lead-vehicle dummy} + \beta_{\text{right/left-follower-vehicle}} \text{ Left-follower-vehicle dummy} \]

The description of the dummy variable is the same as before only the change in the Subject-vehicle-dummy. The Subject-vehicle (car)-dummy is one for the car type vehicle only where as the Subject-vehicle (heavy vehicle)-dummy is one for the heavy vehicles. The estimated result is presented here in the table 5.4.

**Table 5.4:** Estimation result of the model 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated Value</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of the Right/Left-lead-vehicle dummy, ( \beta_{\text{right/left-lead-vehicle}} )</td>
<td>-1.224</td>
<td>-4.37</td>
</tr>
<tr>
<td>Coefficient of the Right/Left-follower-vehicle dummy, ( \beta_{\text{right/left-follower-vehicle}} )</td>
<td>-1.196</td>
<td>-3.85</td>
</tr>
<tr>
<td>Coefficient of the Subject-vehicle-dummy, ( \beta_{\text{subject-vehicle}} )</td>
<td>2.540</td>
<td>98.57</td>
</tr>
<tr>
<td>Coefficient of the Lead-vehicle-dummy, ( \beta_{\text{current-lead-vehicle}} )</td>
<td>-0.181</td>
<td>-0.98</td>
</tr>
<tr>
<td>Coefficient of the speed, ( \beta_{\text{speed}} )</td>
<td>0.228</td>
<td>5.06</td>
</tr>
</tbody>
</table>

No. of parameters: 5
No. of Vehicles: 1975
Adjusted Rho Square: 0.347

The estimated parameters found here are sign intuitive and statistically significant. The \( \beta_{\text{subject-vehicle}} \) states the inertia for staying in the current position for car and heavy vehicle. The greater values of the t-stat indicate that the parameter is statistically more significant. But the sign of the Coefficient of the Lead-vehicle-dummy does not support the hypothesis here.

To observe the effect of the non motorized vehicle and their preferable position to stay on the road following model 3 has been developed over the previous one.
\[ U_{\text{right-strip}} = \beta_{\text{right/left-lead-vehicle}} \text{ Right-lead-vehicle dummy} + \beta_{\text{right/left-follower-vehicle}} \text{ Right-follower-vehicle dummy} \]

\[ U_{\text{current-strip}} = \beta_{\text{current-lead-vehicle}} \text{ Lead-vehicle-dummy} + \beta_{\text{speed}} \text{ Speed of the current leader} + \beta_{\text{subject-vehicle}} \text{ Subject-vehicle(car)-dummy} + \beta_{\text{subject-vehicle}} \text{ Subject-vehicle (heavy vehicle)-dummy} \]

\[ U_{\text{left-strip}} = \beta_{\text{right/left-lead-vehicle}} \text{ Left-lead-vehicle dummy} + \beta_{\text{right/left-follower-vehicle}} \text{ Left-follower-vehicle dummy} + \beta_{\text{subject-vehicle}} \text{ Subject-vehicle (rickshaw)-dummy} + \beta_{\text{subject-vehicle}} \text{ Subject-vehicle (cycle)-dummy} \]

Subject-vehicle (ricksahw)-dummy and Subject-vehicle (cycle)-dummy refers to the vehicle specific variable for the non motorized vehicles. So, if the vehicle is rickshaw or cycle, the value will be one, otherwise zero. As the non motorized vehicle cannot achieve high speed compared to the motorized vehicle, these vehicle should stay more likely at the left side of the road which will be observed in the estimated model result.

**Table 5.5:** Estimation result of the model 3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated Value</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of the Right/Left-lead-vehicle dummy, ( \beta_{\text{right/left-lead-vehicle}} )</td>
<td>-1.748</td>
<td>-6.03</td>
</tr>
<tr>
<td>Coefficient of the Right/Left-follower-vehicle dummy, ( \beta_{\text{right/left-follower-vehicle}} )</td>
<td>-1.526</td>
<td>-4.93</td>
</tr>
<tr>
<td>Coefficient of the Subject-vehicle-dummy, ( \beta_{\text{subject-vehicle}} )</td>
<td>1.505</td>
<td>87.71</td>
</tr>
<tr>
<td>Coefficient of the Lead-vehicle-dummy, ( \beta_{\text{current-lead-vehicle}} )</td>
<td>0.039</td>
<td>0.23</td>
</tr>
<tr>
<td>Coefficient of the speed, ( \beta_{\text{speed}} )</td>
<td>0.409</td>
<td>9.49</td>
</tr>
</tbody>
</table>

No. of parameters: 5
No. of Vehicles: 1975
Adjusted Rho Square: 0.204

The model shows the values of the parameters conforming to the hypothesis. The new parameter indicates that the non motorized vehicle has a preference to move to the left strips to occupy the left portion of the road.

**The Final Model for Discretionary Lateral Movement**

The final model has been estimated considering the effect of increasing the speed in the right strip as a modification from the previous model 3. The final model is presented below and the result has been discussed afterwards to see the effect of the model. The dummy variables have been defined for this model in the table 5.6 and the estimation output has been shown in the table 5.7.
Table 5.6: Description of the dummy variables

<table>
<thead>
<tr>
<th>Dummy Variable</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-lead-vehicle dummy</td>
<td>1</td>
<td>If the probable lead vehicle in the right strip is obstructing vehicle like heavy vehicle (bus and truck) or slow moving vehicle like cycle and rickshaw</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If the probable lead vehicle is other</td>
</tr>
<tr>
<td>Right-follower-vehicle dummy</td>
<td>1</td>
<td>If the probable follower in the right strip is heavy vehicle</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If the probable follower is other</td>
</tr>
<tr>
<td>Subject-vehicle-dummy</td>
<td>1</td>
<td>If the subject vehicle is itself a heavy vehicle</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If the subject vehicle is other</td>
</tr>
<tr>
<td>Lead-vehicle-dummy</td>
<td>1</td>
<td>If there have any current lead vehicle which is only car, jeep or microbus</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If there is no lead vehicle or the current lead vehicle is other than car, jeep or microbus</td>
</tr>
<tr>
<td>Left-lead-vehicle dummy</td>
<td>1</td>
<td>If the probable lead vehicle in the left strip is obstructing vehicle like heavy vehicle (bus and truck) or slow moving vehicle like cycle and rickshaw</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If the probable lead vehicle is other</td>
</tr>
<tr>
<td>Left-follower-vehicle dummy</td>
<td>1</td>
<td>If the probable follower in the left strip is heavy vehicle</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If the probable follower is other</td>
</tr>
<tr>
<td>Right-lead-vehicle-speed dummy</td>
<td>1</td>
<td>If the probable lead vehicle in the right strip is car</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If the probable lead vehicle is other</td>
</tr>
</tbody>
</table>
Table 5.7: Estimation result of the final model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated Value</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of the Right/Left-lead-vehicle dummy, $\beta_{right/left-lead-vehicle}$</td>
<td>-1.782</td>
<td>-6.10</td>
</tr>
<tr>
<td>Coefficient of the Right/Left-follower-vehicle dummy, $\beta_{right/left-follower-vehicle}$</td>
<td>-1.524</td>
<td>-4.92</td>
</tr>
<tr>
<td>Coefficient of the Subject-vehicle-dummy, $\beta_{subject-vehicle}$</td>
<td>1.508</td>
<td>87.78</td>
</tr>
<tr>
<td>Coefficient of the Lead-vehicle-dummy, $\beta_{current-lead-vehicle}$</td>
<td>0.074</td>
<td>0.16</td>
</tr>
<tr>
<td>Coefficient of the speed, $\beta_{speed}$</td>
<td>0.429</td>
<td>5.54</td>
</tr>
<tr>
<td>Coefficient of the Right-lead-vehicle-speed dummy, $\beta_{right-lead-vehicle-speed}$</td>
<td>0.246</td>
<td>2.66</td>
</tr>
</tbody>
</table>

No. of parameters: 6  
No. of Vehicles: 1975  
Adjusted Rho Square: 0.205

**Explanation:**

The estimated result found from the model followed the priori hypothesis of the study. The Coefficient of the Right/Left-lead-vehicle dummy, $\beta_{right/left-lead-vehicle}$ states that the utility of the left or right strip will decrease if there found any probable leader which is either heavy vehicle or slow moving non motorized vehicle. If there have a heavy follower vehicle, no vehicle will usually like to move in front of it. The $\beta_{right/left-follower-vehicle}$ indicated to this conclusion. Moreover, $\beta_{subject-vehicle}$ confirmed that if the subject vehicle is a heavy one or car type vehicle, it does not like to move a lot to the left or right strip. This may be due to the maneuvers difficulty for the heavy vehicle and safety issue for the car type vehicle. Besides that, the coefficient concluded to the fact of likeliness of the non motorized vehicle for the left side strips to avoid the stimulus from the fast moving motorized vehicle from the back.

If there have a lead vehicle, then the subject vehicle would feel comfort to follow that vehicle if it is only car type vehicle. This property is described by the coefficient, $\beta_{current-lead-vehicle}$. Speed is always welcomed by every vehicle. So, increment of the speed lead to the increment of the utility. Coefficient of the speed, $\beta_{speed}$ reveals this hypothesis.

The newly added Coefficient of the Right-lead-vehicle-speed dummy, $\beta_{right-lead-vehicle-speed}$ also showed the expected sign. As the vehicle like to stay at the right side unless
it is a non motorized vehicle, if the speed of the right strips increases, it will always attract the vehicle. But, if there is a lead vehicle other than car type vehicle, the subject vehicle may not go for that space. The output from the coefficient is none other than this.

In summary, all the variables estimated here in the final model are sign intuitive and make a logical sense. Each variable is statistically significant up to greater than 95% confidence level as per the value of the t-stat. The only exception is the Coefficient of the Lead-vehicle-dummy which is found not so significant. This may occur due to the natural tendency of each vehicle to dislike the presence of the lead vehicle being bound to follow that due to the excessive traffic on the road.
5.3.2 Mandatory Lateral Movement Model

In this study, the right turn in the intersection is considered as the mandatory movement. If the vehicle does not stay within the mandatory safe zone for which the vehicle will automatically get the track with the flow, that will be the mandatory right turning vehicle. When a driver requires this movement, he mainly focuses on the turning without considering the improvement of the driving quality much. Considering the urgency of the movement and other usual behavior, the primary model has been estimated where the occupancy of the right strip should be the main concern for the mandatory right turning vehicle.

\[
U_{\text{right-strip}} = \beta_{\text{speed}} \text{Right-lead-vehicle speed} + \beta_{\text{dis2stop}} \text{Distance to the intersection from the mandatory critical line}
\]

\[
U_{\text{current-strip}} = \beta_{\text{current/left-lead-vehicle}} \text{Current-lead-vehicle-dummy-mandatory} + \beta_{\text{current/left-lead-vehicle-speed}} \text{Current-lead-vehicle-speed - mandatory}
\]

\[
U_{\text{left-strip}} = \beta_{\text{current/left-lead-vehicle}} \text{Left-lead-vehicle-dummy-all} + \beta_{\text{current/left-lead-vehicle-speed}} \text{Left lead-vehicle-speed dummy-all} + \beta_{\text{subject-vehicle-mandatory}} \text{Subject-vehicle(mandatory)-dummy}
\]

The description of the dummy variable and the estimation result of the base model are presented in the table 5.8 and table 5.9 respectively.

**Table 5.8: Description of the dummy variables**

<table>
<thead>
<tr>
<th>Dummy Variable</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current lead-vehicle-dummy-mandatory</td>
<td>1</td>
<td>If there have no lead vehicle for the mandatory right turning vehicle only</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If there have leader for the mandatory right turning vehicle only</td>
</tr>
<tr>
<td>Left-lead-vehicle-dummy-all</td>
<td>1</td>
<td>If there have no left lead vehicle considering all vehicle</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If there have left leader considering all vehicle</td>
</tr>
<tr>
<td>Subject-vehicle(mandatory)-dummy</td>
<td>1</td>
<td>If the subject vehicle is itself a mandatory right turning vehicle</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If the subject vehicle is other</td>
</tr>
</tbody>
</table>
Table 5.9: Estimation result of the base model for mandatory movement

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated Value</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of the Right-lead-vehicle speed, $\beta_{\text{speed}}$</td>
<td>1.008</td>
<td>2.83</td>
</tr>
<tr>
<td>Coefficient of the Distance to the intersection from the mandatory critical line, $\beta_{\text{dis2stop}}$</td>
<td>-1.169</td>
<td>-49.98</td>
</tr>
<tr>
<td>Coefficient of the Current/left-lead-vehicle dummy, $\beta_{\text{current/left-lead-vehicle}}$</td>
<td>-2.508</td>
<td>-63.26</td>
</tr>
<tr>
<td>Coefficient of the Current/left lead-vehicle-speed, $\beta_{\text{current/left-lead-vehicle-speed}}$</td>
<td>-1.359</td>
<td>-5.88</td>
</tr>
<tr>
<td>Coefficient of the Subject-vehicle(mandatory)-dummy, $\beta_{\text{subject-vehicle-mandatory}}$</td>
<td>-2.528</td>
<td>-10.89</td>
</tr>
</tbody>
</table>

No. of parameters: 6
No. of Observation: 1106
Adjusted Rho Square: 0.439

The estimated parameters found from the model are statistically significant and all the values along with the sign support the hypothesis. But the model has been modified to select the final model for the mandatory movement. The final model is presented below with the explanation of the model.

The final mandatory lateral movement model

The final model has been estimated taking into consideration the effect of the follower vehicle in the right strips in addition to the previous model. If a probable follower vehicle is found in the right strip where the vehicle need to go to take the required right turn, the movement may be hampered or even postponed to avoid any kind of collision. The model is presented below along with the variable definition and the result.

$$U_{\text{right-strip}} = \beta_{\text{speed}} \text{Right-lead-vehicle speed} + \beta_{\text{dis2stop}} \text{Distance to the intersection from the mandatory critical line} + \beta_{\text{follower-right-strip dummy}} \text{Follower-vehicle-right-strip dummy}$$

$$U_{\text{current-strip}} = \beta_{\text{current/left-lead-vehicle}} \text{Current-lead-vehicle-dummy-mandatory} + \beta_{\text{current/left-lead-vehicle-speed}} \text{Current lead-vehicle-speed - mandatory}$$

$$U_{\text{left-strip}} = \beta_{\text{current/left-lead-vehicle}} \text{Left-lead-vehicle-dummy-all} + \beta_{\text{current/left-lead-vehicle-speed}} \text{Left lead-vehicle-speed dummy-all} + \beta_{\text{subject-vehicle-mandatory}} \text{Subject-vehicle(mandatory)-dummy}$$
Table 5.10: Description of the dummy variables for the final mandatory model

<table>
<thead>
<tr>
<th>Current lead-vehicle-dummy-mandatory</th>
<th>1</th>
<th>If there have no lead vehicle for the mandatory right turning vehicle only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>If there have leader for the mandatory right turning vehicle only</td>
</tr>
<tr>
<td>Left-lead-vehicle-dummy-all</td>
<td>1</td>
<td>If there have no left lead vehicle considering all vehicle</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If there have left leader considering all vehicle</td>
</tr>
<tr>
<td>Subject-vehicle(mandatory)-dummy</td>
<td>1</td>
<td>If the subject vehicle is itself a mandatory right turning vehicle</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If the subject vehicle is other</td>
</tr>
<tr>
<td>Follower-vehicle-right-strip dummy</td>
<td>1</td>
<td>If there is any probable follower vehicle in the right strip</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>If there is no follower vehicle</td>
</tr>
</tbody>
</table>

Table 5.11: Estimation result of the final model for mandatory movement

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated Value</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of the Right-lead-vehicle speed, $\beta_{speed}$</td>
<td>1.022</td>
<td>2.86</td>
</tr>
<tr>
<td>Coefficient of the Distance to the intersection from the mandatory critical line, $\beta_{dis2stop}$</td>
<td>-1.161</td>
<td>-49.79</td>
</tr>
<tr>
<td>Coefficient of the Current/left-lead-vehicle-dummy, $\beta_{current/left-lead-vehicle}$</td>
<td>-2.514</td>
<td>-63.27</td>
</tr>
<tr>
<td>Coefficient of the Current/left lead-vehicle-speed, $\beta_{current/left-lead-vehicle-speed}$</td>
<td>-1.367</td>
<td>-5.88</td>
</tr>
<tr>
<td>Coefficient of the Subject-vehicle(mandatory)-dummy, $\beta_{subject-vehicle-mandatory}$</td>
<td>-2.549</td>
<td>-10.96</td>
</tr>
<tr>
<td>Coefficient of the Follower-vehicle-right-strip dummy, $\beta_{follower-right}$</td>
<td>-1.118</td>
<td>-4.03</td>
</tr>
</tbody>
</table>

No. of parameters: 6
No. of Vehicle: 1106
Adjusted Rho Square: 0.441
Explanation:

If the speed of the right-lane lead vehicle increases then the utility increases as the possibility of the available gap for right movement also increases. The positive value of the $\beta_{\text{speed}}$ supports this hypothesis.

$\beta_{\text{dis2stop}}$ states that the utility of the right lane increases when the distance from the intersection decreases. It supports the hypothesis that the probability of lane changing extends from 0 to 1 with the decrease in the distance from the intersection. As the (0, 0) point is at the intersection, so the $\beta_{\text{dis2stop}}$ is negative here which follows the hypothesis.

In case of the coefficient of the current/left-lead-vehicle-dummy, $\beta_{\text{current/left-lead-vehicle}}$, it indicates by showing negative value that though there is no lead vehicle in the current and left strip, vehicle does not consider those as it needs to move to the right. The coefficient of the current/left lead-vehicle-speed follows the same criteria and states that, in spite of increasing the speed in current lead vehicle and left lead vehicle, the subject vehicle cannot take the benefit due to the requirement of moving right.

To estimate the value of $\beta_{\text{current/left-lead-vehicle}}$ and $\beta_{\text{current/left-lead-vehicle-speed}}$, the vehicles that taking the right turn, have considered for calculating the utility of the current lane. But when the parameters were used in the left lane, then all the vehicle has been considered. It defines the general tendency of the driver to avoid the left side of the road who actually seeks for the speed. Coefficient of the Subject-vehicle (mandatory)-dummy, $\beta_{\text{subject-vehicle-mandatory}}$ is a constant which also indicate the lower utility of the left lane for the mandatory right turning vehicles.

It is the same model as before with an addition of the effect of the FV in the right lane. The negative value of the $\beta_{\text{follower-right}}$ indicates that the utility of right lane become hampered due to the presence of the FV in the targeted right lane. If there exists a follower vehicle in the right strip where the subject vehicle have to move, the maneuver can be interrupted and sometimes the movement may not be completed due to the unavailable adjacent gap or safety issue. Supporting this hypothesis Coefficient of the Follower-vehicle-right-strip dummy represents a negative value in the final model which mimics the real scenario as well.
The values of the t-stat of all the parameters have a numerical value greater than 1.96. It indicates that all the values are statistically significant up to or more than 95% confidence level. Moreover, the higher values of the t-stat corresponding to the $\beta_{\text{dis2stop}}$ and $\beta_{\text{current/left-lead-vehicle}}$ describe the higher significance of those values in the model.

### 5.4 Model Verification

After the calibration, the model is verified using the different data set. The data has been prepared from the same location of the final model estimation for both discretionary and mandatory movement. The time span of the data was more than 30 minutes for both locations. The result of the estimated parameters using the final model and the new data set has been presented here along with the result of the final model. The verification result of the discretionary model and the mandatory model provided in the table 5.12 and 5.13 respectively.

**Table 5.12:** Estimation result of the final model using validation data set (Discretionary Lateral Movement)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated Value</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data set for final estimation</td>
<td>Data set for model verification</td>
</tr>
<tr>
<td>Coefficient of the Right/Left-lead-vehicle dummy, $\beta_{\text{right/left-lead-vehicle}}$</td>
<td>-1.782</td>
<td>-2.454</td>
</tr>
<tr>
<td>Coefficient of the Right/Left-follower-vehicle dummy, $\beta_{\text{right/left-follower-vehicle}}$</td>
<td>-1.524</td>
<td>-1.750</td>
</tr>
<tr>
<td>Coefficient of the Subject-vehicle-dummy, $\beta_{\text{subject-vehicle}}$</td>
<td>1.508</td>
<td>1.487</td>
</tr>
<tr>
<td>Coefficient of the Lead-vehicle-dummy, $\beta_{\text{current-lead-vehicle}}$</td>
<td>0.074</td>
<td>0.075</td>
</tr>
<tr>
<td>Coefficient of the speed, $\beta_{\text{speed}}$</td>
<td>0.429</td>
<td>0.375</td>
</tr>
<tr>
<td>Coefficient of the Right-lead-vehicle- speed dummy, $\beta_{\text{right-lead-vehicle-speed}}$</td>
<td>0.246</td>
<td>0.149</td>
</tr>
</tbody>
</table>
The comparison of the two model presented earlier shows that the sign of all the estimated parameters with the validation data remains same as the final model. Moreover, the numerical values obtained newly do not vary much which actually strengthen the effectiveness of the model. Finally, to check the performance of the model, Chi-Square test has been performed to see the statistical effect. In case of mandatory lateral movement model, all the parameters were found greater than 90% confidence level while comparing the values obtained from two data sets. The Chi-Square test result was also found encouraging for the discretionary lateral movement model. Here, all the estimates were found greater than 90% confidence level except the values of the $\beta_{\text{right/left-lead-vehicle}}$ and $\beta_{\text{right/left-follower-vehicle}}$, which were not found up to the expected level of significance. The data has been considered for is not so big. The improvement of the data set could be an effective solution to produce significant values for all the parameters.

Table 5.13: Estimation result of the final model using validation data set (Mandatory Lateral Movement)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated Value</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data set for final estimation</td>
<td>Data set for model verification</td>
<td>Data set for final estimation</td>
</tr>
<tr>
<td>Coefficient of the Right-lead-vehicle speed, $\beta_{\text{speed}}$</td>
<td>1.022</td>
<td>0.942</td>
</tr>
<tr>
<td>Coefficient of the Distance to the intersection from the mandatory critical line, $\beta_{\text{dis2stop}}$</td>
<td>-1.161</td>
<td>-1.081</td>
</tr>
<tr>
<td>Coefficient of the Current/left-lead-vehicle-dummy, $\beta_{\text{current/left-lead-vehicle}}$</td>
<td>-2.514</td>
<td>-2.383</td>
</tr>
<tr>
<td>Coefficient of the Current/left-lead-vehicle-speed, $\beta_{\text{current/left-lead-vehicle-speed}}$</td>
<td>-1.367</td>
<td>-1.236</td>
</tr>
<tr>
<td>Coefficient of the Subject-vehicle(mandatory)-dummy, $\beta_{\text{subject-vehicle-mandatory}}$</td>
<td>-2.549</td>
<td>-2.592</td>
</tr>
<tr>
<td>Coefficient of the Follower-vehicle-right-strip dummy</td>
<td>-1.118</td>
<td>-1.096</td>
</tr>
</tbody>
</table>
5.5 Summary

In this chapter data processing has been performed to gain trajectory of vehicles and obtain vehicle composition in the traffic stream. Later ‘MATLAB’ code has been utilized to generate lateral movement models for discretionary and mandatory movement. The data analysis result has been presented then. At the end of the analysis, separate model equations have been developed to show the effect of different factors (independent variables) on lateral movement behavior.
6.1 Summary of the Research

Microscopic traffic simulator is an effective tool for the transportation planner. It can simulate the behavior of the driver and predict the effectiveness of any measure or any infrastructure which is thought to be activated on the road before its actual implementation. So the simulator has been emerged as useful solution on the basis of time, economy and other factors. The world has experienced a numbers of simulators already. Those are predominantly prepared for the lane based homogeneous traffic of the developed countries. The main problems in using those simulators for the developing countries like Bangladesh are the difference in the traffic characteristics and the road discipline being followed here. Motorized and non-motorized vehicles are using the same right of way with various size and speed. Moreover, due to the weak based lane discipline on the road, the vehicle can stay anywhere on the road without considering the lane marking. So, an effective traffic simulator for the Dhaka city should considers all of these properties. As a simulator require some model to predict the driver behavior, the study has been performed to estimate a lateral movement model for the traffic of Dhaka city as a useful feed of the simulator for the developing countries. The lateral movement model is nothing but the lane changing model for the lane based traffic which will determine the change in lateral position of the vehicle on the road.

With a view to estimate a significant model for the lateral movement of the heterogeneous weak lane based traffic, firstly the data has been collected from different location of Dhaka city. The data has been recorded by video camera and high precision GPS device. The video data has been processed with video processing software named ‘TRAZER’. The software provided the trajectory data for vehicle captured in the camera frame. The trajectory data is actually the local coordinate of the position of the vehicle whereas the coordinate was customized for the data collection site. After having the trajectory, each and every movement of the vehicles was found available.

The road was considered to be divided into a number of small width strips in lieu of lanes. The width of the strips was considered as 0.5m. So, change of the lateral
position over the strip has been considered as the lane changing. The lateral movement execution and the processed trajectory data was then used for the econometric model formulation using GAUSS.

The estimation of the model was performed considering different data collection site for mandatory and discretionary movement. Data collection site for mandatory movement consideration were fixed in a place where some vehicle needed to take the right turn in the intersection. For considering discretionary lateral change, a straight section of the road was considered where the driver had the freedom to choose for the change.

After formulating the base model, it was calibrated using the trajectory data for both lateral movement condition. There were number of variable observed in the field. But all the factors were not found responsible for this kind of maneuvers. The effective variables were adjusted in the econometric model and ultimately two models were regarded as final model for the mandatory and discretionary movement. The estimated parameters were found significant and sign intuitive to describe the base of the model.

After estimating the final models, it was verified using the different data sets of different time collected from the same mandatory and discretionary movement location. The verification results also satisfactorily matched with the estimated results.

6.2 Main Features of the Study

- Latest data collection technology has been used in the study. Each and every vehicle has been captured by the video recordings to observe their movement on the road. Moreover, high precision GPS equipped vehicle has also been used to supplement the data collection.

- The recorded video has been processed using a software to obtain the trajectories of the vehicle according to the coordinate of the road. The GPS also provides the trajectory data. The detailed trajectory data allows following every detailed movement whether that was more or less. This ensures the microscopic capturing of the movement which is the base for the model estimation.

- The road has been considered to be divided into a number of strips of equal and small width. The strip has been considered as the replacement of the lane concept
by changing the width. As the traffic follow weak lane based discipline, the vehicle can move any distance laterally. So the width has been kept small to capture every single movement to represent the real scenario in the model.

- The obtained trajectory data has been processed using the MATLAB and then the econometric model has been estimated using a statistical software GAUSS. The time step has been regarded as 0.2sec. As the time step is very small, the update of the vehicle position after each time step almost represents the continuous movement of the vehicle.

- The leader and the follower have been identified considering the non collision criteria. The availability of the adjacent gap has been checked and upon the availability the probable leader and the probable follower in the adjacent strip has also been identified. Here, the brake reaction distance has been used to satisfy the non collision criteria.

- Two different models have been estimated for two locations to represent the discretionary and mandatory lateral movement. The type of the movement varies with the destination path of the driver. Though the two models have been regarded as the final model, more than ten models for both locations were estimated first. From the estimated models, the best models according to the physical and statistical significance have been considered as the final models.

- Model verification has been performed using the data of the same location at different time to observe the effectiveness of the model.
6.3 Main Findings of the Research

- Two separate models have been developed to represent the discretionary and the mandatory lateral movement in this study. Due to the difference in the basic property of the movement type, a single model was not found effective to capture all type of factors. Separating the models on the basis of the movement type was found to be more reliable to represent more insight of the driver in case of lateral movement.

- As the vehicle follows weak lane based traffic, the consideration of the strip approach instead of the lane approach has been found more compatible with the real scenario. Strip approach can take into account the smallest lateral movement of the vehicle which actually occurs frequently in case of heterogeneous weak lane based traffic.

- Trajectory data provides the best detailed vehicle position profile on the road. So the use of the trajectory data obtained from the TRAZER was found to be best suited for this kind of model formation even though there were some limitations in the software like the customization of the local coordinate, trajectories for a small distance, effect of the camera position and angle etc.

- If the road conditions remain almost same all over the area, the driver usually do not prefer to change the current position (almost 90% of all movement for both type in the current study do not change position) unless there is a greater difference in the utility. The model result as well as the data analysis result represents the greater inertia of the driver for the current position.

- Considering the hypothesis that the non-motorized slow moving vehicle always try to stay at the left side of the road whereas every other vehicle has a tendency to move in the right side with an expectation to gain speed, the models showed a compatible output.
6.4 Limitation of the Study

- Demographic factors like age of the driver, experiences etc. were not considered for the estimation of the model. These factors could be influencing in case of lateral change.

- The main obstruction was in case of data collection. It was collected from foot over bridge via video camera. It captured the movement of the vehicle approached towards the foot over bridge. The video camera recorded the movement first and then it was processed in the software. But, due to the limitation of the video camera, it was not possible to record the movement of the vehicle for a long distance.

- Due to the shortage of the data, the verification of the model was performed using the data of same location at different time span. The data from another location would be more reliable to defend the model.

- If a vehicle cannot take the mandatory turn even after reaching the intersection line, it is assumed that the vehicle will consider forced merging. But this effect has not been represented here.

6.5 Recommendation

- Data is the main feed for any kind of model development. The data for this study was collected by the use of video camera. It limits the length of the data collection site. Use of more developed data collection method like aerial photography could produce better result.

- This thesis could not show the effect of density variation as the data was collected for a particular period of time. If data can be collected for different time duration, then the effect of density can be understood.

- The effect of demographic factors (e.g. age, gender, driving experience, alcohol addiction) could be addressed to make the models more reasonable.

- Inclusion of the red light effect, congested condition effect, lane blockage could produce more effective model

- More complex functional form of the models can be tested.
REFERENCES


Bertsekas, D. P., 1999, Nonlinear programming, Athena Scientific, Belmont MA.


Central Road Research Institute, 1994, Status Report, “Development and Application of Traffic Simulation Models”, Central Road Research Institute, New Delhi, India.


Appendix
Appendix A

Sample Matlab Code

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%
%           Data Generator for Mandatory Lane Change Analysis
% 
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%

clear all;
warning off;
delete('results.xls');

FRAME_PER_SEC = 25;
V_ID_COL = 2;
FRAME_NUM_COL = 1;
X_COL = 3;
Y_COL = 4;
POLY_ORDER = 5;
INTERVAL = 0.2;
TH_THRES = 3;   %%time headway
SH_THRES = 10;   %%space headway
SPACE_HEADWAY = 0;  %% enable space headway by setting this value to 1
LAT_SAFETY_MARGIN = 0.25;

BOX_X_MIN = 0;
BOX_X_MAX = 6;
BOX_Y_MIN = 0;
BOX_Y_MAX = 40;

STRIP_NUM = 12;
X_INIT = 0;
X_END = 12;

hv_lookup = [0, 0, 0, 0, 0, 0, 1, 1, 0, 0, 0];
h_lookup = [4.54, 4.47, 4.29, 5.78, 3.54, 2.63, 8.46, 6.7, 2.13, 1.78, 2.51];
w_lookup = [1.76, 2.13, 1.78, 2.02, 1.4, 1.3, 2.46, 2.44, .75, .61, 1.22];

data = csvread('trajectory_m.csv',1,0);
data_id = csvread('Vehicle_ID.csv');

%% Separates timing and co-ordinate data of each vehicle.
%% Calculates x & y velocity and acceleration.
%% Final Output is a array of cells, containing vehicle wise data in each
%% element. co-ordinates, velocity & acceleration data all are smoothed.

[vua,index] = sort(data(:, V_ID_COL));
sort_data = data(index, :);
v_id = []; v_data = {}; i = 1; init = 1; LAST_ID = sort_data(end, V_ID_COL);

while 1
    v_id(i) = sort_data(init, V_ID_COL);
    last = find(sort_data(:, V_ID_COL) == v_id(i), 1, 'last');

    if(ismember(v_id(i), data_id(:,2)) == 0)
        if(v_id(i) == LAST_ID)
            break;
        end
        init = last + 1;
        continue;
    end

    v_data_new = sort_data(init:last, [FRAME_NUM_COL, X_COL, Y_COL]);
    nn = find(data_id(:,2) == v_id(i));
    for j = 3:(find(isnan(data_id(nn, :)), 1, 'first') - 1)
        temp_id = data_id(nn, j);
        condition = (sort_data(:, V_ID_COL) == temp_id) &
                    (ismember(sort_data(:, FRAME_NUM_COL), v_data_new(:,1)) == 0);
        cond_data = sort_data(find(condition), [FRAME_NUM_COL, X_COL, Y_COL]);
        for k = 1:size(cond_data, 1)
            if (sum(cond_data(k,3) <= v_data_new(:,3)) ==
                size(v_data_new,1))
                v_data_new = [v_data_new; cond_data(k,:)];
            end
        end
    end

    x_loc = v_data_new(:,2);
    y_loc = v_data_new(:,3);
    pos_ind = (y_loc > 0);
    x_loc = x_loc(pos_ind);
    y_loc = y_loc(pos_ind);

    t = v_data_new(:,1) / FRAME_PER_SEC;
    t = t(pos_ind);
    t_div = (double(int32(t(1)/INTERVAL))*INTERVAL : INTERVAL :
            double(int32(t(end)/INTERVAL))*INTERVAL)';

    x_loc = polyval(polyfit(t, x_loc, POLY_ORDER), t_div);
    y_loc = polyval(polyfit(t, y_loc, POLY_ORDER), t_div);

    x_velocity = (x_loc(2:end) - x_loc(1:end-1)) ./ INTERVAL;
    y_velocity = abs(y_loc(1:end-1) - y_loc(2:end)) ./ INTERVAL;
    x_acceleration = (x_velocity(2:end) - x_velocity(1:end-1)) ./
                    INTERVAL;
    y_acceleration = (y_velocity(2:end) - y_velocity(1:end-1)) ./
                    INTERVAL;

    t_div = t_div(3:end);
if (isempty(t_div) == 0)
    x_velocity = polyval(polyfit(t_div, x_velocity(2:end),
        POLY_ORDER), t_div);
    y_velocity = polyval(polyfit(t_div, y_velocity(2:end),
        POLY_ORDER), t_div);
    x_acceleration = polyval(polyfit(t_div, x_acceleration,
        POLY_ORDER), t_div);
    y_acceleration = polyval(polyfit(t_div, y_acceleration,
        POLY_ORDER), t_div);

    v_data(i) = {[t_div, v_id(i)*ones(length(x_acceleration),1),
        x_loc, y_loc, x_velocity, x_acceleration, y_velocity, y_acceleration,
        data_id(nn, 1)*ones(length(x_acceleration),1),
        w_lookup(data_id(nn, 1))*ones(length(x_acceleration),1),
        hv_lookup(data_id(nn, 1))*ones(length(x_acceleration),1)]};
end

% 1-11
if(v_id(i) == LAST_ID)
    break;
end

if (isempty(t_div) == 0)
    i = i + 1;
end
init = last + 1;
end

pair_data = cell2mat(v_data');

[vua,index] = sort(pair_data(:, FRAME_NUM_COL));
sort_pair_data = pair_data(index, :);
sort_pair_data(:,13:43) = NaN;

% strip position
strip_width = (X_END - X_INIT) / STRIP_NUM;
for i = 1:STRIP_NUM
    ind = find((sort_pair_data(:, 3) >= ((i-1)*strip_width)) &
                (sort_pair_data(:, 3) < (i*strip_width)));
    sort_pair_data(ind, 12) = i; % 12
end

for i = 1:size(sort_pair_data,1)
    sv_t = sort_pair_data(i,1);
    sv_id = sort_pair_data(i,2);
    sv_x = sort_pair_data(i,3);
    sv_y = sort_pair_data(i,4);
    sv_vy = sort_pair_data(i,7);
    W = sort_pair_data(i,10);
sv_H = h_lookup(sort_pair_data(i,9));
margin = LAT_SAFETY_MARGIN;
lim_l = sv_x - W/2 - margin;
lim_r = sv_x + W/2 + margin;

ind = (sort_pair_data(:,1) == sv_t) & (sort_pair_data(:,2) == sv_id);
  temp_id = sort_pair_data(ind,2);
  temp_x = sort_pair_data(ind,3);
  temp_Y = sort_pair_data(ind,4);
  temp_va = sort_pair_data(ind,5:8);
  H = h_lookup(sort_pair_data(ind,9))';
  hv = sort_pair_data(ind,11);
  temp_type = sort_pair_data(ind,9);
  temp_y = (temp_Y + H);
  sp = abs(temp_y - sv_y);
  th = sp/sv_vy;

% calculate safe longitudinal margin ##START
safe_t = 1.5;
safe_a = 3.4;
SAFE_LONG = sv_vy * safe_t + (sv_vy * sv_vy) / (2 * safe_a);
% calculate safe longitudinal margin ##END

cond_th = (th <= TH_THRES);
cond_sh = (sp <= SH_THRES);
if SPACE_HEADWAY == 1
  cond_h = cond_sh;
else
  cond_h = cond_th;
end

t_Wd2 = w_lookup(sort_pair_data(ind,9))' / 2;
  temp_xl = temp_x - t_Wd2;
  temp_xr = temp_x + t_Wd2;

% In boundary box checking
% 13
  sort_pair_data(i,13) = (((sv_x-W/2) >= BOX_X_MIN) & ((sv_x+W/2) <= BOX_X_MAX)) & ((sv_y >= BOX_Y_MIN) & ((sv_y+sv_H) <= BOX_Y_MAX));

% find leader
% 14 ~ 17
  ind_f = (temp_y < sv_y) & cond_h & (((temp_xr > lim_l) & (temp_x < lim_r)) | ((temp_x >= lim_l) & (temp_x <= lim_r)) | ((temp_x > lim_l) & (temp_xl < lim_r)));
  l_id = temp_id(ind_f);
  l_y = temp_y(ind_f);
  [vua,t_ind] = max(l_y);
  if(isempty(t_ind)==0)
    ttt_ind = (temp_id == l_id(t_ind));
    l_data = temp_va(ttt_ind,:);
    sort_pair_data(i,14:17) = [l_id(t_ind), temp_type(ttt_ind),
                           l_data(3:4)];  % id, type, vy, ay
  end

% find follower
% 18 ~ 21
ind_f = (temp_Y > (sv_y+sv_H)) & (((temp.xr > lim_l) & (temp.x < lim_r)) | ((temp.x >= lim_l) & (temp.x <= lim_r)) | ((temp.x > lim_l) & (temp.xl < lim_r)));

l_id = temp_id(ind_f);
l_y = temp_y(ind_f);
[vua,t_ind] = min(l_y);
if(isempty(t.ind)==0)
    ttt_ind = (temp_id == l_id(t_ind));
    l_data = temp.va(ttt_ind,:);
    sort_pair_data(i,18:21) = [l_id(t_ind), temp.type(ttt_ind), l_data(3:4)];    %% id, type, vy, ay
end

%% left strip data
% 22~32
l.strip = floor(sv.x-W/2);
sort_pair_data(i,22) = (l.strip == 0);  %left most

ind_l = find(((temp.xr <= (sv.x-W/2)) & (temp.xr >= (l.strip - 1))) & ((temp.Y >= (sv.y-SAFE_LONG)) & (temp.Y <= (sv.y+sv.H)) | (temp.y >= (sv.y-SAFE_LONG)) & (temp.y <= (sv.y+sv.H)) | (sv.y <= temp.Y) & (sv.y <= temp.y)));
if(isempty(ind_l)==0)
    sort_pair_data(i,23) = 0;
else
    sort_pair_data(i,23) = 1;
    ind_tp1 = find((sort_pair_data(:,1) == (sv.t+INTERVAL)) & (sort_pair_data(:,2) == sv_id));
    if(isempty(ind_tp1)==0)
        sv.x_tp1 = sort_pair_data(ind_tp1,3);
        sv.y_tp1 = sort_pair_data(ind_tp1,4);
        sort_pair_data(i,24) = ((sv.x_tp1-W/2) <= l.strip) & ((sv.x_tp1-W/2) >= (l.strip-1));
        lim_l_tp1 = l.strip - margin;
        lim_r_tp1 = l.strip + W + margin;
        ind = (sort_pair_data(:,1) == (sv.t+INTERVAL)) & (sort_pair_data(:,2) ~= sv_id);
        temp_id_tp1 = sort_pair_data(ind,2);
        temp.x_tp1 = sort_pair_data(ind,3);
        temp.Y_tp1 = sort_pair_data(ind,4);
        temp.va_tp1 = sort_pair_data(ind,5:8);
        H_tp1 = h_lookup(sort_pair_data(ind,9))';
        temp.type_tp1 = sort_pair_data(ind,9);
        temp.y_tp1 = (temp.Y_tp1 + H_tp1);
        sp_tp1 = abs(temp.y_tp1 - sv_y_tp1);
        t_Wd2 = w_lookup(sort_pair_data(ind,9))' / 2;
        temp.xl_tp1 = temp.x_tp1 - t_Wd2;
        temp.xr_tp1 = temp.x tp1 + t_Wd2;
        % find leader
        % 25 ~ 28
        ind_f = (temp.y_tp1 < sv_y_tp1) & (sp_tp1 <= SH.THRES) & (((temp.xr tp1 > lim_l tp1) & (temp.x tp1 < lim_r tp1)) | ((temp.x tp1 > lim_l tp1) & (temp.x tp1 < lim_r tp1)) | ((temp.x tp1 > lim_l tp1) & (temp.xl tp1 < lim_r tp1)));
        l_id = temp.id tp1(ind_f);
l_y = temp_y_tp1(ind_f);
[vua,t_ind] = max(l_y);
if(isempty(t_ind)==0)
    ttt_ind = (temp_id_tp1 == l_id(t_ind));
l_data = temp_va_tp1(ttt_ind,:);
sort_pair_data(i,25:28) = [l_id(t_ind),
temp_type_tp1(ttt_ind), l_data(3:4)];    %% id, type, vy, ay
end

%% find follower
% 29 ~ 32
ind_f = (temp_Y_tp1 > (sv_y_tp1+sv_H)) &
((temp_xr_tp1 > lim_l_tp1) & (temp_x_tp1 < lim_r_tp1)) |
((temp_xTp1 >= lim_lTp1) & (temp_xTp1 <= lim_rTp1)) |
((temp_xTp1 > lim_lTp1) & (temp_xlTp1 < lim_rTp1));
l_id = temp_idTp1(ind_f);
l_y = temp_yTp1(ind_f);
[vua,t_ind] = min(l_y);
if(isempty(t_ind)==0)
    ttt_ind = (temp_id_tp1 == l_id(t_ind));
l_data = temp_va_tp1(ttt_ind,:);
sort_pair_data(i,29:32) = [l_id(t_ind),
temp_type_tp1(ttt_ind), l_data(3:4)];    %% id, type, vy, ay
end
end

%% right strip data
% 33-43
r_strip = ceil(sv_x+W/2);
sort_pair_data(i,33) = (r_strip == 12);  %right most
ind_r = find(((temp_xl >= r_strip) & (temp_xl <= (r_strip + 1))) &
((temp_y >= (sv_y-SAFE_LONG)) & (temp_y <= (sv_y+sv_H))) |
((sv_y >= temp_Y) & (sv_y <= temp_y)));
if(isempty(ind_r)==0)
    sort_pair_data(i,34) = 0;
else
    sort_pair_data(i,34) = 1;
    ind_tp1 = find((sort_pair_data(:,1) == (sv_t+INTERVAL)) &
(sort_pair_data(:,2) == sv_id));
    if(isempty(ind_tp1)==0)
        sv_xTp1 = sort_pair_data(ind_tp1,3);
        sv_yTp1 = sort_pair_data(ind_tp1,4);
        sort_pair_data(i,35) = ((sv_xTp1+W/2) >= r_strip) &
((sv_xTp1+W/2) <= (r_strip + 1));
    end
    lim_lTp1 = r_strip - W - margin;
    lim_rTp1 = r_strip + margin;
    ind = (sort_pair_data(:,1) == (sv_t+INTERVAL)) &
(sort_pair_data(:,2) == sv_id);
    temp_idTp1 = sort_pair_data(ind,2);
    temp_xTp1 = sort_pair_data(ind,3);
    temp_YTp1 = sort_pair_data(ind,4);
    temp_vATp1 = sort_pair_data(ind,5:8);
    HTp1 = h_lookup(sort_pair_data(ind,9))';
    temp_typeTp1 = sort_pair_data(ind,9);
temp_y_tp1 = (temp_Y_tp1 + H_tp1);
sp_tp1 = abs(temp_y_tp1 - sv_y_tp1);

\[
t_\text{Wd2} = w\ \text{lookup}\left(\text{sort_pair_data}(\text{ind},9)\right) / 2;
\]

\[
t_\text{xl}_\text{tp1} = t_\text{Wd2};
\]

\[
t_\text{xr}_\text{tp1} = t_\text{Wd2};
\]

% find leader
% 36 ~ 39
\[
\text{ind}_f = (\text{temp}_y_\text{tp1} < \text{sv}_y_\text{tp1}) \& (\text{sp}_\text{tp1} <= \text{SH}\_\text{THRES}) \& ((\text{temp}_x_\text{r}_\text{tp1} > \text{lim}_l_\text{tp1}) \& (\text{temp}_x_\text{tp1} < \text{lim}_r_\text{tp1}))
\]
\[
\| ((\text{temp}_x_\text{tp1} >= \text{lim}_l_\text{tp1}) \& (\text{temp}_x_\text{tp1} <= \text{lim}_r_\text{tp1})) |
\]
\[
((\text{temp}_x_\text{tp1} > \text{lim}_l_\text{tp1}) \& (\text{temp}_x_\text{tp1} < \text{lim}_r_\text{tp1}));
\]
\[
1_\text{id} = \text{temp_id}_\text{tp1}(\text{ind}_f);
\]
\[
l_y = \text{temp}_y_\text{tp1}(\text{ind}_f);
\]
\[
[vua,t_\text{ind}] = \text{max}(l_y);
\]
\[
\text{if} \text{isempty}(t_\text{ind}) == 0
\]
\[
\text{ttt}_\text{ind} = (\text{temp_id}_\text{tp1} == 1_\text{id}(\text{t_ind}));
\]
\[
\text{l_data} = \text{temp_va}_\text{tp1}(\text{ttt}_\text{ind},:);
\]
\[
\text{sort_pair_data}(\text{i},36:39) = [1_\text{id}(\text{t_ind}),
\]
\[
\text{temp_type}_\text{tp1}(\text{ttt}_\text{ind}), 1_\text{data}(3:4)]; \quad \% \text{id, type, vy, ay}
\]
\end{verbatim}

%% follower
% 40 ~ 43
\[
\text{ind}_f = (\text{temp}_y_\text{tp1} > (\text{sv}_y_\text{tp1}+\text{sv}_H)) \&
\]
\[
((\text{temp}_x_\text{r}_\text{tp1} > \text{lim}_l_\text{tp1}) \& (\text{temp}_x_\text{tp1} < \text{lim}_r_\text{tp1})) \| 
\]
\[
((\text{temp}_x_\text{tp1} >= \text{lim}_l_\text{tp1}) \& (\text{temp}_x_\text{tp1} <= \text{lim}_r_\text{tp1})) \| 
\]
\[
((\text{temp}_x_\text{tp1} > \text{lim}_l_\text{tp1}) \& (\text{temp}_x_\text{tp1} < \text{lim}_r_\text{tp1}));
\]
\[
1_\text{id} = \text{temp_id}_\text{tp1}(\text{ind}_f);
\]
\[
l_y = \text{temp}_y_\text{tp1}(\text{ind}_f);
\]
\[
[vua,t_\text{ind}] = \text{min}(l_y);
\]
\[
\text{if} \text{isempty}(t_\text{ind}) == 0
\]
\[
\text{ttt}_\text{ind} = (\text{temp_id}_\text{tp1} == 1_\text{id}(\text{t_ind}));
\]
\[
\text{l_data} = \text{temp_va}_\text{tp1}(\text{ttt}_\text{ind},:);
\]
\[
\text{sort_pair_data}(\text{i},40:43) = [1_\text{id}(\text{t_ind}),
\]
\[
\text{temp_type}_\text{tp1}(\text{ttt}_\text{ind}), 1_\text{data}(3:4)]; \quad \% \text{id, type, vy, ay}
\]
\end{verbatim}

end

end

sort_pair_data(:,[3,4,10,11]) = [];

%% write result [1~39]

\[
\text{title} = \{\text{Frame_ID'}, \text{SV_ID'}, \text{SV_Vx'}, \text{SV_Ax'}, \text{SV_Vy'}, \text{SV_Ay'},
\]
\[
\text{SV_Type'}, \text{SV_Strip'}, \text{Bound_CHK'}, \text{LV_ID'}, \text{LV_Type'}, \text{LV_Vy'},
\]
\[
\text{LV_Ay'}, \text{FV_ID'}, \text{FV_Type'}, \text{FV_Vy'}, \text{FV_Ay'}, \text{L_CHK'}, \text{L_OCCU'},
\]
\[
\text{L_OCCU_CHK'}, \text{L_LV_ID'}, \text{L_LV_Type'}, \text{L_LV_Vy'}, \text{L_LV_Ay'},
\]
\[
\text{L_FV_ID'}, \text{L_FV_Type'}, \text{L_FV_Vy'}, \text{L_FV_Ay'}, \text{R_CHK'}, \text{R_OCCU'},
\]
\[
\text{R_OCCU_CHK'}, \text{R_LV_ID'}, \text{R_LV_Type'}, \text{R_LV_Vy'}, \text{R_LV_Ay'},
\]
\[
\text{R_FV_ID'}, \text{R_FV_Type'}, \text{R_FV_Vy'}, \text{R_FV_Ay'}\};
\]
\end{verbatim}

xlswrite('results.xls', title, 1, 'A1:AM1');
xlswrite('results.xls', sort_pair_data, 1, ['A2:AM' num2str(size(sort_pair_data,1)+1)]);
Appendix B
Sample GAUSS Code

new;
load choice[21543,1] = "choice.txt";
load other[21543,35] = "other.txt";
load firobs[1975,1]= "firstobs.txt";
load lasobs[1975,1]= "lastobs.txt";

load niuLimits[2,1975]="niuLimits.txt";
numpeople = rows (firobs);
numobservations = rows (choice);
load parameters[7,1]= parameters.asc;
load active[7,1]= active.asc;
one = ones(numobservations, 1);
oneV = ones (numpeople, 1);
niuMax = 3;
niuMin = -3;
//MLCMax = 10;
//MLCMin = 0;
library maxlik;
#include maxlik.ext;
maxset;
start=
/* 1 beta1 */  //0.0 |
/* 2 beta2 */  0.0 |
/* 3 beta3 */  0.0 |
/* 4 beta4 */  0.0 |
/* 5 beta5 */  0.0 |
/* 6 beta6 */  0.0 |
/* 7 beta7 */  0.0 |
/* 8 beta8 */  0.0 |
/* 9 beta9 */  //0.0 |
/* 10 beta10 */ //0.0 |

beta= start;
b= beta;

output file = four_v9.out reset;
_max_Active = active;
_max_ParNames = parameters;
_max_GradTol = 0.0001;
_max_MAXIters = 100;
_intord = 12; //32
_intrec = 0;
_max_Diagnostic = 1;
_max_MaxTry = 100;
//x =beta[1:15];
// print x;
// hes2 = hessp(&logliklihood, x);
// save hes2;
// cv =(-hes2);
/ cov2 = sqrt(abs(diag(cv))); // print (cov2,x, x./cov2); // proc logLiklihood (x); {x6, fn6, g6, cov6, retcode6} = maxlik(oneV, 0, &logLiklihood, start); //max lik calculation {x6, fn6, g6, cov6, retcode6} = maxprt(x6, fn6, g6, cov6, retcode6); // prints results proc logLiklihood (b, oneV); local f; //beta[1:15]=x; beta=b; f = intquad1 (&probf, niuLimits); //single intergration f = (f .> 1) + (f .<= 1) .* f + (f .< 1e-200) .* 1e-200; print (meanc(ln(f))); //debug retp (ln(f)); endp; proc probf (niu); local beta2,beta3,beta4,beta5,beta6,beta7,beta8,lv_car,speed,speed4,L_lv_car,con4,speed2, speed3,R_lv_car,con3,con2,con1,fr1,fr2,fr3,fx1,fx2,fx3,p,p1,p2,p3,b1,b2,b3,cdfNiu,p dfNiu,f2; //beta1 = beta[1]; beta2 = beta[1]; beta3 = beta[2]; beta4 = beta[3]; beta5 = beta[4]; beta6 = beta[5];
beta7 = beta[6];
beta8 = beta[7];

lv_car = other[.,7];
speed = other[.,9];

con1 = lv_car .* speed;
speed2 = other[.,29];

con2 = lv_car .* speed2;

speed3 = other[.,35];

R_lv_car = other[.,24];

con3 = speed3 .* R_lv_car;
speed4 = other[.,34];

L_lv_car = other[.,16];

con4 = speed4 .* L_lv_car;

beta9 = beta[6];
beta10 = beta[6];
beta11 = beta[7];
beta12 = beta[12];
beta13 = beta[13];
beta14 = beta[14];
beta15 = beta[15];

lv_have = other[.,5];

lv_heavy = other[.,6];
fv_have = other[.,8];
fv_heavy = other[.,9];

sv_car = other[.,2];

lv_car = other[.,7];
right CHK = other[.,12];
right OCCU = other[.,13];
left CHK = other[.,10];
left OCCU = other[.,11];/*
//con1 = lv have /*.* lv heavy*/;
//con2 = fv have /*.* fv heavy*/;
//con3 = lv have .* right OCCU;
//con4 = lv have .* left OCCU;
/*lv type lmv = (lv type .==1);
lmv response = lv have .*lv type lmv;
lv car = lv have .*car have;*/

{fr1, fr2, fr3} =
planeaction(beta2,beta3,beta4,beta5,beta6,beta7,beta8,speed4,L_lv car,con4,speed3,
R_lv car,con3,lv car,speed2,con2,speed,con1,niu);

fx1 = ( choice .== 1 ) .* fr1 + ( choice .== 0 ) .* fr2 + ( choice .== -1 ) .* fr3;
//fx2 = ( choice .== 1 ) .* fr1 + ( choice .== 0 ) .* fr2 + ( choice .== -1 ) .* fr3;
//fx3 = ( choice .== 1 ) .* fr1 + ( choice .== 0 ) .* fr2 + ( choice .== -1 ) .* fr3;
p1 = zeros(numpeople, _intord); // initialize
//p2 = zeros(numpeople, _intord);
//p3 = zeros(numpeople, _intord);

for i (1, numpeople, 1);
p1[i, .] = (prodc(fx1[firobs[i]:lasobs[i], .]))';
//p2[i, .] = (prodc(fx2[firobs[i]:lasobs[i], .]))';
//p3[i, .] = (prodc(fx3[firobs[i]:lasobs[i], .]))';
endfor;

//b1 = ( \exp(\beta14) > 1) + (\exp(\beta14) \geq 0 \text{ and } \exp(\beta14) \leq 1) \times \exp(\beta14);

//b2 = ( \exp(\beta14) > 1) + (\exp(\beta14) \geq 0 \text{ and } \exp(\beta14) \leq 1) \times \exp(\beta14);

//b3 = ( \exp(\beta14) > 1) + (\exp(\beta14) \geq 0 \text{ and } \exp(\beta14) \leq 1) \times \exp(\beta14);

//p = b1 \times p1 + b2 \times p2 + (1 - b1 - b2) \times p3;

p = p1;

p = (p > 1) + (p \leq 1) \times p + (p < 1e-200) \times 1e-200;

cdfNiu = cdfn(niuMax) - cdfn(niuMin);

pdfNiu = pdfn(niu) / cdfNiu;

f2 = p \times pdfNiu ; // multiplies by a normal probability distribution of niu

retp (f2);

endp;

proc (3) =
planeaction(beta2,beta3,beta4,beta5,beta6,beta7,beta8,speed3,speed4,L_lv_car,con4,
R_lv_car,con3,lv_car,speed2,con2,speed,con1,niu);
local i,vl1,vl2,vl3,sum1,fr1,fr2,fr3,v1l1,v1l2,v1l3;

vl1= other[.,25] * beta2 + other[.,28] * beta3 + con3 * beta6 ;

vl2= con1 * beta4 + con2 * beta5 + other[.,4] * beta7 + other[.,5] * beta7 ;

vl3= other[.,17] * beta2 + other[.,20] * beta3 + other[.,33] * beta7 + other[.,32] * beta7 + con4 * beta6 ;

v1l1 = vl1[., 1] + niu[1, .] \times \exp(beta8);

v1l2 = vl2[., 1] + niu[1, .] \times \exp(beta8);

v1l3 = vl3[., 1] + niu[1, .] \times \exp(beta8);
v1l1 = exp(v1l1);
v1l2 = exp(v1l2);
v1l3 = exp(v1l3);
sum1=v1l1+v1l2+v1l3;

fr1 = v1l1 ./ sum1;
fr2 = v1l2 ./ sum1;
fr3 = v1l3 ./ sum1;
retp (fr1, fr2, fr3);
endp;