Lane Changing Models

Lecture Notes in Transportation Systems Engineering

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1 Overview

The transfer of a vehicle from one lane to adjacent lane is defined as lane change. Lane changing has significant impact on traffic flow. Lane changing models are therefore an important component in microscopic traffic simulation Modeling the behaviour of a vehicle within its present lane is relatively straightforward, as the only considerations of any importance are the speed and location of the preceding vehicle. Lane changing, on the other hand, is more complex, because of the decision to change lanes depends on several objectives, and at times some of these may conflict.

2 Classification of Lane change

Basic lane change model is described using the framework shown in Figure 1. The subject vehicle in the current lane tries to change direction either to its left or to its right. If the gap in the selected lane is acceptable then the lane change occurs or else it will remain in the current lane The classification of lane change is done based on the execution of the lane change and accordingly two type of lane changes exists, namely the mandatory and discretionary lane changes.

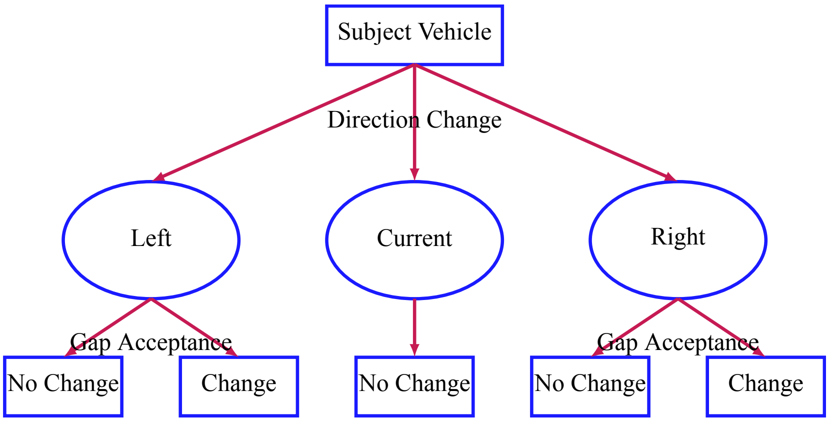

Figure 1: Basic Lane Change Model

2.1 Mandatory Lane Change (MLC):

Mandatory lane change (MLC) occurs when a driver must change lane to follow a specified path. Suppose if a driver wants to make a right turn at the next intersection, then he changes to the right most lane. This type of lane change is referred to as MLC. This lane changing model structure is shown in the left portion of the Figure 2. The MLC branch in the top level corresponds to the case when a driver decides to respond to the MLC condition. Explanatory variables that affect such decision include remaining distance to the point at which lane change must be completed, the number of lanes to cross to reach a lane connected to the next link, delay (time elapsed since the MLC conditions apply), and whether the subject vehicle is a heavy vehicle (bus, truck, etc..,). Drivers are likely to respond to the MLC situations earlier if it involves crossing several lanes. A longer delay makes a driver more anxious and increases the likelihood of responding to the MLC situations. Further, due to lower maneuverability and larger gap length requirement of heavy vehicles as compared to their non heavy counterparts, they have a higher likelihood of responding to the MLC conditions.

2.2 Discretionary Lane Change (DLC):

Discretionary lane change (DLC) occurs when a driver changes to a lane perceived to offer better traffic conditions, such as to achieve desired speed, avoid following trucks, avoid merging traffic, etc. This lane changing model structure is shown in the right portion of the Figure 2.

The DLC corresponds to the case where either a driver does not respond to an MLC condition, or that MLC conditions do not apply. A driver then decides whether to perform a discretionary lane change (DLC). This comprises of two decisions: whether the driving conditions are satisfactory, and if not satisfactory, whether any other lane is better than the current lane. The term driving conditions satisfactory implies that the driver is satisfied with the driving conditions of the current lane as he is able to maintain the desired speed. Important factors affecting the decision whether the driving conditions are satisfactory include the speed of the driver compared to the desired speed, presence of heavy vehicles in front and behind the subject vehicle, if an adjacent on ramp merges with the current lane, whether the subject is tailgated etc.

If the driving conditions are not satisfactory, the driver compares the driving conditions of the current lane with the adjacent lanes. Important factors affecting this decision include the difference between the speed of traffic in target lanes and the driver's desired speed, the density of traffic in target lanes, the relative speed with respect to the lag vehicle in the target lane, the presence of heavy vehicles in target lanes ahead of the subject etc.

In addition, a driver considers DLC when although a mandatory lane change is required but the driver is not responding to the MLC conditions, changing lanes opposite to the direction as required by the MLC conditions may be less desirable. If a driver decides not to perform a discretionary lane change (i.e., either the driving conditions are satisfactory, or, although the driving conditions are not satisfactory, the current is the lane with the best driving conditions) the driver continues in the current lane.

Otherwise, the driver selects a lane from the available alternatives and assesses the adjacent gap in the target lane. When trying to perform a DLC, factors that affect drivers' gap acceptance behavior include the gap length, speed of the subject vehicle, speed of the vehicles ahead of and behind the subject vehicle in the target lane, and the type of the subject vehicle (heavy vehicle or not). For instance, a larger gap is required for merging at a higher travel speed. A heavy vehicle would require a larger gap length compared to a car due to lower maneuverability and the length of the heavy vehicle.

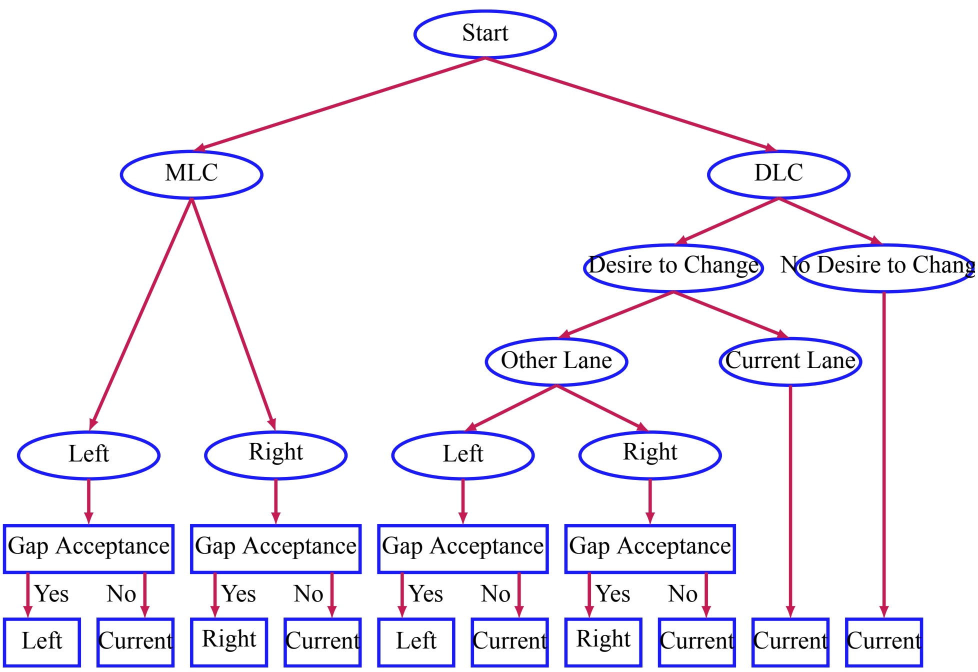

Figure 2: Mandatory and discretionary lane change decision tree

2.3 Forced merging model

Forced merging happens if the gap on the target lane is not acceptable then the subject vehicle forces the lag vehicle on the target to decelerate until the gap is acceptable. At every discrete point in time, a driver is assumed to (a) evaluate the traffic environment in the target lane to decide whether the driver intends to merge in front of the lag vehicle in the target lane and (b) try to communicate with the lag vehicle to understand whether the driver's right of way is established. If a driver intends to merge in front of the lag vehicle and right of way is established, then the decision process ends and the driver gradually move into the target lane. This process may last from less than a second to a few seconds. If right of way is not established, the subject continues the evaluation/communication process during the next time instant.

2.4 Cooperative Merging

The models discussed so far assume that lane changing is executed through gap acceptance. However, in congested traffic conditions acceptable gaps may not be available, and the resultant behaviour would be different. For example, drivers may change lanes through courtesy and cooperation of the lag vehicles on the target lane that will slow down in order to accommodate the lane change.

2.5 Application of different lane changing models

Most models classify lane changes as either mandatory or discretionary lane change. This separation implies that there are no trade-offs between mandatory and discretionary considerations. For example, a vehicle on a freeway that intends to take an off-ramp will not overtake a slower vehicle if the distance to the off-ramp is below a threshold, regardless of the speed of that vehicle. Furthermore, in order to implement MLC and DLC model separately, rules that dictate when drivers begin to respond to MLC conditions needs to be defined. However, this point is observable, and so only judgment-based heuristic rules, which are often defined by the distance from the point where the MLC must be completed, are used. Just like the judgment based lane changing models, there also exist several other models like general acceleration based lane changing models and gap acceptance based lane changing models

3 Lane changing process

There are no analytic relationships that encompass the entire lane changing process. Instead, it is typically modeled as a sequence of several decision-making steps such as:

1. Desire to change the current lane
2. Selection of the target lane
3. Ensuring lane change is feasible
4. Decision to change lane based on gap acceptance

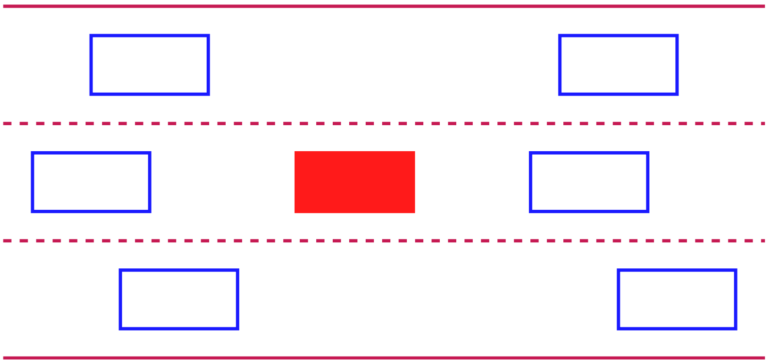

Figure 3: Process of Lane Change

Lane changing process is explained using an example shown in figure ?? where the subject vehicle traversing in the middle lane of a three-lane road undergoes lane changing. Each step of the lane changing process is explained in detail referring to the example. Note that a discretionary lane change is considered here.

3.1 Desire to change the current lane

Desire to change the lane, whether discretionary or mandatory, greatly depends on the driver characteristics and behaviour. Lane changes may be performed due to several factors such as reduced speed in the current lane, queuing, forced deceleration because of the lead vehicle, etc. The desire to change the lane becomes stronger when the driver also perceives a higher utility in the target lane in terms of higher speed or higher acceleration or a better position in the queue. Here we assume that the first step of deciding whether to change the lane arises basically from the current acceleration of the vehicle. This acceleration can be computed using any car following model, say General Motors Model. If the vehicle has to decelerate due to the lead vehicle, then the driver decides to change the lane. Acceleration of the vehicle in the current lane, $a_{(n+1)}$ can be computed by,

$$a_{n+1} = \frac{\alpha v^m \Delta v}{\Delta x^l} \tag{1}$$

where α is the sensitivity coefficient, v is the velocity of the subject vehicle, m is the speed exponent (-2 to +2), Δv is the velocity of the lead vehicle minus the velocity of the vehicle, Δx is the distance gap between the lead and the subject vehicle, and l is the distance headway exponent (+4 to -1). If $a_{(n+1)} < 0$, then it means that the driver has to decelerate his vehicle which is not desired by any driver. In that case, the driver desires a change of lane, otherwise, it will continue in the same lane.

3.2 Selection of the target lane

When there is a desire to change the lane, the driver then targets a lane to shift. Modeling this decision is more for complex for discretionary lane changes, where the driver needs to select a lane based on several factors, such as queue length, operating speed, etc. (Discussion of this is out side the scope of this chapter) A simpler way of modeling target lane selection is based on the concept of utility maximization. In this approach, one assume that the driver will select a lane that maximizes his perceived utility. Utility of i^{th} lane U_i can be taken as a function of several parameters such as velocity, gap between vehicles, acceleration, etc. In this chapter, for ease in analysis, we assume the utility is same as the acceleration. Given utility of i^{th} lane as U_i, then the probability of choosing the i^{th} lane can be given by

$$p(i) = \frac{e^{U_i}}{\sum_{i=1}^{N} e^{U_i}} \tag{2}$$

where N is the number of lanes. It is assumed that the driver will choose the lane that has the maximum probability as his target lane. Note that, in real traffic simulation, a random number is generated and used in the decision.

3.3 Ensuring lane change is feasible

The lane change is said to be feasible if the subject vehicle will not collide with the rear vehicle in the target lane. For avoiding collision, the deceleration of the rear vehicle in the target lane needs to be less than the critical deceleration. The deceleration required for the lag vehicle in the target lane can be computed using car following model as

$$a_{n+1} = \frac{\alpha \; v^m \; \Delta v}{\Delta x^l} \tag{3}$$

If a_{n+1} is less than the critical deceleration, it is feasible to change the lane to the selected target lane. Otherwise, the vehicle will continue in the current lane.

3.4 Decision to change lane based on gap acceptance

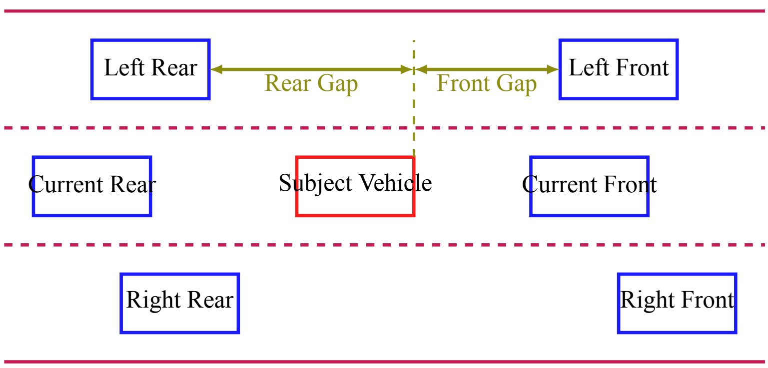

Figure 4: Notation of Lane Change

A gap is defined as the gap in between the lead and lag vehicles in the target lane (see Figure ??). The lead gap is the gap between the subject vehicle and the vehicle ahead of it in the lane it is changing to. The lag gap is defined in the same way relative to the vehicle behind in that lane. For merging into an adjacent lane, a gap is acceptable only when both lead and lag gap are acceptable. Drivers are assumed to have minimum acceptable lead and lag gap lengths which are termed as the lead and lag critical gaps respectively. These critical gaps vary not only among different individuals, but also for a given individual under different traffic conditions. Most models also make a distinction between the lead gap and the lag gap and require that both are acceptable. The probability of gap acceptance as a function of time can be written as:

$$p(t) = \begin{cases} 1 - e^{-\lambda(t-T)} & \text{if } t > T \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

where, λ is a coefficient T is the critical time gap t is the actual time gap which can be computes as:

$$t = \frac{g}{v_{n+1}}$$

where, g is the distance gap, and v_{n+1} is the velocity of the vehicle. Probability that the gap is accepted is the product of the probability that the lead gap is accepted and the probability that the lag gap is accepted, that is.

$$p(t^{lead}, t^{lag}) = p(t^{lead}) \times p(t^{lag}) \tag{5}$$

3.4.1 Numerical Illustration

The mid-block section of a three lane highway with the current traffic state is shown in Figure 5. Determine if the driver of the subject vehicle will change the lane. Given that, the maximum sage deceleration is 2 m/s^2, the critical time gap (both lead and lag) is 0.7 sec, the coefficient of the gap acceptance model is 0.78, the sensitivity coefficient of the car following model is 25, the speed exponent is one, and the distance exponent is two.

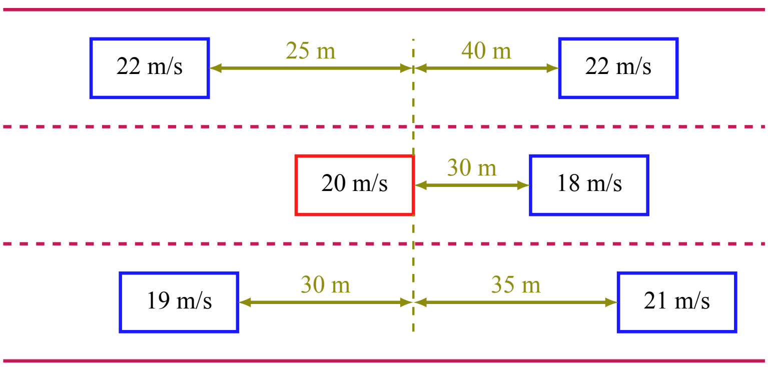

Figure 5: Lane change scenario

3.4.2 Solution

Figure 5 Traffic state on a 3-lane road Solution:

Step 1. Decision to change the lane: If the vehicle n has to decelerate due to the lead vehicle in the current lane cf, then the driver decides to change the lane.

$$a_n = \frac{25 \times 20^1 \times (18 - 20)}{30^2} = -1.11\ m/s^2$$

Since, $a_n < 0$, the driver desires to change the lane.

Step 2. Lane Selection: We assume that the driver will select the lane that will maximizes the utility. Utility of i^{th} lane U_i can be taken as a function of several parameters such as velocity, gap between vehicles, acceleration, etc. The utility of the left, center, and right lanes are computed by finding the respective potential acceleration gain, as below:

$$a_L = \frac{25 \times 20^1 \times (22 - 20)}{40^2} = 0.625\, m/s^2$$

$$a_R = \frac{25 \times 20^1 \times (21 - 20)}{35^2} = 0.408\, m/s^2$$

$$a_C = \frac{25 \times 20^1 \times (18 - 20)}{30^2} = -1.11\, m/s^2$$

Assuming the utility of i^{th} lane U_i is same as a_i, then the probability of choosing the i^{th} lane (left, center, and right) can be computed as:

$$p(L) = \frac{e^{0.625}}{e^{-1.11} + e^{0.625} + e^{0.408}} = 0.505$$

$$p(C) = \frac{e^{-1.11}}{e^{-1.11} + e^{0.625} + e^{0.408}} = 0.089$$

$$p(R) = \frac{e^{0.408}}{e^{-1.11} + e^{0.625} + e^{0.408}} = 0.406$$

Since probability of choosing left lane is higher compared to other two, we assume that left lane is chosen. Note that, this is a deterministic selection, and better reality is to select probabilistic.

Step 3. Check for feasibility: For feasibility, the deceleration of the lag vehicle in the target lane needs to be less than the critical deceleration.

$$a_{l_r} = \frac{\alpha\, v^m\, \Delta v}{\Delta x^l} = \frac{25 \times 22^1 \times (20 - 22)}{25^2} = -1.76\, m/s^2$$

The deceleration of the lag vehicle is lesser than the critical deceleration (-2.0 m/s^2). Hence, the lane change is feasible.

Step 4. Check for gap acceptance: Lead time gap, t^f = 40/20 = 2 sec. Probability that the lead gap is accepted is:

$$1 - e^{-0.78(2-0.7)} = 0.637$$

Lag gap, t^r = 25/20 = 1.25 sec. Probability that the lag gap is accepted is given as:

$$1 - e^{-0.78(1.25-0.7} = 0.349$$

Probability that the gap is accepted,

$$p(t^f, t_r^t) = p(t^f) \times p(t^r) = 0.637 \times 0.349 = 0.222.$$

4 Average Delay for Lane change

The blockage length and the average delay for the lane change are calculated based on the following formula.

$$\begin{aligned} BL &= \frac{T \times Vs}{N} \\ \text{Average delay} &= \frac{1}{2} \times \frac{BL}{Vr} \end{aligned}$$

where, T = Total time of headways rejected, BL = blockage length, Vs = stream velocity, Vr = relative velocity, N = number of acceptable gap

4.0.1 Numerical Example

In a two lane, one way stream of 1000 vph with 360 vehicles in Lane A and the remaining vehicles in lane B. 8% of the vehicles in lane A have gaps less than 1 sec and 18% of the vehicles in lane A have gaps less than 2 sec. Compute the time during which vehicles in Lane B may not change to Lane A in 1 hour. Assume driver requires one second ahead and behind in making a lane change.

Solution Total acceptable time for lane change in an hour = 3600 - total rejected headway - total clearance time. Given that 0 to 1 second Gaps is 8% of 360 = 29 and 1 to 2 second Gaps is (18-8) % of 360 = 36. Total = 65 Gaps. Time spent in Gaps 0 to 1 second = 29 x .5 = 14.5 sec, and Time spent in Gaps 1 to 2 second = 36 x 1.5 = 54.0 sec. As 65 Gaps are rejected, Acceptable Gaps are (360-65) = 295 Gaps. In this 295 Gaps clearance time = 295 x 2 = 590 sec. Time lost in rejected gap = 14.5+54=68.5. Therefore, Total time left in one hour to accept Gap=(3600 - 590 - 68.5) = 2941 sec. Vehicle can change lane in (2941/3600) = 81.7% of the Total time. Vehicle is prevented from changing lane in 18.3% of the time.

Under Construction (qf44 B)

Figure 6: Numerical example

4.0.2 Numerical Example

In a two lane, one way stream of 1000 vph with 360 vehicles in Lane A and the remaining vehicles in lane B. 8% of the vehicles in lane A have gaps less than 1 sec and 18% of the vehicles in lane A have gaps less than 2 sec. Compute the average waiting for the driver to make a lane change. Assume driver velocity in lane B = 40 kmph and stream velocity = 50 kmph.

Solution: The average length of headways and portions of head ways of insufficient length for a lane change, which may be considered as general blockages moving in the stream. Division of this Blockage length by the relative speed determines potential total delay time of the blockade. Finally since a delayed vehicle is as likely to be at the head as at the tail of such a blockade at the moment of desired lane change, the total delay must be divided by 2 for average delay time.

$$\begin{aligned} \text{Average delay} &= \frac{1}{2} \times \frac{BL}{Vr} \\ BL &= \frac{T * Vs}{N} \end{aligned}$$

where T = 3600 × 18.3% = 658.8, V_s = 50 kmph, N = acceptable gaps. So 0 to 2 second Gaps = 18 % of 360 = 65. Therefore N = 360-65 = 295. BL = $\frac{658.8 \times 50}{295}$ = 111.6.

Under Construction (qf55 C)

Figure 7: Numerical example

In the above figure the vertical lines are the center line of the cars and g_r, g_a represents the acceptable and rejected gaps respectively.

$$\begin{aligned} \text{Average delay} &= \frac{1}{2} \times \frac{BL}{Vr} \\ \text{Average delay} &= \frac{1}{2} \times \frac{111.6}{(50-40)} = 5.58 sec \end{aligned}$$

5 Summary

Lane changing is an important component of microscopic traffic simulation model, and has significant impact on the results of analysis that uses these tools. In recent years, interest in the development of lane changing models and their implementation in traffic simulators have increased dramatically. There is significant scope for the improvement of these lane change models like integrating acceleration behavior, impact of the buses, bus stops, traffic signals and queues that form due to lane change maneuver.

Exercises

1. Explain the conceptual frame work of basic lane change model and distinguish between MLC and DLC models
2. A roadway has 3 lanes. A vehicle is travelling in the middle lane (i.e., 2nd) and has the options of either travelling in the same lane or changing either to the 1st or 3rd lanes. These decisions are governed by the utlities of the lanes (U_l) and gaps (U_g) . If the vehicle has decided to leave the current lane, the decisions of choosing among the other two lanes are governed by the utilities of gaps (U_g) in those lanes. On which lane would the vehicle like to travel probably?

   U_l = 3.467 - 0.0757 × Relativespeed - 0.0064 × Frontgap

   U_g = 5.567 - 0.03 × Leadgap - 0.0129 × Laggap

Lane No.	Relative speed (m/s)	Front gap (m)	Lead gap (m)	Lag gap (m)
1	5	8	5	3
2	3	-	-	-
3	8	-	9	6

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Web links

1. Traffic-Simulation
2. Road Traffic Simulation

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