Identifying and Analyzing Stop and Go Traffic based on Asymmetric Theory of Driving Behavior in Acceleration and Deceleration

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Abstract:

Stop and go traffic that leads to oscillate traffic flow frequently is observed on congestion flow. Unexpected reasons such as lane – changing maneuvers, lower speeds of leader vehicle and moving bottleneck cause stop and go traffic and amplifying delay and environment impacts. Stop and go traffic exactly can't be modeled by traffic models, and also car following models based on kinematic flow theory can't be implied correct perception of stop and go traffic. Based on asymmetric microscopic theory and trajectory data of NGSIM, traffic flow can be classified into five phases according to speed and movement of the vehicle: Free flow, acceleration and deceleration, stationary and coasting phases. Analyzing stop and go traffic based on asymmetric theory of acceleration and deceleration phase will result to classify them into three cases: generation, growth and dissipation of traffic waves. Analyzing of traffic oscillation implies that stop-and-go traffic is relatively small and can't be propagated upstream unless the following traffic is also near D-curve; while the effect on lane changes are greater, and can propagate even the following traffic is not near the D-curve. In this paper, using time window in trajectory data clarify relation between the total number of lane changes and stop-and-go waves for congestion traffic. Analyzing net lane changes inside the searching window for incoming and outgoing lane changes about growth and dissipation of traffic waves indicate how characteristics of stop-and-go waves are intimately related to driver's asymmetric behavior of acceleration and deceleration. The comparison result on the growth and dissipation indicated that under the same net lane changes, growth wave case occupy the regions in fundamental diagram, flow – density diagram, deceleration curve, and dissipation wave case occupy the regions of flow – density, acceleration curve.

Keywords: Traffic oscillation, stop-and-go traffic, asymmetric theory, lane-changing maneuver, acceleration and deceleration wave

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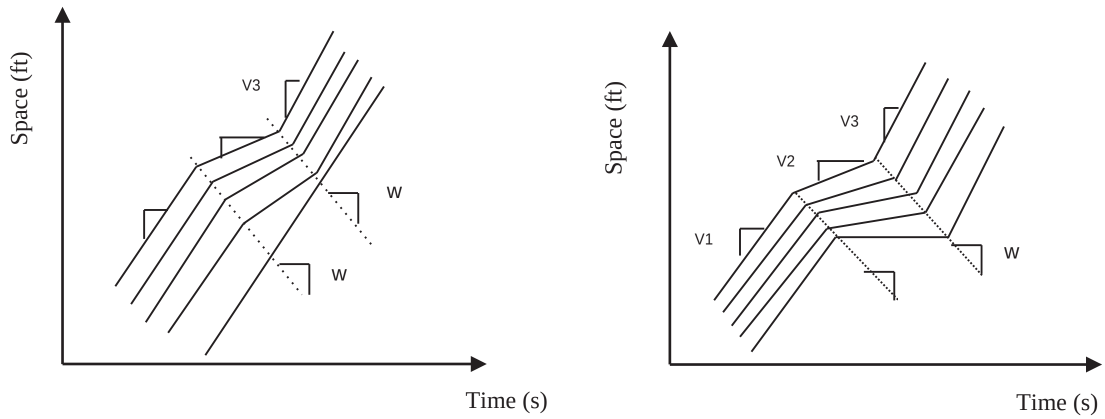
1. Introduction

Stop-and-go driving, or simply traffic oscillation, has raised much concern in the literature due to its severe negative impacts: increased fuel consumption, greenhouse emissions and safety risks [Bilbao-Ubillos, 2008 Zheng, et al, 2011a Zheng,et al, 2011b]. Unfortunately, our understanding of this type of the oscillations in con- gested traffic is still limited. On the one hand, detailed vehicle trajectories data are very scarce, and aggre- gated sensor data are often noisy and insufficient. On the other hand, few attempts have been made to vali- date the oscillations predicted by existing traffic flow models, which are often a result of mathematical cu- riosities rather than driving behavior. A traffic oscilla- tion has two components, formation and propagation. It is known that the formation can be caused by lane- changing activity (Laval and Daganzo, 2006, Ahn and Cassidy, 2006, Laval, 2005) or in general any kind of moving bottleneck (Koshi et al., 1992, Laval, 2006). LWR (Lighthill and Whitham, 1955; Richards, 1956) theory is the first order model for traffic dynamics. It has shown good agreements with experimental observa- tions in congested traffic, but as a coarse representation of traffic, it cannot satisfactorily explain the mechanism of some traffic phenomena such as stop-and-go traffic [Richards, 1956 , Lighthill, Whitham,1955]. Daganzo (1997) pointed out the limitations of LWR model: (1) driver difference, (2) vehicular motion through shock, and (3) traffic instability. Recently, Nagel and Nelson (2005) pointed out the limitations of LWR theory in addressing 1) unstable flow, 2) spontaneous breakdown, 3) two-capacity phenomenon (or "capacity drop"; Banks, 1991). Analyzing aggregate detector data, Kerner (Kerner and Rehborn, 1996a, 1996b, 1999; Kerner, 2004) has developed a three-phase traffic theory. He classified traffic into 3 phases: free flow, synchronized flow, and wide moving jam. He tried to explain spatial-temporal traffic patterns using transitions between these three phases. Although he was not the first, he pointed out two empirical phenomena: (1) synchronization of average speed between different freeway lanes and (2) wide spreading of empirical data in flow-density plane. From these perspectives, Kerner concluded that there does not exist any fundamental relationship in congested region. Furthermore, diverse situation of traffic such as lane changing, merging and diverging also contribute to the wide scattering. For example, in multilane freeway, lane changes can cause speed synchronization. Therefore, the two phenomena Kerner pointed are not unique features of three-phase theory, and can also be understood in fundamental diagram perspectives. Ahn presented that lane change maneuvers create stop and go traffic. Sudden braking effect results in stop and go traffic [Ahn, Cassidy, 2007 , Daganzo, 2006 , Daganzo, 1997]. Applying Newell's (2002) simplified car-following theory, the trajectory of the following vehicle is always parallel to the lead vehicle, and the wave speeds of stop-and-go traffic are same for both deceleration and acceleration for the same vehicle. In reality, it can be easily found that the trajectories in the stop-and-go traffic are not parallel, and the wave speeds for acceleration and deceleration are not same [Newell, 2002]. In Del Castillo's model (2001), vehicle trajectories do not need to be parallel, but wave speeds are same (figure 1). However, waves grow in dense traffic flow and decay in low density flow.

Kim and Zhang (2004) used a stochastic gap time which change over time for each driver and causes different wave speeds for acceleration and deceleration, but still their vehicle trajectories are parallel. Both Del Castillo and Kim and Zhang noticed that the time headway distribution affects the future state of stop-and-go traffic, i.e. with larger headways, stop-and-go wave's decay, and short headway makes the waves grow. But, their approach is limited because they simply regarded time headway as random variable changing over time. A deceleration model can be derived from the safety distance calculation in car-following based on the approach suggested by Gipps (1981). In stationary car-following state, a following vehicle has to keep minimum safe driving spacing for a given speed. Daganzo's searches indicate that stop and go wave model similar to Newell's model based on flow – density triangular diagram [Daganzo 2006]. The first traffic observations related to acceleration-deceleration asymmetry was obtained by Forbes (1965), Foote (1965), and Edie (1965). Forbes (1965) noticed that the driver's response is slower in acceleration than in deceleration. Figure 2 shows diverse driver response times by Forbes (1965), which shows the impact of response time on traffic flow. Re-



1. Wave decays 2. Wave growth

Figure1. Dell Castillo's Model (Del Castillo's, 2001)

sponse time and flow show negative relationship. With higher response time, accelerating vehicles recovering from a slowdown have lower flow.

Foote (1965) observed traffic data obtained in tunnels. Dividing platoons into three types: constant speed, accelerating and decelerating, he traced the platoons, and found that decelerating vehicles have higher flow for given speed than the other types of platoon. Edie (1965) investigated platoon behaviors using analyzed data from aerial photos taken in 6 seconds interval. His study site is one lane of the George Washington Bridge which was not affected by lane changing behaviors. Based on the observations showing asymmetric behavior by Forbes, Foote, and Edie, Newell suggested two separate curves for acceleration and deceleration in congested traffic as shown in figure 3. As illustrated in the figure, the spacing in acceleration is always larger than the one in deceleration for the same speed. This asymmetry in acceleration - deceleration forms a clockwise loop in flow-density plane like Edie's (1965) results shown. Different from Forbes (1965) who noticed only response time change and assumed same jam density, Newell used different jam spacing d0, d1 for deceleration and acceleration respectively. He also ascribed the cause of traffic instability allowing the growth of a small perturbation, to the wave speed difference inherent from the asymmetry.

Laval and Leclercq (2010) conjectured that the formation and propagation of traffic oscillations were due to the aggressive or timid driver behavior. This study suggests a new perspective to explain the mechanism of formation and propagation for traffic oscillations. However, the behavioral model assumed in this model has not been verified empirically. Additionally, this model assumed that drivers behave homogeneously in equilibrium (i.e., following the same fundamental dia-

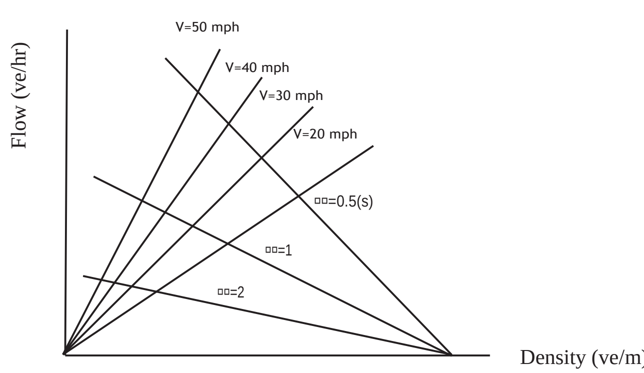


Figure 2. Response time (Forbes, 1965)

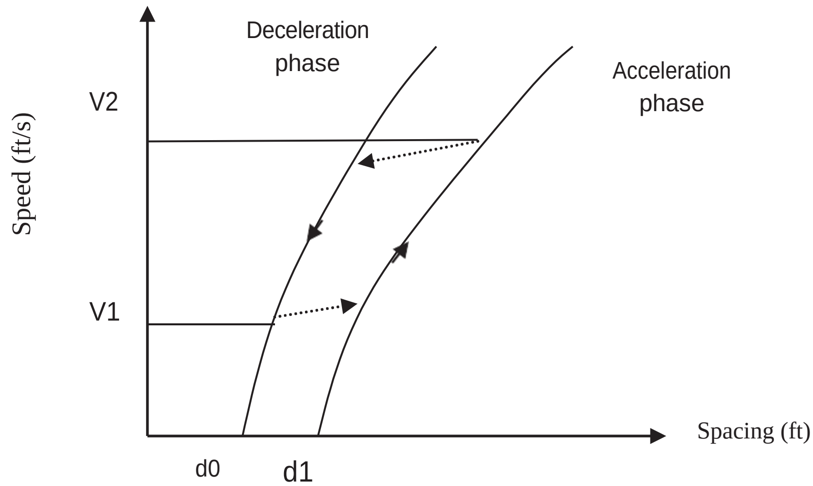


Figure 3. Newell's two-curve theory in congested traffic (Newell, 1965)

gram) and consistently before and after traffic oscillations. These assumptions, however, were not validated by empirical observations. Zielke's researches indicate that wave speed divides into three different regions without regarding different properties. They founded that lane change maneuvers result in developing stop and go traffic waves in platoon [Zielke, Bertini, Treiber, 2008]. In this research, stop and go traffic properties are compared based on asymmetric theory. Also, traffic oscillation is classified into two cases, growth and dissipation case. These cases are compared according to lane change maneuvers.

2. Methodology

First stop and go wave in platoon is presented based on asymmetric theory, in order to determine difference between stop and go wave based on asymmetric theory and Newell's car following model. Then there is a comparison between both two theory and between traffic instability and lane change diffusion wave based on asymmetric theory.

2.1 Asymmetric Driving Behavior Theory

Asymmetric behavior theory is based on different reactions of drivers during deceleration and acceleration phase. It results in asymmetric spacing in two phases. Figure 4 shows an individual vehicle's traffic state of NGSIM data can be classified into five phases: free flow, acceleration, deceleration, stationary and coasting. According to figure 5, flow-density and spacing – speed planes present based on this theory. It is able to explain phase transitions between two phases and describe traffic equilibrium that exists as two dimensional area bounded by A-curve and D-curve. And also, that theory is able to explain several complex traffic phenomena of driver behavior in congested traffic [Yeo, H. 2008, Jonghae, S., Hwasoo,Y. Alexander,S. 2012].

2.1.1 Free Flow

Free flow is a traffic state in which a small disturbance doesn't affect upstream traffic. In other words, if a vehicle is in free flow phase, a small speed change or spacing change from leader vehicle doesn't trigger a deceleration action of the subject vehicle. In free flow, drivers run at their desired speed which is usually a maximum speed.

2.1.2 Deceleration and Acceleration Phase

Acceleration phase is a state in which a vehicle is speeding up to catch up with the speed of the leader vehicle or reduce spacing. Deceleration (acceleration) curve for one vehicle obtains with connecting points that values less (larger) than -1 (+1) ft /sec2 in speed and spacing plane. In a microscopic view, stationary phase is a traffic state in which the speed and spacing between two adjacent vehicles are constant. But, in traffic situation it is almost impossible for these two values to be kept constant for long time because human perception and reaction are not perfect. Flow can be defined in speed-

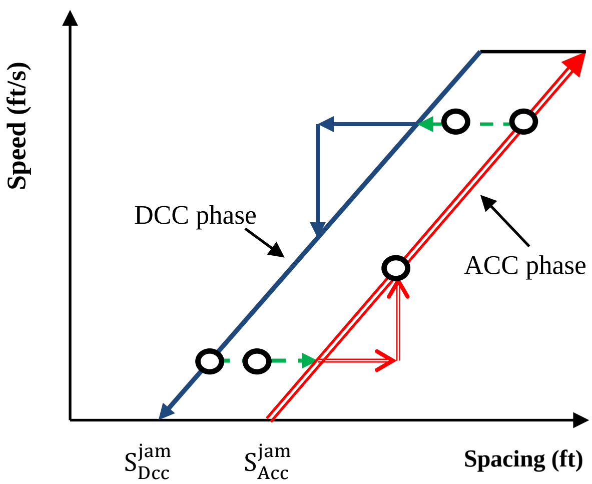


Figure 4. Phases in speed-spacing plane

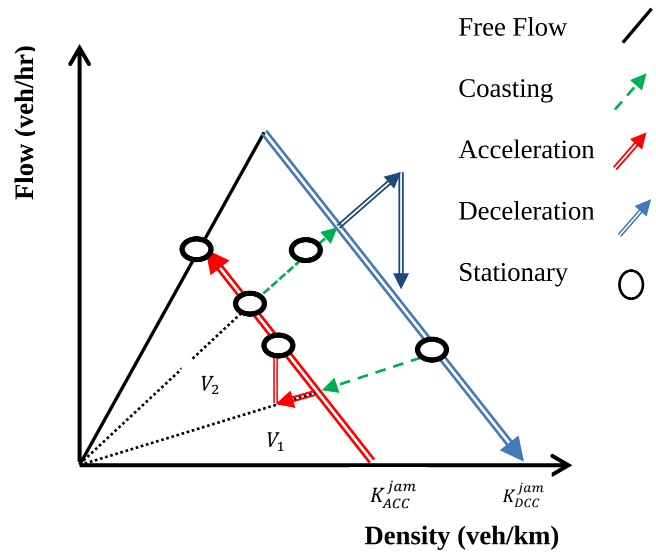


Figure 5. Phases in flow-density plane

Figure 4, 5. Traffic phases based on asymmetric theory (Yeo & Skabaronis, 2009)

spacing plane when the following conditions are satisfied:

$$\left|\frac{dS_n}{dt}\right| \le TH_s \quad , \quad \left|\frac{dV_n}{dT}\right| \le TH_v \qquad (1)$$

TH_s: The spacing thresholds is 5 m.

TH_v: The speed thresholds is within 3 km/h ~ 5km/h.

$\frac{dS_n}{dt}$: change of vehicle's spacing

$\frac{dV_n}{dT}$: change of vehicle's speed

2.1.3 Coasting Phase

In coasting phase vehicle keeps constant both speed and spacing and acceleration value ranges from -1 to 1 ft/sec^2. Coasting is defined as a phase in which a vehicle keeps its speed but spacing is being reduced or enlarged by the leader vehicle's deceleration or acceleration between A/D curve. Every car-following model is used to explain the dependency of the follower vehicle trajectory, and its position at time t, to leader vehicle. According to figure.6, if leader vehicle (n-1), moves with constant speed (v), the follower vehicle must move with constant speed (v), too. Spacing between follower and leader vehicles at the time (t) can be changed, but if the freeway was homogenous, the spacing must be constant at approximately Sn; however, it can be varied for different types of vehicles. In this case, all the vehicles are considered as the same type. According to figure 7.1, in the Newell`s model, when a leader vehicle changes its speed from v to v', the disturbance wave by speed of d^i/τ^i, will be sent to follower vehicle. This process results in an increase in acceleration of follower vehicle. In this model, d_i, τ_i are considered constant and independent of speed. According to figure 7.2, these characteristics result in linear relationship between speed and spacing $s^i=d^i+\tau^i v$.

22 Stop-and-Go traffic Based on Asymmetric Theory

2.2.1. Generating stop-and-Go Wave

According to figure.8, instability of traffic flow and lane change maneuvers stop-and-go waves can be generated in unstable traffic which is near D-curve in congested traffic; also lane changing may cause stop-and-go waves as illustrated in figure 8. But, the instability invoked in stop-and-go traffic is relatively small and cannot be propagated upstream unless the following traffic is also near D-curve; while the effect by lane changes are greater, and can propagate even the following traffic is not near the D-curve.

Figure 9 shows vehicle trajectories in congested traf-

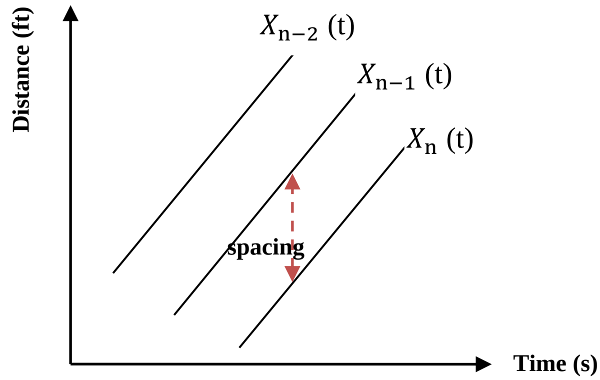


Figure 6. Vehicle trajectory with speed (v) (Newell, 1965)

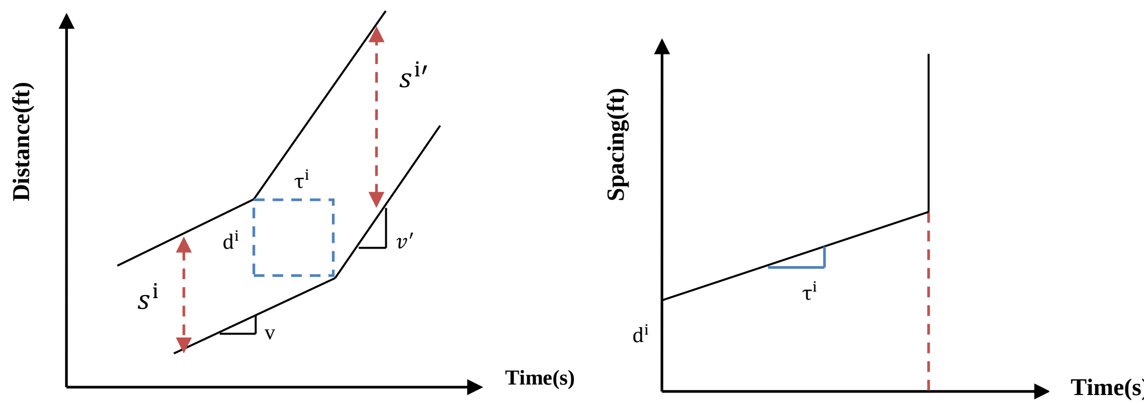
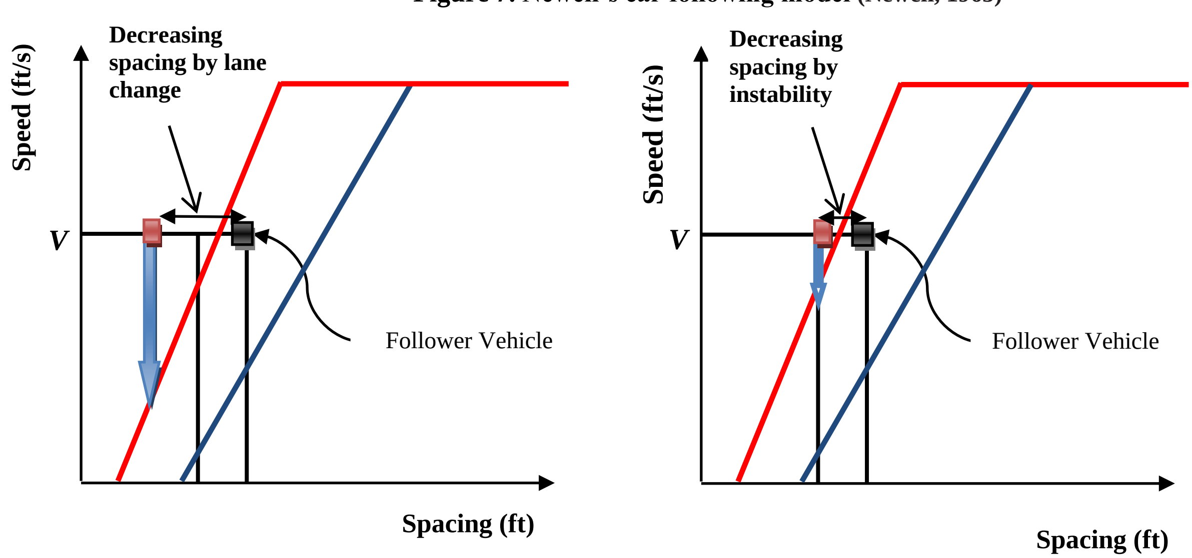


Figure 7.1.
Linear approximate for vehicle trajectory

Figure 7.2.
The relationship between spacing and speed

Figure 7. Newell's car following model (Newell, 1965)



1. Generated wave by traffic instability

2. Generated wave by lane changing

Figure 8. Vehicle movement in lane changing case and traffic instability (Yeo, 2008)

fic and illustrates the generation of stop-and go waves. Figure 8.1 shows the example of stop-and-go generation by instability in congestion. In this case, the waves generated are short-lived with minimal impact. Figure 8.2 shows the generation of waves due to lane changing. Before and immediately after the incoming lane changes, following drivers have to decelerate to yield space to the lane changing vehicle generating stop-and-go waves. This is the reason why stop-and-go waves are frequently observed to be formed near on-ramp merging areas.

2.2.2 Growth

The mechanism of the growth that focuses on the amplification of the waves is basically same with the one of generation. According to figure 10, when stop and go traffic is near D-curve, driving in small spacing and speed drop, a small disturbance can propagate more speed drop to upstream. As long as the upstream traffic is near D curve, stop and go traffic grow and propagate to upstream. In other words, stop and go traffic waves, ACC – DCC, diverge from others. According to figure 11, the mechanism of the dissipation is shown that it is similar to the growth stop-and-go traffic, but stop and go traffic waves, ACC DCC, converge from others.

2.3 Lane Changing Maneuvers

When a vehicle has lane changing maneuver in congestion traffic, decreasing safe spacing results in absorbing stop and go wave effect by follower vehicle and decreasing speed drop. When safe spacing is enough, vehicle platoon increases its speed that results in developing traffic oscillation toward traffic upstream.

2.3.1 Determine platoon size

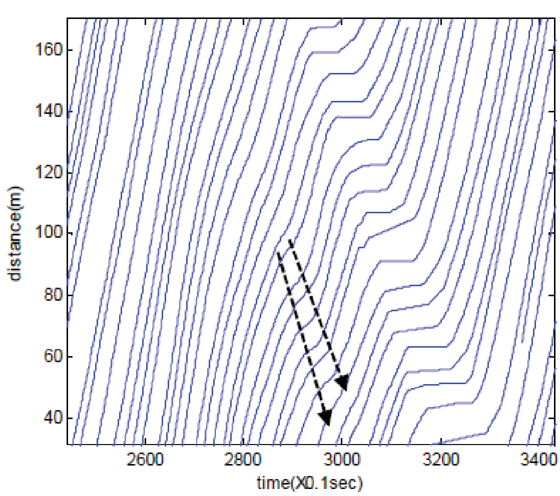
Based on Suh's researches, if platoon size becomes bigger, it may be possible to include heterogeneous traffic in one platoon and traffic variables extracted from the program represent average value of mixed traffic state. In order to find lane change maneuvers and grow stop and go waves, we should select platoon size from 1 to 9 vehicles. For these reasons, we selected a proper platoon size of three vehicles per platoon for NGSIM data.

2.3.2 Draw Trajectory Line

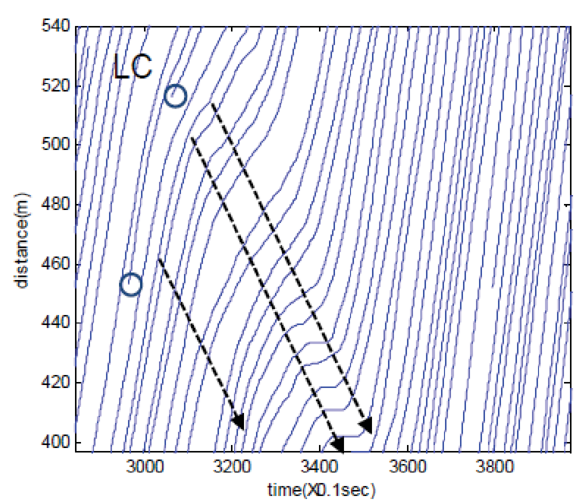
Based on Ahn's researches, the driver has 12-second anticipation period in a lane change. If a lane change occurs before the stop-and-go wave, the driver can be affected by the perturbation. According figure 12, follower trajectory determines during 12 sec prior and posterior to the point.

2.3.3 Draw an Imaginary Trajectory on the Downstream

Based on Ahan's researches, lane change maneuvers of follower driver is during 12-second anticipation period. If lane change maneuvers occur in downstream, downstream wave influences follower vehicle behavior.



1. stop-and-go generation by instability



2 The generation by lane changes.

Figure 9. Generation of stop-and-go traffic (Yeo, 2008)

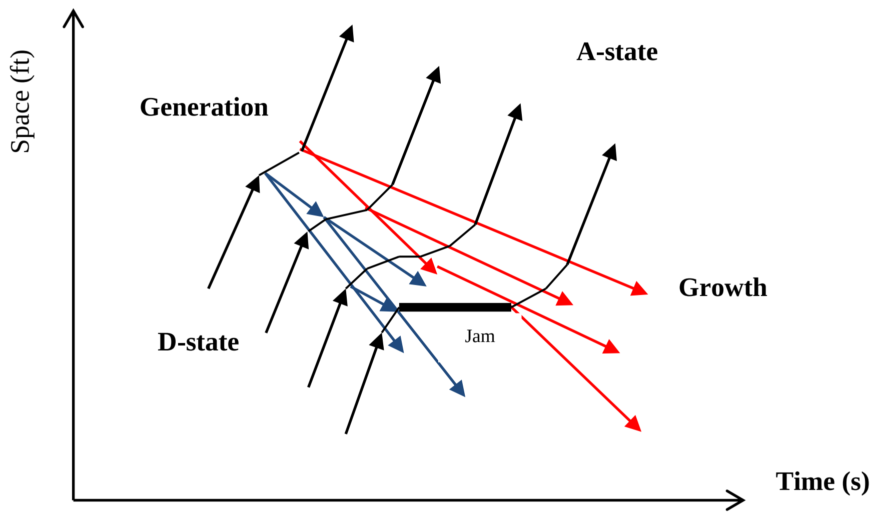


Figure 10. Life cycle of growth stop-and-go traffic (Yeo, 2008)

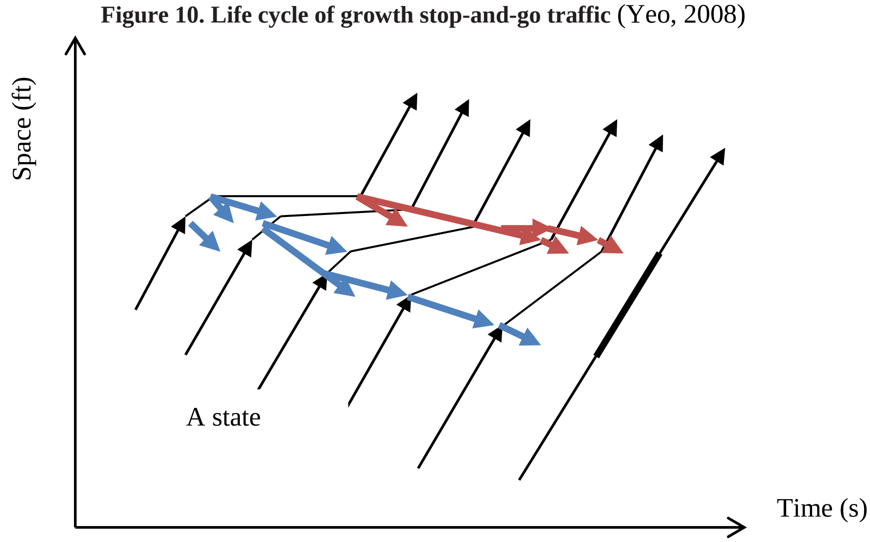


Figure 11. Life cycle of dissipation stop-and-go traffic (Yeo, 2008)

Based on these reasons, imaginary trajectory is determined by shifting the trajectory line as much as the anticipation period. Also, average wave speed is applied about 16kph.

2.3.4 Separate the Time Window

Based on Ahan's researches, incoming and outgoing lane change effects are different each other in the time window. Once the driver enters a stop-and-go wave, his/her driving behavior is independent of whether the outgoing lane changes occur or not. Hence, the time window is divided into two regions due to the separation of the affected area of incoming and outgoing lane changes.

2.3.5 Assign a Value to Lane Changes

It is assigned a positive value (+1) to an incoming lane changes, whereas the outgoing lane changing vehicle is assigned as a negative value (-1). Finally, it is founded that count all lane changes and sum up to find the net lane changes inside the searching window.

1. Analysis of Results

3.1 Comparing Acceleration and Deceleration Wave Speed Based on Two Theories

According to figure 13, acceleration and deceleration phases are analyzed based on Newell's and asymmetric theory in space-time curve. It shows both accel-

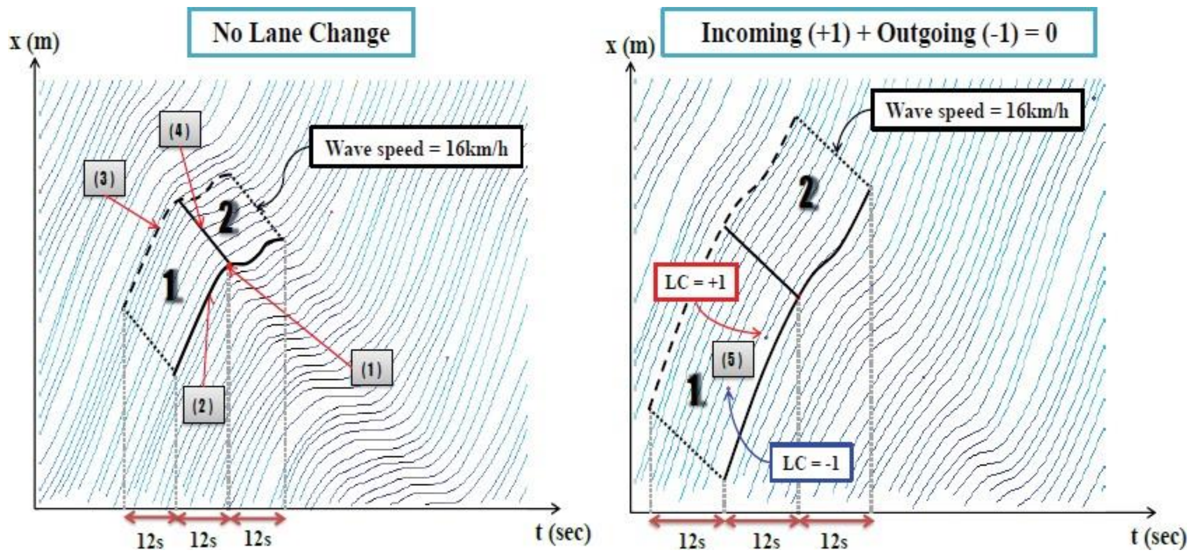
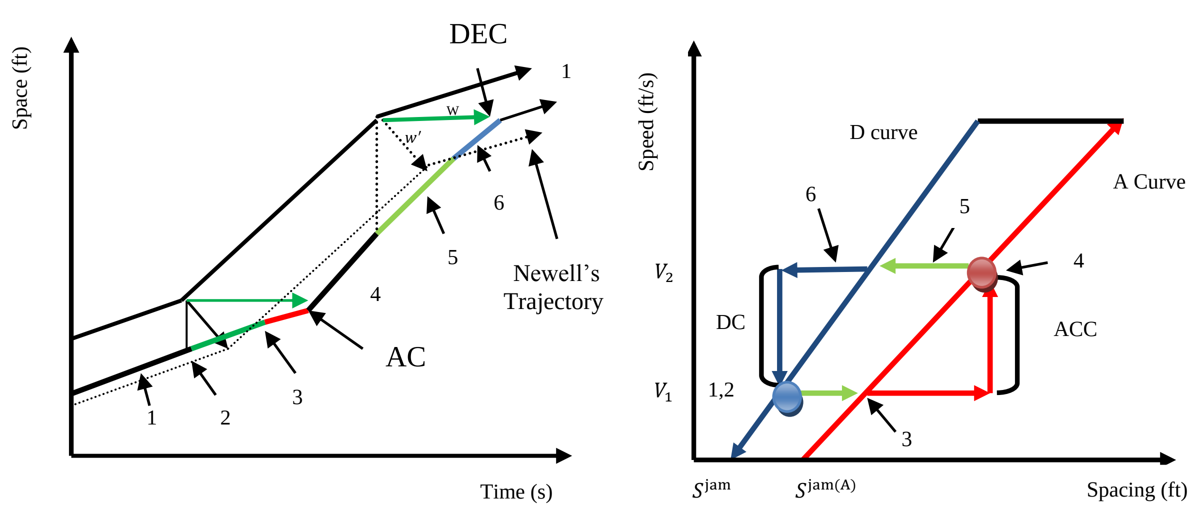


Figure 12. Influencing period of lane changing maneuvers (36sec time window) (Suh and Yeo, 2011)

eration and deceleration processes. There is a comparison between the trajectories of the new theory (solid lines) with the ones (dotted lines) from Newell's simplified car-following theory (2002) which conforms to LWR theory. If vehicle starts from state '1' on D-curve with short spacing and the leader vehicle accelerates, the spacing will be enlarged until the vehicle reaches to point '3' on A-curve. From this point, the follower vehicle will change driving mode to acceleration. After securing sufficient spacing for the new speed, it will speed up and reach state '4'. The vehicle can stay on state '4' until the lead vehicle changes its speed, so state '4' can be an equilibrium point on A-curve. If the lead vehicle starts braking, the subject vehicle will not start deceleration until it reaches D-curve. Passing D-curve, it will start deceleration and find a new equilibrium at point '1'. As shown in figure 13.1, in phase transition, the wave speed w is slower than the one in LWR theory denoted as w'.



1. Expected time-space plot of example

2. Speed-spacing relation of example

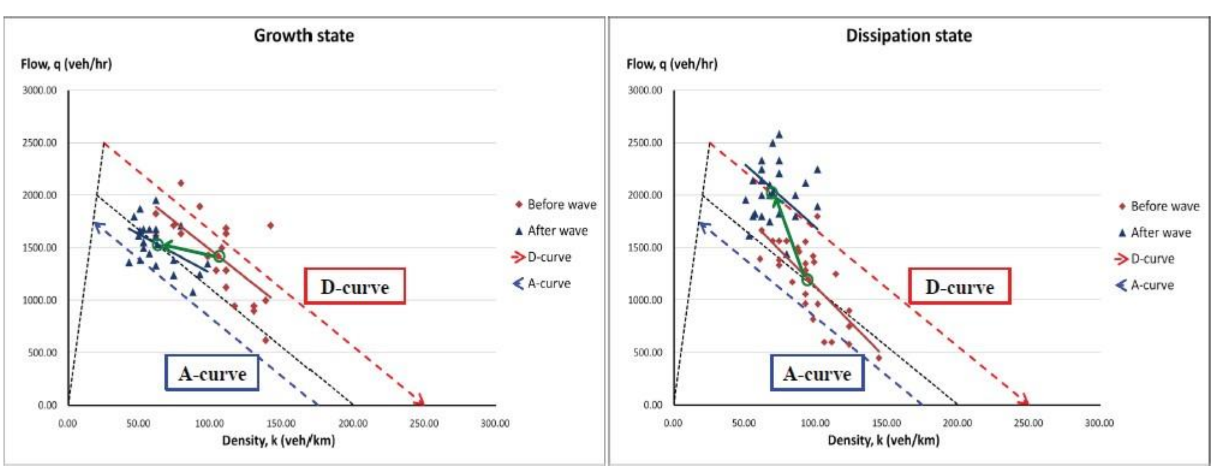
Figure 13. Transition between traffic phases (Yeo, 2008)

3.2 Stop-and-Go Waves of Traffic Instability

According to figure 14, results of analyzing NGSIM data presents based on asymmetric theory traffic state changes before and after meeting a stop-and-go wave. It shows how the traffic state changes in fundamental diagram for two cases of stop-and-go wave; growth and dissipation. In stop-and-go waves' growth case as shown in figure 14.1, traffic state is near D-curve before the platoons enter the stop-and-go wave. As they cross the wave, traffic state moves to near A-curve in fundamental diagram. It implies that stop-and-go waves grow when they propagate in D-state traffic (Traffic state near D-curve), and after the passing, the state changes to A-state (Traffic near A-curve). According to figure 14.2, in the other case of stop-and-go wave's dissipation, traffic states move from A-state to D-state. In other words, stop-and-go waves dissipate when they meet the entering A-state traffic, and A-state traffic absorbs impacts from stop-and-go wave and moves to D-state traffic. It is also noticeable that traffic absorbs impacts from stop-and-go wave and moves to D-state traffic. It is also noticeable that after passing dissipating stop-and-go wave, the traffic state again changes to D-state, in which they can foster stop-and-go waves. This can explain the periodic appearance of stop-and-go waves in congested traffic, which is frequently observed.

Figure 15 shows a detail mechanism of how this happens. It shows a vehicle movement in growth case in speed-spacing plane and time-space plane. If the traffic state of vehicle n is near D-curve. Then, leader vehicle (n-1) starts decreasing the vehicle speed, and the following driver has a deceleration coasting time. So, distance gap to the leader vehicle is reduced. However, the follower cannot help braking to avoid the collision. If the leader vehicle starts acceleration after passing the wave, the following driver keeps the new speed (vn') for a period of time (i.e. acceleration coasting time) until the spacing becomes wide enough. When the follower finds that the spacing is big enough to avoid additional braking, he/she also starts accelerating. Through these procedures, the traffic state after passing moves to near A-curve.

According to figure 16, since drivers are near A-curve before meeting a stop and-go wave, they have a margin of gap to absorb impacts (gap reduction) of stop-and-go wave. If possible, people are unwilling to reduce speed of vehicle, and drivers keep coasting with the same speed. Finally, traffic state moves to D-state, or even if they have to decelerate, the impact (speed drop and the period) is much less than the other case, which results in the dissipation of stop-and-go waves. In spite of a small perturbation of leader vehicle, the nth vehicle does not decrease vehicle speed since he has a large gap to offset the effect of perturbation. He does not brake but accept the small gap. In the speed-spacing plane, vehicle moves to near D-curve due to the leader vehicle's perturbation. Therefore, in dissipation case, the traffic that passes a stop-and-go wave becomes unstable. Accordingly, the results obtained coincide with the asymmetric traffic theory.



1. Growth state 2. Dissipation

Figure 14. Traffic state transition of a platoon before and after passing stop-and-go wave (Suh and Yeo, 2011)

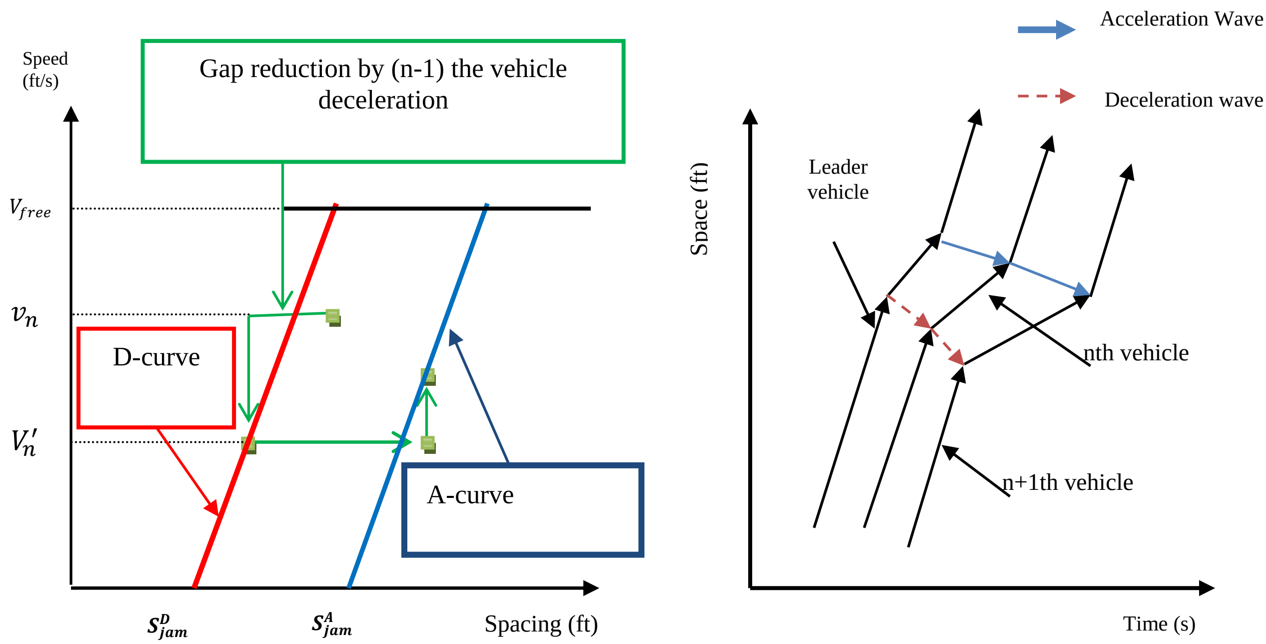


Figure 15. Vehicle movement of growth case (Suh and Yeo, 2011)

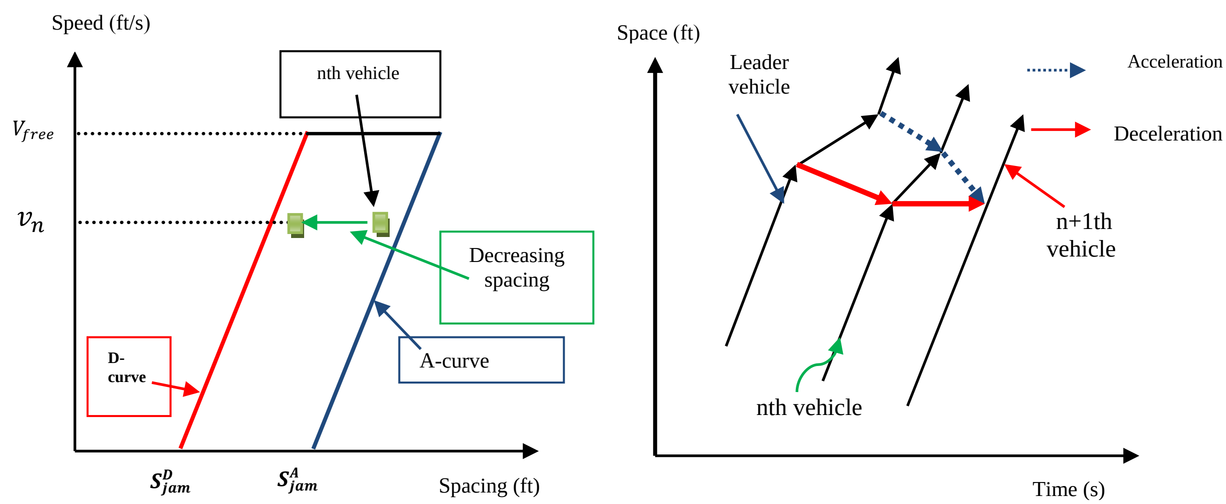


Figure 16. Vehicle movement of dissipation case (Suh and Yeo, 2011)

33 Stop-and-Go Waves of Lane Changing

According to fig.16, lane changing impacts on stop-and-go waves are studied using 36 sec time window. Figure 17 compares the traffic states according to the net lane changes for growth and dissipation case. In all of the net lane changes, wave growth case occupies higher part in the flow-density plane than dissipation case for the same number of net lane changes. It means that if the traffic state is more stable, it is more probable that the wave develops into dissipation than growth. According to figure 18, if a lane changing vehicle come in the target lane as nth vehicle drives a large spacing, near A curve in speed-spacing plane, the gap has almost halved due to the new incoming vehicle and the follower's gap suddenly drops. Finally, stop-and-go wave grows in platoon. Consequently, as the net lane changes increases, even a very stable traffic can be developed into growth state of stop-and-go wave. Gap becomes wider as a result of outgoing lane changing vehicles. Then, drivers are able to follow more comfortably. Nevertheless, even if outgoing lane changes occur, a very precarious traffic causes growth of stop-and-go waves. In this situation, stability of traffic gets poor and the positive effects of outgoing lane changes on follow-

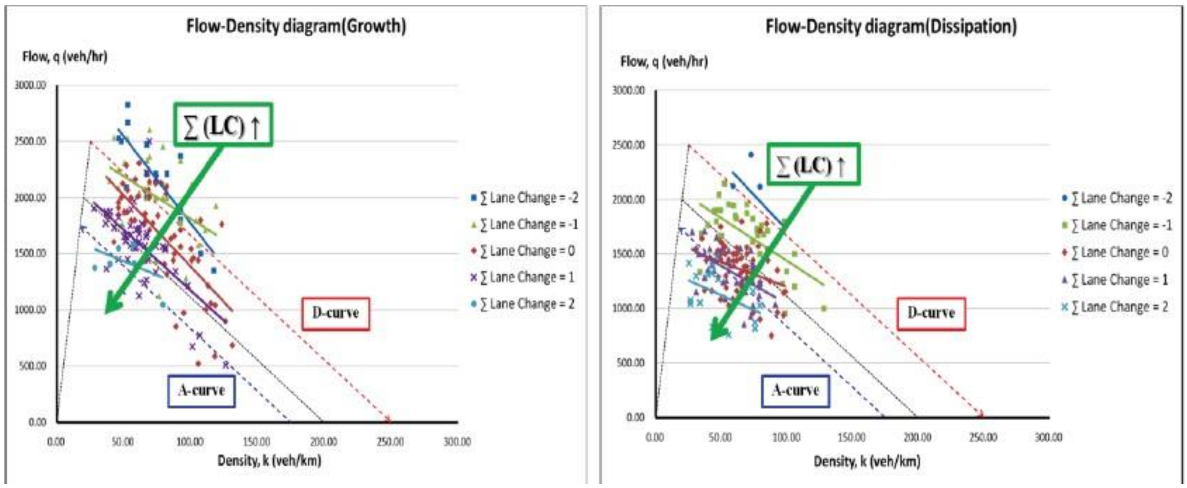


Figure 17. Lane changes and stop-and-go waves (Suh and Yeo, 2011)

ing traffic are cancelled out. In dissipation case, it has a similar aspect with the growth case. As the net lane changes increase, traffic state developed into dissipation also moves downward in fundamental diagram.

About dissipation case, when go out to other lanes, wave in platoon dissipate because of increasing spacing and driving near A curve, free speed. In comparing, when a vehicle comes in target lane, spacing decreases between follower and leader vehicles. But wave effect in platoon absorbs and dissipates because of enough safe spacing. According to results of lane changing movements, because spacing isn't enough, wave grows in platoon as coming in or going out target line in congestion traffic condition that results in increasing or decreasing spacing. In free speed condition, because spacing is enough, wave effects absorb and dissipate in follower platoon while both coming in and going out target line. According to figure 19, comparing between both growth and dissipation cases in change lane maneuvers indicate following results. In all of the cases, wave growth case occupies higher flow – density diagram, near D curve and wave dissipation case occupies lower flow – density diagram, A curve. Also, increasing lane changing maneuvers results in trending growth and dissipation wave cases to lower part of fundamental diagram.

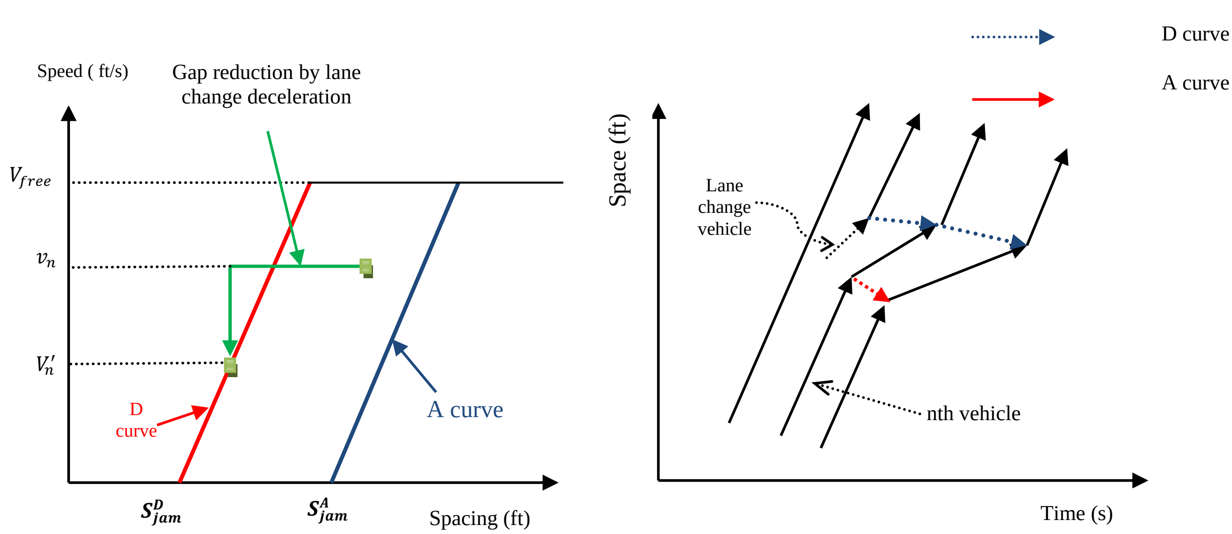


Figure 18. Vehicle movement in lane changing case (Suh and Yeo, 2011)

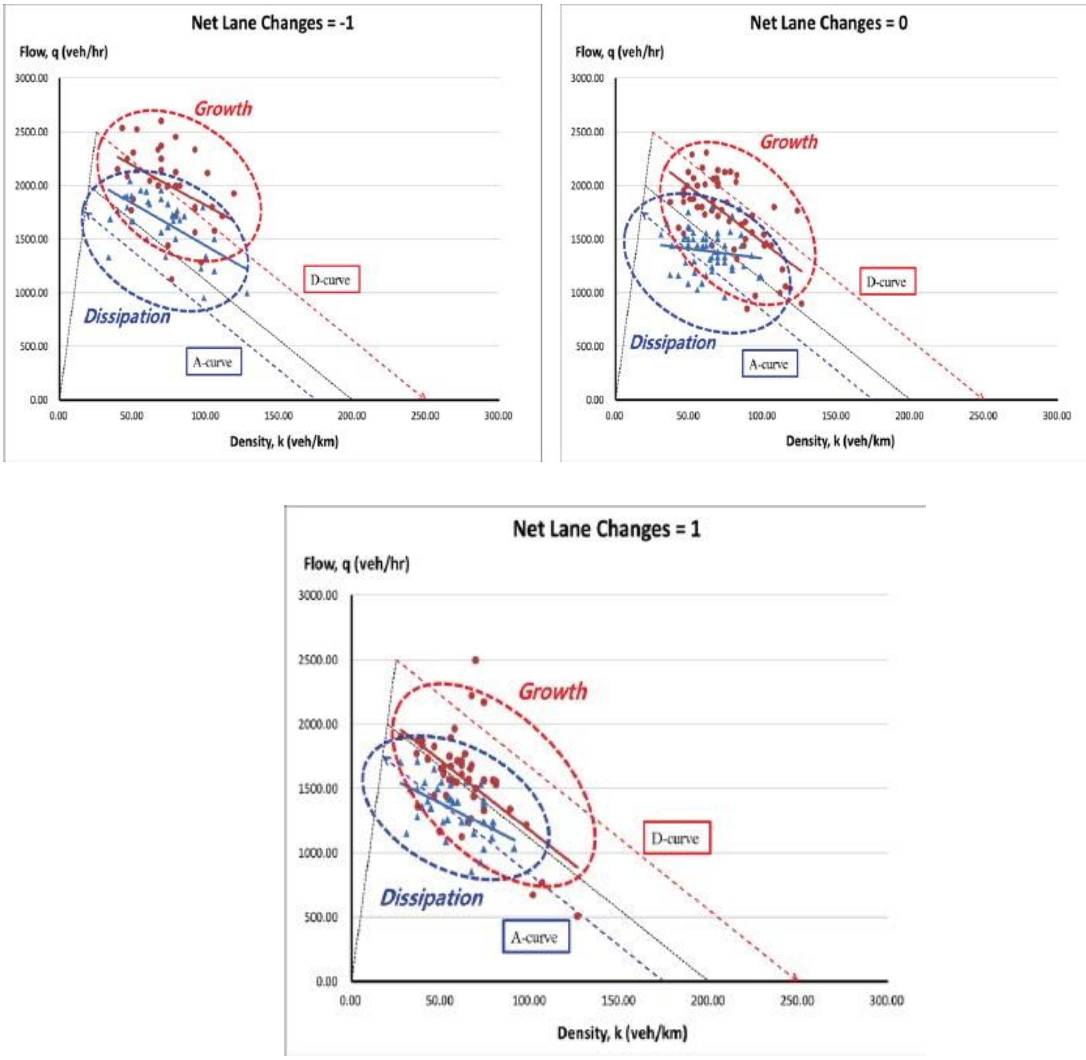


Figure 19. Comparison of growth and dissipation under same net lane changes (Suh and Yeo, 2011)

2. Conclusions

Stop and go traffic commonly observed in congested freeway traffic results in traffic oscillation. In order to model stop and go traffic phenomena, many traffic theorists have adopted theories from other fields such as fluid mechanics and thermodynamics or car following models based on kinematic. Because of numerous parameters, their efforts to model the traffic at a microscopic level haven't been successful yet. Also, it isn't found relation to growth and dissipation of stop-and-go waves and the total number of lane changing maneuvers. In order to overcome the limitations of the existing theories, a microscopic asymmetric traffic theory is proposed based on analysis of individual vehicle trajectories. According to the proposed theory, vehicle traffic is classified into 5 phases: free flow, acceleration, deceleration, coasting, and stationary. The proposed theory suggests that traffic equilibrium exists as 2-dimensional area bounded by A-curve and D-curve, and explains phase transitions. Results indicate that coasting phase results in the smaller wave speed than Newell's car following model based on comparing stop and go traffic based on asymmetric theory and Newell's car following model. Asymmetric traffic flow theory is applied to explain the stop-and-go traffic phenomenon. The life-cycle of stop-and go traffic is classified the generation, growth and dissipation of traffic waves. Results present that traffic instability creates stop and go traffic near A, D curves. But it isn't developed toward upstream traffic because of being enough safe spacing. The lane changing maneuvers create a perturbation to congested traffic. Because safe spacing isn't enough, stop and go wave develops toward upstream traffic. If traffic is near A curve, stop and go wave dissipates because of safe spacing. To reflect the needs in identifying the impacts of the lane changing events on stop-and-go traffic, time window for searching lane changes and the net lane changes have been employed. Finally, the development and evolutionary characteristics of stop-and-go traffic have been observed according to the net lane changes. Moreover, traffic state transition by a stop-and-go wave has been investigated and the comparison between growing and dissipating waves has been conducted. The comparison result in the growth and dissipation indicated that under the same net lane changes, the regions of traffic state occupied in growing and dissipating wave are different in fundamental diagram. It is occupied higher fundamental diagram, near D curve, in growth condition. Although vehicle goes out from target lane and increasing safe spacing, but wave develops in platoon because of driving near D curve. Also, dissipation condition occupies the lower fundamental diagram, near A curve. However coming in target line of vehicle results in decreasing safe spacing but safe spacing is enough because of driving near A curve.

3. References

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