Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

Using the Asymmetric Theory of Driving Behavior in Acceleration and Deceleration to Detect and Analyze Stop and Go Traffic

*1*S.Soumya Harichandan, [2] Santosh Sahoo*
[1] Asst. Professor, Dept. OF Civil Engineering, NIT BBSR,*
Asst. Professor DEPT. of Civil Engineering, MITM, BBSR
[1]panda.sweta2012@gmail.com, sahoo.santosh1@gmail.com*

Abstract:
During traffic flow during congestion, stop-and-go traffic that causes oscillations in traffic flow is frequently seen. Unexpected events including lane-changing movements, slower leader vehicle speeds, and moving bottlenecks increase delays and have an adverse effect on the environment by causing stop-and-go traffic. Traffic models cannot accurately represent stop and go traffic, and car-following models based on kinematic flow theory cannot suggest a right perception of stop and go traffic. Traffic flow can be divided into five stages based on vehicle movement and speed, as determined by asymmetric microscopic theory using NGSIM trajectory data: free flow, acceleration and deceleration, stationary, and coasting phases. Stop and go traffic will be divided into three categories after being analysed using the asymmetric theory of acceleration and deceleration phase: generation, growth, and dissipation of traffic waves. According to traffic oscillation analysis, lane changes have a bigger impact than stop-and-go traffic and can spread even if the following traffic is not near the D-curve. The effect of lane changes is greater than stop-and-go traffic. In this study, the relationship between the overall number of lane shifts and stop-and-go waves for congested traffic is clarified utilising time windows in trajectory data. The characteristics of stop-and-go waves are closely related to drivers' asymmetric behaviour of acceleration and deceleration, according to an analysis of net lane changes inside the searching window for incoming and outgoing lane changes about traffic wave growth and dissipation. According to the comparison of growth and dissipation, growth wave cases occupy the regions of the fundamental diagram, flow-density diagram, and deceleration curve whereas dissipation wave cases occupy the regions of the flow-density, acceleration curve.

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

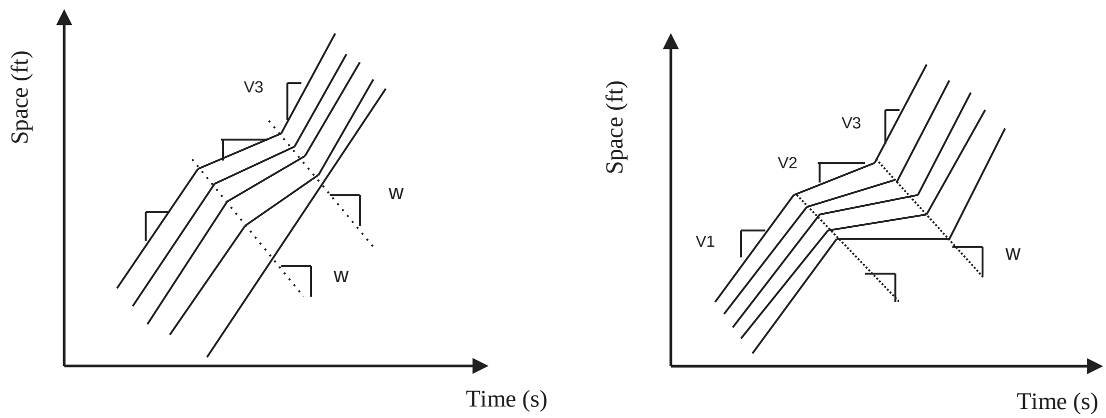
1. Introduction

Due to its significant negative effects, including higher fuel consumption, greenhouse gas emissions, and safety concerns, stop-and-go driving, or simply traffic oscillation, has drawn a lot of attention in the literature [Bilbao-Ubillos, 2008 Zheng, et al, 2011a Zheng, et al, 2011b]. Sadly, we still have a limited knowledge of how oscillations in congested traffic work. On the one hand, accurate sensor data and detailed vehicle trajectory data are exceedingly difficult to come by. The oscillations anticipated by current traffic flow models, which are frequently the product of mathematical curiosities rather than driving behaviour, have, on the other hand, rarely been attempted to be validated. The generation and propagation phases make up a traffic oscillation. It is well recognised that lane-changing activity or, more generally, any type of moving bottleneck can result in the formation (Laval and Daganzo, 2006; Ahn and Cassidy, 2006; Laval, 2005). (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 observations 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 ad- dressing 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-densityplane. 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-follow- ing theory, the trajectory of the following vehicle is al- ways 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 acceler- ation 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 dif- ferent wave speeds for acceleration and deceleration, but still their vehicle trajectories are parallel. Both Del Castillo and Kim and Zhang noticed that the time head- way 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 ob- tained by Forbes (1965), Foote (1965), and Edie (1965). Forbes (1965) noticed that the driver's response is slow- er 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-

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022



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-

Flow (ve/hr)

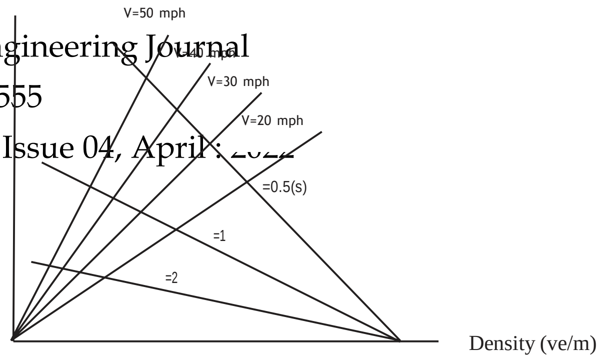


Figure 2. Response time)Forbes, 1965)

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

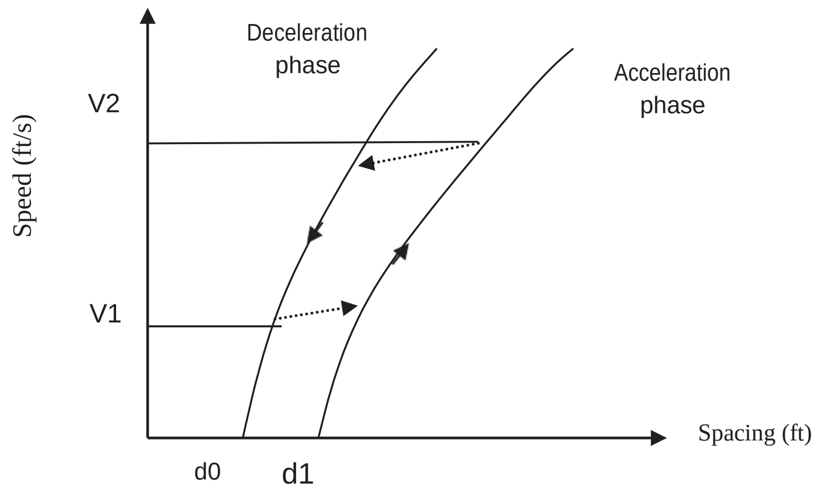


Figure 3. Newell's two-curve theory in congested traffic (Newell, 1965)

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.

Asymmetric Driving Behavior Theory Asymmetric behavior theory is based on different re- actions 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 coast-

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

ing. 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 de- scribe 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 phe- nomena of driver behavior in congested traffic [Yeo, H. 2008, Jonghae, S., Hwasoo,Y. Alexander,S. 2012].

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.

Deceleration and Acceleration Phase Acceleration phase is a state in which a vehicle is speed- ing 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 traf- fic 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-

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

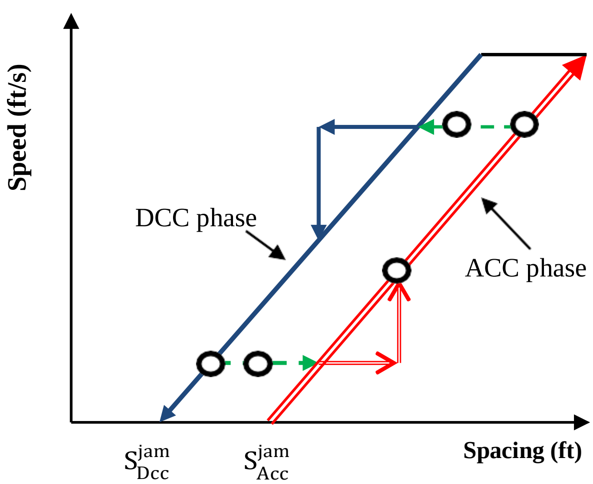


Figure 4. Phases in speed-spacing plane

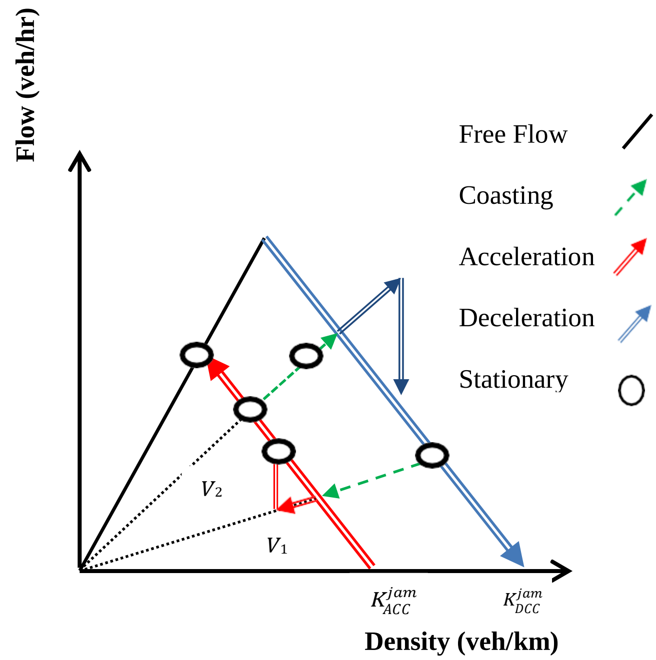


Figure 5. Phases in flow-density plane

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

spacing plane when the following conditions are satisfied:

$$\left|\frac{dSn}{dt}\right| \leq TH_s \quad , \quad \left|\frac{dVn}{dT}\right| \leq TH_v \qquad (1)$$

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

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 dif- ferent 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$s^i=d^i+\tau^i v$.

Stop-and-Go traffic Based on Asymmetric Theory

Generating stop-and-Go Wave

According to figure.8, instability of traffic flow and lane change maneuvers stop-and-go waves can begenerated 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 in- voked in stop-and-go traffic is relatively small and can- not 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-

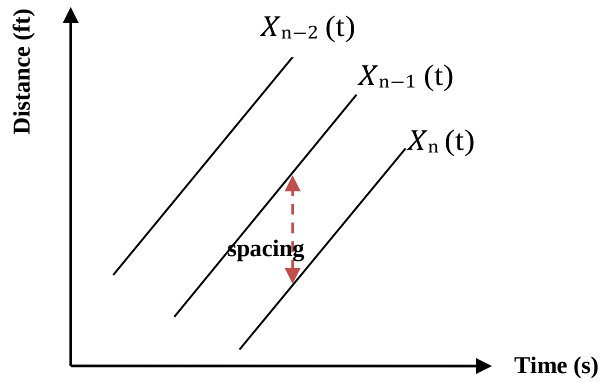


Figure 6. Vehicle trajectory with speed (v) (Newell, 1965)

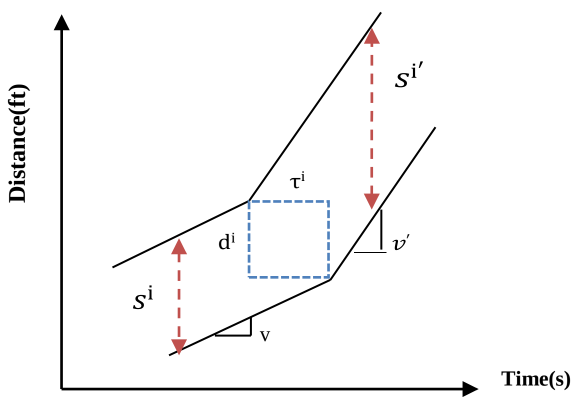


Figure 7.1.
Linear approximate for vehicle trajectory

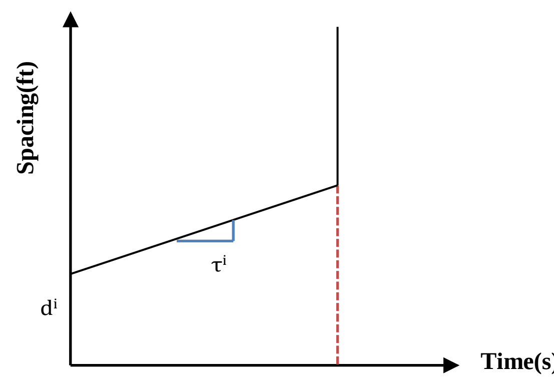
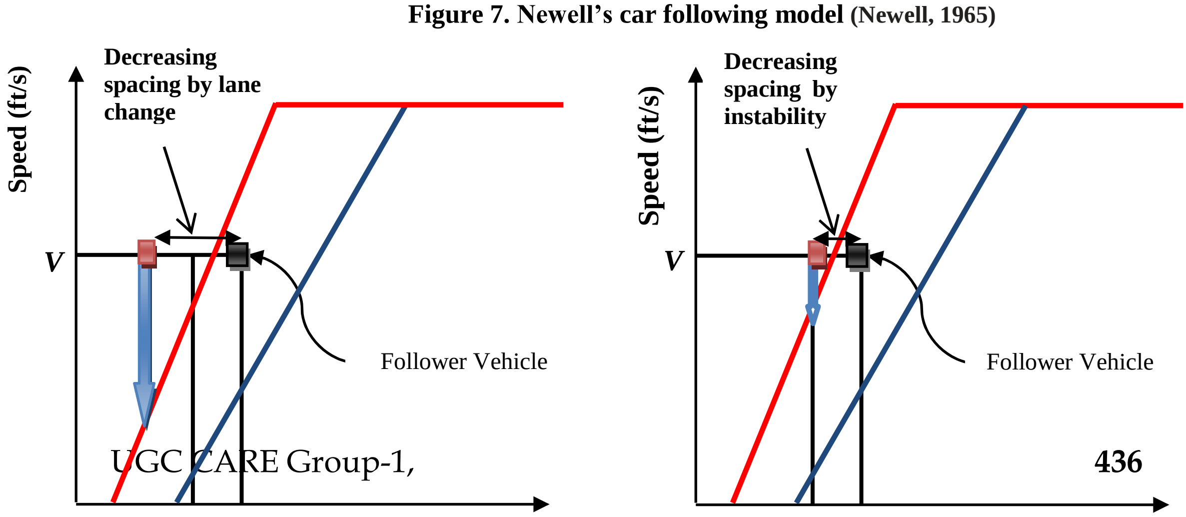


Figure 7.2.
The relationship between spacing and speed

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



Spacing (ft)

Spacing (ft)

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)

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

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 fromothers.

2.3 Lane Changing Maneuvers

When a vehicle has lane changing maneuver incongestion 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.

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.

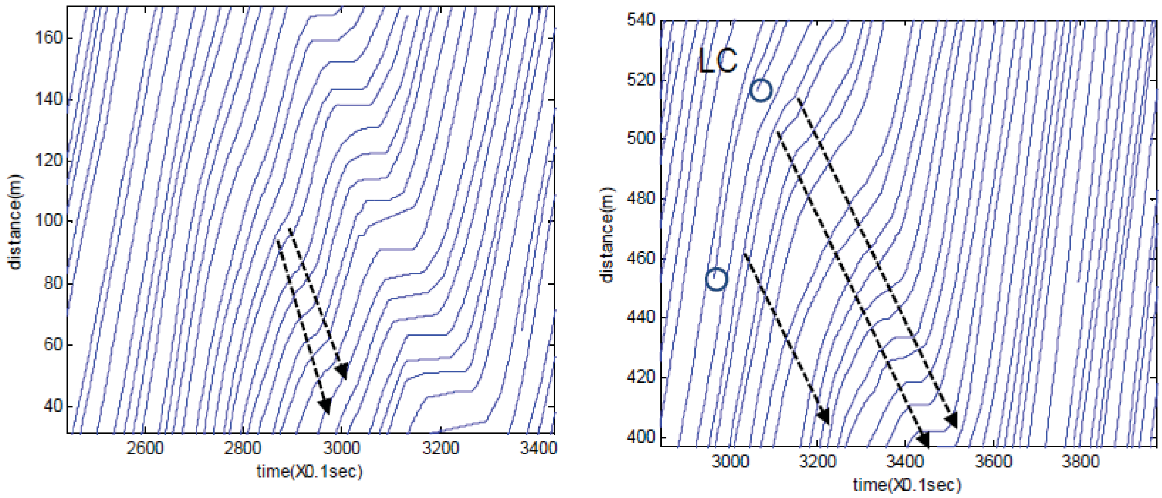
Draw Trajectory Line

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.

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.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022



1. stop-and-go generation by instability 2 The generation by lane changes.

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

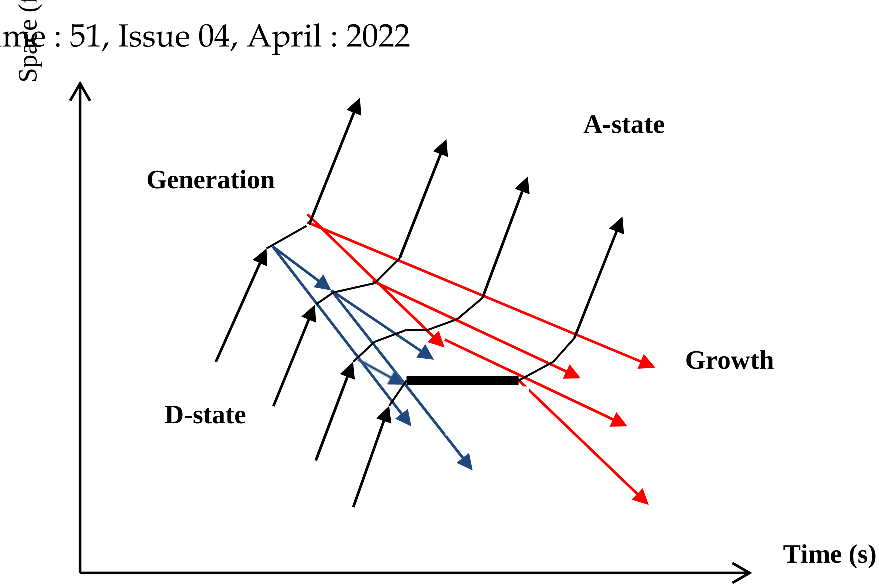


Figure 10. Life cycle of growth stop-and-go traffic (Yeo, 2008)

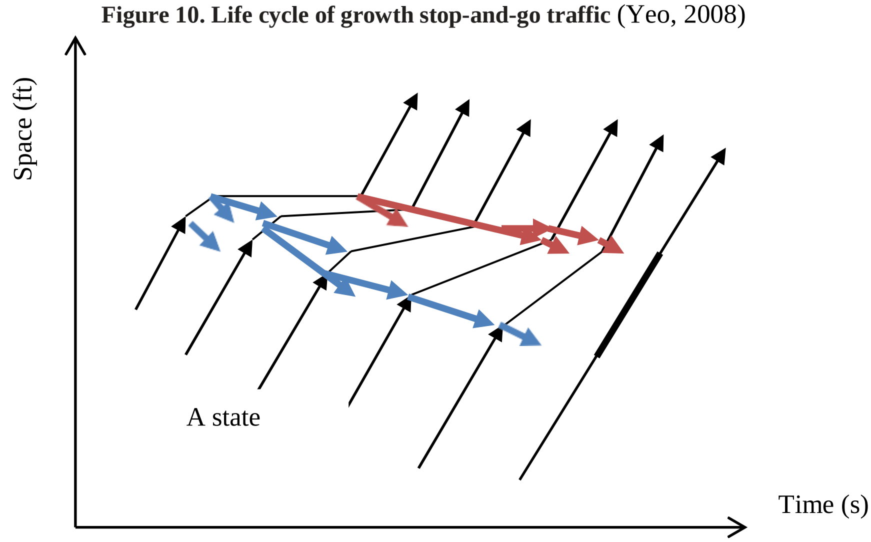


Figure 11. Life cycle of dissipation stop-and-go traffic (Yeo, 2008)

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.

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.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

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

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-

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

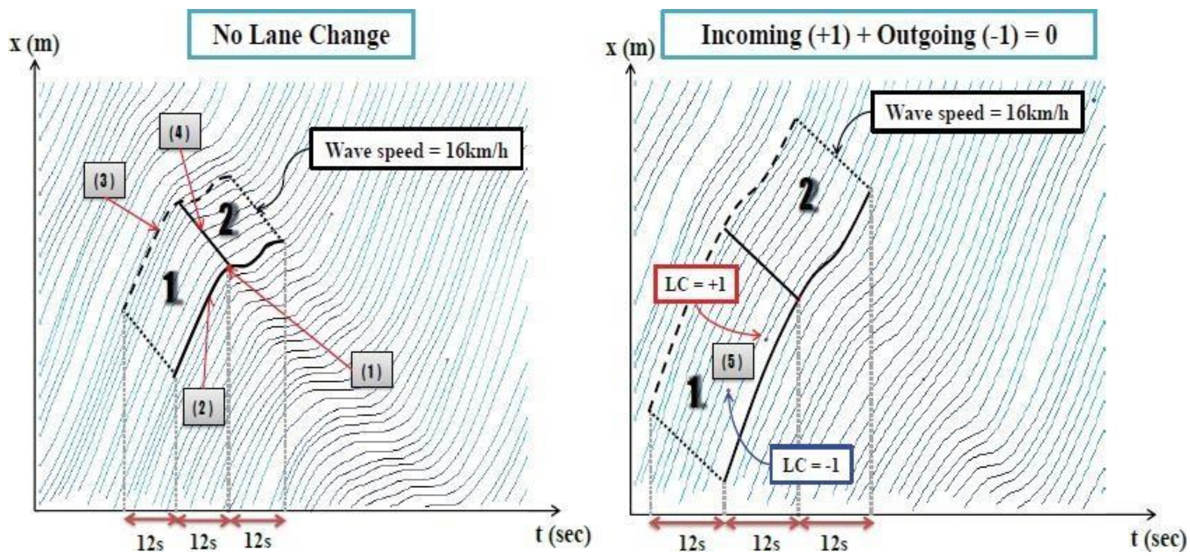
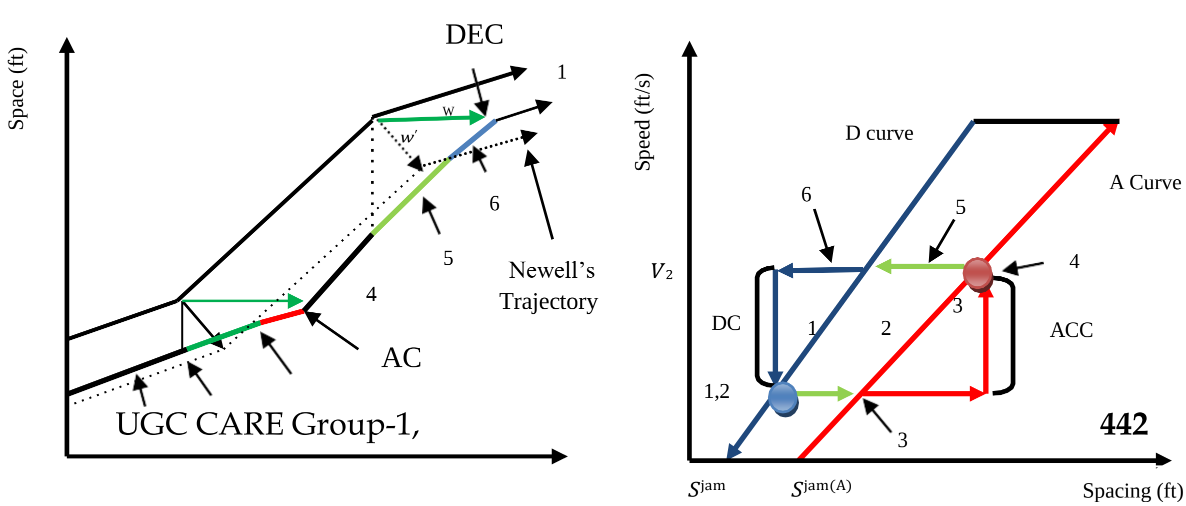


Figure 12. Influencing period of lane changing maneuvers (36sec time window) (Suh and Yeo, 2011)

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'.



V_1

Time (s)

1. Expected time-space plot of example 2. Speed-spacing relation of example

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

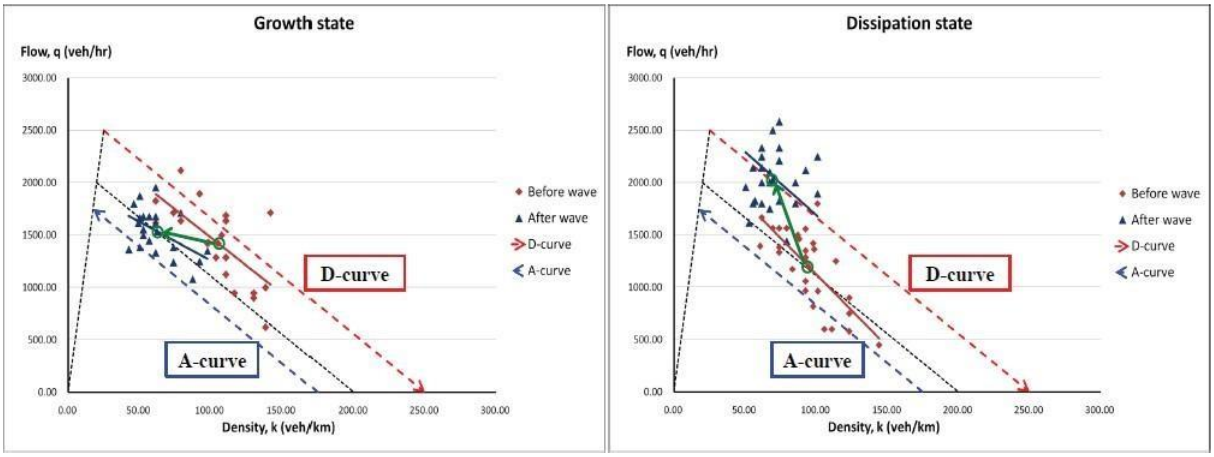
Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

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)

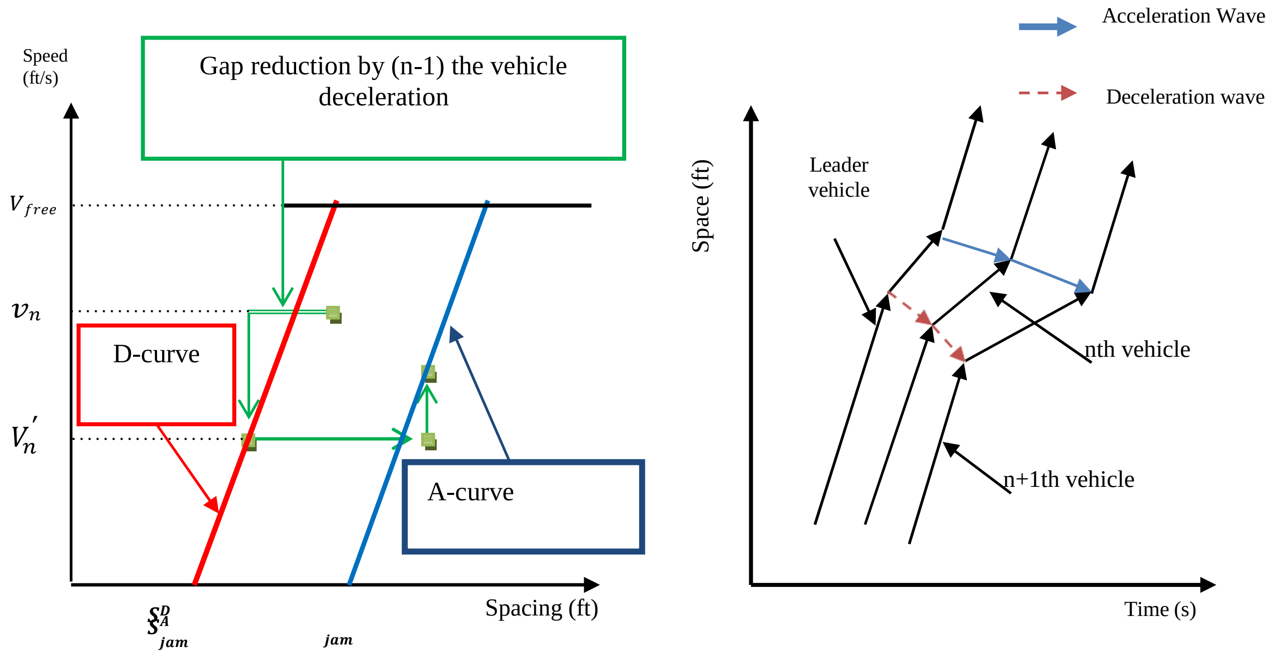


Figure 15. Vehicle movement of growth case (Suh and Yeo, 2011)

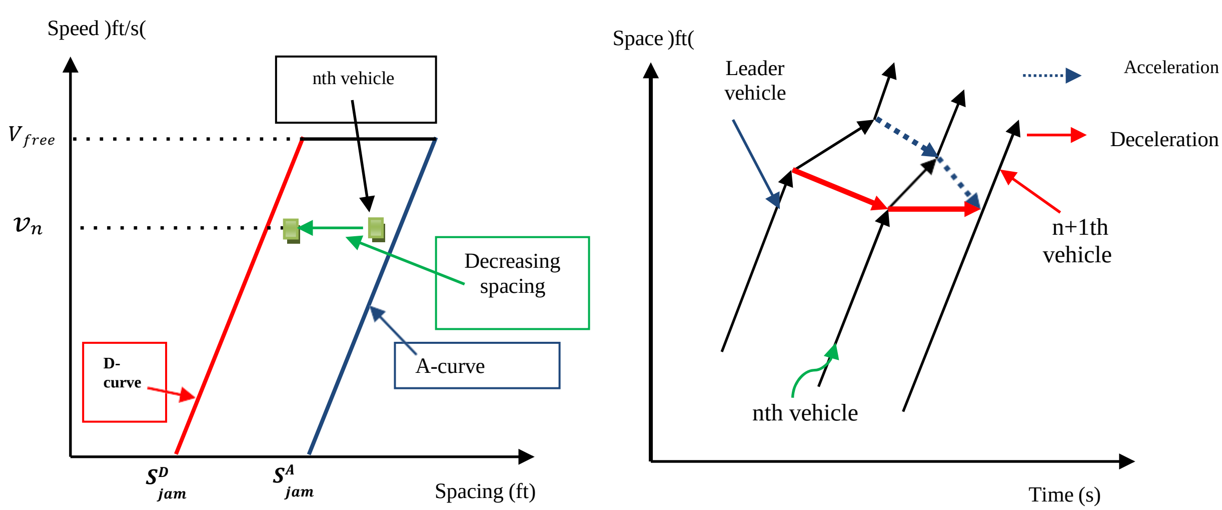


Figure 16. Vehicle movement of dissipation case (Suh and Yeo, 2011)

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-

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

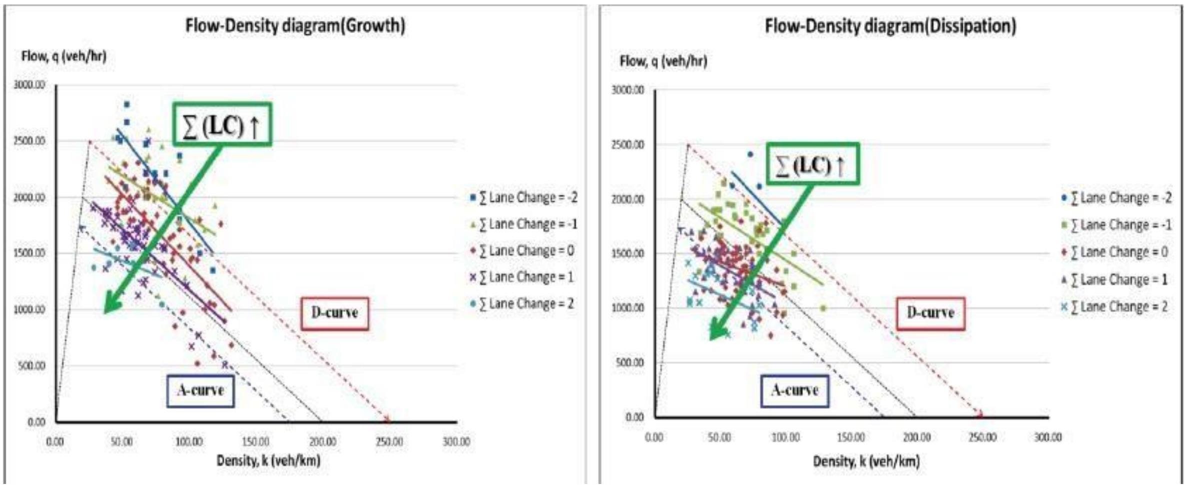
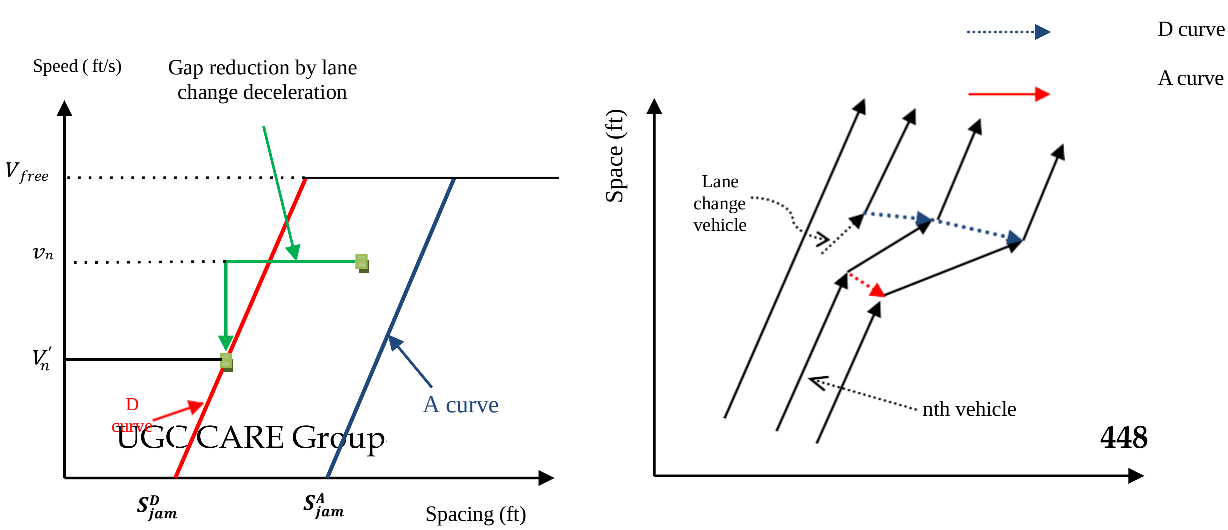


Figure 17. Lane changes and stop-and-go waves (Suh and Yeo, 2011)

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 lowerflow – density diagram, A curve. Also, increasing lane changing maneuvers results in trending growth and dissipation wave cases to lower part of fundamental diagram.



Time (s)

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

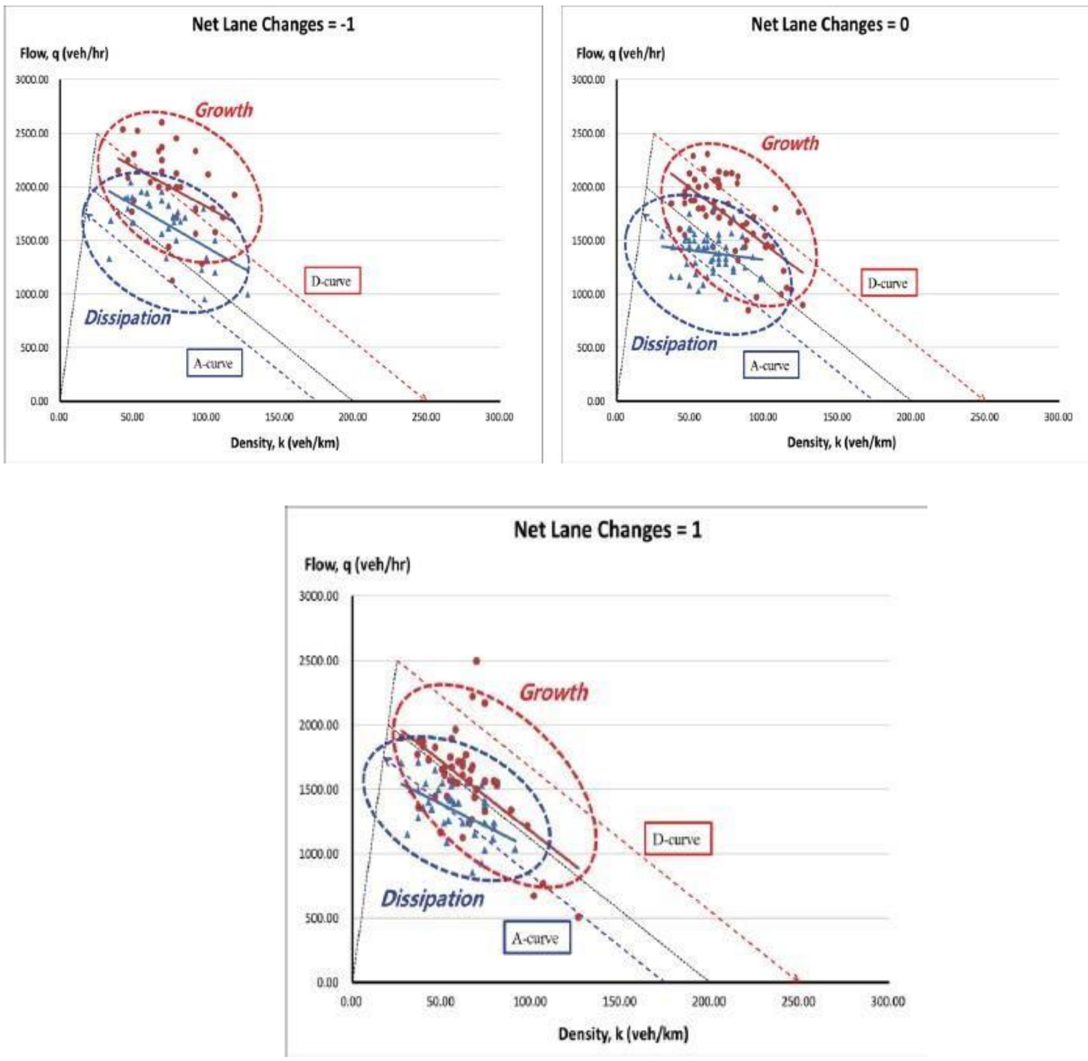


Figure 19. Comparison of growth and dissipation under same net lane changes (Suh and Yeo, 2011)

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 maneu- vers. In order to overcome the limitations of the exist- ing theories, a microscopic asymmetric traffic theory is proposed based on analysis of individual vehicletrajectories. 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 fol- lowing model based on comparing stop and go traffic based on asymmetric theory and Newell's car follow- ing model. Asymmetric traffic flow theory is appliedto 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. Resultspresent 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 Acurve.

3. References

- Ahn, S. and Cassidy, M. (2007) "Freeway traffic oscillations and vehicle lane-change maneuvers", The 17th International Symposium on Transportation and Traffic Theory, Elsevier, New York., pp. 691-710.

- Bilbao-Ubillos, J. (2008) "The costs of urban congestion: estimation of welfare losses arising from congestion on cross-town link roads", Transportation Research Part A, 42 (8), pp.1098–11082- Authors of the paper, Date, Title of the paper, Conference Title, pp.256-300.

- Daganzo, C. F. (1997) "Fundamentals of transportation and traffic operations", Transportation Research Part B, Vol. 33, pp. 366-379.

- Del Castillo, J.M. (2001) " Propagation of perturbations in dense traffic flow: a model and its implications", Transportation Research Part B Vol. 35, pp. 367-389.

- Daganzo, C.,F. (2006) “In traffic flow, cellular autom- ata = kinematic waves”, Transportation Research Part B, Vol. 40, pp. 396-403.

- Edie, L.C. (1965) "Discussion of traffic upstream measurements and definitions", Proceedings of The Second International Symposium on The Theory of Road Traffic Flow London, pp. 139-154.

- Forbes, T.W. (1963) "Human factor consideration in traffic flow theory", Highway research Record 15, pp. 60-66.

- Foote, R. S. (1965) "Single lane traffic flow control", Proceedings of The Second International Symposium on The Theory of Road Traffic Flow, London, pp. 84-103.

- Gipps, P. G. (1981) "A behavioural car-following model for computer simulation", Transportation Re- search Part B, Vol. 15, pp. 106-111.

- Jonghae,S., Hwasoo,Y. and Alexander, S. (2012) "A Study on the Wave Development And Evolution Char- acteristics of Stop-and-Go Traffic", The 91th Annual Meeting Transportation Research Board Washington, DC. pp. 176-140

- Koshi, M., Kuwahara, M. and Akahane, H. (1992) "Capacity of sags and tunnels in Japanese motorways",ITE Journal (May issue), pp. 17–22.

- Kerner, B.S. and Rehborn, H. (1996a) "Experimental features and characteristics of traffic jams", Physical Review E Vol. 53, pp. 1297-1300.

- Kerner, B.S. and Rehborn, H. (1999) "Theory of con- gested traffic flow: self-organization without bottle- necks", Proceedings of the 14th International Sympo- sium on Transportation and Traffic Theory, Pergamon,New York, pp.147–171.

- Kerner, B. (2004) "Three-phase traffic theory and highway capacity", Physica A 333,pp. 379-440.

- Kim, T., Zhang, H.M. (2004) "Gap time and stochastic wave propagation", 2004 IEEE Intelligent Transportation Systems Conference, pp. 88-93.

- Lighthill, M.J., Whitham, G.B. (1955) "On kinematic waves: II. A theory of traffic flow on long crowded roads", Proceedings of the Royal Society, London, Ser.A 229 1178, pp. 317–345.

- Laval, J. A. (2005) "Linking synchronized flow and kinematic wave theory. In: Schadschneider, A. and Poschel, T., Kuhne, R., Schreckenberg, M., Wolf, D. (Eds.)", Traffic and Granular Flow ’05. Springer, pp. 521–526.

- Laval, J. A. and Daganzo, C. F. (2006) "Lane-changing in traffic streams", Transportation Research Part B, 40 (3), pp. 251–264.

- Laval, J. A.(2006)" Stochastic processes of moving bottlenecks: Approximate formulas for highway capacity", Transportation Research Record 1988, pp. 86–91.

- Laval, J.A. and Leclercq, L. (2010) "A Mechanism to describe the formation and propagation of stop-and-go waves in congested freeway traffic", Philosophical Transactions of The Royal Society A., 368(1928), pp. 4519-4541.

- Ma, T. and Ahn, S. (2008) "Comparisons of speed-spacing relations under general car following versus lane changing", Transportation Research Record: Journal of the Transportation Research Board, No. 2088. pp. 138-147.

- Newell, G. F. (2002) "A Simplified car-following theory: a lower order model", Transportation Research Part B, Vol. 36, pp. 196-205.

- Nagel, K. and Nelson, P. (2005) "A critical compari- son of the kinematic wave model with observational data", Transportation and Traffic Theory, Proceedings of the 16th International Symposium on Transportation and Traffic Theory, pp. 145-163.

- Richards, P.I. (1956) "Shock waves on the highway", Operations Research 4, pp.42–51.

- Suh, J. (2009) "A study on the Wave Characteristics of Stop-and-Go Traffic", Master Dissertation, Depart- ment of Civil and Environmental Engineering, KAIST. pp.1325-1334

- Suh, J., & Yeo, H. (2011) “A Study on the Wave Development and Evolution Characteristics of Stop- and-Go Traffic”, In Proceedings of the Eastern Asia Society for Transportation Studies The 9th International Conference of Eastern Asia Society for Transportation Studies, pp. 340-340.

- Yeo, H. (2008) "Asymmetric Microscopic Driving Behavior Theory, Doctoral Dissertation, Department of Civil and Environmental Engineering", University of California, Berkeley, U.S.A. pp.150–31

- Yeo, H. and Skabardonis, A. (2009) "Understanding stop-and-go traffic in view of asymmetric traffic the- ory", Transportation and Traffic theory 2009: Golden Jubilee, Springer, pp. 99-115.

- Zielke, B.A., Bertini, R.L. and Treiber, M. (2008) "Empirical Measurement of Freeway Oscillation Char- acteristics: An International Comparison", Transporta- tion Research Record: Journal of the Transportation Research Board, No. 2088. pp. 57-67.

- Zheng, Z., Ahn, S., Chen, D. and Laval, J. (2010) "Freeway Traffic Oscillations: Microscopic Analysis of Formations and Propagations using Wavelet Trans- form", The 19th International Symposium on Transpor- tation and Traffic Theory, pp. 812-542.

- Zheng, Z., Ahn, S., Chen, D. and Laval, J. (2011a) "Applications of wavelet transform for analysis of free-way traffic: bottlenecks, transient traffic, and traffic os-cillations", Transportation Research Part B 45 (2), pp. 372–384.

Zheng, Z., Ahn, S., Chen, D. and Laval, J.A. (2011b) "Freeway traffic oscillations: microscopic analysis of formations and propagations using wavelet transform", The 19th International Symposium on Transportation and Traffic flow Theory, pp. 717–731.