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# Congestion Identification for Multilane Highway by Vehicle Lane Change as Driver Behavior

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## ABSTRACT

This work introduces a new way to assess the condition of highways as congested or uncongested highways. This was done by recording a video and extracting data from the video to performing a microscopic simulation studying the driver's behavior. It is adequate to record a video and count the number of vehicles that change their lanes, then compare with the results that have been determined in the search to judge the highway is congested or not.

The study area was achieved by choosing five segments of multilane arterial roads (six lanes divided) on the left coast of Mosul city. These segments were selected to be as similar as possible in the geometric configuration as well as like traffic flow. After that, cameras were installed according to criteria to record traffic movement and for a time not less than ten hours for each segment on the workdays. Then, the videos were uploaded using the Goodvision traffic data recognition program. These outputs were converted to be entered into the PTV-VISSIM traffic simulation program. The normal distribution and the uniform nature of the data representation of the observed event on the segments were examined using the Z-test and the K-S test, the results were normal and significant. Then the results were verified and the traffic parameters such as density and flow rate were checked to ensure the nature of the traffic flow. The process was also verified using the vehicle motion graphic representation method (Vehicle Trajectory).

A new variable has been extracted, which is one of the traffic movement variables, which depends on the percentage of complete and proper lane change completion within the parameters imposed by the simulation program, it's the Lane Change Occupancy factor (LnChOc.). It describes traffic conditions on highways and the results are verified and calibrated. It's a simple statistical model was obtained to estimate the traffic movement from this variable and vice versa from the following equation:  $LnChOc = 0.001 e^{0.001FR}$ , Which gave results for critical traffic on multi-lane roads in the Mosul city as follows: -

- $LnChOc = 45.559 \approx$  One lane change per 46 Vehicle hour
- **Max. flow rate** = 2558 pcphpl
- **Critical Density** = 48.925 pcpkmpl
- **Optimum Speed** = 52.28 kmphr

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## 1. Introduction

The most common problem of multilane highways is traffic congestion. Traffic Congestion defines: as a status that describes the highways as a condition in transport that is designated by slower speeds, longer trip times, and increased vehicular queueing. As demand approaches the capacity of a road (or of the intersections along the road), extreme traffic congestion sets in. When vehicles are fully stopped for periods, this is known as traffic congestion or (traffic jam).

Traffic congestion leads to different behaviors of the driver due to the pressure, tension, and anger that befalls him, and the effect of this may result in unacceptable behaviors, so the driver's behavior must be studied before and after the state of congestion to accurately describe the effect of the driver's behavior on highways. So, we need to define driver behavior.

Driver Behavior: is the set of actions taken by the driver to ensure the safety of people and compliance with the driving rules. One of the most driver behaviors that happened frequently is Lane Change: which is a driving maneuver that moves a vehicle from one lane to another where both lanes have the same direction of travel whenever the gap between the lag vehicle and the leading one in the adjacent lane allows.

We take the idea of this research from HCM "Graphically, this situation is represented by trajectory lines crossing each other. Second, some vehicles might change lanes. Lane changes cannot be represented in the Exhibit plots because the distance is shown as a dimensional scalar quantity. Because of these complexities, multiple-lane trajectories are much harder to analyze"[1]. This research aims to facilitate the highway assessment process, as an alternative or supplementary method of highway evaluation by the Highway Capacity Manual 2010.

Traffic congestion is growing and it may occur greatly on the arterial highway, so its continuous evaluation is not an easy thing, especially when monitoring the roadway with cameras. We have come up with a way to indicate reaching the state of congestion from traffic camera monitoring.

Statistical data on highway traffic accidents show that human error is a major cause of about 90% of accidents. A lane-change maneuver is the cause of many highway accidents due to the miscalculation of the surrounding environment (distances, speed, or vehicle behavior) or the wrong maneuvering (longitudinal and lateral movement) of the human driver.

Later, we'll make it clear that the lane change is a complex maneuver and relies heavily on the behavior and dynamics of the surrounding vehicles. By analyzing data changing the human passage including adjacent vehicles and motion behavior data, we realized that the human model is not a single stage. In this work, we suggest multi-action behavior and motion model simulate the process of lane changing maneuver occupied by the human driver.

The research aims to collect and analyze traffic data easily and convert it from visual data to digital data, analyze it and find a new variable describing the

highway's status.

This research presents the development and evaluation of results using a simulation method to generate a suitable longitudinal control of the lane change. In the specific scenario, the host car is the desire to travel at a faster speed than the traffic stream in its lane and vital to assign to the adjacent lane. That can be accomplished by setting the speed safely and comfortably to match the speed in the new lane. This may be gained by an opinion survey for the drivers.

The idea of the research is based on coming into the simulation program with the type of data available from the video. The data for software analysis is taken from the site, such as the location, speed, and acceleration of both the host vehicle and the surrounding vehicles. The results of the simulation process will be the movement characteristics of an isolated vehicle with a microscopic study. Therefore, a very large amount of data will be produced with which we can determine the parameters of traffic flow, and the effect of the measures of effectiveness on the performance of traffic flow on the multilane highway (often it will be six lanes divided highway which the lane change ensue more frequently).

## 2. Literature Review

In the close future world's population living in cities end up to three-quarters of the total inhabitant, putting enlarged transport systems in a serious challenge (Kaneyasu et al., 2017) [2]. Among the resulting problems, traffic congestion will continuously be one of the most vital ones to be solved. As this is happen, the roads will congest and lose a large part of their main function in the transportation system. Therefore, understanding the influence of traffic congestion on driver behavior as well as, other features in the systems would enhance traffic flow in congested related situations.

The specific area of the highway with the inability to expand, and these congestions increase the number of cars that change their lanes to get rid of congestion and thus these congestions increase or accidents increase. Struggle to obtain the optimal model due to the difficulty of obtaining data from the sites themselves, also the difficulty in obtaining traffic data, as well as the exertion in obtaining information on the driver's behavior. Therefore, the process of creating a simulation model to study road congestion is not easy too. The simulation program provides traffic flow characteristics based on video photography, and from analyzing this video the traffic data and driver behavior can be explained.

Congestion can be defined as a highway traffic volume on any facility that is near or more than its capacity. Generally, congestion is caused due to violations, improper parking, accidents, heavy vehicles, poorly designed intersections, etc. It led to fuel consumption, pollution, travel time delay, and low-speed volume. Increasing population is also one of the causes for increased congestion, as well as, defects in the public transport system. In one-word traffic congestion harms the community as well[2].

The lane-changing model in VISSIM is composed of a complex set of rules, which depends much on the type of streets and other parameters (Fellendorf, 1994; PTV, 2004). For example, if a faster driver approaches a slower one on the same lane, it checks if it can improve the position by changing to a neighboring lane. The difference between freeways and urban arterials is considered significant in VISSIM. In urban streets, the next turning direction is one of the most important parameters for deciding the present lane. Some other driver vehicle parameters are considered important in the VISSIM lane-changing model, including, technical description of a vehicle, behavior of a driver, and interaction between several drivers. The parameter “minimum headway (front/rear)” defines the minimum distance that must be available for a lane changing in standstill conditions[3].

### 2.1) Lane Change Definition

As one of the most common movements on highways and arterial roads, free lane change has been defined as a driving maneuver that moves a vehicle from one lane to another while both lanes have the same direction of travel[4]. Free lane changes are needed so that cars can overtake slower driving cars and trucks. When designing rules for lane changes, one should take care that cars taking over do not disturb the traffic on the lane they use to overtake too much, and one has to take account of traffic laws, which prohibit overtaking a car to the left. Further, is advantageous to prohibit trucks to overtake on the left lane. Especially, trucks are not allowed to overtake at all if the highway has less than three lanes.

### 2.2) Lane-Change Modes and Types:

Reading driver's conduct for achieved of finished lane changes or not, the moves were ordered into three modes, they are (constrained, free, and serious/helpful) given studies [5]. considering vehicle collaborations as follows:

- **Forced lane change:** this sort of lane change is trailed by the deceleration of the slack vehicle. By and large, the subject driver doesn't utilize blinkers or uses them quickly before moving to another lane. The slack vehicle doesn't back off until part of the subject vehicle has entered the objective path.
- **Free lane change:** there is no recognizable communication between the subject and slack vehicle(s). The relative hole between the lead and slack vehicle(s) is sufficiently enormous, so the subject vehicle can move to the objective path with or without an adjustment in its speeding up.
- **Competitive/Cooperative (C/C) lane change:** this sort of lane change includes a grouping of connections. the combining vehicle may surrender the lane-changing endeavor during the cycle. the consolidating vehicle sends a lane-changing solicitation to the slack vehicle by turning on the blinker. The slack vehicle assesses the solicitation and may either participate by easing back down or not coordinating. The subject vehicle rethinks the reaction depending on the new gap and the speed of the slack vehicle

The standards for recognizing C/C lane changes and the other two sorts of lane changes depend on the underlying hole on the objective lane (gap1), basic holes for various lane evolving modes, the subject vehicle length (LS1), and the subject driver type. The yield of this progression is the likelihood of event for every lane evolving mode. The circumstances wherein distinctive lane changing modes may happen. There are six potential dispersing stretches for gap1: I, II, III, IV, V, and VI. For instance, if a hole falls into any periods, II, IV, and VI, a deterministic move happens as no lane changing, constrained lane evolving, C/C lane changing, and free lane evolving, separately. Something else, if the hole falls into the stretches III or V, two probabilistic choices may occur. Numerical equations and rules for every circumstance, alongside the yield lane evolving mode(s), are communicated as follows.

On the other hand, lane change may be classified into three types depending on the way it happens as well as the location in the carriageway of the direction of movement, these types can be: -

- (i.) **Mandatory Lane Change (MLC):** that means the vehicles should change the lane this found in merge route or needed because of the speed, gap, and other traffic flow characteristics. Mandatory lane change (MLC) occurs when the driver must change a lane to follow a lane. If MLC is needed, it overrides any other considerations,
- (ii.) **Discretionary Lane Change (DLC):** that means the vehicles could change the lane or not change the lane, that happened when the distance (gap) between cars is enough to make a change. Discretionary lane change (DLC) occurs when a driver changes to a lane perceived to offer better traffic conditions,
- (iii.) **No Lane Change (NLC):** that means the vehicle should not change the lane or they will be causing collisions[6].

In Ahmed's dissertation (1999), a general framework that captures lane-changing behavior under both the MLC and DLC situations was developed. In this model, lane-changing is divided as a sequence of four steps:

- 1) decision to consider a lane-changing,
- 2) target lane choice,
- 3) acceptance of gap conditions in the target lane, and
- 4) performing the lane-changing maneuver.

A discrete choice concept was adopted to model the impact of the surrounding traffic environment and lane configuration as well as driver characteristics. The whole procedure is modeled as a decision tree

### 2.3) Recent Researches

- In 2016 “Empirical Investigation of Strategy-Based Lane Change Choice A driving experiment and questionnaire”, this research gives us a background on Microscopic Models (Car-Following and Lane Change) behavior. (Baat, 2016) [7].

- In 2016 “A Safety and Comfort Lane Change for Sportive Highly Automated Driving Truck”, this research gives us heavy vehicles' effect on lane change. (Yangyu Zhang,2016) [8].
- In 2017 “Driver Modeling and Simulation of Lane Change Situations”, this research gives us information about Collision caused by the Lane change effect on the lag gap. (Naturwissenschaften, 2017) [9].
- In 2018 “Lane Change Path Planning With state-dependent safety constraints using Nonlinear Model Predictive Control”, this research gives us driver's errors and cope of them. (Berger, 2018) [10].
- In the 2018 "In-car advisory system for lane-changing in a connected vehicle environment”, this research gives us suggest location and timing where and when lane changes should be executed. (Title, 2018) [11] .
- In 2019 “Lane Change Intention Recognition Models Using Hidden Markov Models and Relevance Vector Machines”, this research gives us the effect of lane change driver behavior is complex and dangerous. (Hidden, Models and Machines, 2019) [12].
- In 2020 “A Survey of Road Traffic Congestion Measures towards a Sustainable and Resilient Transportation System”, this research gives us the definition of traffic congestions and described the types of congestions and current approaches to measuring congestion. (Afrin and Yodo, 2020) [13] .
- In 2020 “Estimating a congested road capacity – headway relationship of a multi-lane highway in an urban area based on lane position”, this research gives us the definition of the capacity flow and headway and gave the low to calculate the capacity for congested traffic and estimating the capacity of each lane using the developed flow-headway model, headway, effect of lane position. (Gofran J. Qasim, Abeer K. Jameel, 2020) [14].
- In 2020 “Understanding the discretionary lane-changing behavior in the connected environment”, this research gives us the definition of the discretionary lane-change and gap-acceptance behavior during DLC, a summary of representative DLC studies, DLC duration, Safety duration DLC. (Yasir Ali, Zuduo Zheng, Md. Mazharul Haque, Mehmet Yildirimoglu, 2020) [15].
- In 2020 “Trajectory data-based traffic flow studies: A revisit”, this research gives us the definition of new phenomena for Traffic models (Microscopic, Macroscopic, Mesoscopic) also, a new traffic flow model built upon trajectory data. (Li Li, Rui Jiang, Zhengbing He, Xiqun (Michael) Chen,2020) [16].
- In 2020 “Lane Changing Characteristics for Different Types of Roads in Najaf” this research gives us driver behavior under different traffic conditions is the main point to develop a microscopic traffic model such as the Frequency of Lane Changing (FLC) and Lane Utilization (LU). (Hamid A. Al-jameel,2020) [17].
- In 2020 “Integrated Variable Speed Limits and Lane-Changing Control for Freeway Lane-Drop Bottlenecks”, this research gives us the kinds of traffic control strategies to relieve traffic congestion in lane-drop bottlenecks: variable speed limits (VSL) control and lane-changing (LC) control. (Yuqing Guo, Huile Xu, Yi Zhang, 2020) [18].
- In 2020 “A Study on Following Behavior Based on the Time Headway”, this research gives us consideration of lateral distance led to dividing driving behavior into intervals (based on the average TH), including Unsafe (0-0.7 sec), non-lane-based car-following (0.9 sec), lane-based car-following (1.0 sec), overtaking TH (1.3 sec), and free driving (larger than 2.5 sec). (Ehsan Ramezani Khansari, Masoud Tabibi, 2020) [19].
- In 2020 “Goal Estimation of Mandatory Lane Changes Based on Interaction Between Drivers”, this research gives us that the vehicles keep their current lane in highways and lane change due to external effects. (Hanwool Woo, et al.,2020) [20].
- In 2020 “Long-Term Prediction of Lane Change Maneuver Through a Multilayer Perceptron”, this research gives us the way to capture real lane change maneuvers by using models. (Zhenyu Shou, et al., 2020) [21] .
- In 2020 “Factors affecting lane change crashes”, this research gives us the effect of the factors on the lane-change behavior which cause crashes and collisions. (Ain, 2020) [22].
- In 2020 “A Simulation Study on Overtakings and Lane Changing Behavior On An Urban Road Corridor” this research gives us the traffic simulation, urban roads, lane-change, queue formation. (K. Durga Rani, et al.,2020) ) [23]
- In 2020 “A two-dimensional car-following model for two-dimensional traffic flow problems” this research gives us an idea about the lane force and lane change and lateral friction and the effect of the experiment and relaxation on lane change behavior. (K. Durage Rani, K.Venkata Subbaiah, C.N.V Satyanarayana Reddy, 2020) [24].
- In the 2020 "Importance Weighted Gaussian Process Regression for Transferable Driver Behaviour Learning in the Lane Change Scenario”, this research gives us a new lane-change scenario by using Gaussian process regression and comparing its results with our thesis. (Zirui Li, Jianwei Gong, Chao Lu, 2020) [25] .
- In 2020 “Influence of traffic congestion on driver behavior in post-congestion driving” this research gives us the effect of (driving safety, driving behavior, traffic congestion, hierarchical clustering & advanced driver assistance systems) on lane change. (Guofa Li, et al., 2020) [26].
- In 2020 “Traffic Flow Theory and Calibration Issues” this research gives us the relationship between speed and density also the HCM procedure to calibrate the model for lane capacity and (speed-flow-density) relationship and comparing with our thesis. (Rakha, 2020) [27].
- In 2020 “Optimal Lane Selection on Freeways within

a Connected Vehicle Environment” this research gives us the microscopic traffic simulation using Integration and simulation network and parameters. (Kang et al., 2020) [28].

- In 2020 “Performance Analyses of Information-Based Managed Lane Choice Decisions in a Connected Vehicle Environment” this research gives us the managed lanes and CAV/CVs and value of travel time distribution and VISSIM simulation network. (Xiaoyu Guo, Yongxin Peng, Sruthi Ashraf, 2020) [29].
- In 2020 “Driver’s Intention Identification With the Involvement of Emotional Factors in Two-Lane Roads,” this research gives us the model verification based on computer simulation data. (Xiaoyuan Wang, Yongqing Guo, Chenglin Bai, Quan Yuan, Shanliang Liu, 2020) [30].

### 3. Methodology

Traffic congestion solution for the multilane highway is still for many years the flow system complexity for the whole road users. Today it is clear that simply providing more road space creates more vehicle travel. To establish this goal, the first step is the adaptation of the study according to the proposal features of the highways network, road profiles, and the actual lanes. The second step arranged the number of locations using test samples as a reference to find the

statistical approval using the known suggestion features of the test sample. Third, gather the data and the factors of each lane through tracking trajectories. Experiments were conducted using lane trajectories of the vehicle as reflect of microscopic driving behaviors Li(2020) [5]. The simulation of lane-level highway information was verified to be of higher quality in terms of displaying detailed highway features with the lane change characteristics of each condition.

The method of the study can be concerned with traffic movement in terms of collecting and extracting traffic data from videotaping. Simulate the traffic movement modeling to extract the variables. The ending is verifying the data and statistical examination with traffic analysis. A sequential statistical test was done for data verification, so the data was examined and prepared for the final treatment.

#### 3.1) Site Selection:

Five locations on the left coast of Mosul city/Iraq were selected to collect the traffic flow data for traffic congestion study on the multilane highway with six lanes. The exact locations should be decided while taking an understanding of the potential use of data collected. These locations have stable flow as we can to accommodate the normal speed with less acceleration, except this for completing the maneuver. For those criteria, the five locations are shown in Fig. (1).

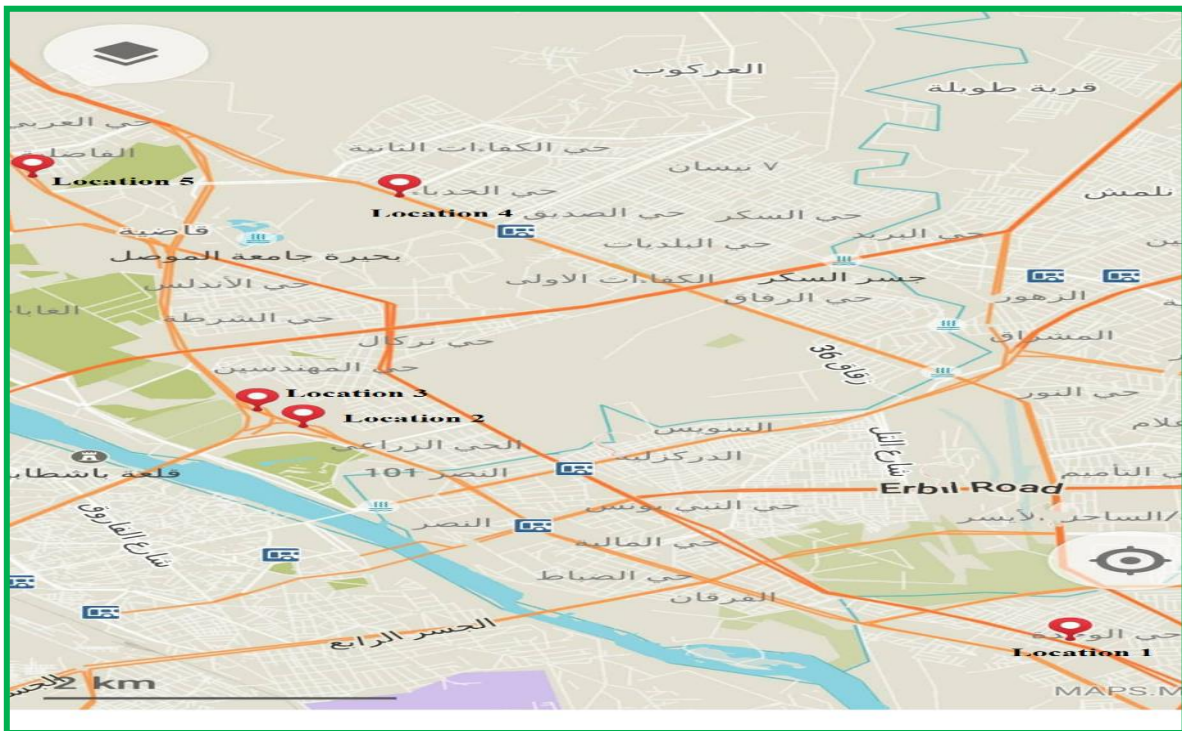


Fig. 1 Map Location of the Five Segments for the Study Area in Mosul City/Iraq.

#### 3.2) Traffic Data Recording and Extraction:

In particularly estimating intermediate traffic states given downstream and upstream traffic flow [6]. Presented a method using video of the selected sectors that can work for an adequate period even after the situation was terminated, and presented a stochastic traffic state estimation method using multiple data

sources. The accuracy of traffic states estimation (especially in reconstructing traffic volume) using various penetration rates and sampling frequency of shooting of camera to the estimation of all other traffic parameters (such as average speed, number of stops, flow movement, or status) for traffic operations under a connected vehicle environment.

The video insight program (Goodvision) was used instead of the manual traffic count methods or any usual data gathering for many reasons. The manual traffic count methods required labor force so it may be inaccurate and expensive. This method had many factors affecting the accuracy of data extraction. Traffic flow level influences the capability of enumerators to carry out traffic counts manually on high-volume roads. Where the enumerator is expected to count more than one traffic lane on a busy road, an observational error is commonly encountered.

### 3.3) PTV-VISSIM Traffic Variables Extraction

The PTV VISSIM-2020-10(student) Simulation run was executed for ten hours for each segment in the study. The operation is done by segmentation for every 10 minutes of the process with a time increment equal to one-tenth of the second, this takes about 500 work hours if without any fault. Also, each highway lane segment for each location had a section for every five meters from the segment length for identity reading values of microscopic parameters of traffic flow in the simulation process.

After that, the urgent steps for the result verification and validation of the result obtained from PTV VISSIM by statistical test and compare with the individual calculation of corresponding parameters or measures. The most parameter that might be the independent one is the space of each vehicle. The simulation value computed from VISSIM compared with the actual one got from the vehicle position in the microscopic study data extraction. This process greatly contributed to getting rid of abnormal data or that gives unreasonable or biased results, as some observations occur in simulation programs, which are the interference of traffic movement. Therefore, such observations were

organized and excluded from the measurements and treatment process of inspection of data and results, so the total result observations were more than (36,000) of the lane change process for all sites and at all times of measurement.

One of the most important next steps is to represent and examine the data, as it is illustrated by statistical graphics to visualize the congruence of values in terms of normal distribution, as well as identify the engineering features for them. Through which this appropriate method of selection of variables and precise analysis process the finding of mathematical and statistical relations can be determined.

These variables can be shown as follows:

❖ **Current and destination lane number:** these plots describe the allocation of the vehicle on a lane and the lane which is desired to change to it for each (lane1, lane2, and lane3) as shown in Fig. (2). These same values in pie charts may illustrate that lane change perhaps not because of looking for higher speed but to improve the driving state it's to find the most comfortable lane for driving state.

❖ **Speed frequency plot:** The most important variable in the simulation process is speed. Since the Goodvision program gives the speed for each vehicle in addition to an essential range of speed in the simulation process. These values for the speed were extracted for each vehicle, the first is the theoretical speed and the second is the default speed from the VISSIM program as shown in Fig. (3). The percentage distributed describe the cases of lane change for each speed and its frequent to find the range of speed causing a higher number of lane change. The statistical check showed that there is no significant difference between these values and that the value of the Z test  $> 0.5$ .

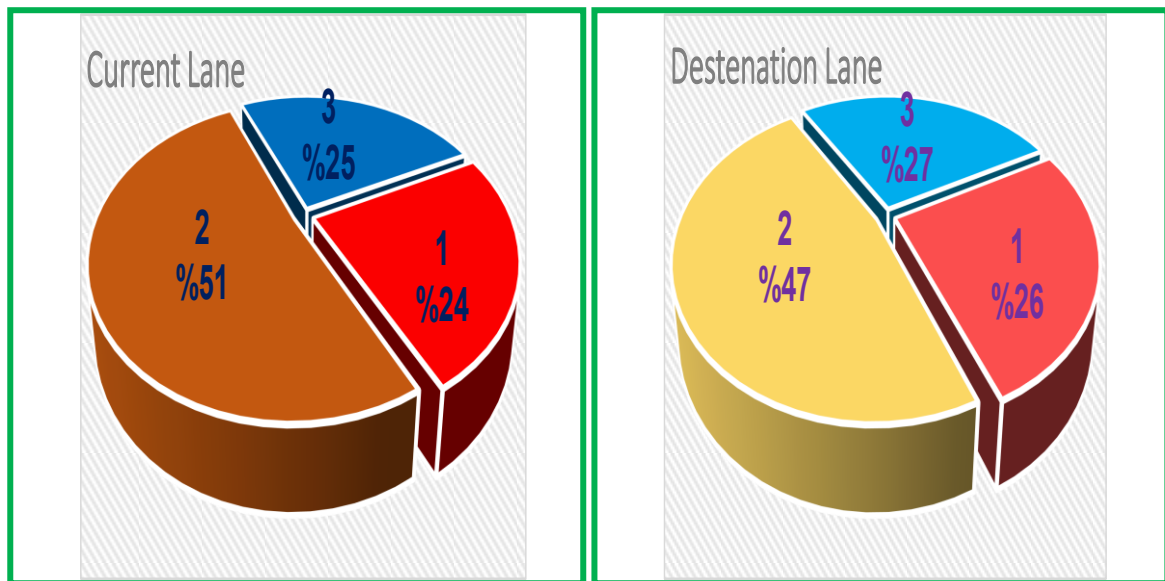


Fig. 2 Lane Number in Current Direction vis Destination Lane for the Study. Where lane 2 is the middle lane, lane 3 is the left, and lane 1 is the right.

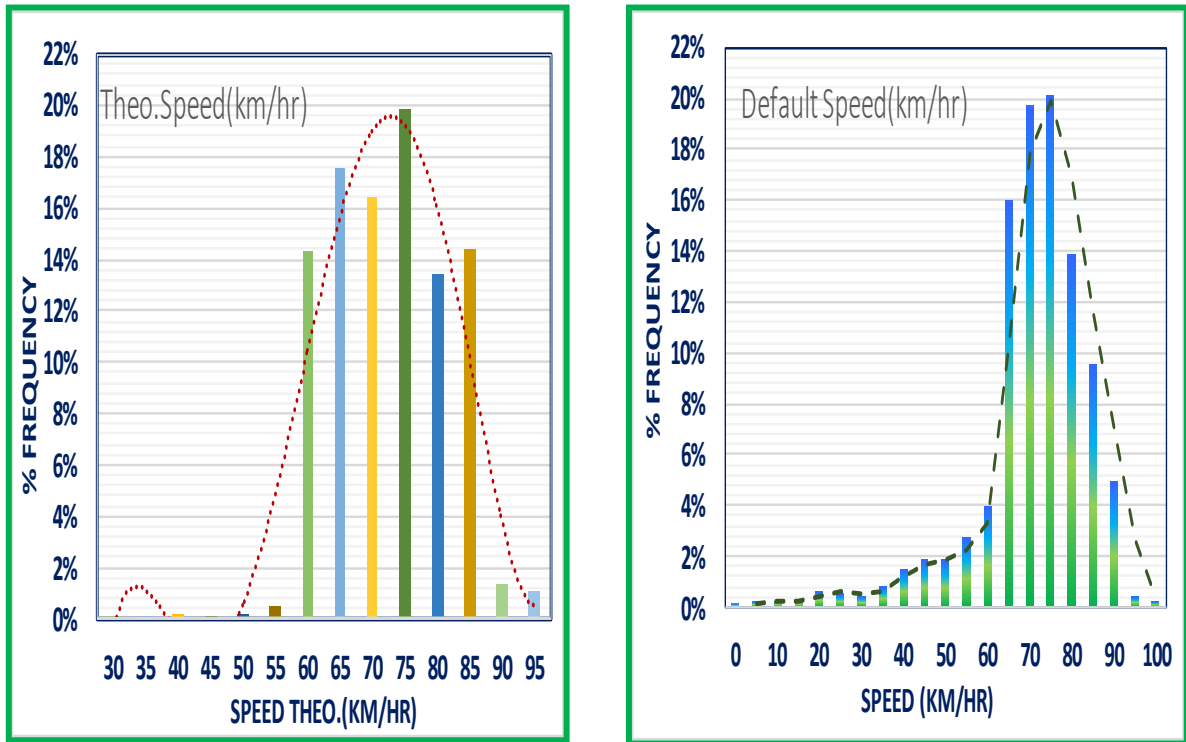


Fig. 3 Theoretical Speed vis Default Speed Percent Frequency for Lane Change Traffic Study.

4. Results and Discussions

The critical point that distinguishes where the road is congested or not, at which there are a certain number of lane change cases at it. To calculate this point, it is necessary to know the characteristics of traffic and all available measures of effectiveness which can be found using the PTV VISSIM program.

4.1) Verification of the Results:

The results verification and validation for the essential variable (spacing) must be organized. To accomplish this, we calculated the spacing by using the distance difference between the position location of each vehicle that is analyzed, also for each vehicle anticipated to activate lane-change maneuver. Then by comparing

this actual value and the estimated value by microsimulation made by VISSIM, the difference was tested to normality as shown in Fig. (4). From this Fig., we can see by the drawing validation method that the difference between actual spacing and VISSIM spacing has no significant difference. Although the result is clear for the absence of the moral difference, statistical checks were performed with the help of the SPSS v26 program shown in table (1) for all observations in segment locations. The statistical validation of results shows that the results are correct and accurate, and we can use these values of spacing to find the headway and gap then flow rate and density.

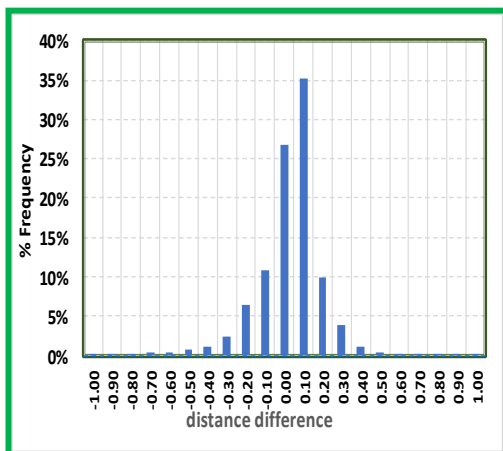


Fig. 4 Drawing Method Validation of the Difference between Actual Spacing and VISSIM Spacing to Validate the Results.

Table 1

Statistical Validation of the Difference between Lane Change VISSIM Spacing and Lane Change Actual Distance Using Two Tests by SPSS Program

		LnChSpace	LnChDistance	Difference
Parameters <sup>a</sup>	<i>n</i>	9913	9913	9913
	Mean	42.2217	42.2164	0.0053
	Std. Deviation	28.46327	28.43812	0.19636
	Minimum	2.16	2.71	-0.98
	Maximum	187.92	187.43	0.92
Kolmogorov-Smirnov Z <sup>b</sup>		12.418	12.364	10.953
		49.72	49.821	29.288

<sup>a</sup>. Test distribution is Normal

<sup>b</sup>. Test distribution is Uniform

4.2) Traffic Lane Change Result:

Lane change result is the observed number of vehicles that complete a lane change maneuver on the multilane highway segment. The changes of driving performance measures were compared between the congestion conditions for all segments using the microscopic measures of effectiveness for the traffic flow. No significant differences were found between these conditions, which indicates that these events could be combined for further analysis. By calculating the headway and gap for lane change observation only and aggregating them to evaluate the traffic movement conditions for the traffic analysis study. This can be established by the askew distribution of that measures as shown in fig. (5) for headway distribution and gap distribution.

Therefore, the analysis and re-drawing of the relationships between these variables and the basic variable which was the speed were done. This is

considered one of the most important variables related to traffic flow and can be considered as an input as well. The results of these relationships are shown in Fig. (6) for speed – headway relation for lane change observations, and speed – gap relation for lane change observations of each study's location segment. These relationships show the suitability of the results and the precision of the relationships, where the models that the study aims at in devising the new variable can be built, which can be as the lane change criterion.

To drive an equation for these correlations, the aggregation of data was made, and results validate test of the density and flow rate by using drawing method after calculating the flow rate and density by VISSIM spacing and the actual spacing as shown in Fig. (7) for flow rate percent frequency and density percent frequency. These drawings and checks all qualified the results to deduce the variable that would measure the amount of lane change.

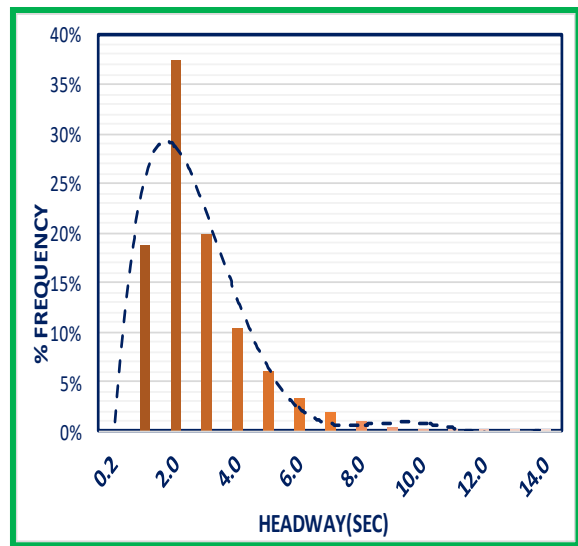
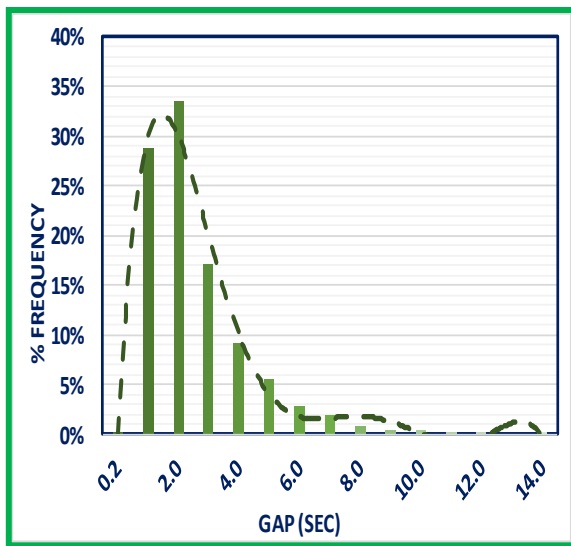


Fig. 5 Headway and Gap Percent Frequency Results for Lane Change Observations for Segments.

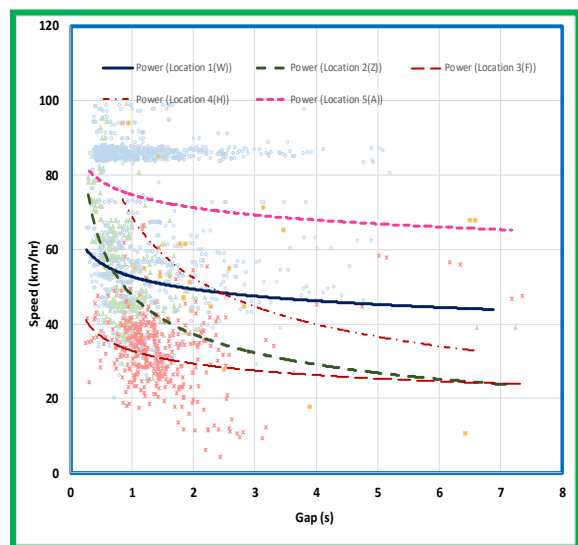
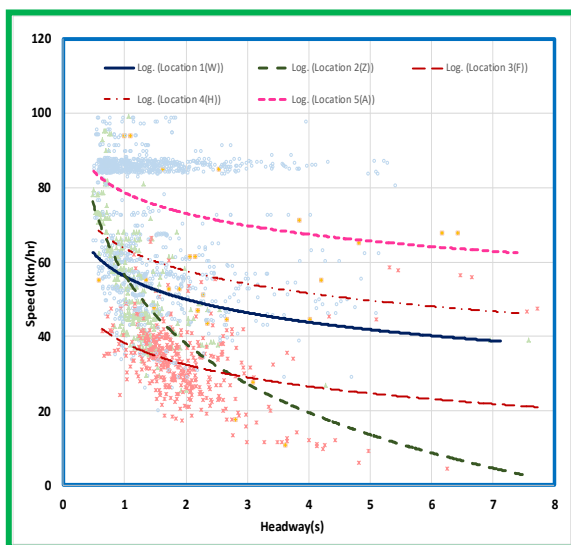


Fig. 6 Speed – Headway and Speed- Gap relations of Lane Change Observations for Study's Location Segments.



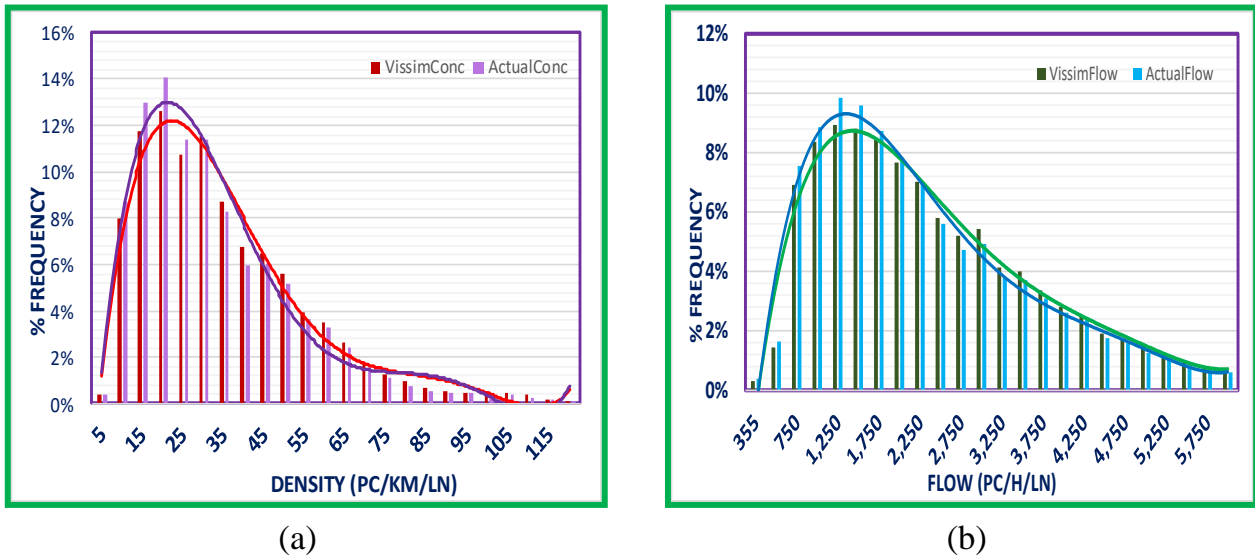


Fig.7 Percent Frequency Results for Lane Change VISSIM and Actual Observations for all Segments. (a) Flow Rate, (b) Density

#### 4.3) Develop of Lane Change Occupancy:

Lane change's result is a microscopic parameter because it is a behavior for one vehicle, so this variable as itself is not useful because it does not describe the status of the highways, however, the status of highways is a macroscopic parameter. The new method is to use these observations to generate a new parameter that could describe the status of the highways. The step at present is to find the lane change occupancy. Thus, we have reached one of the most important objectives of the research, which is to find a new variable for determining the point of assessment to state traffic congestion on multilane highways.

The Lane Change Occupancy (*LnChOc.*) is the new parameter that describes the highway status, and it may be used to discover the traffic conditions if it's congested or uncongested. It's equal to the inverse of the percentage value of lane change (*% Ln Chg*) as shown in equations:

$$\% Ln Chg = \frac{\text{Lane Change Results}}{\text{total Volume}} \times 100$$

$$LnChOc. = \frac{1}{\% Ln Chg}$$

This method describes the status of highways by knowing the driving behavior instead of knowing the traffic parameters, and this parameter is very easy to find and easier the way to describe the status of highways than the traffic parameters because we need to find one variable instead of three different variables. Now we generate the relationship among lane change occupancy and all available traffic parameters (density, and flow rate), as well as with the other measurements that may be related to this developed variable *LnChOc.*, they are clearance, spacing, and V/C as follow:

- Lane Change Occupancy-Headway and Gap relationships: as previously invented headway and gap have more representation with the lane change occupancy as shown in Fig. (8). Where values headway can represent the instantaneous traffic flow for each vehicle trying or practicing to lane change (and as we

mentioned that it does not represent aggregate flow). Its values as

- well as, the gap values, undergo almost the same relationship of traffic flow, but inversely, that is, it will decrease with the increase of the variable *LnChOc* until the critical point is reached, it has a lower value than it gives the capacity. After which it will increase and the traffic volume will decrease as a natural behavior to increase congestion.

- Lane Change Occupancy-Flow Rate relationship: the relationship statistically is significant with the coefficient of correlation ( $R = +0.805$ ). The flow rate and the lane change occupancy are increasing until the critical point after that flow rate will decrease as shown in Fig. (9). This means that the new variable shows a logical explanation for the separation between the two conditions of stable flow rate with uncongested or the unstable flow with congestion occur after the volume exceed the capacity. Thus, this measure of effectiveness can be used despite traffic flow evaluation parameters for the balance system.

- Lane Change Occupancy - v/c relationship: this relationship can be illustrated in Fig. (10). The saturation ratio v/c and the lane change occupancy are increasing till the critical point after that the v/c will decrease in the same manner. As mentioned in Lane Change Occupancy - Flow Rate relationship and this relationship will validate the results of the study.

- Lane Change Occupancy-Density relationship: the relationship explain that the density and the lane change occupancy have correlations of more than 78%, in which they increase together until the critical point, after this point the density will decrease while the lane change occupancy is increasing as shown in Fig. (11). All these relationships must be examined again using statistical programs SPSS to verify the significance of the relationships and the equations formed, as well as to examine the collinearity between these independent variables and their regression with the dependent one.

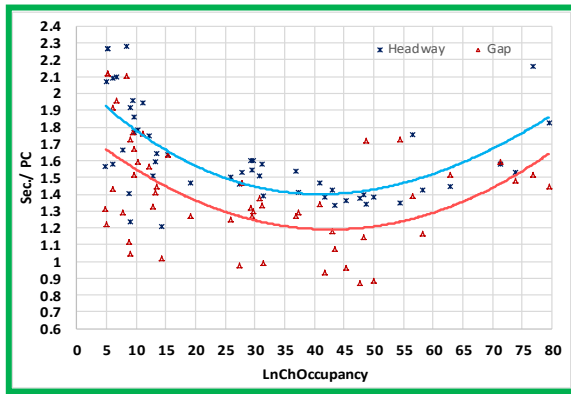


Fig. 8 Lane Change Occupancy- Headway and Gap Relationships for Study's Location Segment.

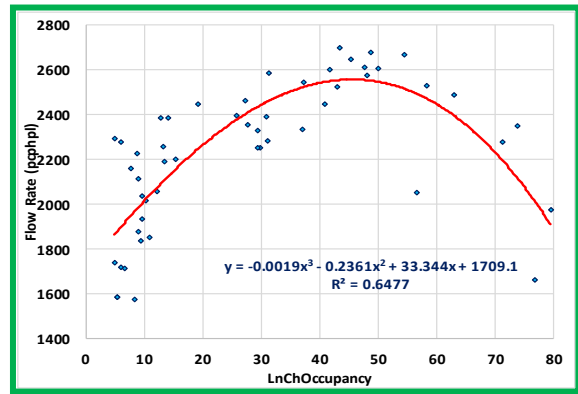


Fig. 9 Flow Rate-Lane Change Occupancy Relationship for Study's Location Segment.

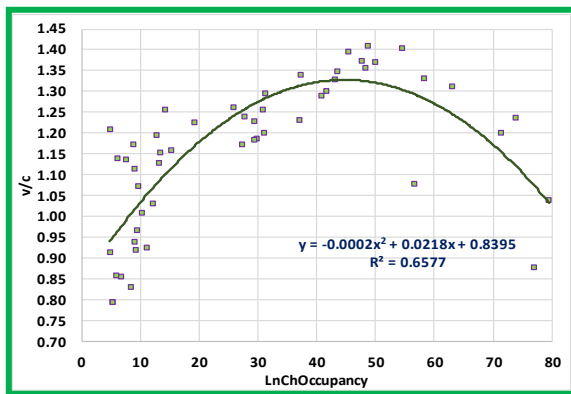


Fig. 10 Lane Change Occupancy-v/c Relationship for Study's Location Segment

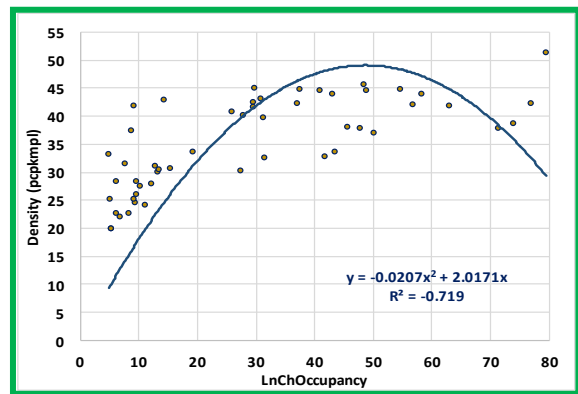


Fig. 11 Lane Change Occupancy-Density Relationship for Study's Location Segment

#### 4.4) Traffic Congestion and Lane Change Occupancy Model

The first analysis step is executed to the traffic parameters to find the critical point by the typical way to describe the status of highways, then to compare with the results of the driver behavior parameters to prove that the same parameters give the same condition for the same highway.

Traffic flow will be uncongested when lane change results are less than lane change congested and congested when equal or more than lane change congested. The point of inflection that describes the flow as uncongested before it and congested after it is called the point of lane change occupancy congested. Both results show that the traffic flow is uninterrupted, and the relationships among traffic parameters and traffic parameters, and driver behavior parameters are logical and acceptable values.

To get the mathematical model, the SPSS program was used to produce a statistical model, the statistical parametric. This analysis is a summary of all the attempts and relationships that can arise between the dependent variables and all the independent variables that have been found but individually. The multiple regressions have not been used because the strength of the correlation between the variables in the previous correlation tables has not been observed. The relationships that gave an absolute value of the correlation more than 63 % were fixed, taking into account not to use logarithmic or complex functions as

much as possible, and resorting to simple equations even if they give a degree of determination slightly less than those given by the complex functions, but it's significance where F- calculated is more than the (F-tabulated =3.98). So the functions that were involved for analysis {Cubic, Exponential, Logistic, Compound, Power, S- curve, Quadratic and Inverse}.

From this analysis the extraction of the mathematical model for each dependent and independent variable is as follows:

- Lane Change Occupancy-Flow rate mathematical model: this model find the value of lane change occupancy which is the dependent variable by knowing the flow rate which is the independent variable, the mathematical model is four types (Exponential, Logistic, Compound, and Power) as follows:

$$LnChOc = 0.001 e^{0.001FR}$$

- Lane change occupancy-Speed Theoretical mathematical model: this model find the value of lane change occupancy which is the dependent variable by knowing the speed theoretical which is the independent, the mathematical model is Exponential as follows:

$$LnChOc = e^{194.924/SPT}$$

- Lane Change Occupancy-Density mathematical model: this model find the value of lane change occupancy which is the dependent variable by knowing the density which is the independent variable, the mathematical model is a Compound model as follows:

$$LnChOc = 1.024^D$$

• Lane Change Occupancy-V/C Ratio mathematical model: this is the most important model because we can find LCC by this model to describe the highway as congested or not, by this model we can find V/C by entering the value of LnChOc, the mathematical model is as follows:

$$LnChOc = 14.125^{V/C}$$

From this equation by substituting  $v/c = 1$  we find  $LnChOc = 14.125$  which is equal to LCC value

4.5) Determine the Critical Point for Traffic Congestion

After we arrived here at the final model to estimate the value of the developed variable lane change occupancy ( $LnChOc$ ), it is necessary to determine the limitation ends and critical points of the models and transfer them to the rest of the variables to find the optimal values for these variables such as speed and the maximum value of the traffic volume that represents the capacity, at which a reversal occurs in the state of traffic flow from stable flow (uncongested) to troubled flow (congested).

Several equations described the relationship between traffic flow and the substitution variable, where these equations can be represented at the most significant form in one diagram as shown in Fig. (12), which represents equations of three types to represent data (Polynomial, Exponential, Compound).

These relationships of traffic flow with the new variable lane change occupancy ( $LnChOc$ ), although not all of them contain an inflection point due to the type of function such as the exponential function, they all pass through the region in which the state of traffic flow changes, and to accurately reach this point, it can be inferred from the derivation of each equation as follows:

1- The polynomial equation shown in the following equation

$$LnChOc = -0.0019FR^3 - 0.2361FR^2 + 33.344FR + 1709.1$$

Where this equation can be easily derived to reach the ultimate value of traffic volume, which can be considered the capacity, and then the transition from stable flow to unstable flow takes place, as follows:

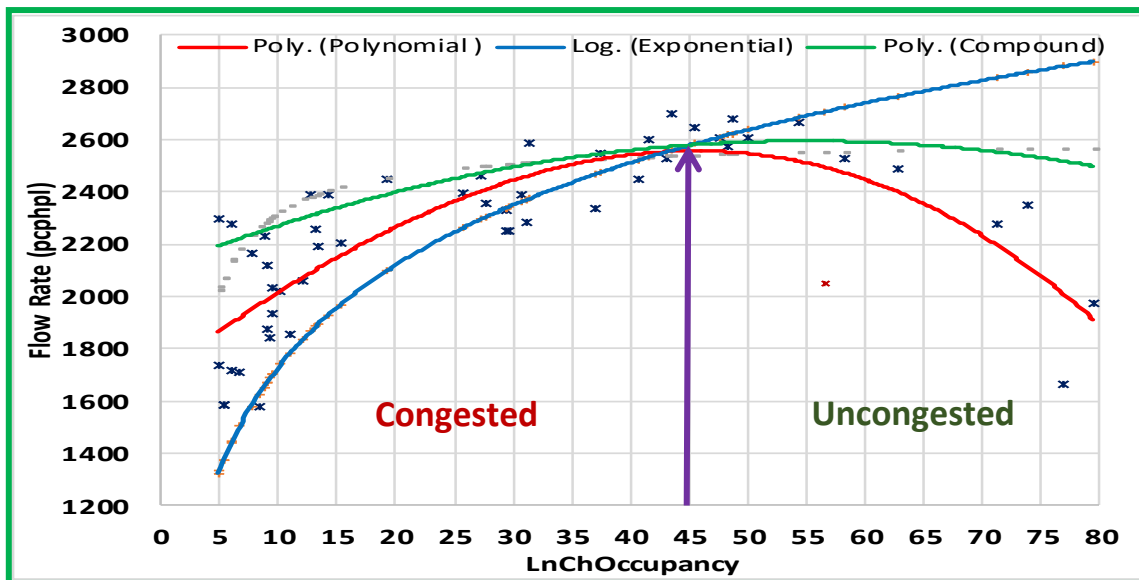


Fig. 12 Flow Rate for Lane Change Occupancy Equations with Critical Point for Study Segments.

$$LnChOc = -0.0057FR^2 - 0.4722FR + 33.344$$

So these critical point for the uninterrupted flow that was studied to determine the critical point of lane change occupancy ( $LnChOc$ ) are:-

- $LnChOc = 45.559 \approx$   
**One lane change per 46 Vehicle hour**
- **Max. flow rate = 2558 pcphpl**
- **Critical Density =**  
**48.925 pcpkmpl**
- **Optimum Speed = 52.28 kmphr**

2- As for the second equation, the derivation of the exponential equation leads to the Taylor series, and then its derivation can be found, thus the roots are close to the values obtained from the first equation.

$$LnChOc = 0.00093 + 1.86E^{-6} * x + 1.86E^{-9} * x^2 + 1.241.86E^{-12} * x^3 + 6.21E^{-16} * x^4$$

Also, the critical point where near the optimum value obtained.

3- As for the last equation, which is represented by the following compound function, it can be derived to reach the critical point as follows

$$ln(LnChOc) = ln(1.001) + 0.998/FR$$

The derivations of this formula provide a critical point near the regain found in the first equation.

Finally, the process of linking with the driver's behavior deceptions in the representation of this critical point of the boundaries that were reached from the traffic questionnaire. The minimum time to perform the lane change maneuver that gets from driver behavior study compared with the value get from the Fig. (8) for the critical point of the ( $LnChOc$ ) variable, are: -

- **Min Headway = 1.42 sec/PC**
- **Min Gap Accept. = 1.2 sec/PC**

## 5. Conclusions

From the study, we came to the following conclusions:

1) Using the Goodvision program alone eradicates the use of other programs because it gives many parameters like Gap, Speed, Vehicle trajectory which describe the lane change process, also we can get the vehicles changing their lanes only and their traffic data, and can export the model to VISSIM. Despite that, we used a simulation program to validate the results extracted from the Goodvision.

2) It's very important to export the extracted data from Goodvision to generate the PTV VISSIM model. It's an identical worthy manner to record from the top or by using drones, but it's impossible because of the unavailability. The use of simulation programs "i.e. PTV VISSIM", to verify the results extracted from the video analyzer is more authorities. The most efficient method is to add the geometrical data to the models, then selecting the rest of the elements that it requires in VISSIM regularly and within the correct actions of the driver such as (type of model "i.e. Car-Following Wiedemann 74 model, Lane-Change model, Gap-acceptance model, etc.", type of the road "i.e. urban, rural, freeway, arterial").

3) The specific outputs of the VISSIM program were determined in addition to some other outputs that may affect such as delay and acceleration. There was a large number of outputs, but only predict the most correlated one with the dependent variable, were exported to Excel sheet to modify them in a such manner

4) A newly developed variable was created in the name of lane change occupancy (*LnChOc*), which gives a new indicator of the state of traffic congestion in addition to the variables or measures that HCM gives concerning multi-lane highways. This variable shows its significance with the basic flow variables (speed, density, and flow) and gives a separating boundary between congested and uncongested. The predicted models are: -

- ❖ With flow rate:  $LnChOc = 0.001 e^{0.001 * F}$

- ❖ With speed:  $LnChOc = e^{194.924 / SP}$

- ❖ With Density:  $LnChOc = 1.024^D$

- ❖ With v/c ratio:  $LnChOc = 14.125^{V/C}$

The critical point that discrete the un-congestion from the congestion state is:

- $LnChOc = 45.559 \approx$   
*One lane change per 46 Vehicle hour*
- *Max. flow rate = 2558 pc/h/l*
- *Critical Density = 48.925 pc/km/ln*
- *Optimum Speed = 52.28 km/hr*

## 6. Recommendations:

a) Record the video from a point higher than the segment of the highway (i.e. from the top "or use the drones") and use a fixed camera to avoid the vibration in the footage which causes mistakes in the analysis too.

b) Our study does not focus on the difference of the results of DLC and MLC so try to extract the difference if there is any, also another type of lane change.

c) Study the effect of the junction and merge and diverge routes and parking routes on the lane change process and how does it affect the *LnChOc*.

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