An Overview of Traffic Modeling, Congestion Detection and Prediction

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***Abstract*—Traffic problem has become a global problem especially in the urban areas. Every day, traffic congestions cause waste of fuel, road rage, and economical problems. In order to assess and remove the problem of traffic congestion, we should know how to model traffic, and how such congestions occur. In this paper while we focus on discrete traffic modeling, we take a first look at traffic congestion detection, traffic congestion prediction, and some congestion avoidance technologies.**

Keywords—traffic modeling, Nagel-Schreckenberg, RNSL, DM, traffic congestion detection, congestion forecasting, traffic congestion prediction, traffic stream terminology

I. Introduction

Since the modern traffic became an issue, scientists have been looking into ways to define and simulate the traffic in order to overcome the problems that arise with traffic. These simulations are expected to give solutions regarding traffic stream that would define quantitative and qualitative metrics for the projectization of the transportation agents (such as roads and bridges), and also give a solution to the traffic jam problem. Nowadays, analysis of the traffic stream is highly used in Transportation Planning, Traffic Control, and Traffic Engineering [1]. Traffic phenomenon that is described by those fields help us monitor, model, simulate, and analyze the traffic in order to better understand the problems and produce solutions to overcome them.

One good way that is used to deliver traffic stream testing is through traffic modeling. There are three essential traffic modeling types described since 1950s [2] [3]. These model types involve Microscopic modeling (Car-Following model), Macroscopic modeling (LWR model), and Mesoscopic traffic model (Gas-Kinetic Traffic Flow model) [1]. There are also discrete models such as cellular automaton model, which are highly being used in traffic monitoring and instruments, especially in Germany [2]. The discrete models that will be explained in this paper can provide various tools to perform simulations for scenerios such as accidents, start-stop conditions, traffic jams, and closed lane segments (construction sites) [3].

In this paper, we will be primarily discussing about discrete traffic models and how they can be used as tools to provide robust traffic simulations to find solutions to the problems in highways. Furthermore, we will give an overview and literature review of how to assess and predict traffic congestion.

II. Traffic Stream Terminology

In order to understand the traffic stream, one should understand the terms that are related to it first.

1) Speed: The distance a vehicle travels per time unit is described as its speed. Vehicles usually have non-uniform speeds in highway traffic [4]. Speed of a vehicle is calculated by (1), with V being the speed of the vehicle, d being the distance travelled, and t being the time it took to travel.

$$V = \frac{d}{t} \quad (1)$$

2) Average Speed: Average speed in a traffic stream is found by averaging speed of each vehicle [4]. Average speed is a measure that is used in finding the traffic jams for some cases. Average speed can be described by (2), where $\overline{V}$ is the average speed, N being the number of vehicles to be averaged, and V_i being the speeds of individual vehicles.

$$\overline{V} = \frac{\sum_{i=1}^{N} V_i}{N} \quad (2)$$

3) Volume and Flow: Volume can be described as the number vehicles passing from a point in traffic per time unit. Typically, a 1-hour volume of vehicles is given by the Flow parameter. Flow is defined as the rate at which vehicles are passing from a given point on the road. The typical unit for Flow is vehicles per hour [4]. In [4], it is given that the volume can simply be converted to flow by converting the time base to 1 hour. It is important to keep in mind that flow or volume is a parameter that is only given for a certain lane and a certain direction [5]. Flow q is given by (3).

$$q = \frac{N}{t} \quad (3)$$

4) Density: Density is given as the number of vehicles per a certain length of a road. Typical unit for density is given as vehicles per kilometer or vehicles per mile [4]. There are also some literature that uses the unit vehicles per kilometer per lane [14]. We can learn from [5] that the vehicle density is a measure that defines proximity of vehicles and their ability to drive comfortably. It is also important to know that vehicle density is a metric that directly expresses traffic demand [5]. With the help of (4), one can calculate the traffic density in a given road, given that ρ is the traffic density, L is the distance that is taken into account and r is the average distance between vehicles for the calculation. Also, one can calculate the average density per lane $\overline{\rho}$ with the help of (5), given that n is the number of lanes in the system [6].

$$\rho = \frac{N}{L} = \frac{1}{r} \qquad (4)$$

$$\overline{\rho} = \frac{N}{nL} \qquad (5)$$

5) Gap: The distance between the front of the vehicle of interest and the back of the vehicle in front is referred to as gap [4]. It is a term used in traffic modeling in order to describe the positional relationship between vehicles.

III. Discrete Traffic Models

Discrete traffic models are models that are described by state machines and not with the differential equations. These models are linear and are successfully used in simulations. Since the position and velocity of vehicles are discretized, with the help of applying some set of rules, these models can be easier to create compated to non discrete traffic models [3].

A. One Lane Discrete Traffic Models

1) Nagel-Schreckenberg Model: One of the earliest theoretical traffic models was created by Kai Nagel and Michael Schreckenberg around early 1990s [7]. The Nagel-Schreckenberg traffic model was later used widely in one-lane and multi-lane traffic simulations and became a key model in traffic phenomenon. Nagel and Schreckenberg described their math essentially as a simple cellular automaton model for traffic flow in order to show how traffic jams occur. Their model shows a slow down in average car speed in a lane when the vehicles are dense. More interestingly, the model also shows that the traffic jams are emerged from the interaction of vehicles on the road and that traffic jams tend to move backwards as the time progresses [7][2]. It is important to mention that Nagel-Schreckenberg (N-S) model is defined for only one lane of vehicles and that in N-S, the vehicles are thought to be uniform (each vehicle has the same length and maximum speed) [2].

In Nagel-Schreckenberg cellular automaton traffic model, a road that contains L cells is defined. In the original paper, this road is configured as a circle so that the vehicle that exits from the cell #L would return to the road from the first cell. This wrap-up mechanic is used for having a closed-loop traffic [2] and is illustrated in Fig 1. It is important to mention that one can create a non-circular Nagel-Schreckenberg model in order to simulate real traffic objects that are gathered from highways.

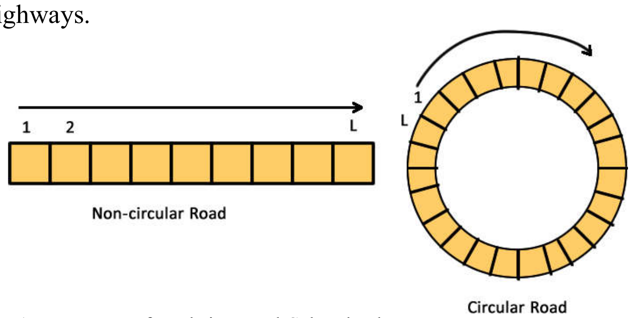

Fig 1. Two types of roads in Nagel-Schreckenberg

In N-S model, cars are assigned to velocities that vary between 0 and maximum speed. Maximum speed can be thought as the speed limit for the fastest vehicle on that road [7]. Moreover, it is important to note that N-S original paper simulates the Maximum speed of all vehicles to be 5, for ease of analysis. Using time discrete steps, one can use the following pseudo code in order to create a basic N-S model [8]:

Table 1. N-S Pseudocode

```
1. Create Initially Populated Traffic
2. For every time step until simulation is over
3.       Apply Acceleration Rule to All Vehicles
4.       Apply Slowing down Rule to All Vehicles
5.       Apply Randomization Rule to All Vehicles
6.       Print Traffic Status
7.       Apply Car Motion Rule to All Vehicles
8.        Generate new cars entering the road //or wrap-up for circular model
9. End
```

As it is seen from Table 1, N-S has a set of rules in order to function. Those rules can be said to be the discrete implementations of physical behavior of vehicles in traffic. These four consecutive rules must be applied to all vehicles in parallel in order to find the next state of all vehicles [2]. Practically, since this parallelism is hard to achieve, we can consider creating a new array for vehicles and updating the old array with the new array after all steps. This would help us achieve the concurrency that is desired. In addition, it must be noticed that printing of the traffic status in order to observe the vehicles should be done right after the velocity updates and before the Car motion rule [2]. The rules for N-S model is described in the original paper [2] as follows:

a) Acceleration: If a vehicle is not at maximum speed and there is sufficient gap in front, then that vehicle accelerates by 1. Practically, if the velocity v of a vehicle is lower than $V\max$ and if the distance to the next vehicle ahead is larger than $'v+1'$, the speed is advanced by 1.

b) Slowing down (due to other cars): If the vehicle ahead is slower and the gap is insufficient, then the vehicle slows down by 1. Practically, if a vehicle at site i sees the next vehicle at site $i+j$ (with $j \leq v$), it reduces its speed to $j-1$.

c) Randomization: With probability p , the velocity of each vehicle (if greater than zero) is decreased by one $[v \rightarrow v-1]$.

This probability refers to non-deterministic slow-down of a vehicle that produces traffic jams and is often as a value around $P_{deceleration}$ = 0.2.

d) Car motion: Each vehicle is moves forward by v cells after steps a, b, and c are applied.

Using the traffic model that they've created, in [2] Nagel and Schreckenberg simulated one-lane roadway traffic and found the output that is given in Fig 2. The figure shows vehicles in both time and space, each line representing a 1-lane road in a time step. Using a density $\rho = 0.1$ in a circular system, one can see that the traffic congestion moves backwards as the time progresses as seen from Fig 2. The clusters having 0's in the figure are the typical examples of start-stop situations in traffic. It is important to note that one can use different parameter values in order to simulate different situations with N-S [2].

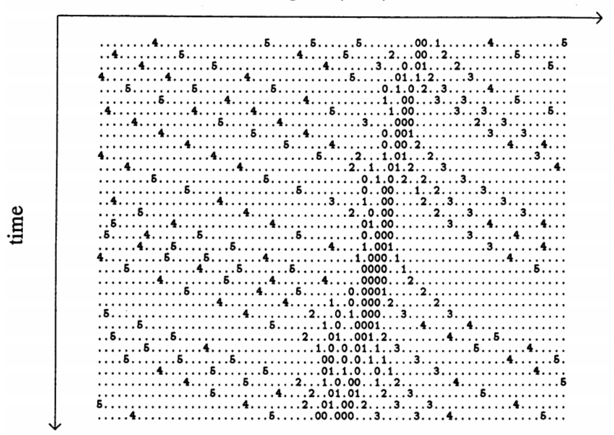

Fig 2. Nagel-Schreckenberg simulation with a density of 0.1 [2]

One very important inference of Nagel-Schreckenberg model of course would be the relationship between traffic flow and traffic density. Fig 3 shows the flow of cars depending on the density of the simulation, and the line is the averaged results over 1 million time steps. It is seen from the figure that up until around $\rho = 0.08 = \rho_{j\max}$ flow increases as density increases [2]. After the changeover point of $\rho_{j\max} \approx 0.08$, flow decreases since the vehicles are starting to slow down because of other vehicles. It should be clear that $\rho_{j\max}$ is the point that the flow is greatest and that lowest and highest density points such as $\rho = 0.8$ and $\rho = 0.02$ will achieve us the same results at which the flow of vehicles are very low.

One should visualize this situation in Fig 4. In the upper figure, a vehicle simulation with $\rho = 0.02$ is shown, whereas in the second figure, a simulation with $\rho = 0.8$ is shown. Assuming a vehicle counter located at the red line and the traffic is moving to the right; we can see that the traffic flow resulted from both of the conditions will be similar, regardless of the amount of congestion in the road.

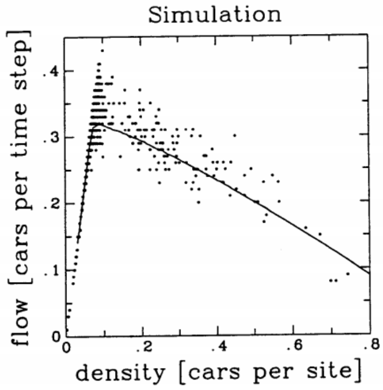

Fig 3. N-S Flow-density relationship graph [2]

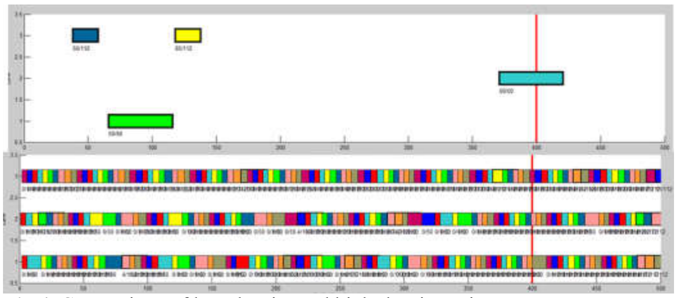

Fig 4. Comparison of low-density and high-density points

In the original paper [2], authors point out that using the discrete model of N-S has a lot of benefits regarding computation, and that it takes the driver factor more into account compared to other traffic models.

B. Multi Lane Discrete Traffic Models

1) RNSL Model: Since a one-lane model is not able to model realistic highway traffic, N-S was followed by creation of 2-lane traffic models. A generalization of Nagel-Schreckenberg model for 2-lane traffic is presented in RNSL model [6][9]. In N-S, it was mentioned that vehicles have uniform sizes and maximum speeds (i.e. vehicle types are the same). However in RNSL model, it is introduced that different vehicle types can have different desired speeds. In addition, one can think of RNSL being two adjacent single-lane arrays with size L that are subjected to Nagel-Schreckenberg rules individually, and that have a lane changing model between them [9]. For the sake of better understanding, we present a pseudocode for RNSL model in Table 2.

Table 2. RNSL Pseudocode

```
1. Create Initially Populated Traffic
2. For every time step until simulation is over
3.       Apply Lane Changing Rules
4.       Apply Nagel-Schreckenberg Rules to results of (3)
5.        Generate new cars entering the road //or wrap-up for
circular model
6. End
```

Update of the system every time step could be extended as follows (Table 2 - steps 3 and 4) according to [6]:
i. For every vehicle, check if lane changing rules are met. If the rules are met, vehicles are only moved sideways. While the fact that vehicles are not advancing when they're changing their lanes is undesired, combined with step *ii*, it gives feasible outcome. An important note for this time step is that it has to be updated parallel, i.e the vehicle configuration before step *i* is used for decision making of each vehicle. At the end the vehicle array must be updated all at once.
ii. Update every vehicle regardless of their lane with Nagel-Schreckenberg rules by using the system obtained by step *i*.

Two-lane RNSL lane changing model can have two types: (1)-asymmetric lane changes (2)-symmetric lane changes. In asymmetric version, cars always try to return to right lane whereas in symmetric version, vehicles remain on their lane until a lane-change is required. We can comment that the asymmetric version would give more realistic results and it would be a nice step in introducing fast-lanes in our simulations. Moreover, we should consider that in order to have proper lane changes, a vehicle should not only check its lane but also the adjacent lanes [6].

RNSL model introduces stochasticity into lane-changes by defining a probability value $P_{changelane}$ even if all the criteria is met for a lane change. The reason it reduces the lane changes by doing so is to prevent slow platoons of congested vehicles [6]. It justifies this by pointing out that if every vehicle were to change lane from a congested lane to an open lane, then the other lane will be congested since none of the vehicle has reached their maximum speed [6]. This stochasticity helps us to achieve more realistic results.

In order to understand the lane changing model, one should know about the gaps according to an ego vehicle. In Fig 5, we illustrate a road with an ego vehicle that is considering to change its lane. This vehicle has the following gaps: gap which is its distance to the vehicle in the front in its own line, gap_o which is its distance to the vehicle in the front in the opposite lane, and $gap_{o,back}$ which is its distance to the vehicle in the back in the opposite lane. One can describe a lane changing algorithm based on those gaps, as RNSL delicately did.

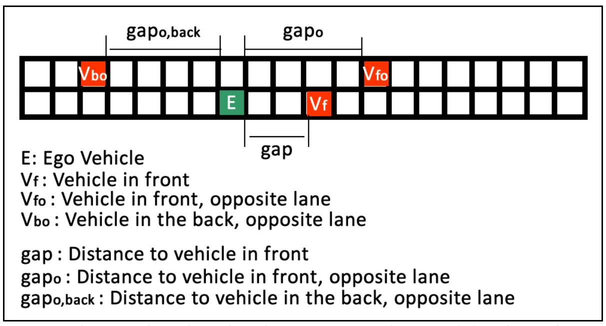

Fig 5. Gaps that needs to be taken into account when applying lane changes

In RNSL, a vehicle changes lane if all the following rules are met:
a) *T1: If there is a vehicle in your way*
- $gap(i) < l$ where l is how far distance to check in your lane for a lane change and i being the index of the ego vehicle.

b) *T2: If the other lane is less congested, i.e. there is more space in the other lane*
- $gap_o(i) > l_o$ where l_o is how far distance to check in the opposite lane for a lane change and i being the index of the ego vehicle.

c) *T3: If there is no closeby vehicle coming from the back*
- $gap_{o,back}(i) > l_{o,back}$ where l_o is how far distance to check in the opposite lane for a lane change and i being the index of the ego vehicle.

d) *T4: Stochasticity criterion*
- $rand() < P_{changelane}$ where $P_{changelane}$ is the probability to change the lane if all other criteria is met.

In the original paper [6], the parameters for the system are defined as $l = l_o = v + 1$ and $l_{o,back} = v_{\max} = 5$ and $P_{changelane} = 1$. This means that the first $v+1$ cells are checked ahead from the ego vehicle for lane change and $v_{\max}$ amount of cells are checked in the back for safety. Notice that l and l_o are proportional to the velocity of the ego vehicle, but the $l_{o,back}$ is related to the maximum speed of other vehicles [6].

Lane changing behavior, as mentioned before, can be expressed with two different versions of RNSL model: asymmetric and symmetric. In Fig 6, the results related to the frequency of the lane change is given. It is seen that lane changing frequency is much higher in asymmetric version as opposed to the symmetric one. Moreover, one should notice the sharp bends in the asymmetric case after $\rho = 0.08$ which is known as the density of high interaction in single lane traffic [6].

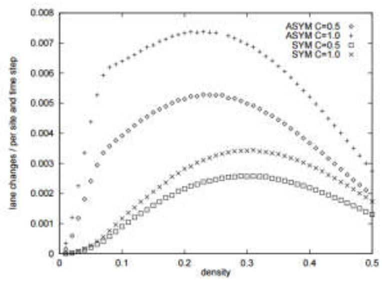

Fig 6. Frequency of lane change vs density graph with lookback (l_o) = 5

All in all, we see from RNSL model that the application of some discrete lane changing principles and making use of Nagel-Schreckenberg are useful and provides ease in the traffic simulations.

2) DM Model: DM model [10] is a three-lane discrete traffic model which is a cellular automaton that makes use of Nagel-Schreckenberg model. This model is similar to RNSL, and it extends the lane-changing methodology to three lane roadway traffic. DM model, which was created by A.Karim Doudia and Najem Moussa in 2003 considers the cellular automaton to be three adjacent 1-dimentional arrays with length L [9]. The purpose of DM model is essentially to take a look at the slowing of cars caused by trucks in the traffic [10], since it can only be seen properly in a three-lane traffic model. The study involves fast and slow vehicles such as cars and trucks; and analyses the dynamic effects of different vehicle types to the system; and is designed to simulate closed circuit (i.e. having periodic boundary conditions) [10]. Furthermore, one can understand the DM model steps with the help of a similar model (RNSL) pseudocode found in Table 2.
DM model, like in RNSL, have two types of lane-changing models: asymmetric and symmetric. However, the description of asymmetric and symmetric lane-changing is different in DM model. In the asymmetric version, trucks are only allowed in second and third lanes (i.e. every lane except fast lane); where as in symmetric version, both cars and trucks are allowed to drive in every lane [10].

Lane changing model in DM is taken from Knospe *et al.* [11] two-lane exchange rules and adjusted for three-lane systems. In this model, a vehicle in lane 1 and 3 can change only to lane 2, whereas a vehicle in lane 2 can change its lane to either lane 1 or 3 [10]. The latter condition raises the issue of picking the correct lane to change to. This issue, according to [10], is resolved by the speed optimization criteria, i.e. vehicle changes its lane to the faster moving lane (where the precedessor is fastest). It is important to note that the issue of finding the correct lane to change can be dealt with the application of other methods, such as checking the gaps.

While the DM also accepts NaSch as its single-lane model, the extended lane exchanges parallel to the single-lane model can be given as follows [10]:

a) A vehicle that is not going with maximum speed, will hope to go faster. We denote this by $v_{hope} = \min(v+1, v_{\max})$. With the hoped velocity, we can define the incentive criterion, which determines if a vehicle wants to make a lane change:

- $v_{hope} > gap$

b) Consider the gaps presented in Fig 5. Now we extend this information to three-lane by adding (i, j) index to gaps, indicating the gap according to a vehicle in lane i that is considering to make a lane change to the lane j . For example, $gap_o(2,3)$ would be the gap from a vehicle in lane 2 to its successor vehicle in lane 3. It is important to add that $gap(i)$ still means the gap that belongs to ego vehicle at lane i .

With this information, the safety criteria for the DM lane-changing model can be described as follows:

- If the vehicle is in the lane i =1 or 3:
  - If $gap_o(i,2) > gap(i)$ and $gap_{o,back}(i,2) \geq v_{\max}$, the vehicle changes lane from lane i to lane.

- If the vehicle is in the lane i =2
  - If $gap_o(2,j) > gap(2)$ and $gap_{o,back}(2,j) \geq v_{\max}$, the vehicle changes lane from lane i to lane j .

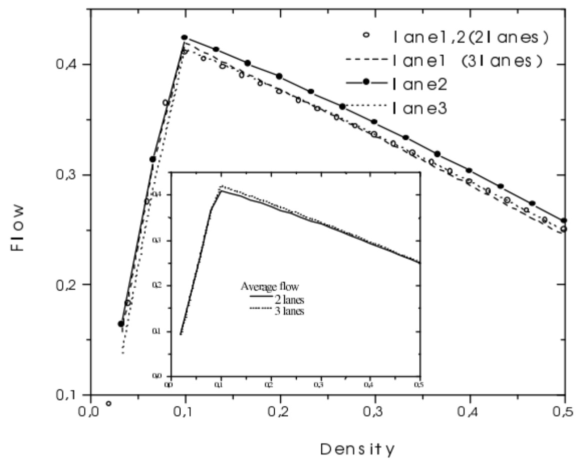

Fig 7. Flow/Density graph and Average flow graph obtained from DM [10]

Simulations using a homogeneous system (i.e. only fast cars in the system) with braking noise $P_{deceleration}$ = 0.4 (i.e. Probability of deceleration in N-S) and $v_{\max}$ = 5 gave several interesting results in [10]. These results can be observed in Fig 7 and Fig 8. First of all, Fig 7 shows the flow-density relation in such a system. One should see that average flow per lane in lanes 1 and 3 are similar, and the lane 2 has comparatively higher maximum flow. Additionally, it is also important that the flow reaches maximum at $\rho_{j\max} \approx 0.1$ which is expectedly around the previously mentioned changeover point $\rho_{j\max} \approx 0.08$. Secondly, looking at the Fig 8, one should get an idea of the lane changing frequency depending on the system density. With the lane changing dynamics presented by DM, one can see that the maximum number of lane changes occurs at densities much higher than $\rho_{j\max}$. We also observe that frequency of lane changes is much higher in two-lane system compared to three-lane system because of the fact that vehicles are able to optimize their speed by changing to a faster lane. Finally, the comparison of the ping-pong lane change (i.e. changing lanes in two consequtive time steps) frequency in two-lane and three-lane system is given in Fig 8. Since ping pong lane changes are not realistic, minimalising the frequency of ping pong lane changes are quite important. Fig 8 shows that the frequency is much lower in three-lane system compared to two-lane system. This indicates that the three-lane system presented by DM is closer to real traffic flow [10].

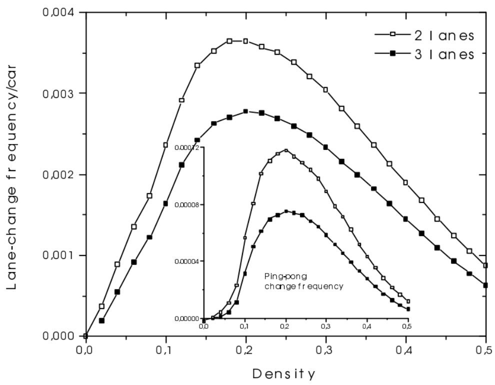

Fig 8. Lane changing frequency and ping-pong change frequency graphs obtained from DM [10]

DM also investigates the effect of having inhomogeneous traffic in asymmetric lane-changing model, i.e. introducing trucks to the system. In Fig 9, the flow-density fundamental graph that belongs to a system with 10% trucks and 90% fast moving vehicles are given with $P_{changelane,cars} = P_{changelane,trucks} = 0.4$. It is seen from the graph that in asymmetric three-lane model, flow of lane1 is considerably higher than others, and flow of lane2 is higher than lane3. This shows that lane1 is more fluid than others since slow-moving vehicles are not allowed in it. The center lane has a medium-degree flow since it allows lane-changing to and from a faster and a slower lane.

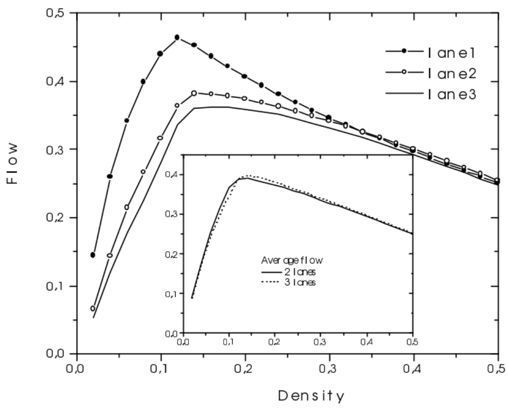

Fig 9. Fundamental graph of inhomogeneous traffic with 10% trucks [10]

Comparing the nonhomogeneous (only fast cars) and inhomogeneous models, one can obtain an interesting average flow/density graph, given in Fig 10. One should notice that the introduction of the symmetric lane changes improves the average flow. For the average flow, the homogeneous versions are more significant than the inhomogeneous versions [10].

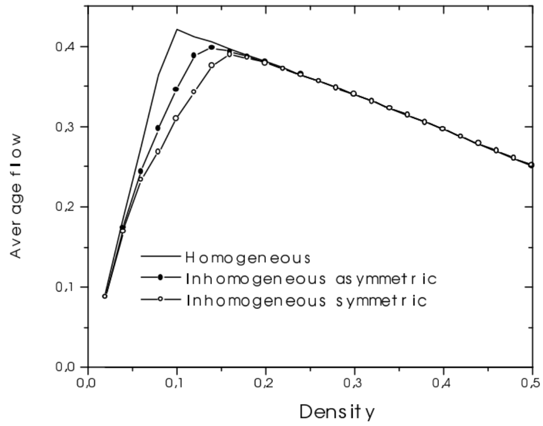

Fig 10. Comparison of homogeneous, inhomogeneous asymmetric, and inhomogeneous symmetric versions of DM model [10]

Please note that there are many discrete traffic models evolved from NaSch, RNSL, and D-M using different parameters. For further reading, we recommend to take a look at 2C/3C Models [9] developed by Benjamin Buna Benoso et al.

IV. TRAFFIC CONGESTION DETECTION AND PREDICTION

Traffic congestions are backbones for any traffic-related systems. Since the number of vehicles on the road is increasing each passing day, the cruciality of the traffic congestion problem is increasing. Considering that traffic congestions cause road rage, pollution, and waste of fuel, it is important that this problem is correctly addressed and prevented. In order to address the severity of the traffic congestion there are several technologies and methods proposed.

A. Understanding Traffic Congestion

Although we might constantly hear the phrase "traffic congestion", it is at most importance to understand what it means in traffic stream in order to detect and prevent it. Morris J. Rothenberg describes urban highway congestion as "a condition in which the number of vehicles attempting to use a roadway at any given time exceeds the ability of the roadway to carry the load at generally acceptable service levels" [12] [13]. The terms Levels Of Service (LOS) and Travel Time Index (TTI) are used in establishing a correct background in order to find how congested a road is. While LOS depends on Q/C (volume over capacity ratio), TTI can be defined as the ratio of peak-period travel time (rush hours) over free flow travel time [13]. It is important to understand that LOS gives an idea of how is the quality of the provided roads and services in a particular road and it varies between A and F. If a road is very congested as in picture F of Fig 11, then the dedicated LOS in that particular road is given as F.

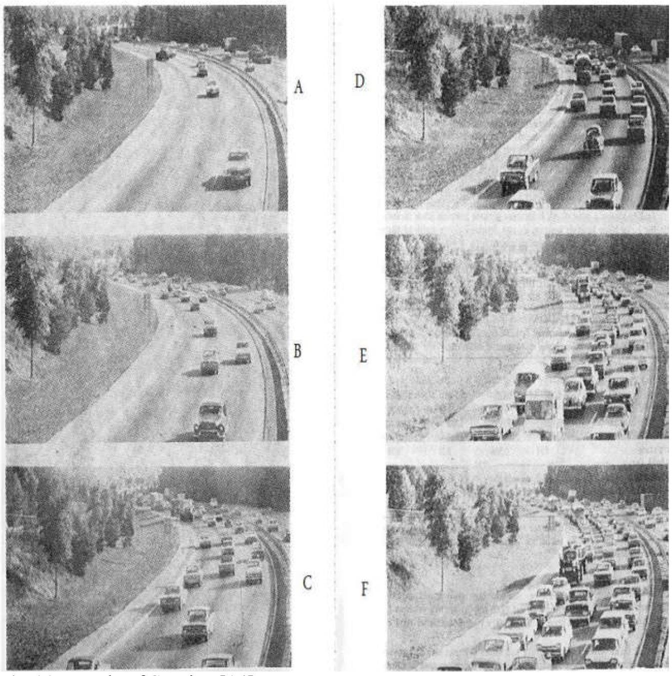

Fig 11. Levels of Service [14]

Levels of Service can be briefly given as follows [14]:
A- Traffic density is low, free flow situation. Speed of vehicles are determined by the will of the driver and the physical conditions on the road.
B- Traffic speed is slightly affected by traffic conditions. Drivers are still able to overtake and speed as they like.
C- Speed and overtaking is slightly affected by traffic volume.
D- Traffic volume can affect the speed of the vehicles greatly. Low comfort and the drivers are not able to overtake or speed freely.
E- Average speed is about 50km/h, lower comfort and freedom of drivers.
F- Traffic flow is lower than the capacity. Stop and go situation is observed very often.

As an example, work of [14] gives the levels of service for a road with maximum speed of 110km/h. It is seen from Table 3 that average speed of vehicles, density and traffic flow rate are highly correlated to Levels of Service, and thus the congestion levels.

Table 3. Levels of Service for a road with V max = 110km/h [14]

LOS	Density auto/km/lane	Speed km/h	Volume/Capacity Q/C	Maximum service flow rate vehicles/hour
A	≤ 7.5	≥ 91	0.36	700
B	≤ 12.5	≥ 85	0.54	1100
C	≤ 18.8	≥ 80	0.71	1400
D	≤ 26.3	≥ 64	0.87	1750
E	≤ 41.9	≥ 48	1.00	2000
F	> 41.9	< 48	varies	varies

It should be noticed that in Table 3, density is in vehicles/km/lane. This unit describes how many vehicles are in a kilometer road in each lane. For simulations, this term could be transferred to percentage using (6), with N_i being the number of automotives seen by the sensor in a particular lane, $\overline{l}$ being average length of vehicles, and L being the distance covered by the sensor. This expression can be extended for nonunifrom vehicles as in (7). One can plug in $N = \rho_{auto/km/lane}$ for $L = 1000m$ in order to calculate density in percentage $\rho_{\%}$.

$$\rho_{\%,lane_i} \approx \frac{N_i \overline{l}}{L} \qquad (6)$$

$$\rho_{\%,lane_i} \approx \frac{N_{trucks,lane_i} l_{truck} + N_{autos,lane_i} l_{auto}}{L} \qquad (7)$$

B. Traffic Congestion Detection

A review of traffic congestion detection technologies are made in [15]. Technologies that are used in traffic congestion detection are stated as Image Processing (using aerial images or images extracted from cameras mounted on the roads), Sensing Techniques (using sensing devices such as RADAR, LIDAR on roads), and Probe-vehicle based Techniques (using devices such as GPS and GSM for localization) [15]. For the Image Processing technique, there are several work that involves the methods of background extraction [16] [17] [18], foreground extraction [19] [20], and aerial images [21] [22]. For the Sensing Techniques, inductive loop sensors [23] [24], magnetic sensors [25] [26], and acoustic sensors [27] are mostly used. Finally, for the Probe-vehicle based techniques there are several work that uses GPS [28] [29] and smartphones [30] in order to deal with traffic congestion detection. It is stated in [15] that using Image processing has the limitation of computational complexity and sensitivity to external events and lighting. It is added that Sensing Techniques have the limitation of the need for maintenance and installation efforts. The limitation for the Probe-vehicle based techniques is mentioned as the fact that proliferation of GPS receivers in vehicles is low [31] [15].

While the mentioned technologies help us find the traffic stream parameters, it is needed that those data is gathered and converted to useful traffic congestion information. The technologies are used to determine parameters such as traffic density ρ, average speed of the vehicles $\overline{V}$, and traffic flow q. Using these parameters, one should obtain the accurate congestion levels in order to correctly judge in which degree a road is congested. As an example, works of [32] [33] uses weighted average of parameters, whereas [13] uses Fuzzy Logic in order to combine the traffic stream parameters in a meaningful way. We can add that the congestion levels can also be improved by using statistical information of the road that is is being used (as in the work of Grabec et al. [34]) and offline simulations.

C. Traffic Congestion Prediction

As the traffic congestion problem grows everyday, maintaining and controlling an acceptable traffic flow gains more importance. To that purpose, engineers have been looking into ways to predict the traffic congestion in order to avoid them by taking measures such as regulating the traffic flow at bottlenecks. Congestion avoidance techniques are emerged from traffic congestion prediction.

There are several proposed methods that are used in traffic congestion prediction and avoidance. These methods involves usage of the same technologies mentioned in the section B-Traffic Congestion Detection. There are two types of traffic congestion prediction :(1)-short term forecasting, (2)- long term forecasting. In the short term forecasting, the traffic congestion is predicted a few minutes away from it by observing intersections and flow inputs from other roads, whereas in the long-term forecasting the past traffic history statistics are analyzed and combined with real-time information for a longer term prediction. A good example of forecasting the traffic congestion (in other words, traffic congestion prediction) is given in [35]. This work uses road agents, vehicle counting sensors and a central server to gather data from intersections and other roads (given in Fig 12) in order to forecast traffic flow. Additionaly, we can give the example of [34] for the long-term forecasting of congestion in which roads and bottlenecks are statistically analyzed in order to predict the traffic [35].

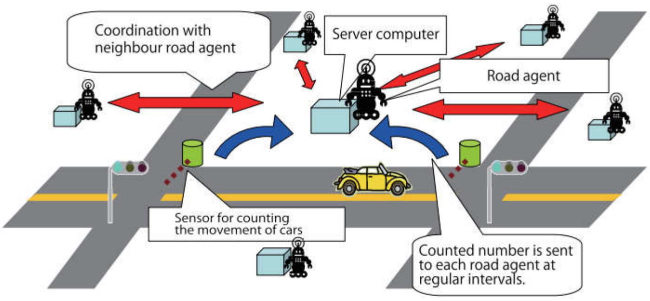

Fig 12. Pheromone-based Traffic Prediction Road Model [35]

After the traffic is predicted, congestion avoidance technologies are applied in order to prevent traffic congestion. These technologies are reviewed in [15] and involve Vehicle rerouting using Prediction algorithm, Vanet-based prediction, and Signal timing optimization. In Vehicle rerouting, a congestion avoidance algorithm is used that involves Extended Kalman Filter. In Vanet-based prediction, Vehicle-to-Vehicle and Vehicle-to-X technologies are used in order to talk about other agents that knows the vehicle status. Signal timing optimization focuses on interfering with traffic lights in order to regulate congestion. Using the strategies and technologies mentioned, the congestion avoidance becomes possible in both short-term and long-term durations [15].

V. Conclusions

Traffic problem is growing each passing day. We name the 'problem of having higher density of what a road could handle on a road' as traffic congestion. The most important criteria in determining road congestion can be given as Levels of Service (LOS). In order to assess and prevent traffic congestions, one should know about traffic modeling, traffic congestion detection, analysis, and prediction. In this paper, we tried to give an outlook to traffic congestion detection and prediction, as well as describing a few discrete traffic models including Nagel-Schreckenberg, RNSL, and DM models. These models have several types such as multi-lane, asymmetric, and symmetric types. As our traffic model gets more realistic due its parameters and properties, it should be expected that the retrieval of basic traffic stream parameters and the traffic congestion assessment will be more accurate.

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