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TO MEASURE SPEED FLOW DENSITY RELATIONSHIP BETWEEN TWO DIFFERENT ROADS

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ABSTRACT: Nowadays congestion is one of the major problems prevalent on National Highways of India. In this respect, a better traffic management requires a clear understanding of traffic flow operations. For this purpose, during the recent past many models have evolved to replicate the complex traffic flow phenomenon, though with little success. In this review the applicability of different models are discussed in general. The application of Cellular Automata based models considering the heterogeneity of Indian traffic is discussed in detail. It was observed that Cellular Automata models offer fast and efficient means of simulating the homogeneous highway traffic. However, this efficiency may have to be sacrificed for variable vehicle types in heterogeneous traffic environment.

I. INTRODUCTION

The interaction between different vehicles, their drivers and the infrastructure give rise to many complex phenomena on our roads. Traffic flow theory describes these traffic phenomena and reproduces them through mathematical models. These dynamic traffic models are of practical significance in a variety of ways. First and foremost, they help explain traffic phenomenon. They both steer and stimulate the search into the true mechanism of the traffic process.

As the traffic increases these models are becoming very significant in managing the traffic with the existing infrastructure. Dynamic traffic models play an important role in the operation of the traffic process. Predicting the effects of various scenarios, computing traffic control strategies and making real time forecasts of traffic situations are some of the practical application areas of these models. Detailed models accurately replicate the behavior of individual vehicles. Since it is practically impossible to reproduce the exact decision making mechanism of individual drivers, these models resort to a probabilistic approach.

As far as Indian traffic is concerned it is composed of several vehicle types and among those buses, cars, trucks and two wheelers are predominant. The main difficulty in modelling this mix of traffic is to replicate the driving behavior of different vehicle drivers and simulating their movement. Vehicles observed in Indian traffic widely differ in their size, control and guidance system as well as in performance capability. The difference in static and dynamic characteristics of vehicles affects the traffic flow. Due to the complex flow process, absence of lane markings, and avoidance of regulatory measures, drivers are not able to maintain lane discipline. Variation in dimensions of different Categories of vehicles significantly affect overtaking and passing maneuvers. Wide-bodied vehicles such as trucks, occupy the full lane while moving, whereas smaller two or three-wheelers can travel side by side in one lane. All these features make it difficult to model the traffic at microscopic level. In the recent past, Cellular Automata (CA) model, a new technique has evolved to model complex traffic interactions based on simple rules (Nagel and Schreckenberg, 1992). Nagel – Schreckenberg (NS) model has many advantages over the conventional models in terms of efficiency. However its applicability for the heterogeneous traffic environment is not known. An attempt has been in this paper to explore the possibility of modelling heterogeneous traffic on National Highways of India.

Organization of this paper is as follows: Section 2 discusses typical traffic characteristics on the highways. In Section 3, several models are discussed briefly for their suitability of traffic flow modeling. Cellular Automata based traffic flow models and its variants are discussed thoroughly in Section 4. Considering the heterogeneity of Indian traffic, a few modifications for Cellular Automata models are discussed in Section 5. Summary of the paper is given at the end.

II. BACK GROUND

One of the practical questions concerning traffic flow modeling even under largely homogeneous traffic flow conditions is, what is the fundamental relationship between flow and density? Obviously traffic flow phenomenon strongly depends on the occupancy of the road. So long as the density is small, flow is independent of density as the vehicles are too far apart to interact mutually. Therefore, at sufficiently low density of vehicles, practically “free flow” takes place. The forward movement of vehicles is strongly hindered by others because of the reduction in the average separation between them.

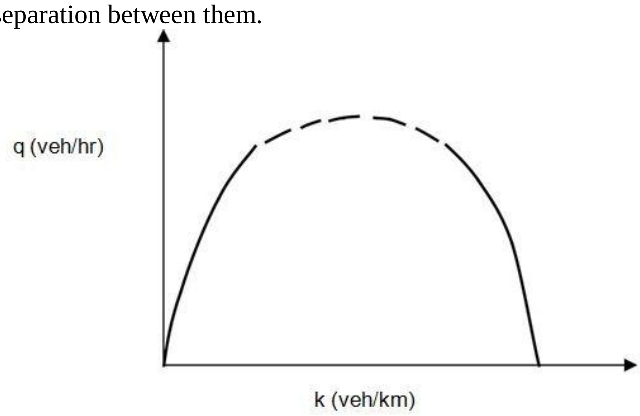

Fig. 1: Flow – density relationship

A faster than linear monotonic decrease in the speed with increasing density can lead to maximum flow at maximum density. Beyond maximum density increase in density would lead to overall decrease of flow. A typical flow density diagram is as shown in Fig. 1. However contrary to this naïve expectation in recent years some nontrivial variation of flow with density has been observed. The nature of variation of flow with density is still not clearly understood.
In Fig. 2, a typical time-averaged local measurement of the density and flow is shown. At low densities the data indicates a linear dependence of the flow on density. In contrast strong fluctuations of the flow exist at large densities, which prevent a direct evaluation of the functional form at high densities. After several empirical studies, discontinuity of the fundamental diagram seems to be well established while no consistent picture for the high-density branch exists. In several situations it has been observed that flow does not depend uniquely on density. In an intermediate regime of density; it indicates the existence of Hysteresis effects and Meta-stable states. In the context of traffic flow hysteresis means: if a measurement starts in the free flow regime, an increase in the density leads to an increase of the flow up to a certain density beyond which a further increase of density leads to a discontinuous reduction of the stationery flow and jams emerge.

The results for the flow density relation also suggest the existence of at least two dynamical phases of vehicular traffic, namely a free flow phase and a congested phase. Careful empirical observations in the recent years indicate the existence of two different congested phases, namely, the synchronized phase and the stop-and-go traffic phase (Kerner, 1996).

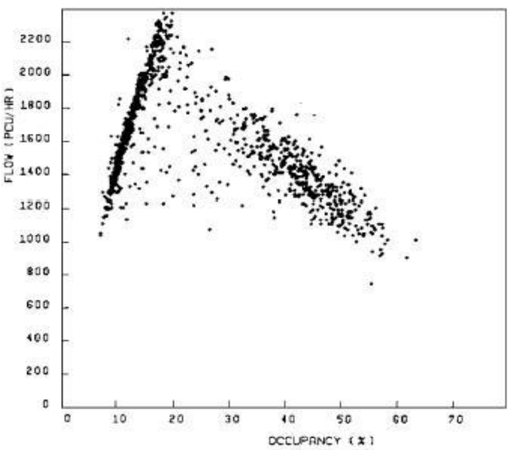

Fig. 2: Time averaged flow density relationship.

Vehicles move rather slowly in synchronized states, as compared to the free flow state, but the flow in this state can take a value close to the optimum flow value because of relatively small headways. The stop-and-go traffic differs from the synchronized states in the sense that every vehicle inside a jam comes to a complete halt for a certain period of time.

III. REVIEW OF DIFFERENT MODELLING APPROACHES:

Based on the level-of-detail the modelling approaches can be classified into three types (Hoogendoorn and Bovy, 2001), namely:
Microscopic models, e.g. Car following models, CA models
Mesoscopic models, e.g. Gas Kinetic models
Macroscopic models, e.g. LWR models, Cell Transmission models
Microscopic Models – Car following models:
Microscopic models describe traffic operations during discrete time intervals over continuous time. Amongst these, the car following models, namely safe-distance models, stimulus- response models and psychos pacing models the former models are the foundation for a number of contemporary microscopic simulation models. Krauss et. al. (1999), addressed the issues like capacity drop, and stability of jams in microscopic models. The multitude of parameters in these models can render them somewhat obscure and require a lot of computing power.

Mesoscopic Models – Gas Kinetic theories of vehicular traffic:
Mesoscopic models bridge the gap between macroscopic and microscopic models by combining the aggregate traffic flow variables with the assumptions on the interaction between vehicles. In kinetic theory, traffic is treated as a gas of interacting particles where each particle represents a vehicle. Instead of describing the traffic dynamics of individual vehicles, gas-kinetic traffic flow models describe the dynamics of the velocity distribution functions of vehicles in the traffic flow. Recent years have shown an increasing interest in the application of gas kinetic traffic flow models (Hoogendoorn, 1999; Klar& Wegener, 1999).

Macroscopic Models – LWR model:
In the 1950's Lighthill (L) and Whitham (W), and Richards (R) independently developed the first dynamic traffic model. The LWR model describes the traffic on a link using conservation law. The strongest point of the LWR model is its capacity for analytical solutions. The fundamental diagram is the prime parameter of the LWR model. It shows the relation between flow q and density k when traffic is stationary and homogeneous. Because of this non-homogeneous and non-stationary nature of real traffic cannot be modeled with this fundamental diagram. Several advancements are made to describe non-stationary and heterogeneous characteristics of traffic flow. Each time an extension of the LWR model requires new assumptions regarding the traffic mechanism while new parameters increase the input for the model thus losing the analytical tractability.

IV. CELLULAR AUTOMATA FOR TRAFFIC FLOW MODELLING

Cremer and Ludwig (1986) proposed the first cellular automata (CA) model for vehicular traffic. A CA approach to traffic simulation is potentially useful in order to achieve a very high computational rate in microscopic simulation, and to facilitate distributed computing. There are many obvious reasons for this, for example

- The rule set that describes the update of each vehicle is very small;
- Different pieces of roadway are represented in identical or nearly – identical ways;
- The update schedule, being completely parallel, is extremely simple

and there is one additional, more subtle reason for the high speed of CA: much of the behavioral pattern of the vehicles is computed implicitly. The beneficial aspect of using implicit computation is that it minimizes the computation and thereby increases speed. In the CA models of traffic the position, speed, acceleration as well as time are treated as discrete variables. In this approach, a lane is represented by one-dimensional lattice.Each of the lattice sites represents a cell (Length 7.5m), which can be either empty or occupied by at most one vehicle at a given instant of time (see Fig. 3).

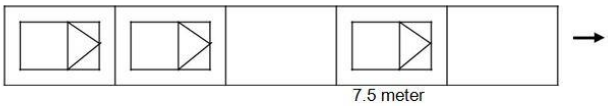

Fig. 3: A typical configuration of Nagel-Schreckenberg (1992) model

Basic variables of the CA:
The variables of the CA (i.e. positions, velocities) are all in units of lattice spacing. It is relatively easy to determine what this unit must correspond to in reality. The cell length in the CA lattice corresponds to the space a vehicle occupies in a jam. This is composed of vehicle length *l*, and some spacing $gap_{jam.}$ As a consequence, if one knows the average vehicle density at a complete standstill, $k_{jam,}$ then the cell length is given by

$$L = \frac{1}{k_{jam}} \qquad (1)$$

The maximum speed v_{max} in CA model is the maximum speed attainable in reality. The parameter v_{max} roughly determines the density at which maximum flow occurs, and so we can use this density to set v_{max} .

In CA setup time is entirely implicit, and is derived from some knowledge of the traffic being simulated.

$$\tau = \frac{L * (v_{max} - p)}{v_{max}^{real}} \qquad (2)$$

where the denominator is the real maximum velocity.
At each discrete time step the state of the system is updated following a well-defined prescription. The computational efficiency of the discrete CA models is the main advantage of this approach over the car-following models. The updating procedure at each time step is according to the following rules;
Step 1.Acceleration. If v_n is less than v_{max} the speed of the nth vehicle is increased by one but v_n remains unaltered if $v_n = v_{max}$, i. e.,

$$v_n \rightarrow \min (v_n + 1, v_{max}).$$

Step 2.Deceleration (due to other vehicles). If $d_n < v_n$ the speed of the nth vehicle is reduced to $d_n – 1$, i. e.,
$v_n \rightarrow \min(v_n, d_n - 1)$.
Step 3.Randomization. If $v_n > 0$, the speed of the nth vehicle is reduced randomly by unity with probability p but v_n does not change if $v_n = 0$, i. e.,
$v_n \rightarrow \max(v_n - 1, 0)$ with probability p.
Step 4.Vehicle movement. Each vehicle is moved forward according to its new velocity determined in steps 1 to 3, i. e.,
$x_n \rightarrow x_n + v_n$
The NS model is a minimal model in the sense that all the four steps are necessary to reproduce the basic features of real traffic; however, additional rules need to be formulated to capture more complex situations. The randomization in step 3 takes into account the different behavioral patterns of the individual drivers, especially, non-deterministic acceleration as well as overreaction while slowing down; this is crucially important for the spontaneous formation of traffic jams.

Generalizations and extensions of the NS model:
As stated earlier, the NS model is a minimal model. The first obvious possible generalization would be to replace the acceleration stage of updating rule to
$v_n \rightarrow \min (v_n + a_n, v_{max})$,
where$a_{n,}$ acceleration assigned to the nth vehicle, need not be unity and, in general, may depend on n.

Slow-to-start rules, meta-stability and hystersis:
The slow-to-start rules can lead not only to meta-stability and, consequently, hystersis, but also to phase separated states at high densities. Takayasu and Takayasu (1993) were the first to suggest a CA model with slow-to-start rule.

Benjamin et al. (1996), modified the updating rule of the NS model by introducing an extra step where their “slow-to-start” rule is implemented; this slow -to-start rule is different from that introduced by TT model. According to the BJH rule, the vehicles which had to brake due to the next vehicle ahead will move on the next opportunity only with probability $1 – p_s$.

Barlović et al., (1998) proposed velocity dependent randomized model which exhibits meta-stable states and hysteresis. Here, in contrast to the original NS model, the randomization parameter depends on the velocity of the vehicle.

CA model for Multi-lane highways:
For a realistic description of traffic on highways the idealized single lane models must be generalized to develop CA models of multi-lane traffic; the main ingredient required for this generalization being the lane-changing rules. Two general prerequisites have to be fulfilled in order to initiate a lane change: first, there must be an incentive and second, the safety rules must be fulfilled. Rickert et al. (1996), have proposed a model according to these rules.

V. CA MODELLING ADVANTAGES

The basic idea of CA is not to try to describe a complex system using difficult equations, but simulating this system by interaction of cells following easy rules. Many complex systems may be broken down into identical components, each obeying simple laws, and the huge number of components that make up the whole system act together to yield very complex behaviour. CA provides mathematical models for a wide variety of complex phenomena, from turbulence in fluids to patterns in biological growth.

As seen in the previous section on CA models, they are very much capable of simulating complex traffic flow phenomenon with minimum computational effort. Coming to Indian traffic scenario the situation is more complex. In this case number of states associated with each cell is quite high. The typical road occupation of vehicles on Indian roads is shown in Fig. 4. Each small grid is considered as a single cell in the two-dimensional lattice.

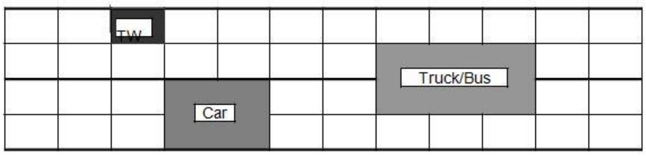

Fig. 4: Cells occupied by various vehicle types

Relevance of CA modeling for Indian Traffic:
As discussed earlier the parameters of the cellular automata model are obtained from the features observed from the traffic to be modeled. In this way one can get more appropriate parameter values suitable to model the heterogeneous traffic. Barrett, et. al., (1995), discussed the implications of refining the cell size. According to them, by refining the lattice one can represent all the length variables in the simulation and hence all velocity and acceleration possibilities also. Recently Ez-Zahraouyet. al., (2004) demonstrated the effect of mixed lengths of vehicles in the one dimensional CA model. One obvious way to take advantage of this refinement is to set up the initial conditions at new finer scale. One disadvantage in enhancing the resolution of the CA is that it leads to slower computing speed. Using some of the automata rules a modified CA model for simulating the heterogeneous traffic flow on national highways is discussed in detail in Sinha et al. (2005).

VI. SUMMARY

An overview of the traffic flow modeling is presented here. It was observed that for nearly homogeneous traffic CA model has advantage over several other models. As this model has provision for inclusion of several kinds of vehicles, and their mechanical characteristics with further inclusion of fineness, CA model can be applied for modeling heterogeneous traffic. In order to model the absence of any lane following characteristic of heterogeneous traffic, CA models used for modelling pedestrian dynamics might be useful.

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