Automata 2007
13th International Workshop on Cellular Automata

Traffic flow modelling with safety embedded notions

María Elena Lárraga

Instituto de Ingeniería

UNAM

México

mlarragar@iingen.unam.mx

Joint work with: L. Álvarez-Icaza

On leave from Facultad de Ciencias, UAEM

Why to model traffic flow?

Traffic jam is one of the most serious issues in modern societies

Introduction

•Ecological considerations, space and budget constraints limit solving traffic congestion by upgrading and constructing new roadway systems.

Solutions are now oriented to a better management of existing systems and thus to

- solve traffic congestion,
- decrease environmental issues and
- improve traffic safety.

Traffic flow

Traffic = macroscopic system of interacting particles

Various approaches:

- hydrodynamic
- gas-kinetic
- car-following
- cellular automata (CA)

Cellular automata?…

Why are CA able to model traffic flow?

Cellular automata are able to reproduce many aspects of highway traffic (despite their simplicity):

- Spontaneous jam formation
- Metastability, hysteresis
- Existence of 3 phases: Free, synchronized and jam flow)

Advantage: Simulations of networks faster than real-time possible

- Online simulation
- Forecasting

What are the specific properties that should be considered by a realistic traffic model?

(i)Velocity anticipation: the anticipation of the leaders velocity avoids abrupt braking of the traffic behind and therefore reduces the probability to form jams.

(ii)Retarded acceleration: Comfortable driving also implies that cars do not accelerate immediately in case of a larger gap ahead if they observe slow downstream traffic.

(iii)Timely braking: Finally, timely braking suppresses another mechanism of jam formation: When the velocity adjustment is only based on the distance to the next car ahead, jams often emerge in the layer between free-flow and synchronized traffic.

-The drivers to adjust their speed to the vehicles ahead.

Lárraga, et al, J. Phys A:Math and Gen. 2004;

Lárraga, et al., Trans. Res. Emergent Techs, C, 2005

Realistic traffic models

- To anticipate the actions of other cars in the next timestep.

- This implies that drivers need more information about the next car ahead, not just its distance.

New model…

Different models

Nagel-Schreckenberg model (NaSch)

1. acceleration (up to maximal velocity)
2. braking (avoidance of accidents)
3. randomization (“dawdle”)
4. motion

plus:

Safety distances

velocity anticipation

smaller cells

Realistic acceleration and deceleration capabilities

Emergency braking

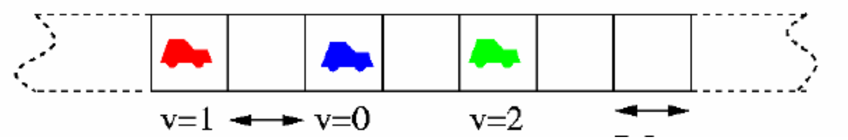
…

LA model

Lárraga-Álvarez, 2007

Our model

The model



- The street is divided into L cells of length Δx m

- Δx can take values of 1.25, 2.5 or 5m that is a finer discretization than the used in NaSch model.

- For all cases, the car length is 5m, i.e., a car occupies $l_c=5/\ \Delta x$ cells.

- Vehicles can only have integer velocity values, $v_i=0, 1, ..., v_{max}$.

- We used $v_{max}=6*l_c$ *, which is equivalent to 108 km/h* in real world units (24, 12 and 6 cells).

- This corresponds to time steps $\Delta t = 1$s.

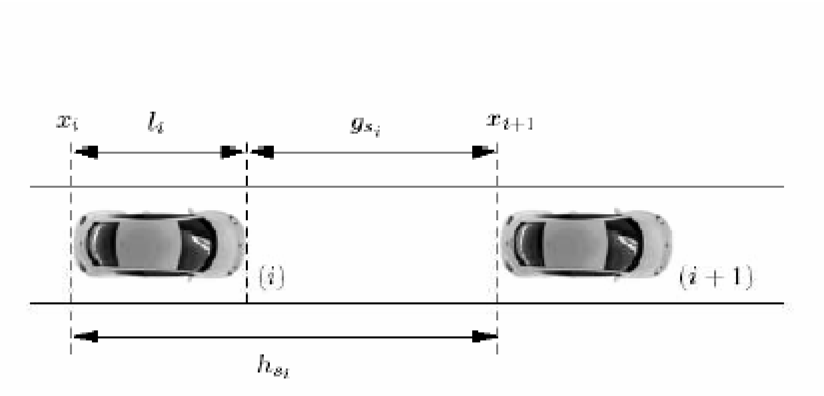
Rules of change

Variables

•The *nth* car is characterized by its position $x_n(t)$ and velocity $v_n(t)$ at time t.

•Cars are numbered in the driving direction, i.e. vehicle

(n + 1) precedes vehicle *n*.



•The gap between consecutive cars (where *s* is the length of the cars in cells) is

$$d_n = x_{n+1} . x_n - s$$

–It is assumed that a vehicle position denotes the cell that contains its rear bumper

Dynamic

R0: Read its safety distances $d_{decc}(t)$, $d_{acc}(n)$ and $d_{keep}(t)$ from matrixes D, A and K respectively

R1: Acceleration.

If $d_n(t) \geq d_{acc_n}(t)$, the velocity of the car n is increased by one, i.e.,

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

R2a: Cruising.

If $d_{acc_n}(t) > d_n(t) \geq d_{keep_n}(t)$, velocity of vehicle n is kept equal with probability $1-R$, i.e.,

$$v_n(t+1) \rightarrow v_n(t) \text{ with probability } 1-R.$$

R2b: Random braking.

If $d_{acc_n}(t) > d_n(t) \geq d_{keep_n}(t)$ and $v_n(t) > 0$, velocity of vehicle n is reduced by one with probability R:

$$v_n(t+1) \rightarrow max(v_n(t)-1, 0) \text{ with probability } R.$$

R3: Braking.

If $d_{keep_n}(t) > d_n(t) \geq d_{decc_n}(t)$ and $v_n(t) > 0$, velocity of vehicle n is reduced by one:

$$v_n(t) \rightarrow max(v_n(t)-1, 0)$$

R4: Emergency braking.

If $v_n(t) > 0$ and $d_n(t) < d_{decc_n}(t)$, velocity of vehicle n is reduced by M, provided it does not go below zero:

$$v_n(t+1) \rightarrow max(v_n - M, 0)$$

R5: Vehicle movement.

Each vehicle is moved forward according to its new velocity determined in rules 1-4:

$$x_n(t+1) \rightarrow x_n(t) + v_n(t+1)$$

Safety distances

$$
\begin{aligned}
d_{accce_n}(t) = \frac{M}{2}&[[(v_n(t)+1) \ \ \textbf{Div} \ \ M]+1][(v_n(t)+1) \ \ \textbf{Div} \ \ M] \\
&+[(v_n(t)+1) \ \ \textbf{Mod} \ \ M][[(v_n(t)+1) \ \ \textbf{Div} \ \ M]+1] \\
&-\frac{M}{2}[[(v_{n+1}(t)-M) \ \ \textbf{Div} \ \ M]+1][(v_{n+1}(t)-M) \ \ \textbf{Div} \ \ M] \\
&-[(v_{n+1}(t)-M) \ \ \textbf{Mod} \ \ M][[(v_{n+1}(t)-M) \ \ \textbf{Div} \ \ M]+1]
\end{aligned} \tag{1}
$$

$$
\begin{aligned}
d_{keepn}(t) = \frac{M}{2}&[[v_n(t) \ \ \textbf{Div} \ \ M]+1][v_n(t) \ \ \textbf{Div} \ \ M] \\
&+[v_n(t) \ \ \textbf{Mod} \ \ M][[v_n(t) \ \ \textbf{Div} \ \ M]+1] \\
&-\frac{M}{2}[[(v_{n+1}(t)-M) \ \ \textbf{Div} \ \ M]+1][(v_{n+1}(t)-M) \ \ \textbf{Div} \ \ M] \\
&-[(v_{n+1}(t)-M) \ \ \textbf{Mod} \ \ M][[(v_{n+1}(t)-M) \ \ \textbf{Div} \ \ M]+1]
\end{aligned} \tag{2}
$$

$$
\begin{aligned}
d_{dec_n}(t) = \frac{M}{2}&[[(v_n(t)-1) \ \ \textbf{Div} \ \ M]+1][(v_n(t)-1) \ \ \textbf{Div} \ \ M] \\
&+[(v_n(t)-1) \ \ \textbf{Mod} \ \ M][[(v_n(t)-1) \ \ \textbf{Div} \ \ M]+1] \\
&-\frac{M}{2}[[(v_{n+1}(t)-M) \ \ \textbf{Div} \ \ M]+1][(v_{n+1}(t)-M) \ \ \textbf{Div} \ \ M] \\
&-[(v_{n+1}(t)-M) \ \ \textbf{Mod} \ \ M][[(v_{n+1}(t)-M) \ \ \textbf{Div} \ \ M]+1]
\end{aligned} \tag{3}
$$

M=time-steps to reach the minimum allowable deceleration

Three fixed tables are generated: $A_{(vmax+1)\times(vmax+1)}$, $K_{(vmax+1)\times(vmax+1)}$, $D_{(vmax+1)\times(vmax+1)}$

Distances meaning

Safety distances

- In each term in the r.h.s. of the equations (1)-(3), we incorporate implicit anticipation effects and reduced acceleration and deceleration capabilities by means of relative distances (according to cars' velocities).

- Each term on the r.h.s. is derived based on the kinematics of two neighbor vehicles, assuming that in the next time step the leader vehicle will apply full brakes.

- The equations predict the traveled distance by each vehicle. The difference between these two distances yield the safety gap.

Interpretation of the Rules

R1. Acceleration: Drivers want to move as fast as possible (or allowed)

R2a Cruising: Drivers will try to keep their velocites if they perceive the distance with the vehicle in front as sure.

R2b Random braking

a) overreactions at braking

b) delayed acceleration

c) psychological effects (fluctuations in driving)

d) road conditions

R3 Braking: In normal situations driver decelerates to expand the gap to reach his/her desired gap and keep safety.

R4 Emergency braking: Avoid accidents when the leader brakes suddenly or follower approaches a stopped vehicle

R5 Driving: Motion of cars

Example: Safety distances

Δx=2.5 m → s=2, M=2

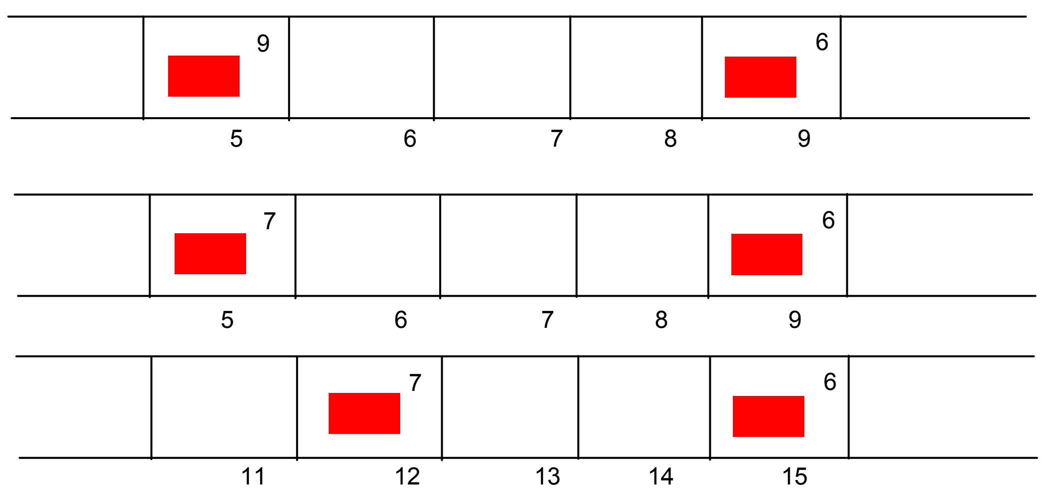
Maximum acceleration= 2.50 m/s^2 (0-100 km/h in 12 s)

Emergency braking= -5.00 m/s^2

v_{max}=12 cells =108 km/h → d_{acc}= 24, d_{dec}=19, d_{keep}=14

Configuration at time t:

Motion (state at time t+1):



Aim

- To reproduce macroscopic and microscopic traffic flow behavior.

- To guarantee that microscopic vehicle behavior follows capabilities of real ones by incorporating implicit anticipations effects and reduced acceleration and deceleration capacities.
    - To reproduce a real driver behavior.

- To preserve the simplicity of CA models.

Simulation Results…

Real values

- Emergency braking in all cases of Δx will have a value of $-5 m/s^2$ and will be reached in one time-step.

- Maximum acceleration will be 5 m/s^2, 2. 5 m/s^2 and 1.25 m/s^2 for cell lengths of 5.00 2.50 and 1.25 m, resectively.

Fundamental diagram

R = 0.15

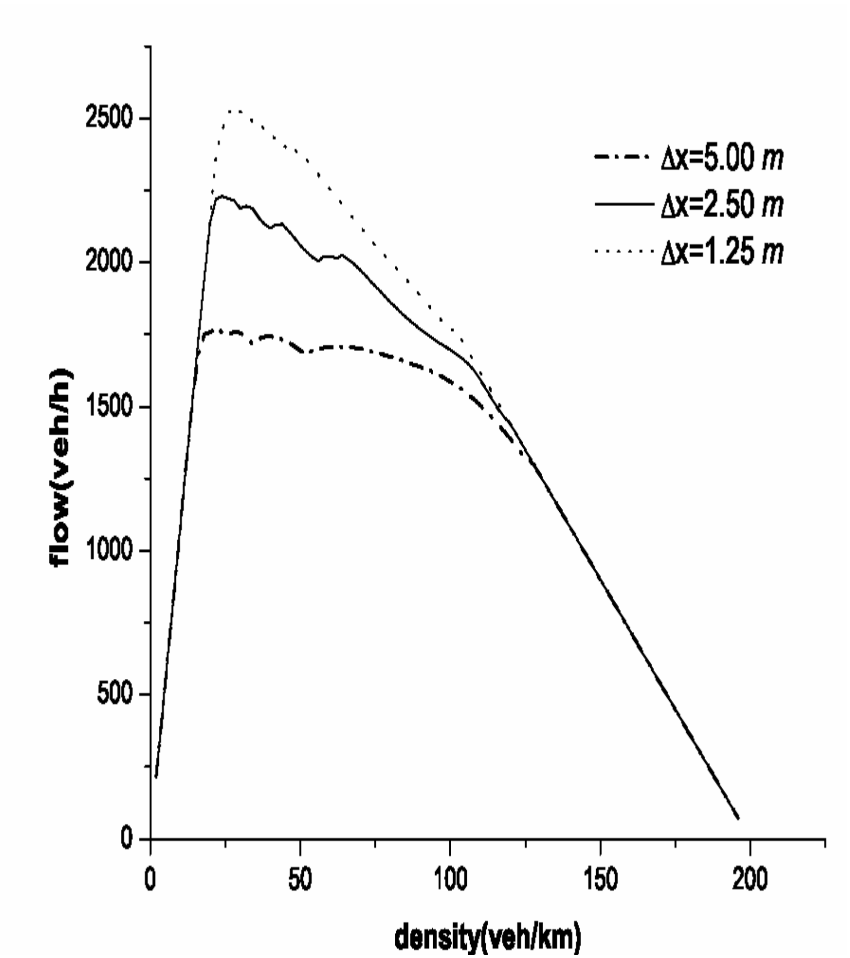
L = N_{max} *s, N_{max} =10,000

Density ρ=N/L varying from 2 to 200 veh/km in steps of 2 veh/km in real units.

Smaller values of Δx, that is lower acceleration levels, imply larger flows.

T = 15*N_{max} time-steps

•Data are averaged over the final 5*N_{max} time-steps.



Traffic flow organization

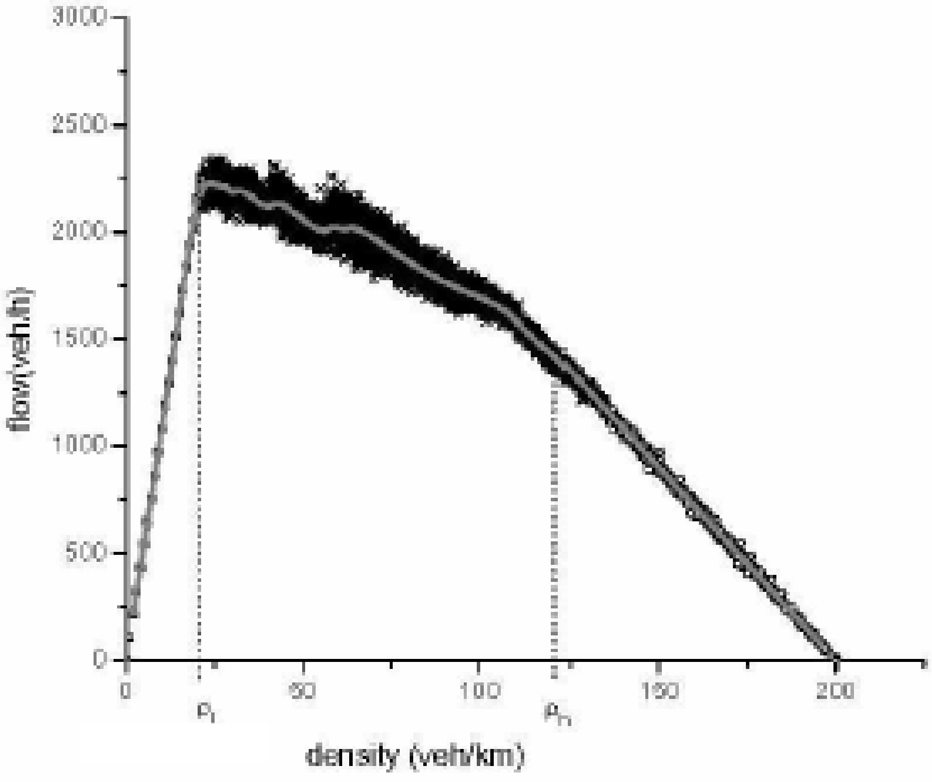


Figure 3. Fundamental diagram resulting from random initial conditions. The simulations are performed on a ring with a length of 20000 cells, each corresponding to 2.5 m. The parameters of the model are $v_{max} = 108\ km\ h^{-1} = 12\ cells\ s^{-1}$, $R = 0.15$, $\Delta x = 2.5\ m$, and $M = 2$

Space diagrams

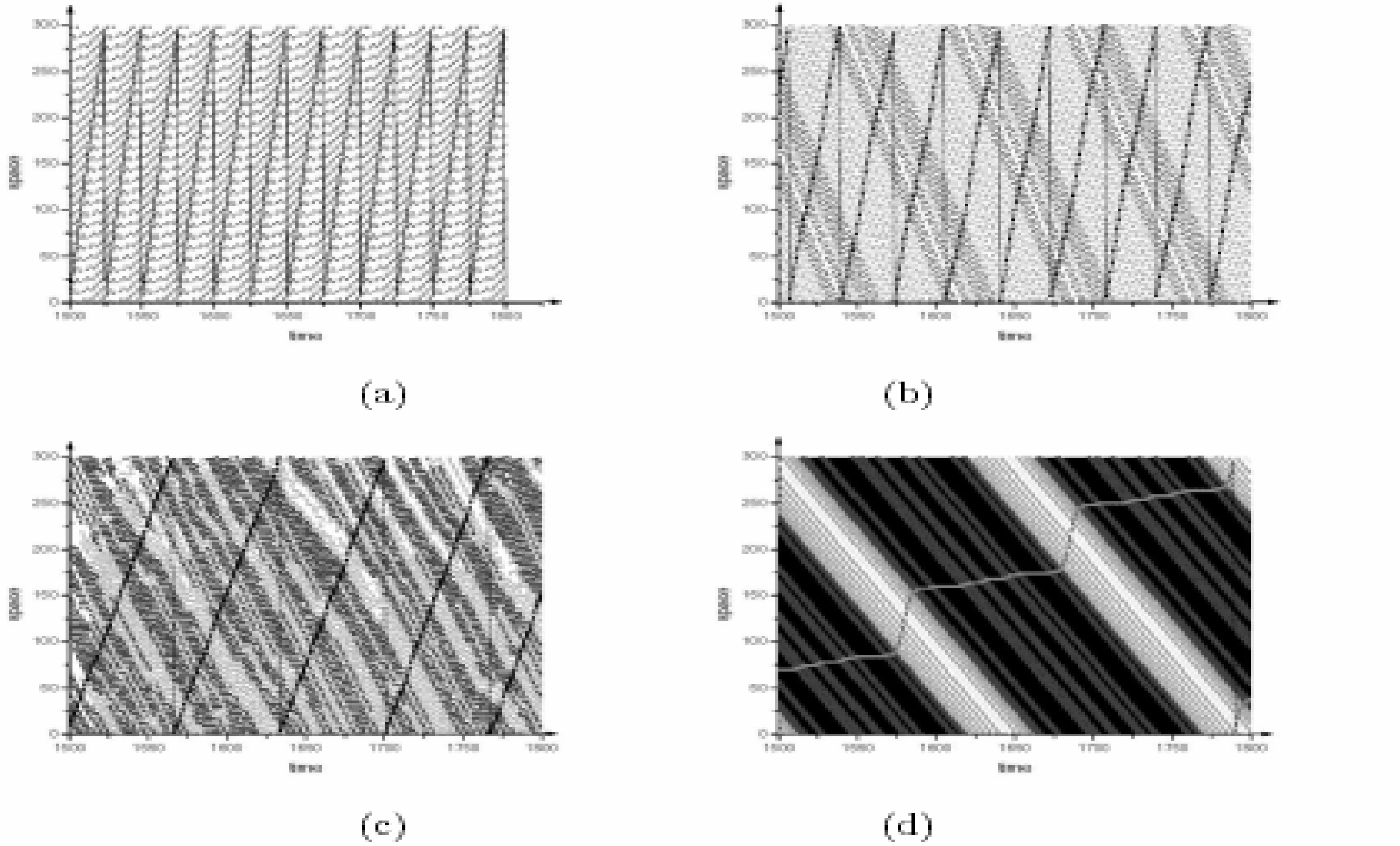
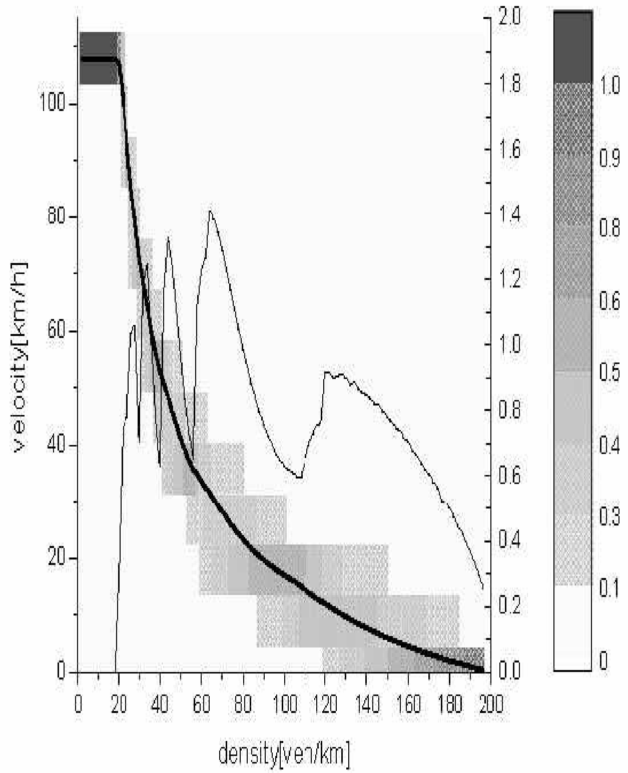
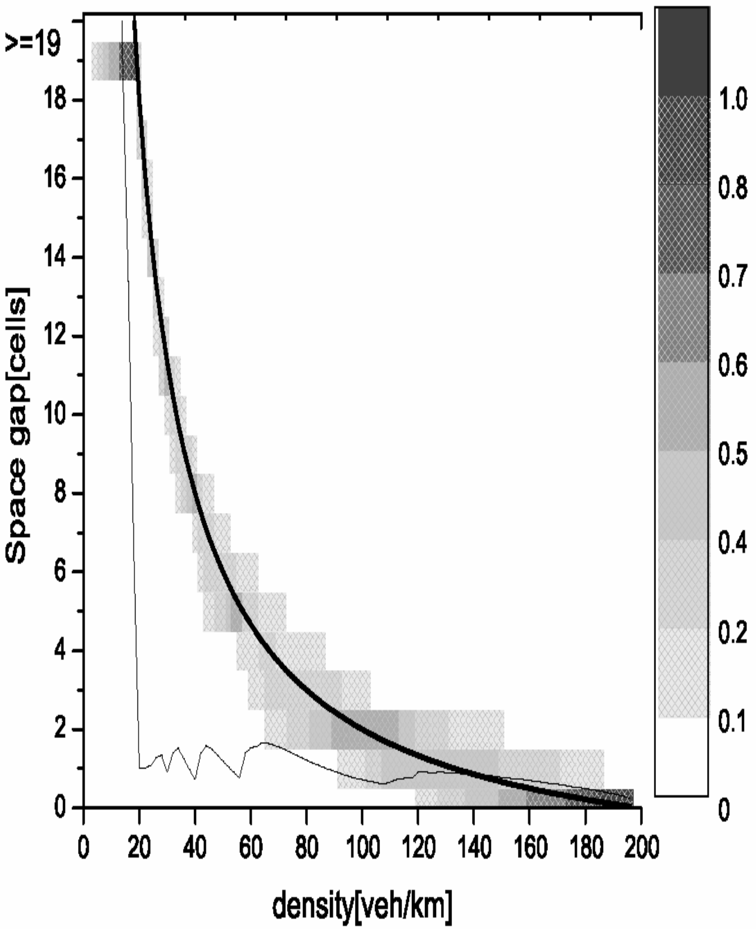


Fig ie-space diagram for $R = 0.15$, $\Delta x = 2.5\ m$ and different values of density. The solid lines in diagrams correspond to the trajectory for a specific car at different time-steps. (a) corresponds to a low density range, for $\rho = 16\ veh/km$. (b)-(c) correspond to a intermediate density range for $\rho = 30$ and $\rho = 50\ veh/km$, respectively. (d) corresponds to $\rho = 140\ veh/km$

Speed and gap distribution





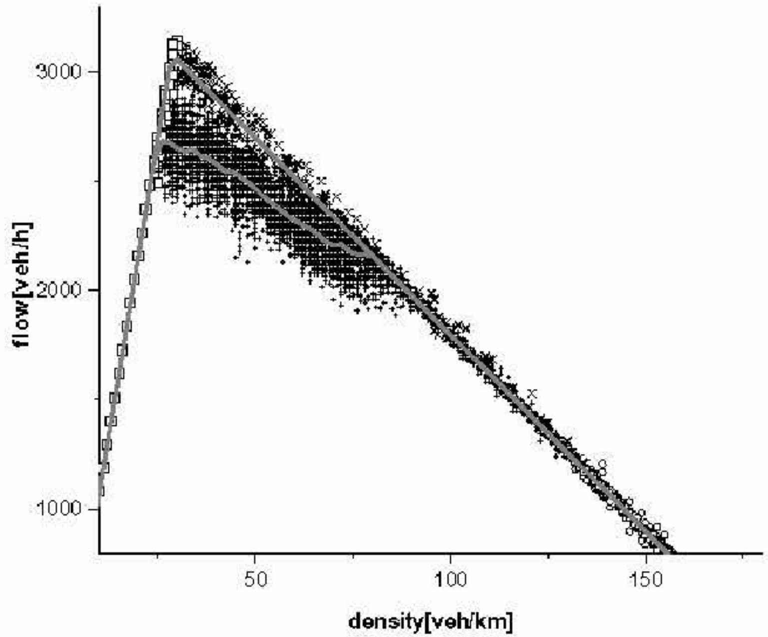
Metastability

Homogeneous state:

$$g_{ini} = \frac{L}{N} - s$$

v_{ini}= maximum speed such that

$$g_{ini} \geq d_{keep}$$



System initialized homogeneously →A metastable high-flow branch exists

Figure 7. Fundamental diagram resulting from two different initial conditions for $R = 0$. The upper curve was calculated by starting from an homogeneous state, whereas the lower curve was obtained from random initial distribution

$$\rho_{max} = \frac{L}{v_{max} + s}$$

$$\rho_{max} = 28.57 \ veh/km$$

q_{max}=3085 veh/km

Summary

- Due to simplicity and easy implementation on computers for numerical investigations, the CA traffic flow models developed very quickly in the last years.
- However it have not obtained the best traffic CA model which should be both realistic as well as simple.
- The aim of the proposed model is to describe more faithfully the behavior of real drivers and the macroscopic behavior of traffic flow observed.

Summary

- A simple and natural set of rules to better capture driver reactions allowed to describe the three states of flow observed in the reality: Free, synchronized and jam flow.

- Moreover, the model still preserved simplicity of CA model and at the same time, as vehicles' behavior was based on a safety analysis to determine the most appropriate action for a vehicle to take, made results closer to real highway behavior.

- Besides, there is an intuitive explanation for all rules in the model.

Thank you