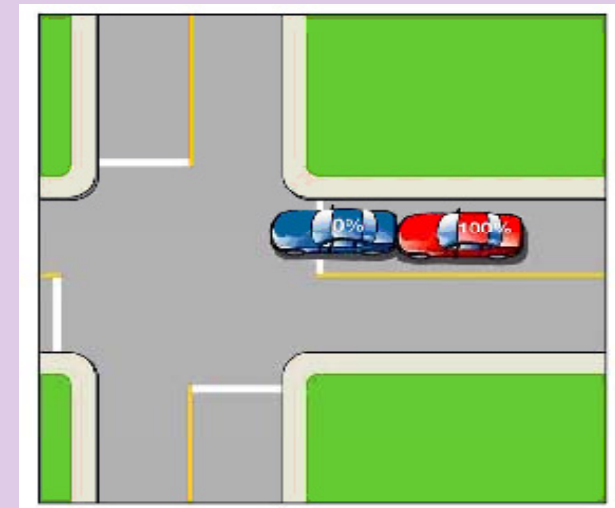


From Existing Accident-Free Car-Following Models to Colliding Particles: Exploration and Assessment



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Washington DC
13-17 January 2008



- Introduction: Motivation/Objective/Approach
- Comparative Assessment of Major Car-Following Models
- Suggested Car-Following Model with Simplified Lane Modeling Scheme
- Numerical Analysis
- Conclusion and Future Research

Motivation:

- 1- Little work has been done on understanding driver behavior under multiple regimes: extreme conditions (over-saturated conditions, evacuation scenarios) and “normal” daily traffic conditions
- 2- Existing Car-Following/Lane Changing Models are built in an “accident-free” environment

Objective:

This work explores specifications of a microscopic traffic model that could capture congestion dynamics and model accident-prone behaviors on a highway section in greater realism than existing models currently used in practice (commercial software)

Approach:

- 1- Major acceleration models are implemented on a common platform.
- 2- Comparative assessment is conducted in regards to congestion formation (fundamental diagram), trajectories and incident modeling.
- 3- Alternative specifications for car-following/lane changing model are developed and implemented in a microscopic simulation framework.
- 4- Experiments are conducted with the modified model under different degrees of relaxation of safety constraints (Sensitivity Analysis).
- 5- The ability of the proposed specifications to capture traffic behavior in extreme situations is examined.

Comparative Assessment of Car-Following Models

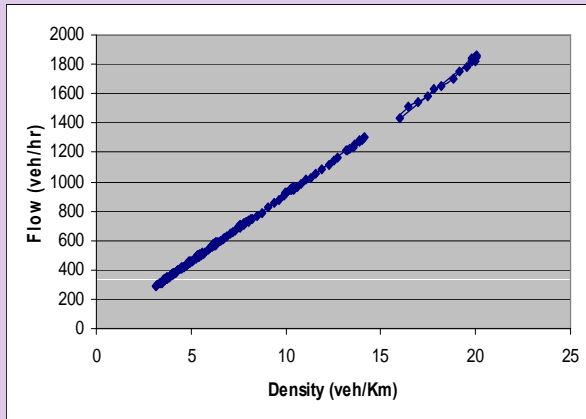
Department of Civil and Environmental Engineering

- Seven car-following models are tested in this study:
 1. GHR (GM) (Gazis, Herman and Rothery, 1959)
 2. Gipps (Gipps, 1981)
 3. CA (Nagel and Shreckenberg, 1992) / (Krauss et al., 1996)
 4. SK (Krauss and Wagner, 1997)
 5. IDM (Treiber et al., 2000)
 6. IDMM (Treiber and Helbing, 2003)
 7. Wiedemann (Wiedemann, 1974)

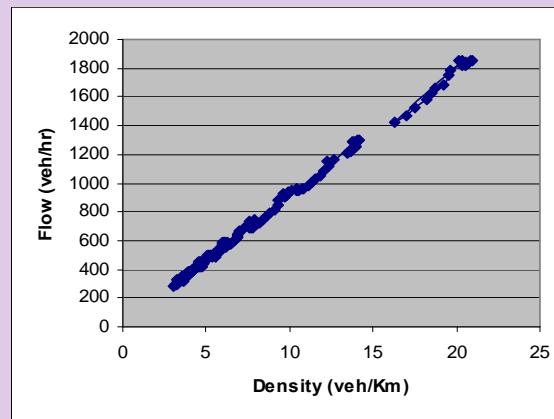
- The seven models were implemented on the same simulation platform with a simplified road geometry for comparison in terms of:
 1. Flow-density relation
 2. Trajectories
 3. Performance when relaxing safety constraints

- Parameters were calibrated using NGSIM data, collected on interstate 80, California, on April 13, 2005

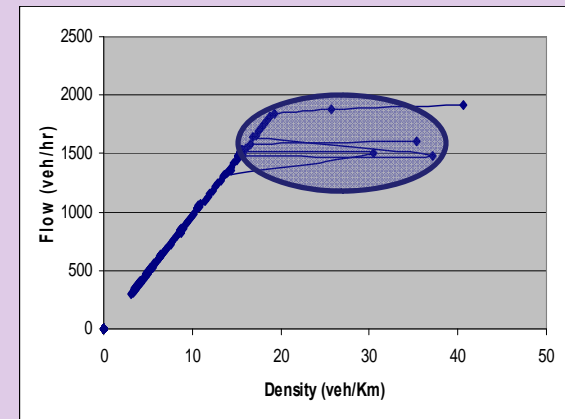
Fundamental Diagrams of Implemented Models



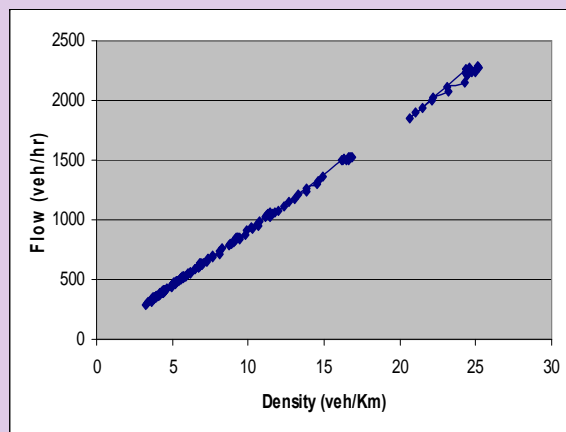
GHR



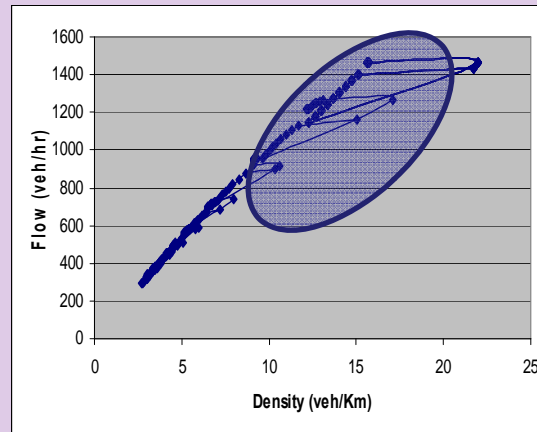
Gipps



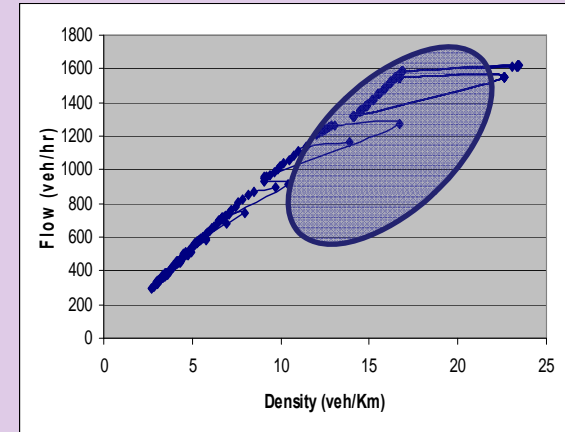
CA



SK

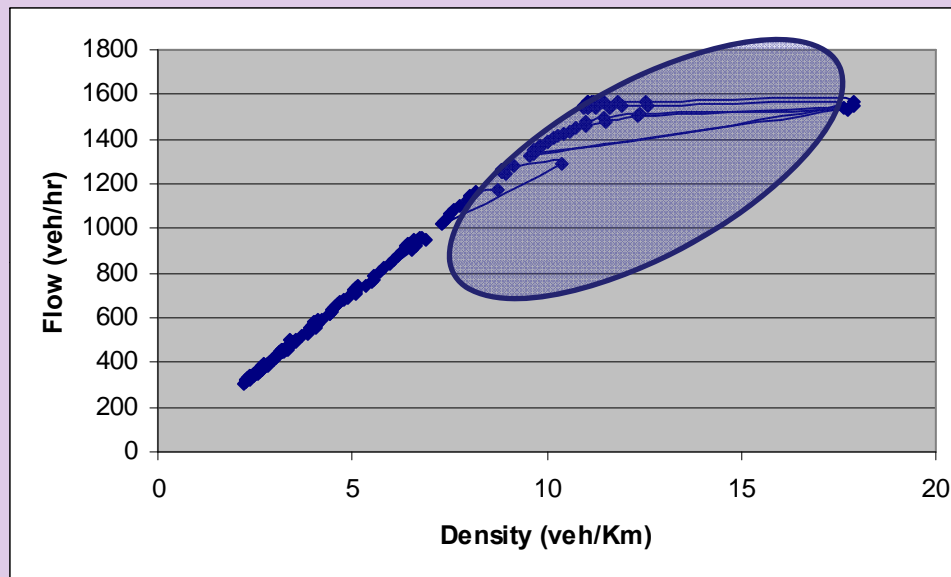


IDM



IDMM

Fundamental Diagrams of Implemented Models (2)

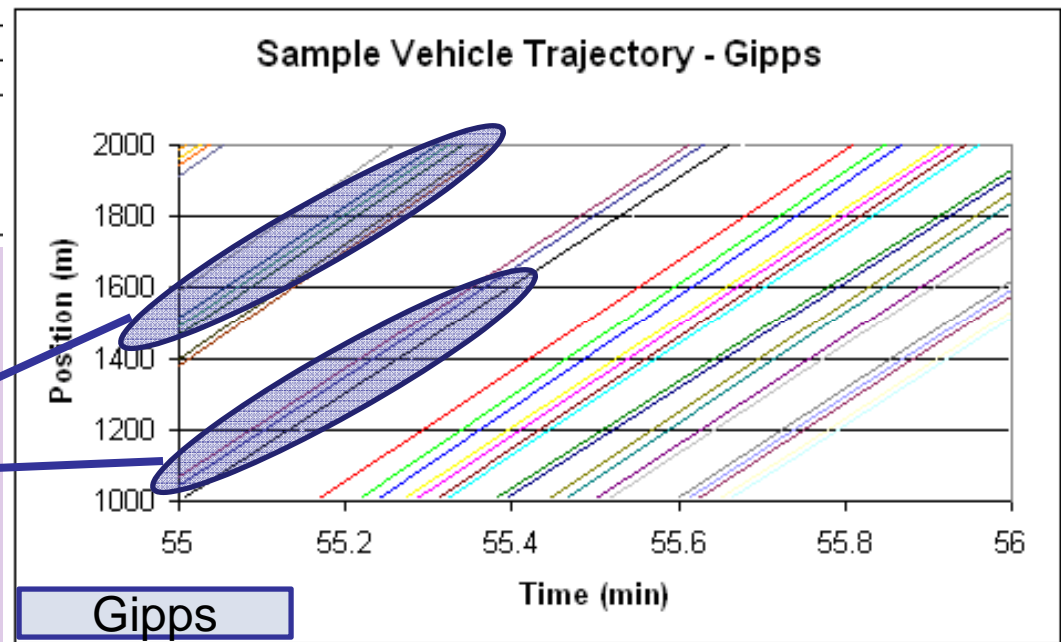
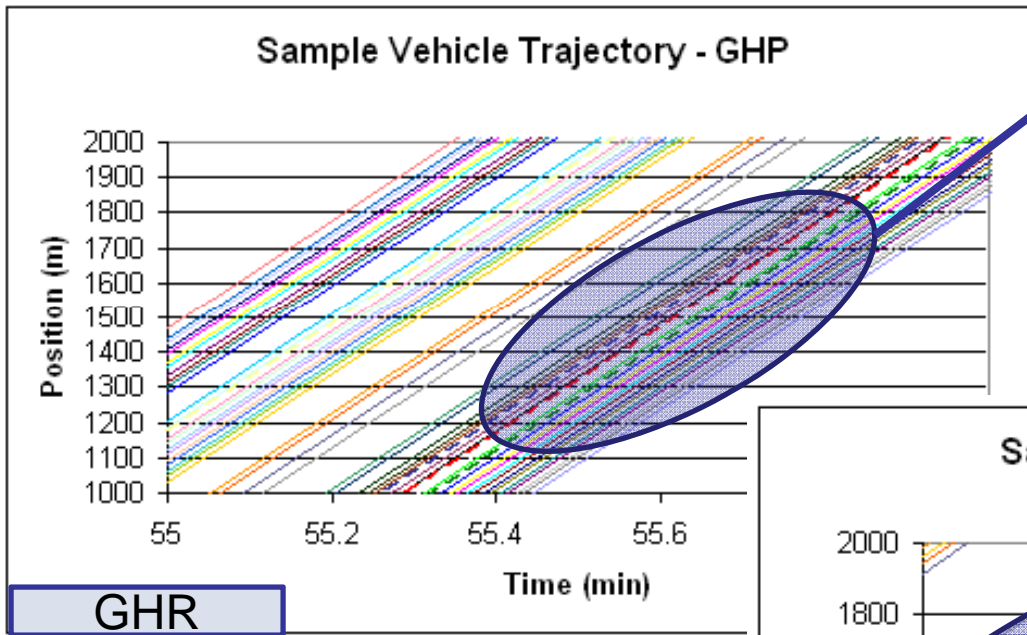


Wiedemann

As expected (except for the S-K Model), the models that showed perturbations in the “congested region” of the flow-density diagrams are: CA, IDM/IDMM and Wiedemann

Resulting Trajectories (1)

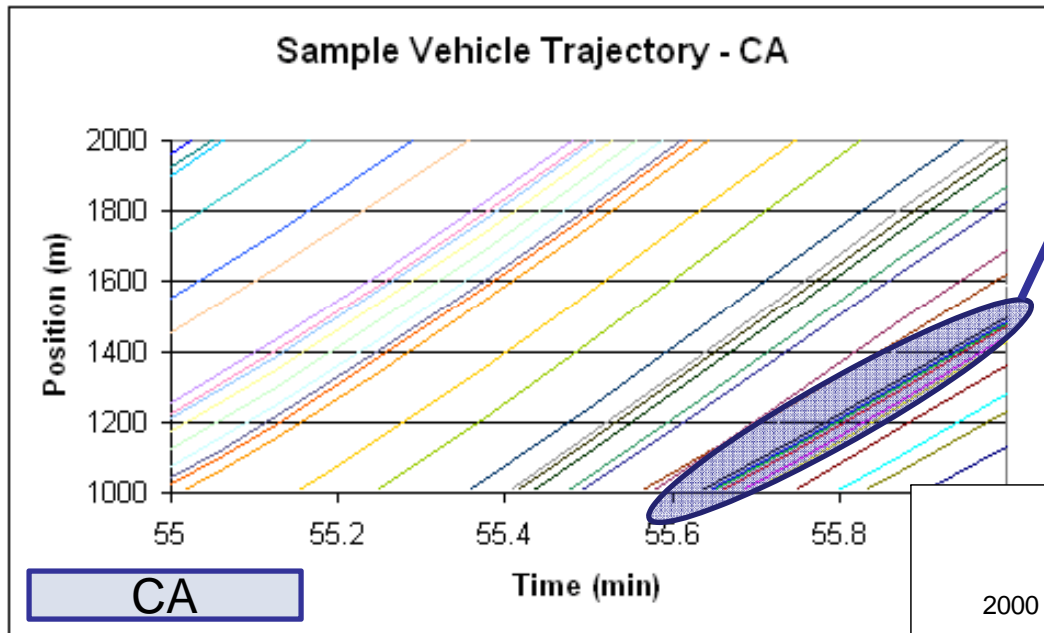
Space gaps unrealistically small at high speeds: capacity over-estimation



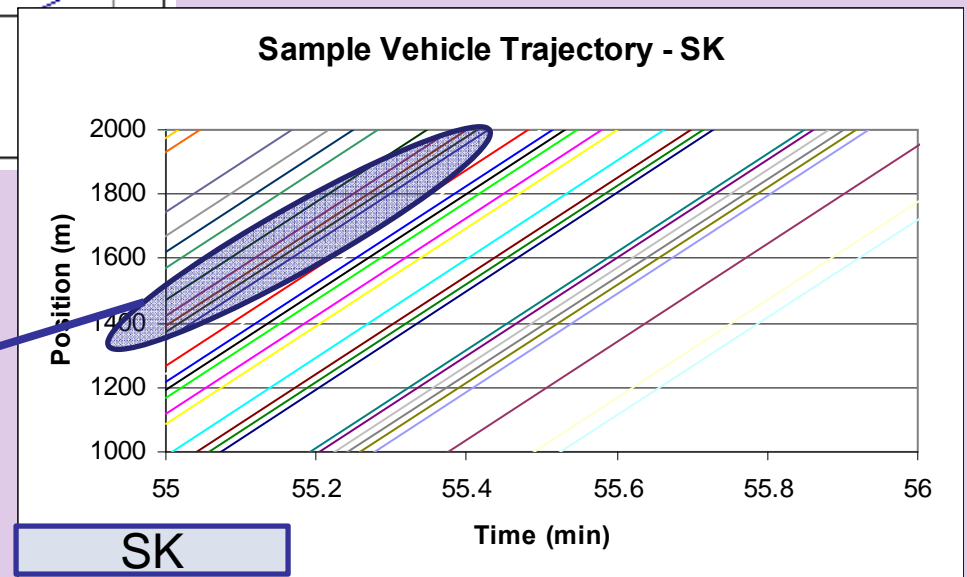
Resulting Trajectories (3)

To avoid incidents, a deceleration value is forced on drivers to stop at the rear-end bumper of their leaders

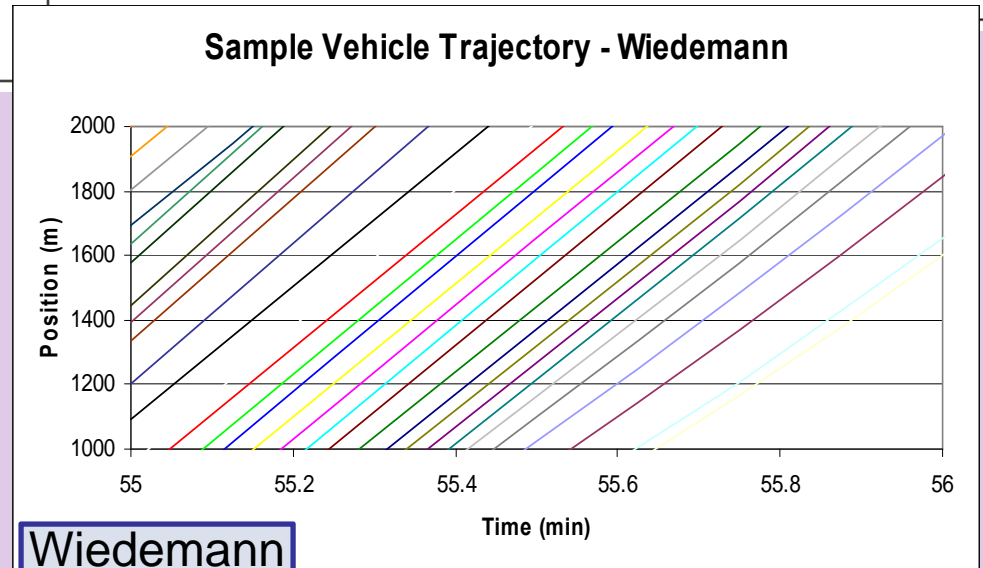
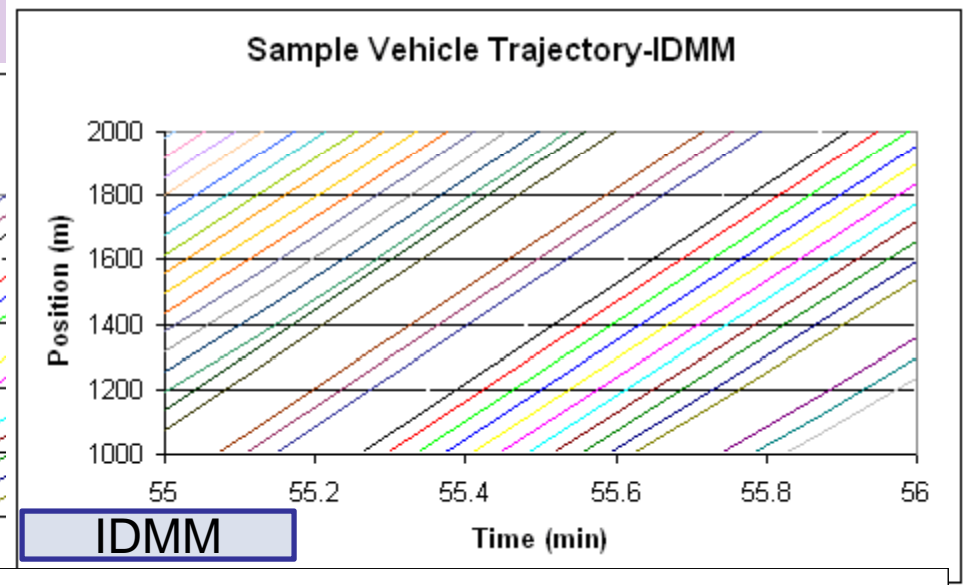
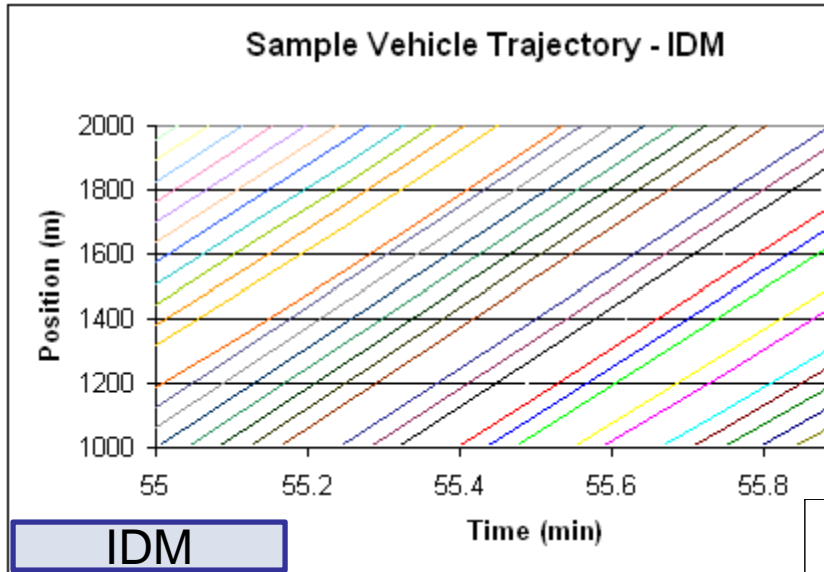
Drastic effect of deceleration "b" on resulting fundamental diagram



Platoons where drivers follow closely a slower lead vehicle

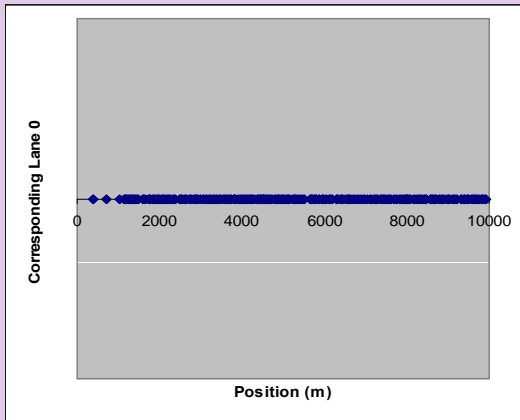


Resulting Trajectories (2)

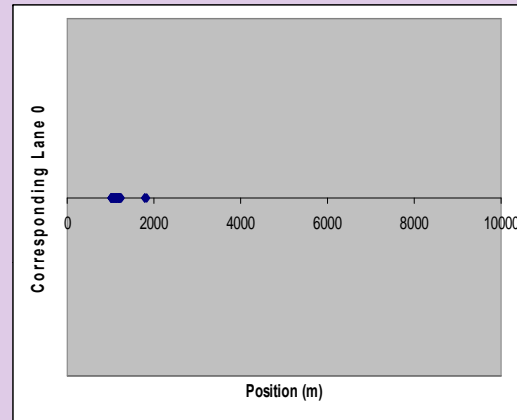


IDM, IDMM and Wiedemann showed more stable uniform trajectories: time headway is constant

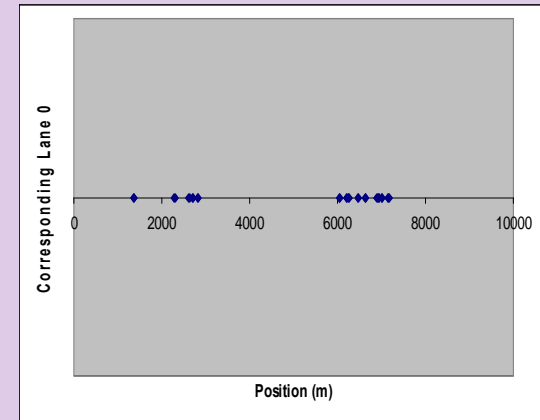
Sample Accident Results when Safety Conditions Relaxed



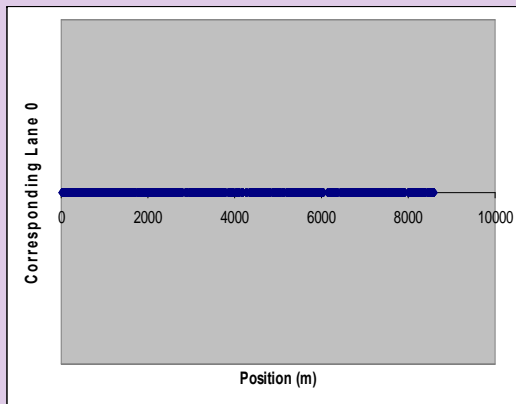
GHR (561 Collisions)



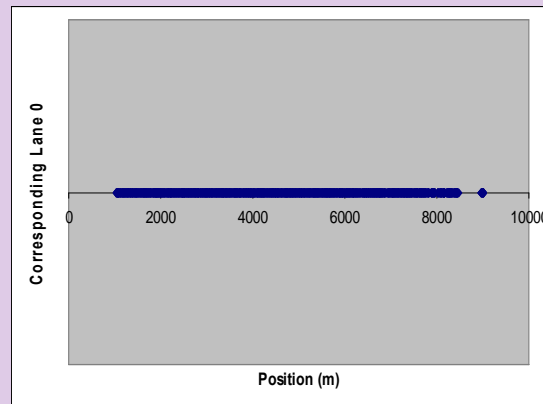
Gipps (42 Collisions)



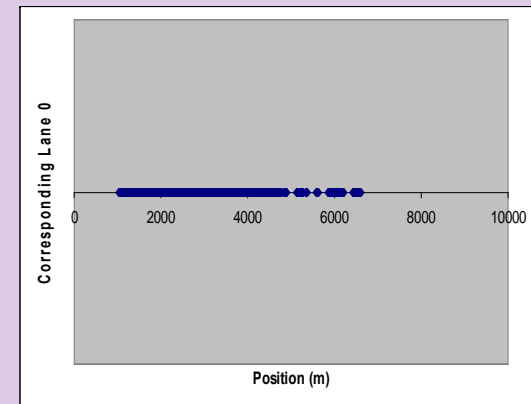
CA (29 Collisions)



SK (2013 Collisions)



IDM (1211 Collisions)



IDMM (674 Collisions)

Sample Accident Results when Safety Conditions Relaxed (2)



Simple Relaxation of the Safety Constraints cause unrealistic high number of chain-type accidents. Further “heuristics” are needed to capture accident behavior.

Suggested Micro-Simulation Model

The suggested microscopic model uses specifications from:

- 1. Gipps Model (relative stability when safety constraints are relaxed)**
- 2. Wiedemann Model (ability to capture traffic perturbation during congestion).**

Three elements of the model are introduced:

- 1. Change of parameters under extreme conditions (literature)**
- 2. Core car-Following/lane Changing Model (Gipps Model)**
- 3. Driver characteristics dynamics (Wiedemann Model)**

The change of parameters related to drivers behavior during extreme/incident conditions is driven by the following observations:

- Tailgating/decrease of headways.
 - Sudden lane changing.
 - Emergency breaking and rubber-necking.
 - Increase in velocity for aggressive drivers with higher acceleration and deceleration rates.
 - Decrease of critical allowable gaps (increase in impatience level).
 - Reduction in alertness due to the higher number of “active” stimulus during extreme conditions.
 - Tendency to disrespect traffic signs and signals.
 - Herding behavior (Helbing, 2000).
 - Higher variance in velocities: traffic disruption due to presence of so-called “slugs” and “rabbits” (Daganzo, 1999).
- **Increase in the number of accidents: increase of congestion (National Highway Traffic Safety Administration, 1998).**

Micro-Simulation Model Main Parameters:

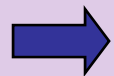
- τ_n (s): apparent reaction time
- **Vd1 and Vd2** (m/s): desired velocities of “Slug” (Slow Drivers) and “Rabbit” (Aggressive Drivers) respectively; different percentages of Slug/Rabbit drivers are adopted.
- **LCT_n** (s): lane changing time for vehicle n.
- **D_n** (m): risk factor: Distance a driver is willing to travel beyond the point of safety. This factor is the main cause of accidents
- **b_n** (m/s²): desired deceleration rate for driver n.
- **Vd_n** (m/s): desired velocity for driver n.

Micro-Simulation Model: Car Following (Gipps, 1981)

➤ Safety Constraint:

$$x_{n-1}(t) - \frac{v_{n-1}(t)^2}{2b_{n-1}} - s_{n-1} - D_n \geq x_n(t) + [v_n(t) + v_n(t + \tau_n)] \frac{\tau_n}{2} - \frac{v_n(t + \tau_n)^2}{2b_n}$$

Risk factor



Final Equation:

$$v_n(t + \tau_n) = \min \left\{ v_n(t) + 2.5a_n \tau_n \left(1 - \frac{v_n(t)}{V_n}\right) \left(0.025 + \frac{v_n(t)}{V_n}\right)^{1/2}; \right.$$

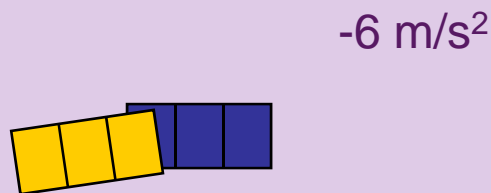
$$\left. b_n \left(\frac{\tau_n}{2}\right) + \sqrt{\frac{b_n^2 \tau_n^2}{4} - b_n \left[2(x_{n-1}(t) - s_{n-1} - x_n(t)) - v_n(t) \tau_n - \frac{v_{n-1}(t)^2}{b_{n-1}} + D_n \right]} \right\}$$

Micro-Simulation Model: Lane Changing

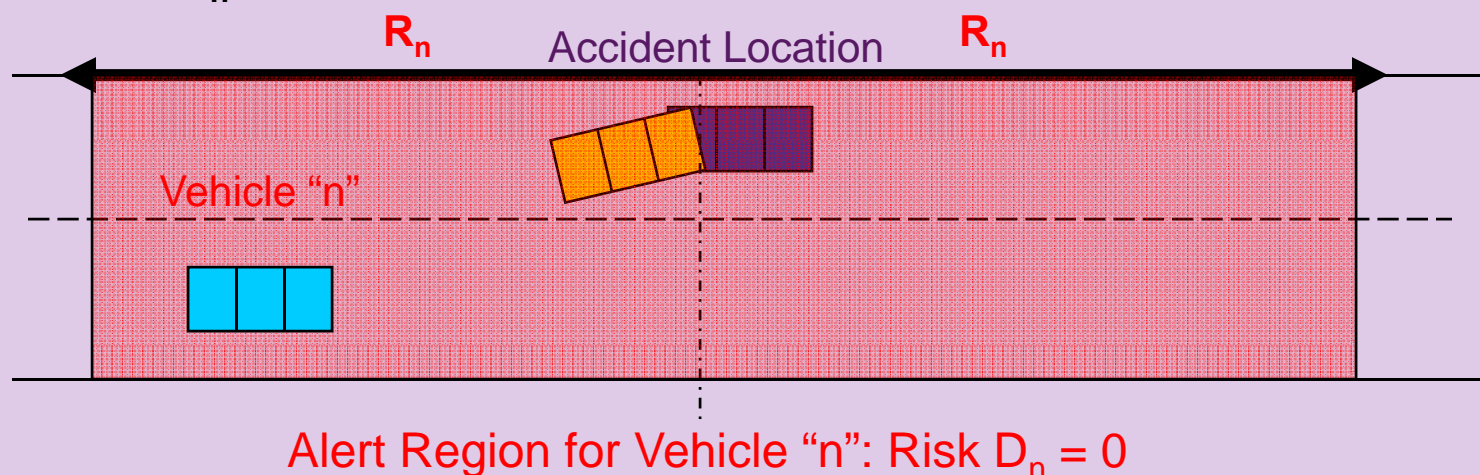
- Simulation time-step = 0.1 s.
- If
 - a driver is within 5 meters of the leading car without reaching his/her desired velocity and,
 - lane Changing is accepted based on the safe lead/lag equation
 - **then:** vehicle inserted on adjacent lane after $LCT_n * 10$ time-steps.
- Gaps checked once every $LCT_n * 10$ time-steps.

Micro-Simulation Model: Accident Modeling

If the space separation < 0 : velocity of vehicles involved is decreased to zero at a rate of -6m/s^2 : an accident is generated.

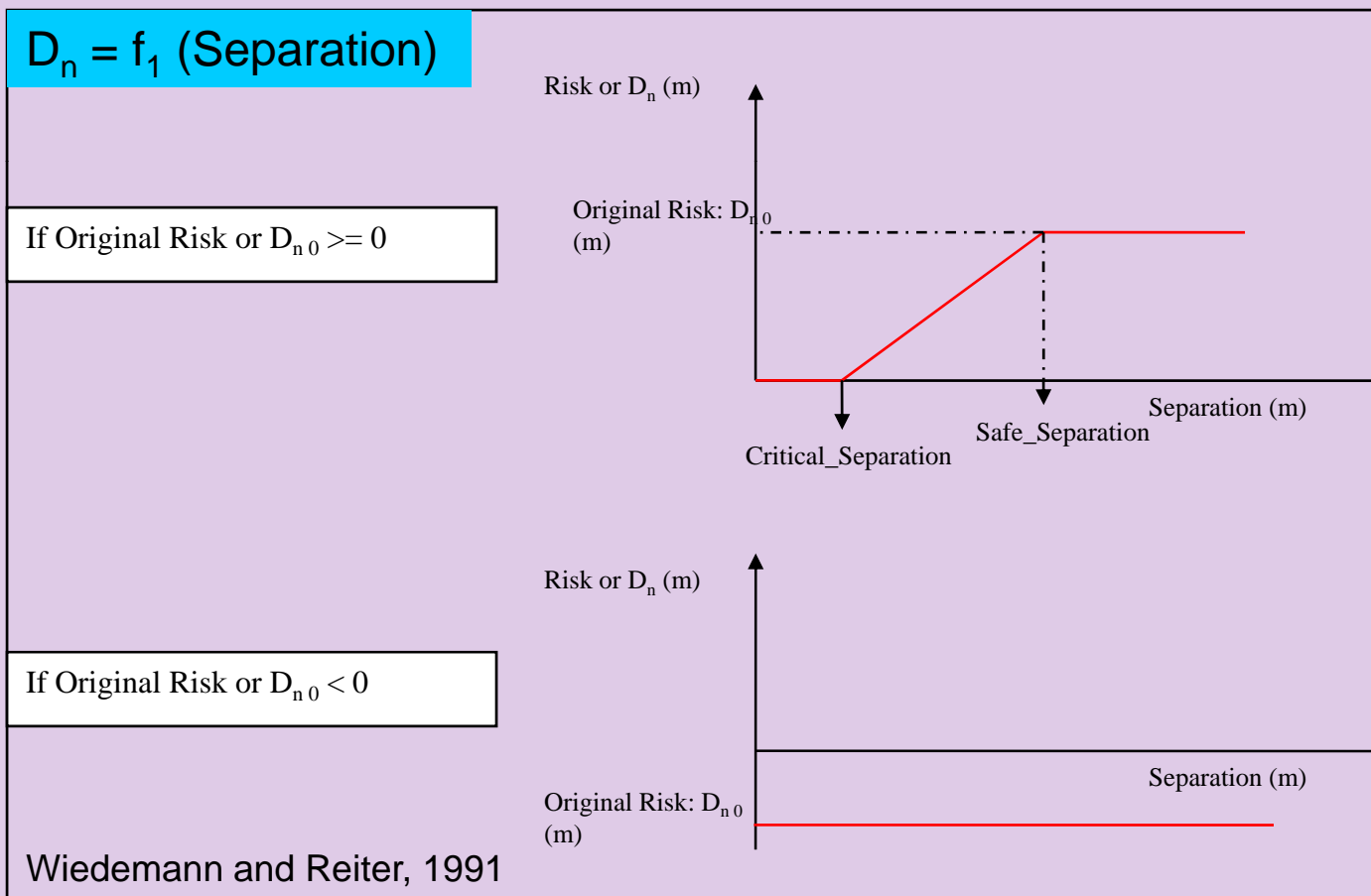


The risk is set to zero for all vehicles existing at an alert distance (R_n) of the accident

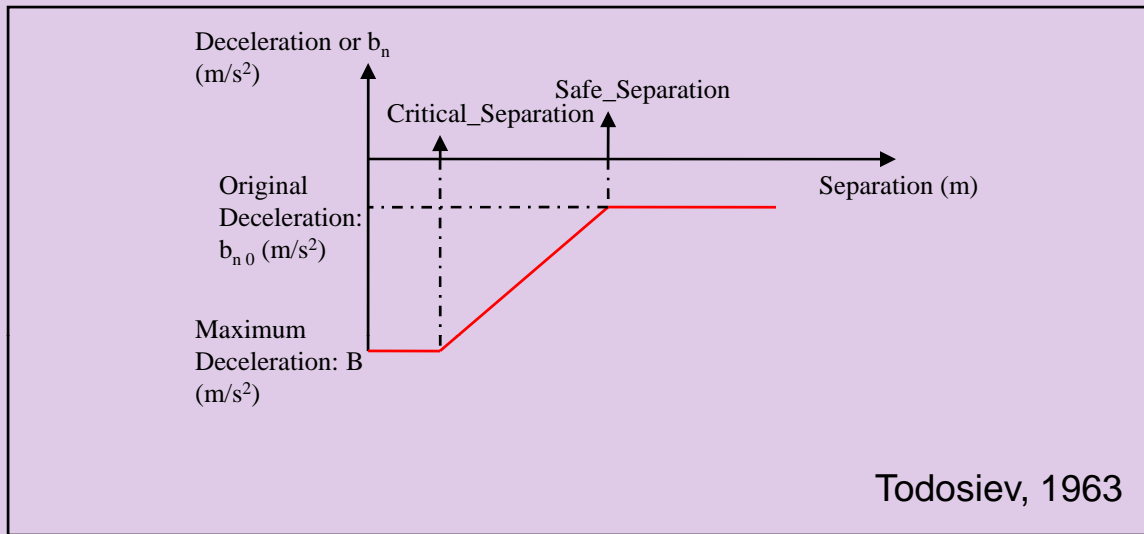


Driver Characteristics Dynamics (1)

- Driver's Characteristics are linked to an attribute that changes over time: driver's headway (Separation)
- This linking is performed through piece-wise linear functions:

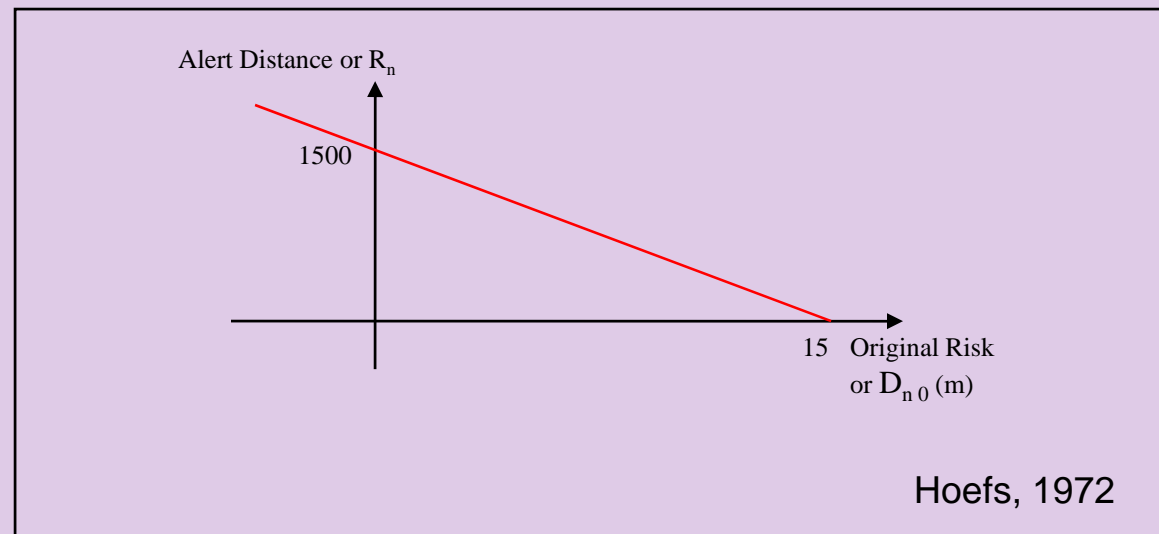


Driver Characteristics Dynamics (2)



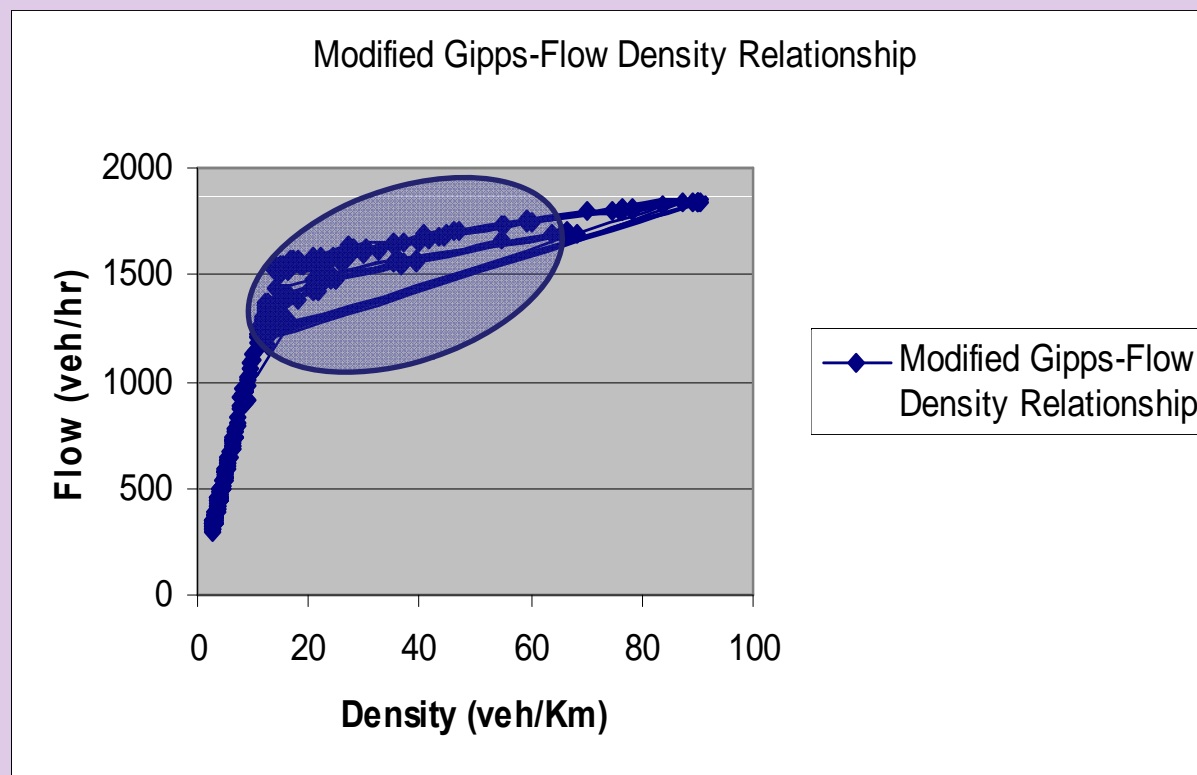
$$b_n = f_4 (\text{Separation})$$

$$R_n = f_5 (D_{n0})$$



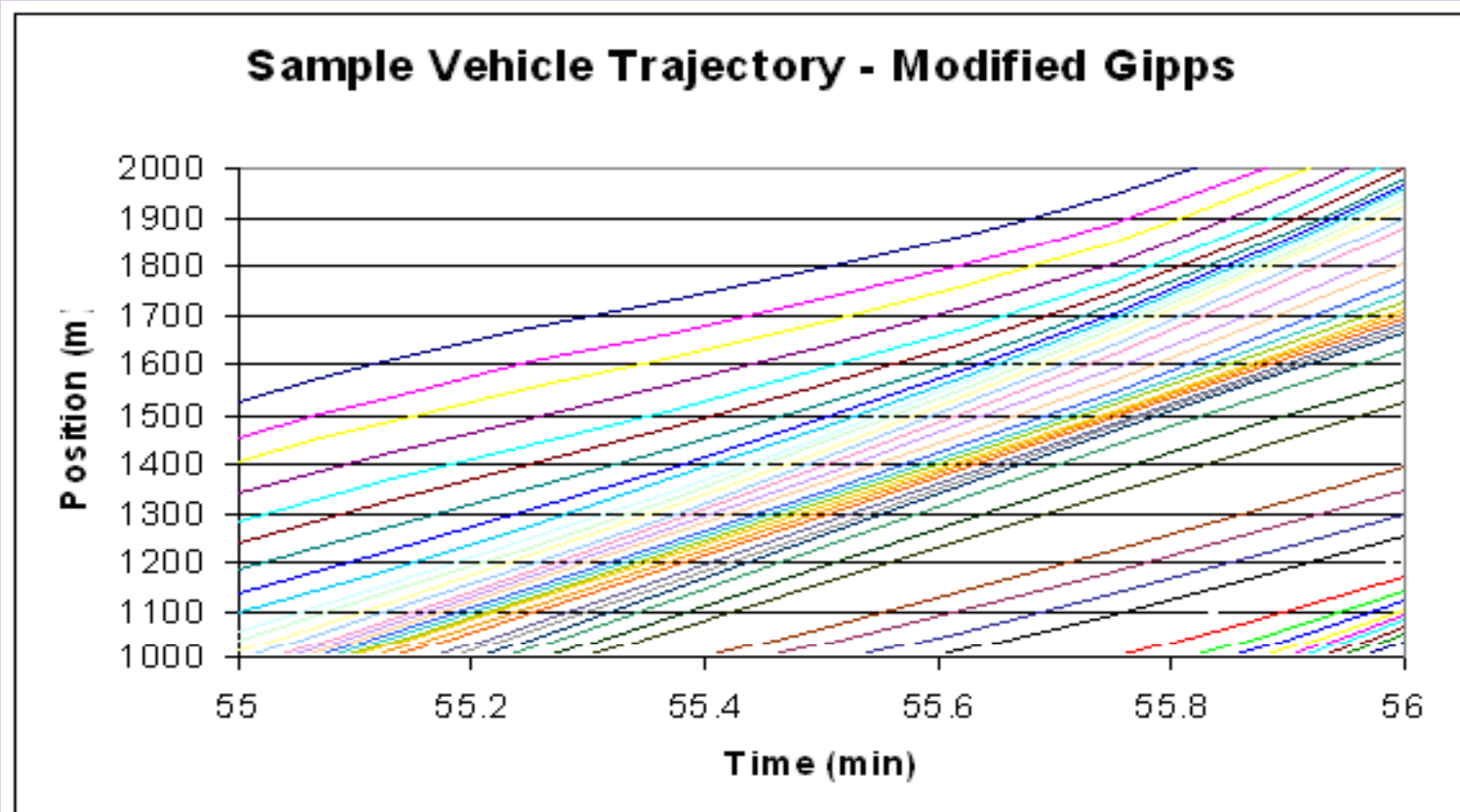
Numerical Results

Results: Flow-Density Diagram when Risk = 0/ Single Lane Freeway



PS: parameters calibrated using NGSIM Data

Results: Trajectories



PS: parameters calibrated using NGSIM Data

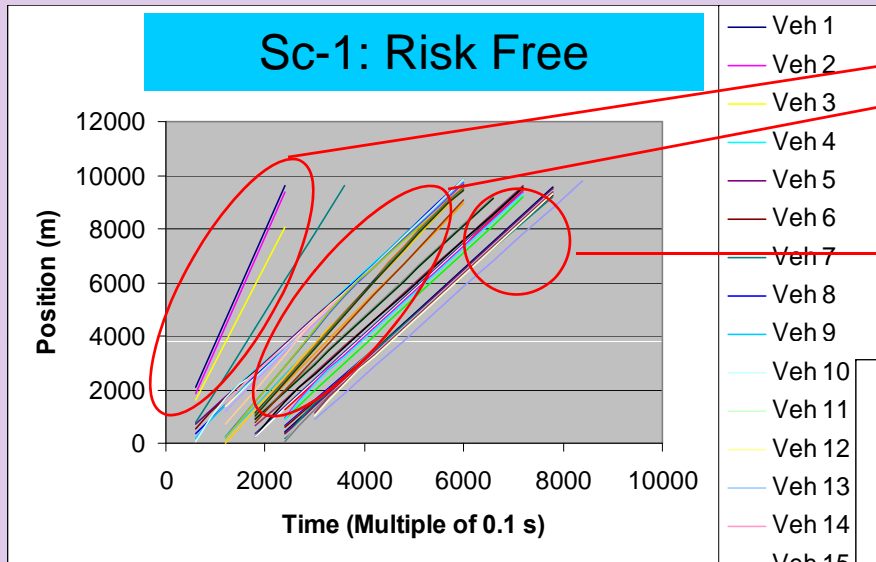
Results: Input Parameters (for Sensitivity Analysis)

Input Variable	Value
Time T (s)	7200
Road Length L (m)	10000
Mean Reaction Time (s)	1
Mean Vd1 (m/s)	20
Mean Vd2 (m/s)	35
Percent Vd1(%)	40
Mean LCT (s)	2.5
Mean Acceleration (m/s ²)	2
Mean Deceleration (m/s ²)	-3

Results: Sensitivity Analysis Scenarios

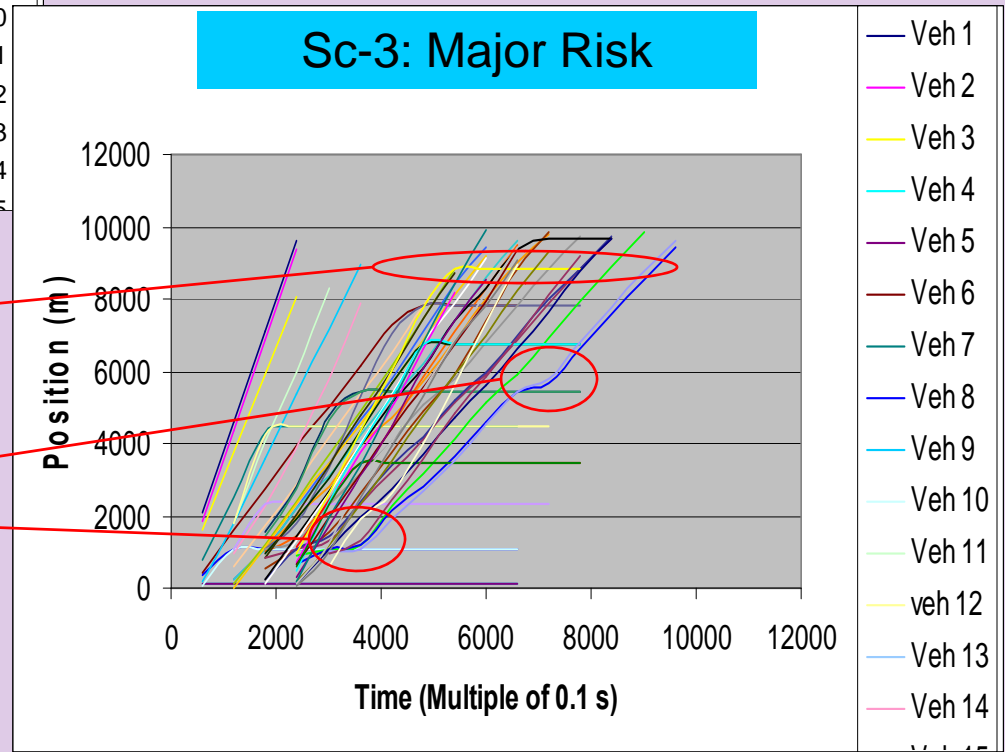
Scenario Description	Scenario #	# of Vehicles	Mean Interrarrival Time (s)	Risk (m)
Free-Flow Risk Free	1	1200	6	0
Free-Flow Minor Risk	2	1200	6	1
Free-Flow Major Risk	3	1200	6	5
Free-Flow Break Down	4	1200	6	10
Congested Risk Free	5	3600	2	0
Congested Minor Risk	6	3600	2	1
Congested Major Risk	7	3600	2	5
Congested Break Down	8	3600	2	10

Results: Time-Space Diagrams



2 Classes of Drivers

Intersecting lines indicates the presence of a lane change or over-passing



Permanent horizontal lines indicates an accident

Vehicles can be stuck behind An accident for sometime before Lane changing

Results: Output Performance Measures

Perf. Measure \ Scenario #	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8
Avg Travel Time per KM (s)	54.9	46.7	48.9	50.9	60.1	59.9	74.0	49.2
Average Speed (m/s)	18.3	27.4	25.4	22.8	16.7	27.8	23.7	22.4
Number of Cars Crashed	0.0	14.0	24.0	161.0	0.0	14.0	39.0	108.0
Number of Lane Changes	74.0	8733.0	11753.0	3247.0	268.0	37162.0	50542.0	995.0
Average Flow Rate (veh/h)	291.3	290.0	287.4	43.7	874.9	822.8	842.4	15.9
Average density (veh/km/lane)	4.5	4.7	5.2	8.1	14.6	15.2	19.6	6.1

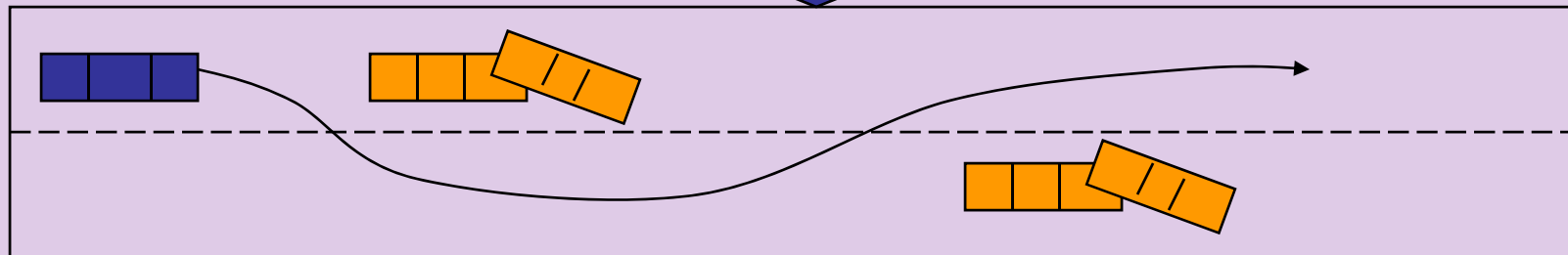
Increase in number
of accidents as risk increases

Drastic decrease in flow
Indicates traffic breakdown

Results: Illustrative Behavior of Lane Changes and Accidents

P/Road Segment Index (1 km)		1	2	3	4	5	6	7	8	9	10
Number of cars Crashed	Lane 1	0	2	0	2	2	0	0	2	2	0
	Lane 2	2	2	2	0	0	2	2	2	0	2
# of Lane Changes		1023	1575	1086	1135	1022	1193	1036	1363	1128	1192

Number of Lane Changes increase with Accidents:
 $1575 > 1023, 1086$
 $1363 > 1036, 1128$



Zig-Zagging Movement

Conclusion and Future Research Needs

- Existing car-following models do not accommodate traffic breakdowns with incident occurrence in their current structure.
- Based on the numerical analysis in this work, the specifications of the modified Gipps Model offer an improved basis for microscopic traffic simulation for situations that do not require an accident free environment.
- The same basic behavior model structure could accommodate both extreme situations (evacuation scenarios, over-saturated networks) as well as “normal” daily traffic conditions.
- Future Research Needs:
 - The lane changing logic needs to be developed based on existing more realistic models (MOBIL, SYTRAS ...etc)
 - Incident Data or Data Collected during extreme conditions are extremely helpful for validation purposes
 - The transition phase between “normal” mode and “incident” mode in the suggested model is still a subject of research.

Thank you for your attention!

Questions?

Acceleration Models	Ability to Capture Congestion/Breakdowns	Ability to Model Accidents
GHR (GM) (Gazis et al., 1959)	GHR models failed to capture traffic breakdowns by offering over-estimated freeway capacities: unrealistically high velocities when drivers are following each other closely.	<p>The calibrated value of the sensitivity factor λ or its structure $\lambda = \frac{c}{s^n}$ prohibited the creation of accidents.</p> <p>Relaxation: randomness added on the stimulus term (relative velocity)</p>
Gipps (Gipps, 1981)	The model loses its realistic property in its deterministic properties at the limits: drivers' interactions in dense traffic are not well captured	<p>The explicit introduction of a safety condition in the model formulation prohibited any accident creation:</p> $x_{n-1}(t) - \frac{v_{n-1}(t)^2}{2b_{n-1}} - s_{n-1} \geq x_n(t) + [v_n(t) + v_n(t + \tau_n)] \frac{\tau}{2} + v_n(t + \tau_n)\theta - \frac{v_n(t + \tau_n)^2}{2b_n}$ <p>Relaxation: relax the above inequality by a distance term D_n (Distance Based Risk)</p>
CA (Nagel and Shreckenberg, 1992) (Krauss et al., 1996)	Congested clusters characterized by typical start-stop-waves are found in freeway traffic.	<p>Due to a safety constraint explicitly imposed by the modelers, unrealistic decelerations are used forcing drivers to stop in the available gaps in front of them:</p> $v_{des} = \min[v(t) + a_{max}, v_{max}, s_{gap}(t)],$ $v(t + 1) = \max[0, v_{des} - \sigma_{n_{ran}, 0,1}],$ $x(t + 1) = x(t) + v(t + 1)$ <p>Relaxation: $s_{gap}(t)$ is replaced by $s_{gap}(t) + 0.1$</p>

Acceleration Models	Ability to Capture Congestion/Breakdowns	Ability to Model Accidents
SK (Krauss and Wagner, 1997)	The SK model is able to capture the metastable state but still cannot imitate the hysteresis effects and the traffic instabilities near-traffic breakdown.	SK Model is a modified CA model with a desired velocity concept adopted from the Gipps model. Accordingly, like Gipps' safety condition, a safe velocity is imposed with: $v_s \leq v_{safe} = b(\alpha_{safe} + \beta_{safe})$ Relaxation: the above safe velocity term is increased by 0.27 m/s
IDM/IDMM (Treiber et al., 2000) (Treiber and Helbing, 2006)	IDM and IDMM are some of the few models claiming that it they are able to capture multiphase states in the fundamental diagram (congestion build up, stop and go waves, then traffic deterioration).	With an acceleration equation of: $\dot{v}_\alpha = a^{(\alpha)} \left[1 - \left(\frac{v_\alpha}{v_0^{(\alpha)}} \right)^\delta - \left(\frac{s^*(v_\alpha, \Delta v_\alpha)}{s_\alpha} \right)^2 \right]$ An implicit car following mode is imposed with: $b_{int}(s_\alpha, v_\alpha, \Delta v_\alpha) = -a^{(\alpha)} \left(\frac{s^*(v_\alpha, \Delta v_\alpha)}{s_\alpha} \right)^2$ $s^*(v, \Delta v) = s_0^{(\alpha)} + s_1^{(\alpha)} \sqrt{\frac{v}{v_0^{(\alpha)}}} + T^{(\alpha)} v + \frac{v \Delta v}{2\sqrt{a^{(\alpha)} b^{(\alpha)}}}$ This structure of the car following equation above (spacing in the denominator) and last term of the desired spacing prohibit the creation of accidents. Relaxation: removing the last term of the desired spacing
Wiedemann (Wiedemann, 1974)	Traffic Breakdown is captured in Wiedemann Model	An emergency braking mode will impose the vehicle to stop before an accident is generated: $B(I) = \frac{1}{2} * \frac{DV^2}{AX - DX} + B(I - 1) + BMIN * \frac{ABX - DX}{BX}$ Relaxation: replacement of the emergency braking mode with the normal braking mode

Deceleration “b” versus Fundamental Diagram in CA Model

