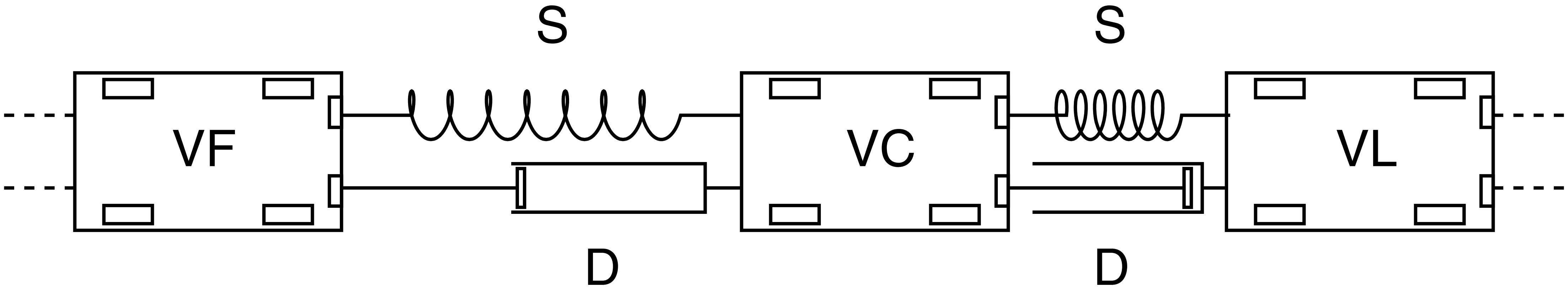
suppressing traffic flow instabilities



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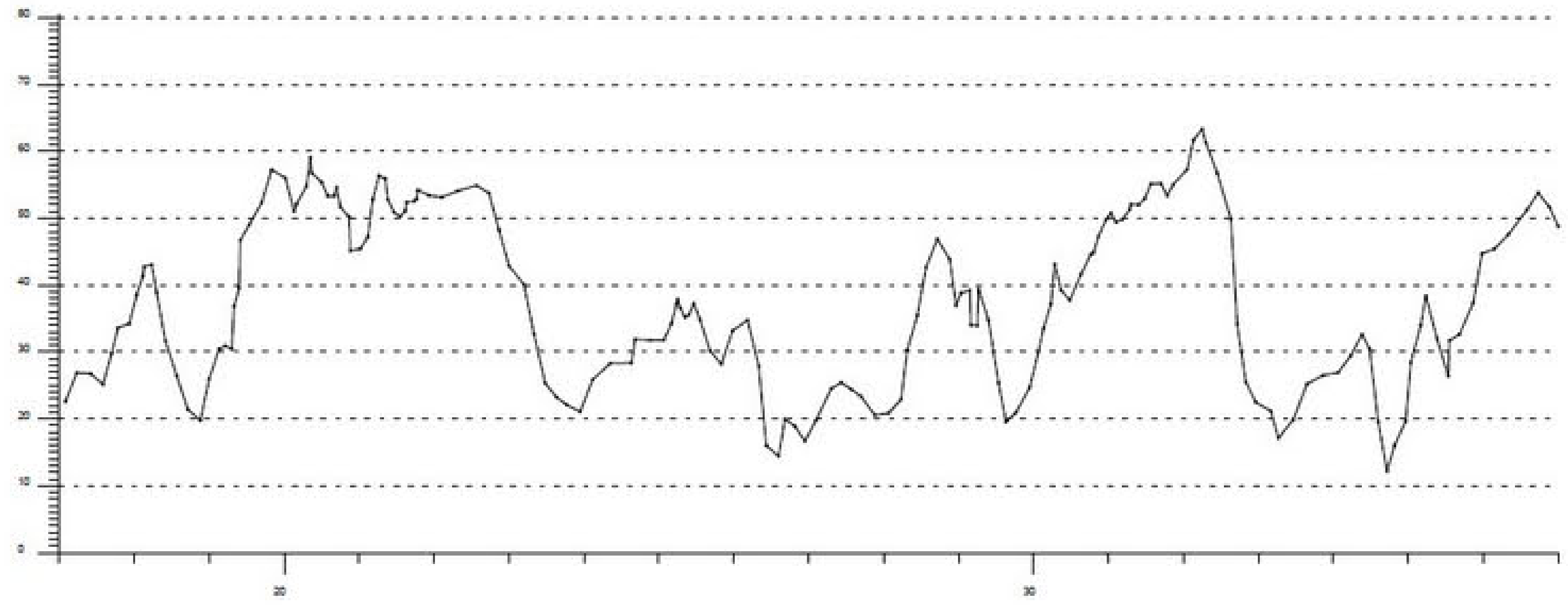
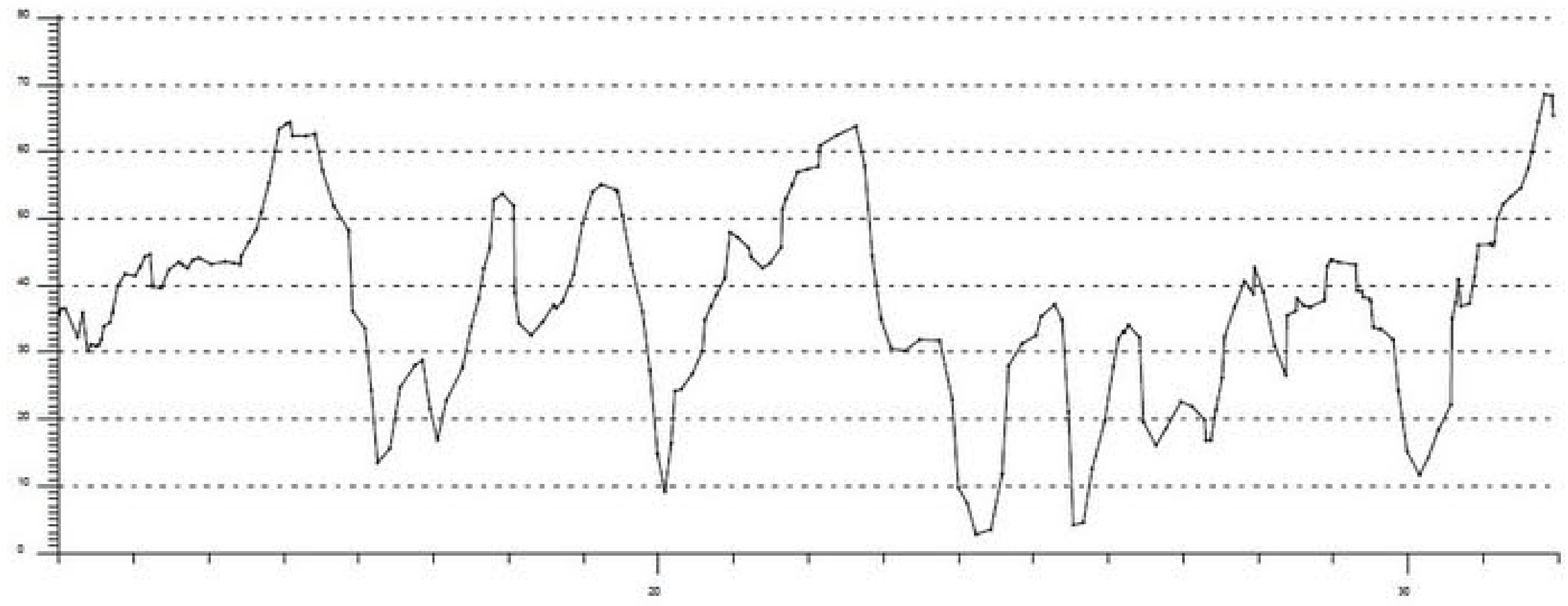
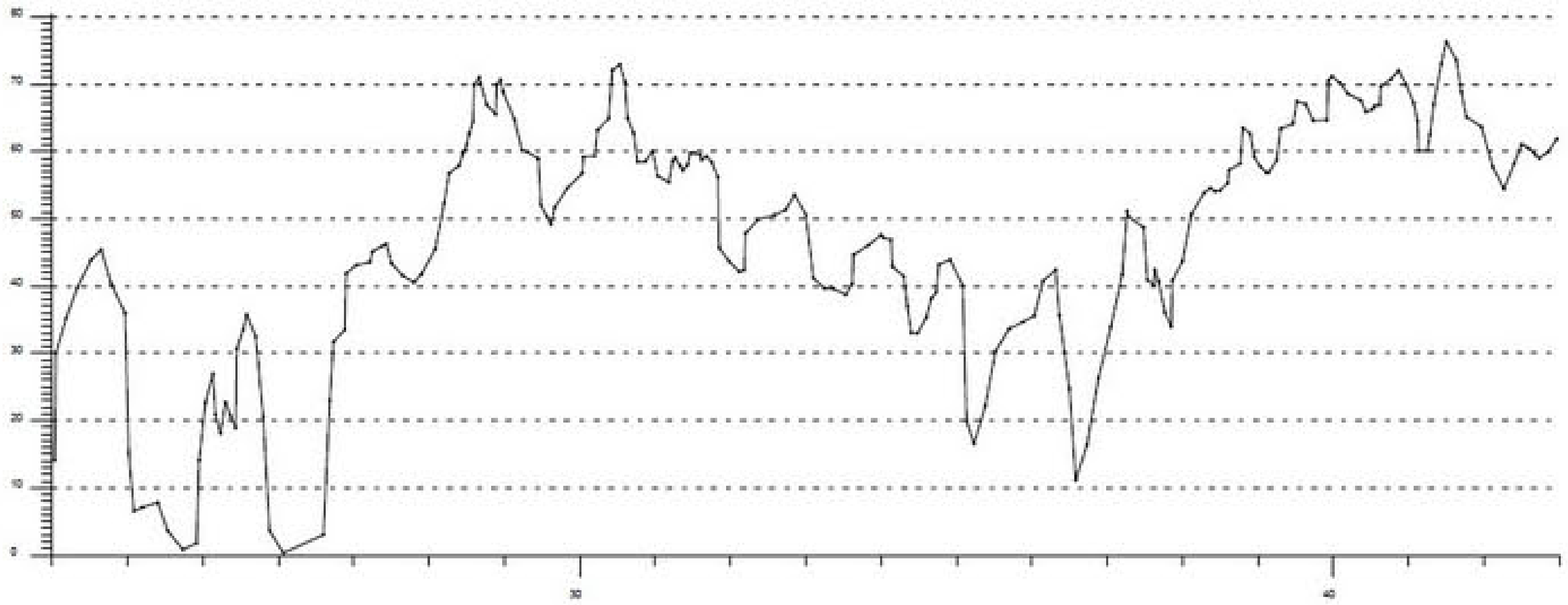


RT93 North, Boston, 2011 March 31



RT93 North, Boston, 2011 April 14



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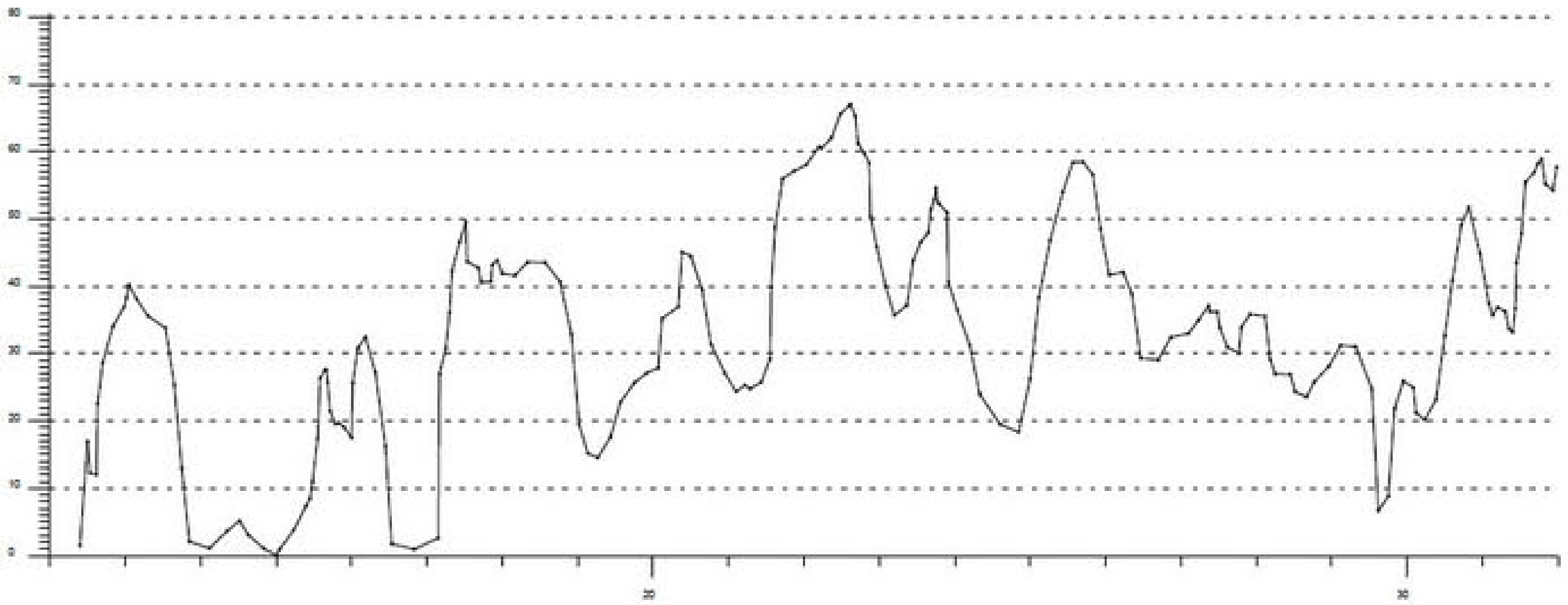
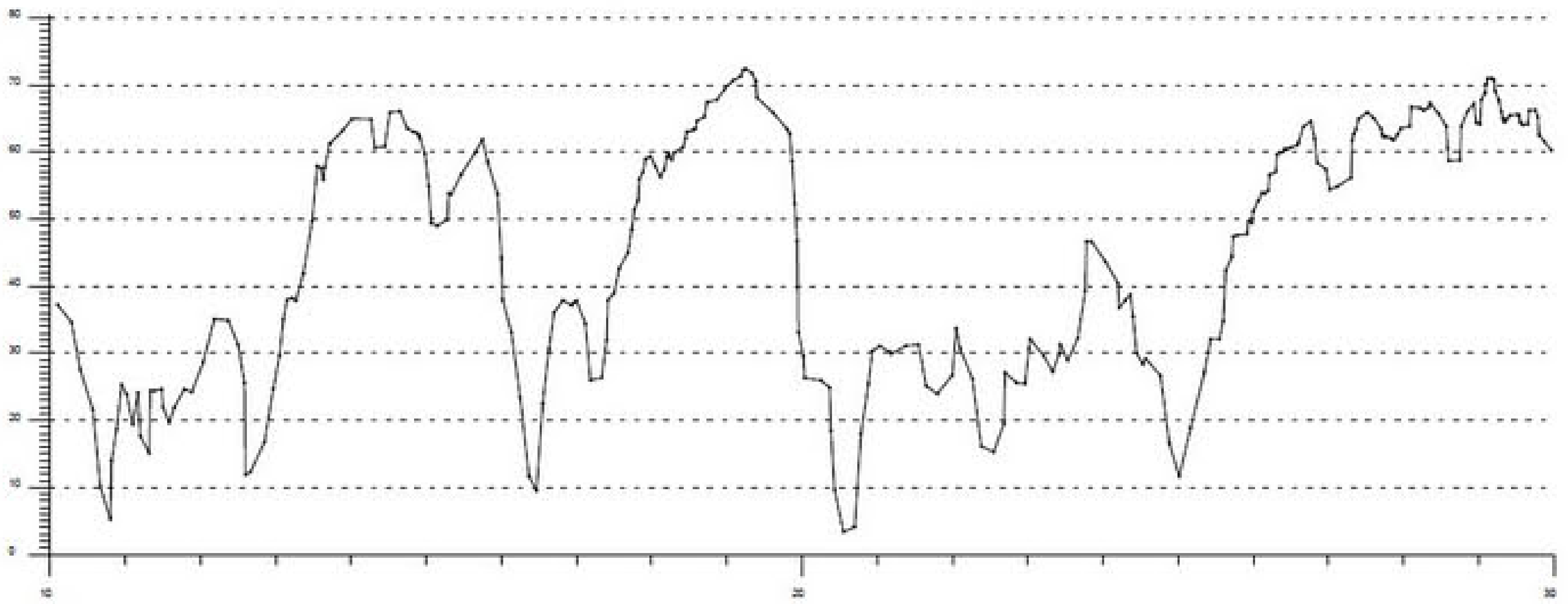
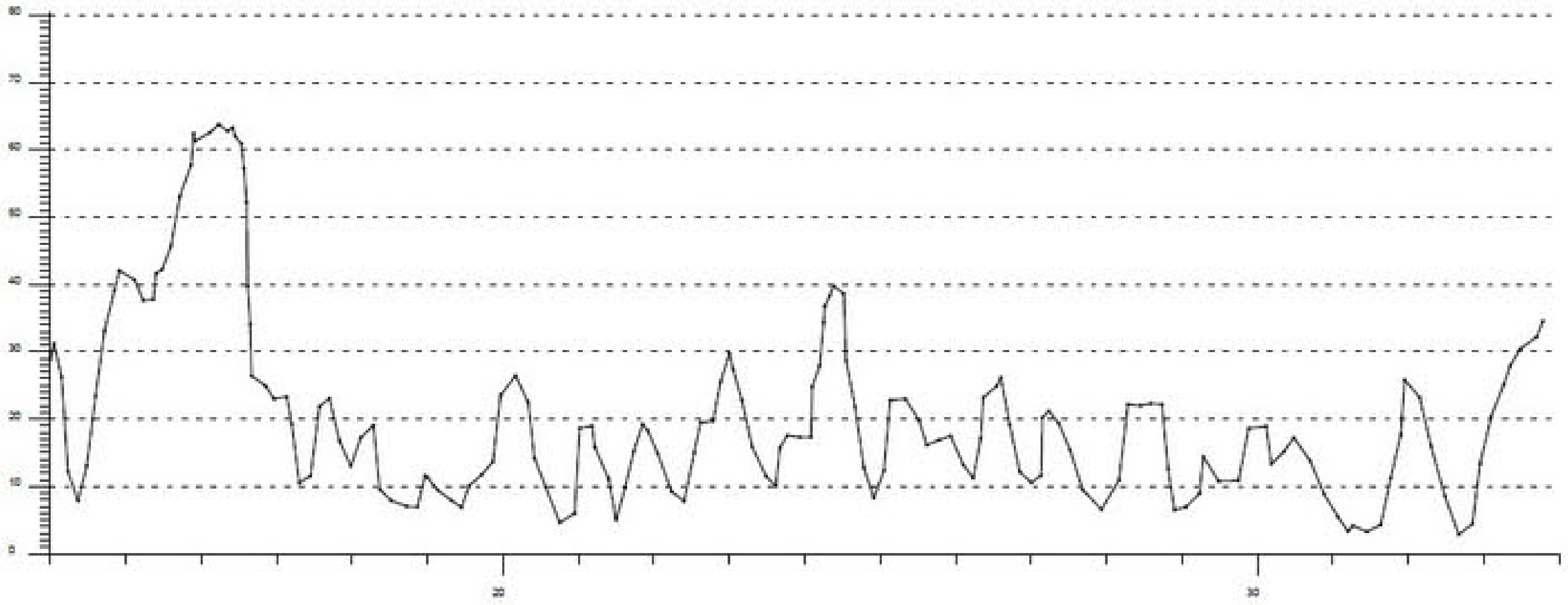


RT93 North, Boston, 2011 April 28



RT93 North, Boston, 2011 May 19



RT95 North, Burlington, 2011 May 12


Map
Traffic
200 ft
100 m
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Report a problem

Traffic flow instabilities waste energy:

- At high densities traffic flow becomes unstable
- Traffic acts as if it was a *dilatant* (shear thickening) fluid

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- Building more roads has high energy cost as well
- “Metering” reduces potential throughput

Source of Instabilities

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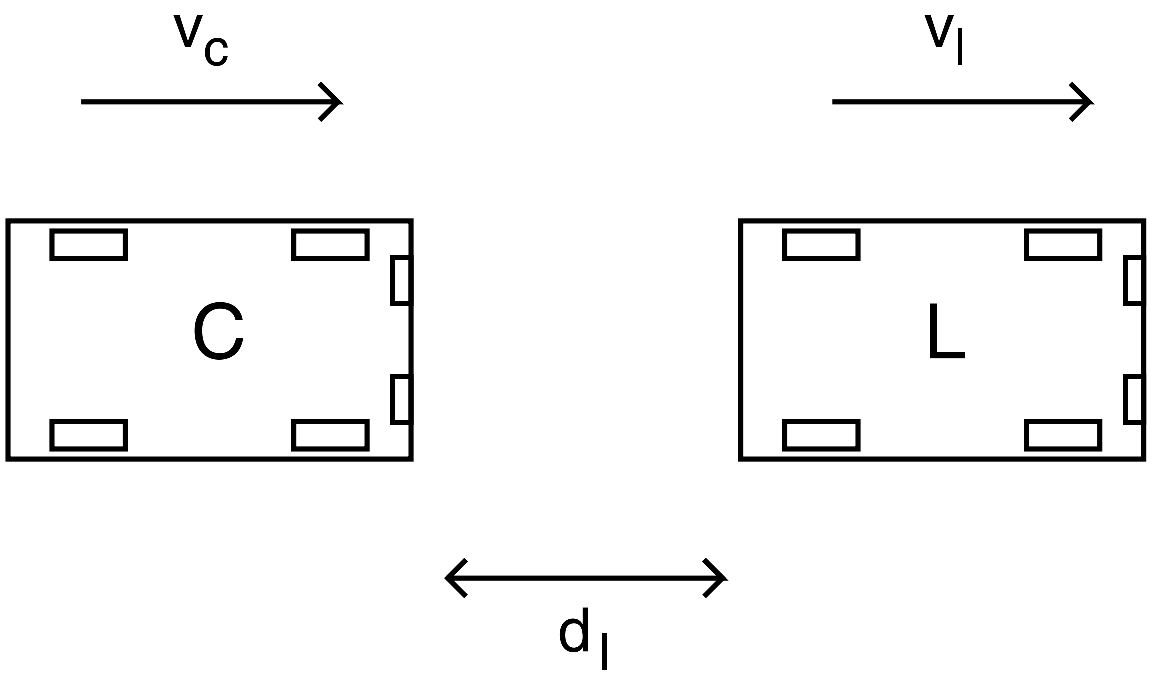
- At high flow densities, traffic flow becomes unstable
- Travelling waves of velocity and density fluctuations
- Perturbations are amplified
- Effects propagate upstream
- Instabilities reduce average speed and throughput
- Instabilities limit the carrying capacity of a roadway
- Increase wear and tear on vehicles — and on nerves
- **Stop-and-go traffic greatly reduces fuel efficiency**

Alternative Schemes

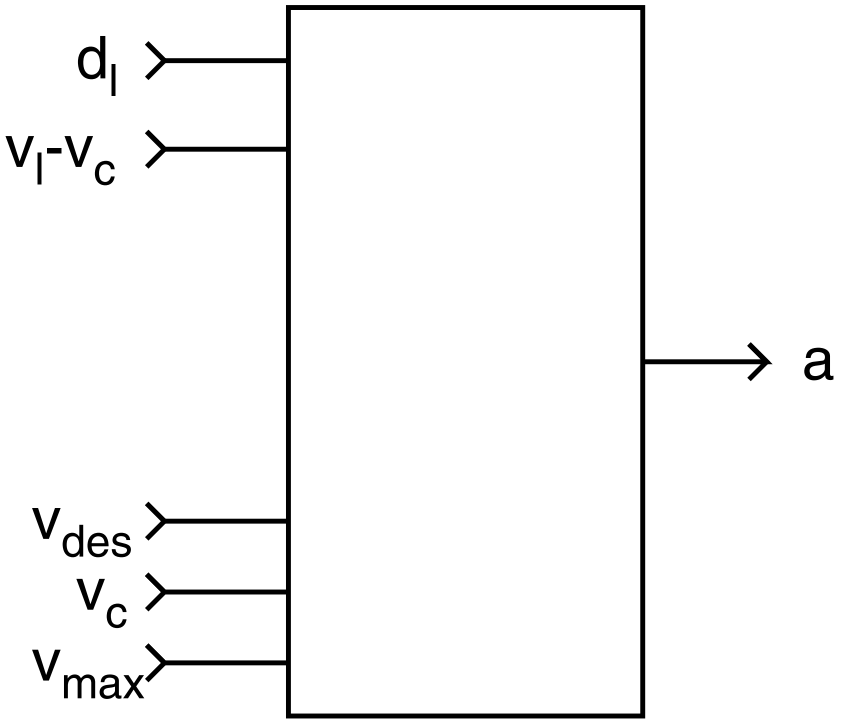
- Building more roads reduces density — for a while;
- “Metering” reduces instabilities by limiting density;
- Reduction in reaction time allows higher density;
- Platooning allows small inter-vehicle distances;
- . . .
- *not*

Car-Following Model



- Control of car C depends on d_l and $v_l - v_c$

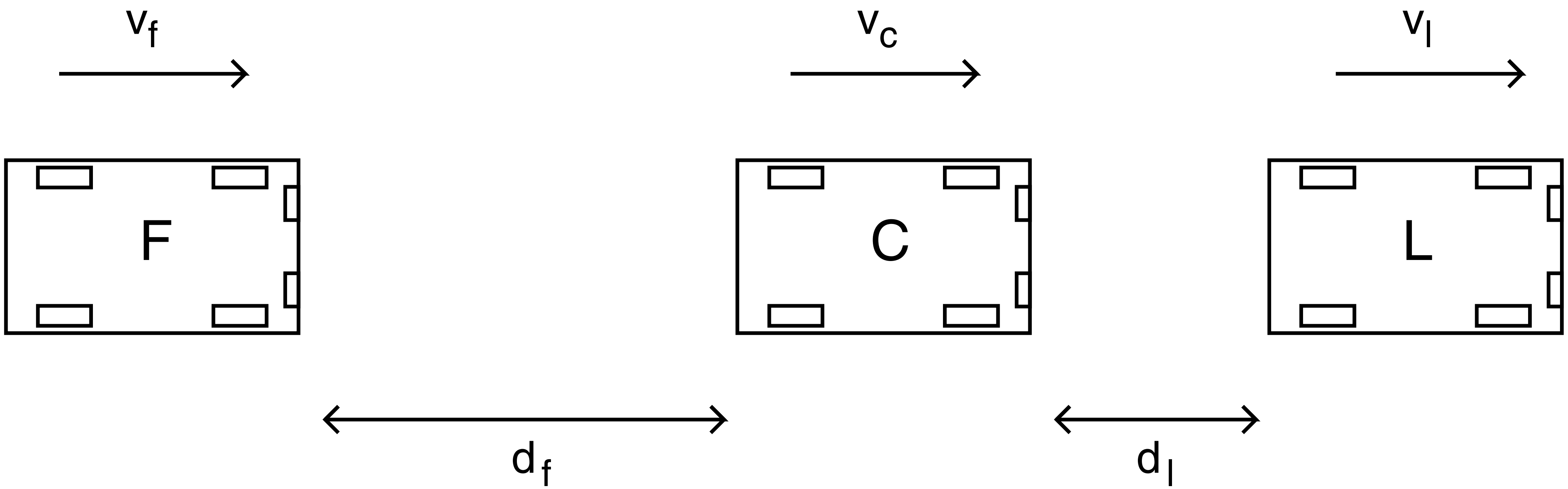
Car-Following Feedback Control



Acceleration depends on d_l and $v_l - v_c$

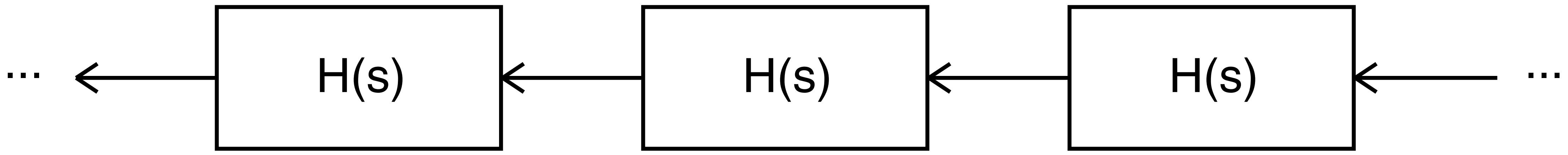
(and possibly v_{des}, v_c, and v_{max})

Car-Following Model

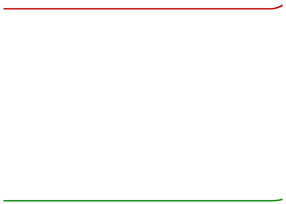


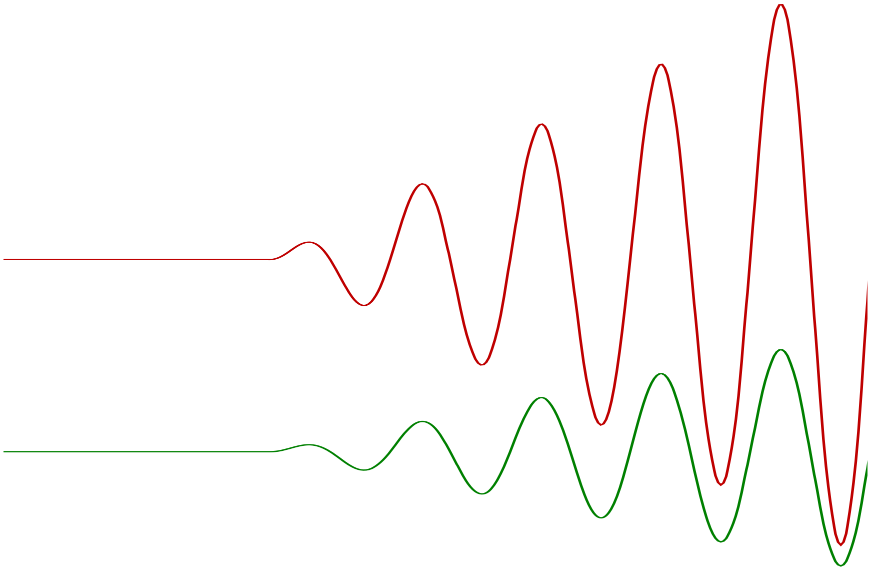
- Control of car C depends on d_l and $v_l - v_c$
- Control of car F depends on d_f and $v_c - v_f$

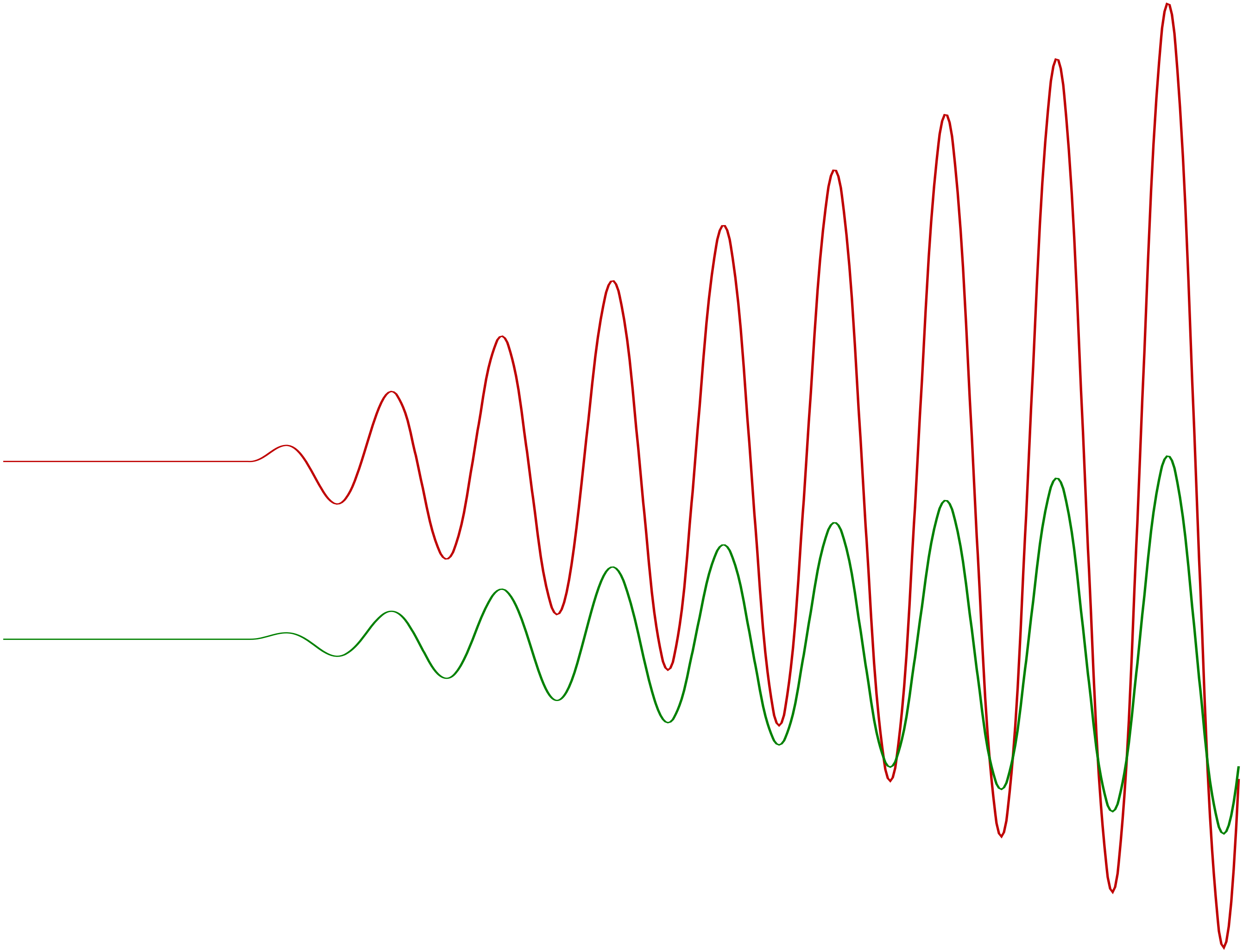
Car-Following System Model



Overall transfer function $\left(H(s)\right)^n$







Need more than “adaptive cruise control”

- Many explanations for how flow instabilities arise
- For example: Simple car-following model

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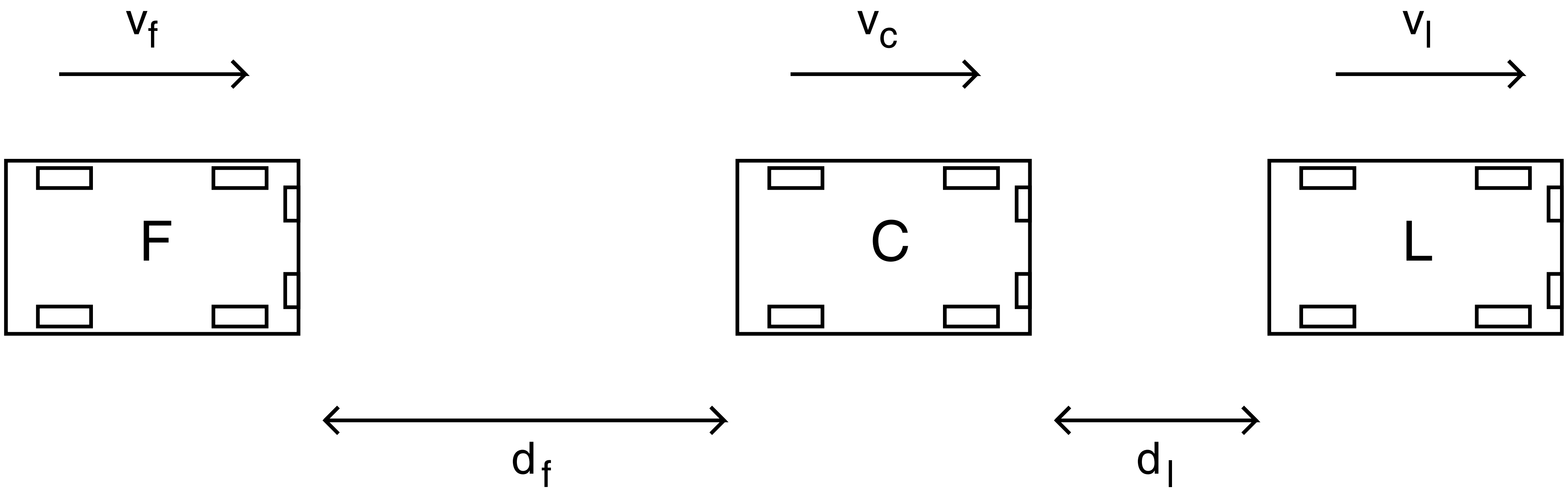
- Many explanations for how flow instabilities arise
- For example: Simple car-following model

- But, few ideas on what to do about it
- “Adaptive cruise control” does not solve the problem

- Solution is to use bilateral information flow
- Cheap machine vision systems support bilateral control

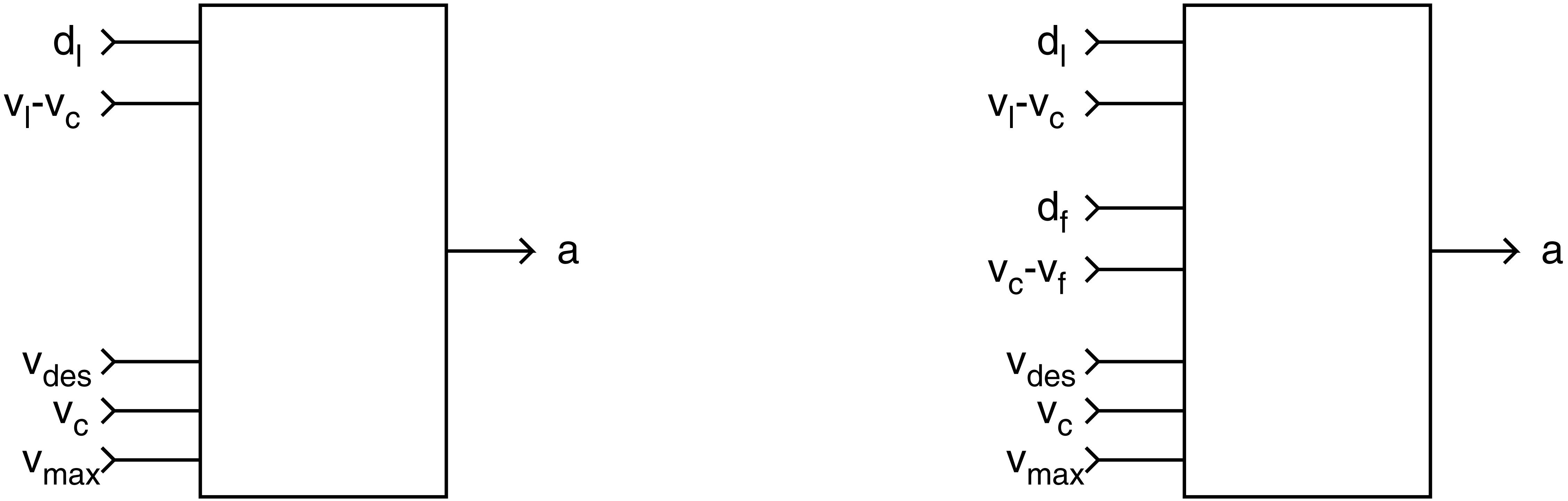
Bilateral Control



Control of car C depends on d_l and $v_l - v_c$

and on d_f and $v_c - v_f$

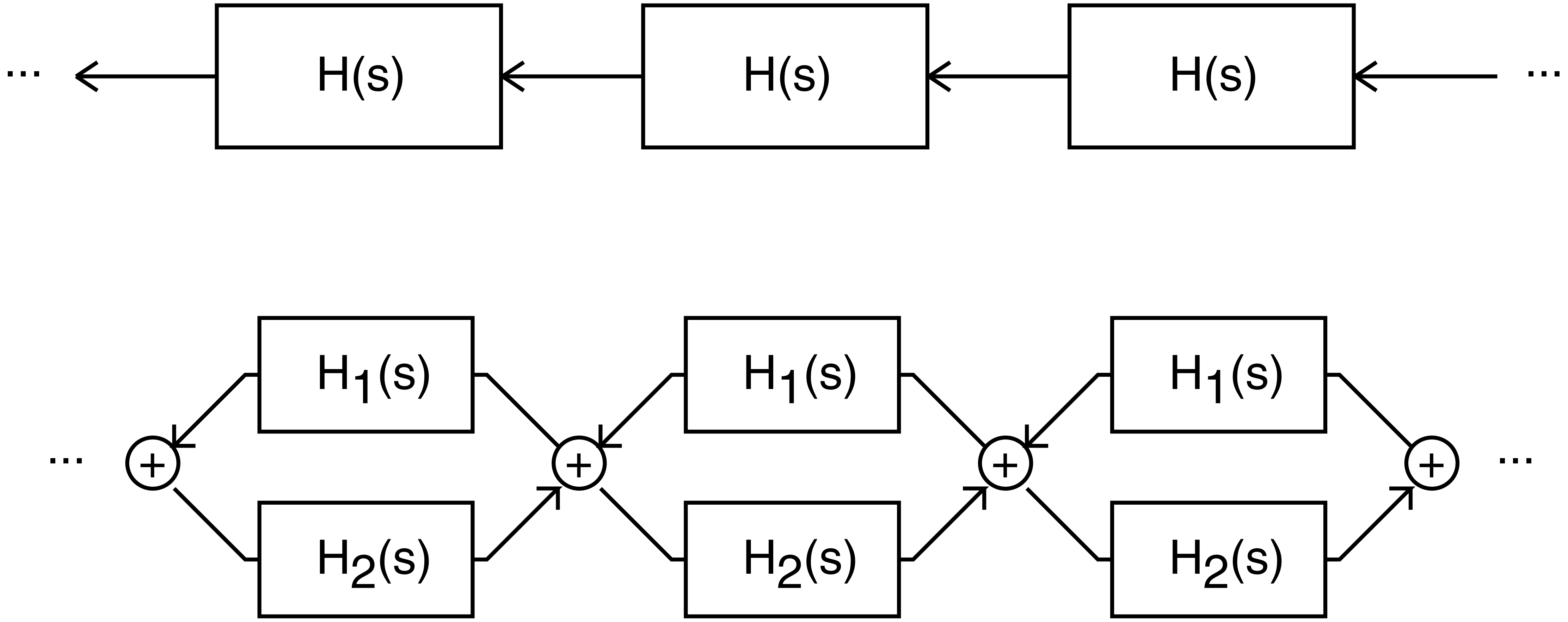
Feedback Control Comparison



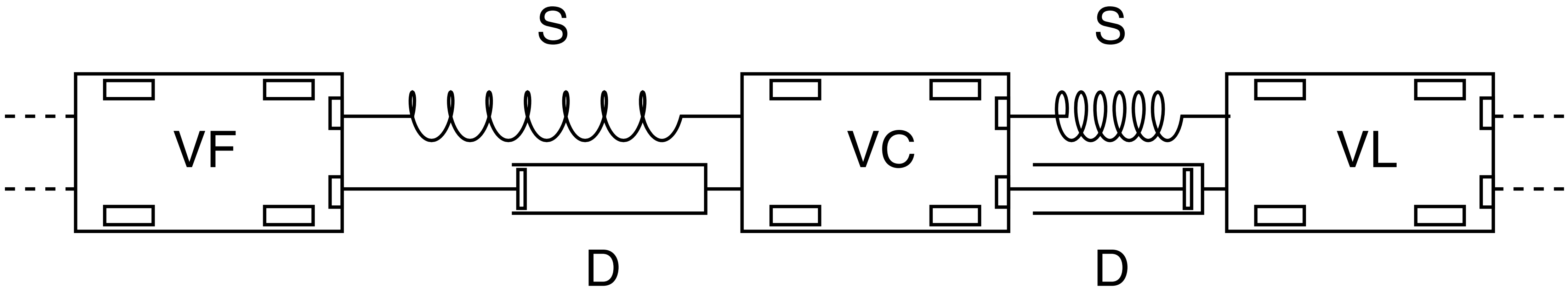
(a) acceleration depends on d_l, $v_l - v_c$,

(b) acceleration depends on d_l, $v_l - v_c$,
— *as well* as d_f and $v_c - v_f$

System Model Comparison



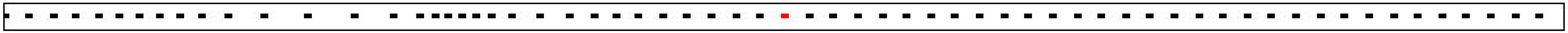
Model of Bilateral Control



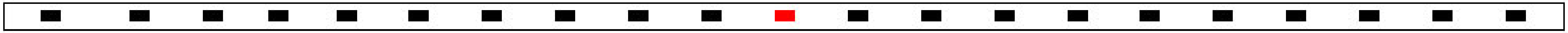
Force in springs —
proportional to difference from rest length

Force in damper —
proportional to difference in velocities

(1) CAR FOLLOWING:

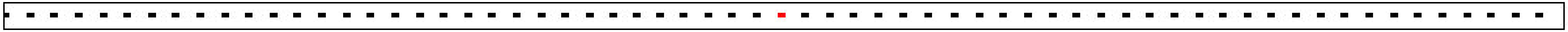


Closeup of track:



- With “car following” control, disturbances move upstream (to the left) only, and increase in amplitude as they go.
- The disturbance near the initial cause dies down, but the wave travelling upstream does not.
- (In car following, acceleration of each vehicle depends on distance and relative velocity of the leading vehicle.)

(2) BILATERAL CONTROL:

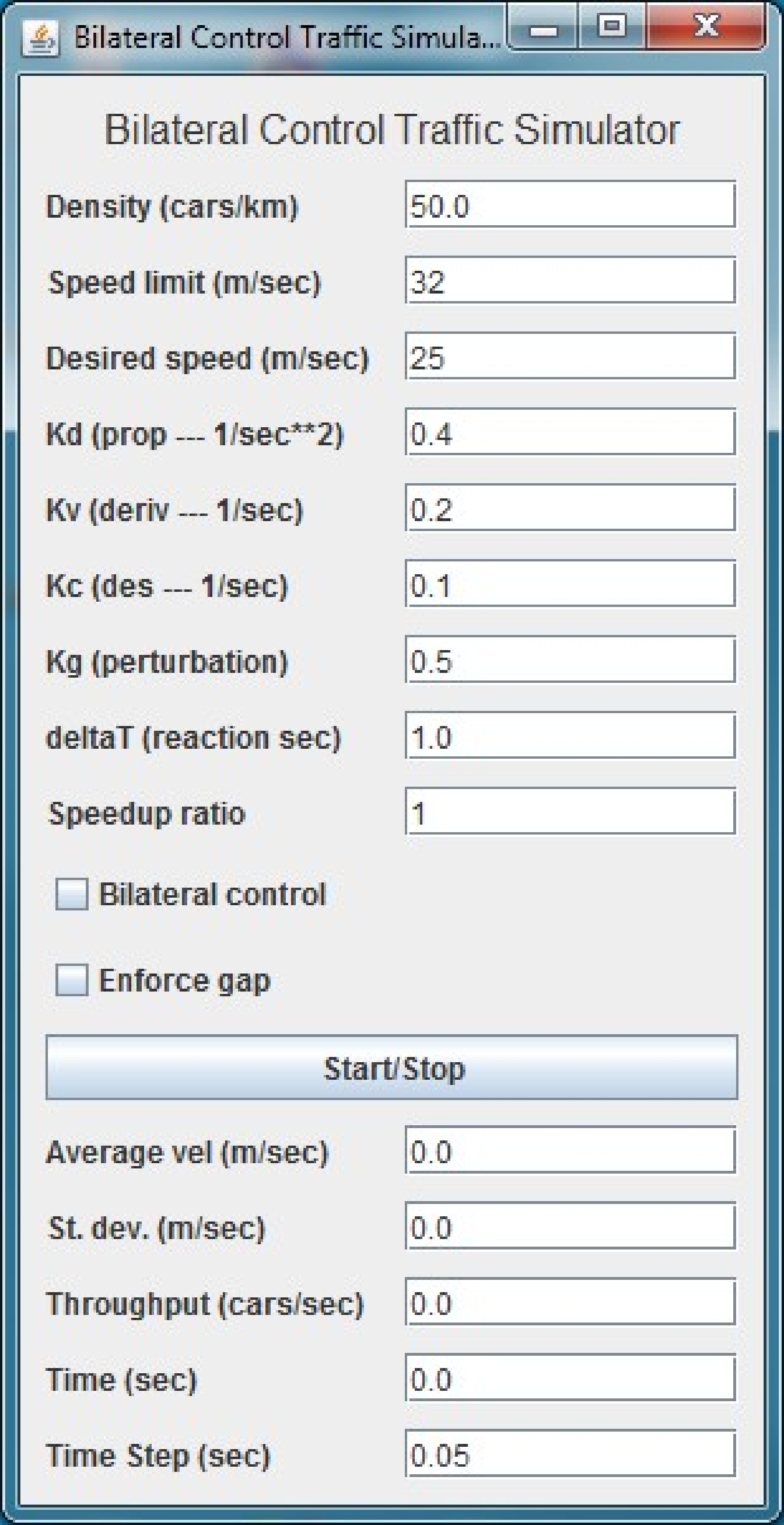


Closeup of track:

- With “bilateral” control, disturbances travel in both directions and decrease in amplitude.
- The system soon returns to smooth flow.
- (In bilateral control, accelerationof each vehicle depends on distance and relative velocity of leading *and* following vehicle.)

For additional details:

- search for Suppressing Traffic Flow Instabilities
- or search for bkph traffic



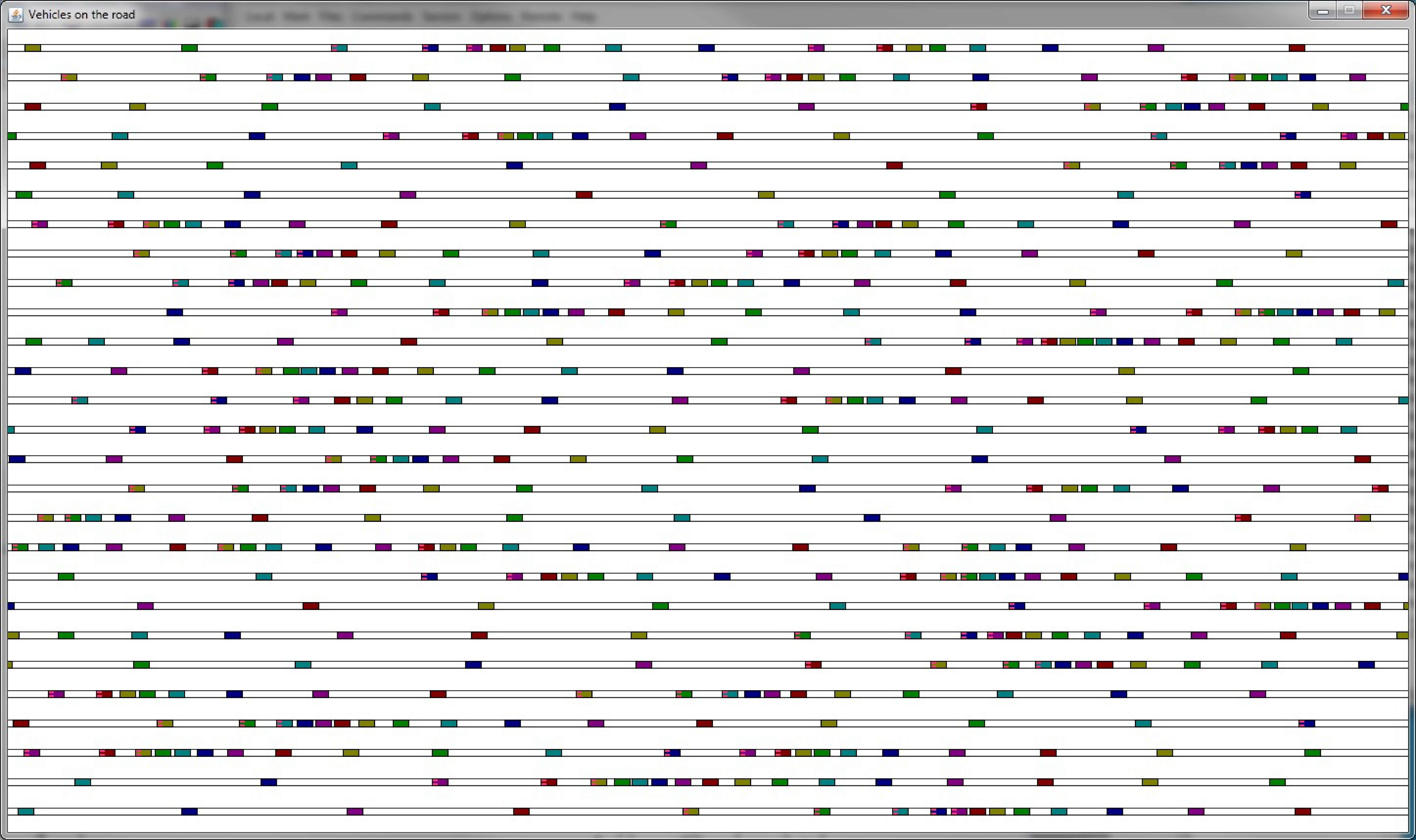
Bilateral Control Traffic Simulator

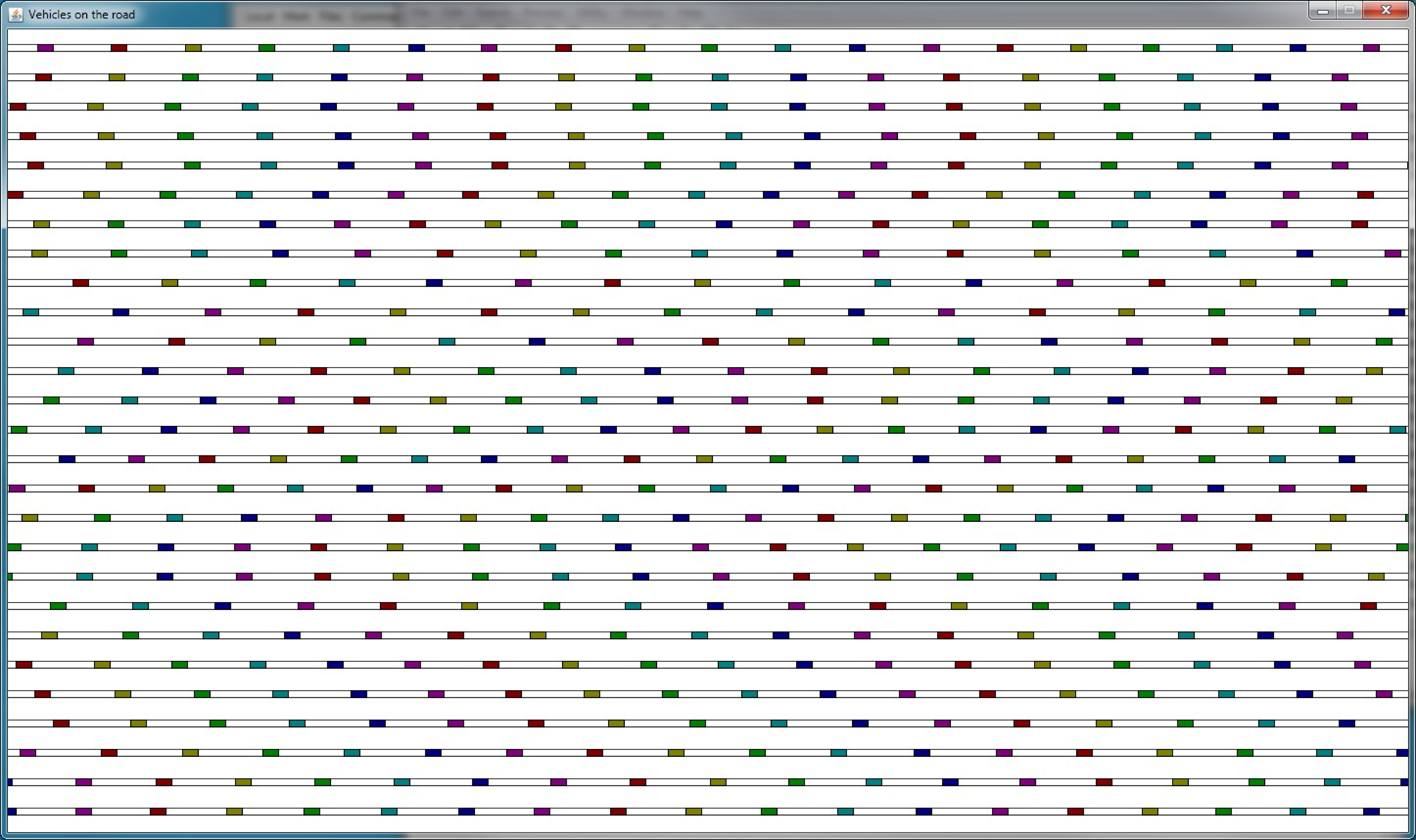
Density (cars/km): 50.0
Speed limit (m/sec): 32
Desired speed (m/sec): 25
Kd (prop --- 1/sec**2): 0.4
Kv (deriv --- 1/sec): 0.2
Kc (des --- 1/sec): 0.1
Kg (perturbation): 0.5
deltaT (reaction sec): 1.0
Speedup ratio: 1

☐ Bilateral control

☐ Enforce gap

Average vel (m/sec): 0.0
St. dev. (m/sec): 0.0
Throughput (cars/sec): 0.0
Time (sec): 0.0
Time Step (sec): 0.05


Vehicles on the road


Vehicles on the road

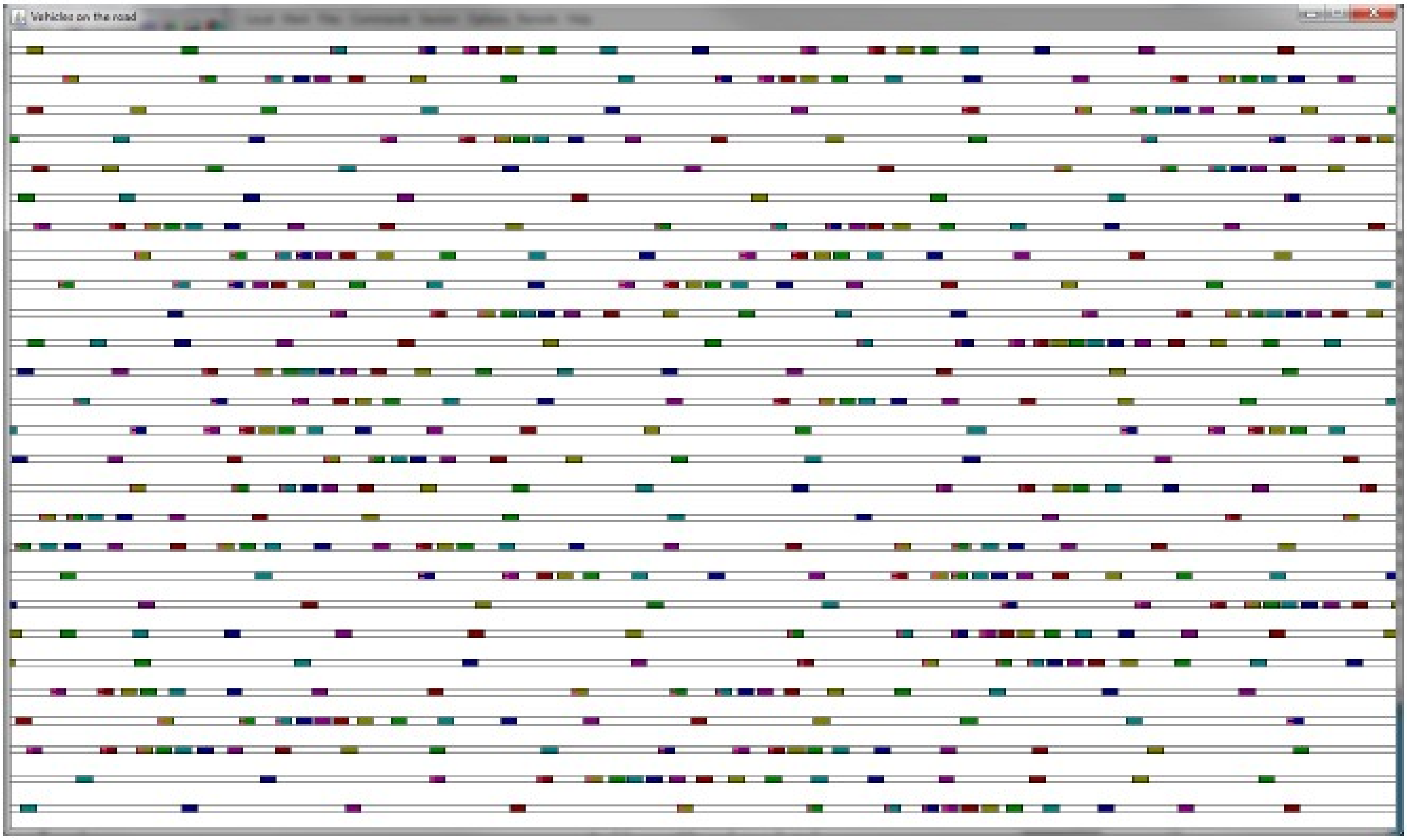


Fig. 12. Unstable traffic flow using car following model.

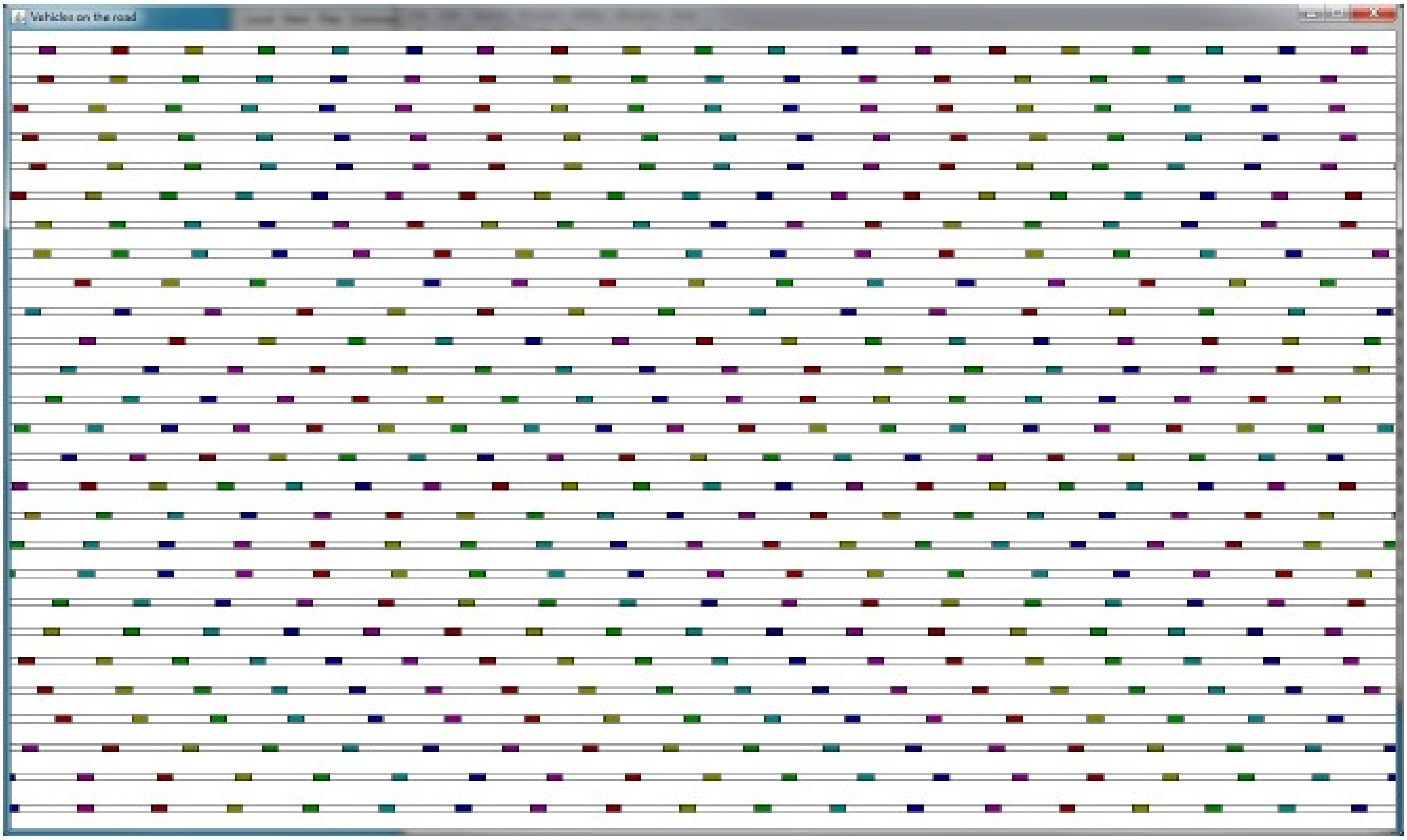


Fig. 13. Stable traffic flow using bilateral control.

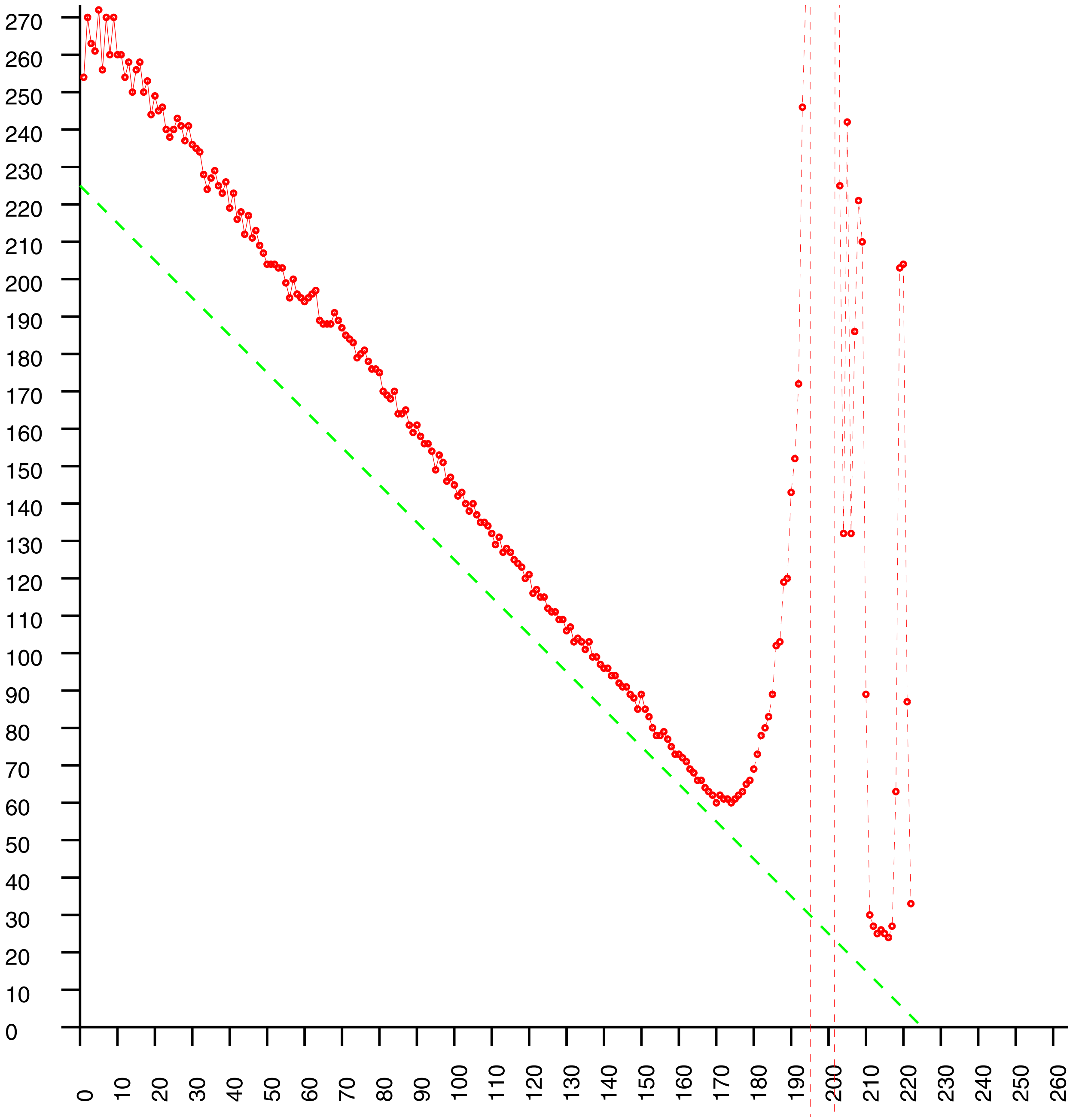
Sensors

- Need sensors for distance and (relative) velocity
- Alternatives: radar, lidar, sonar, and machine vision
- Imaging chips are low cost — as is on-board processing

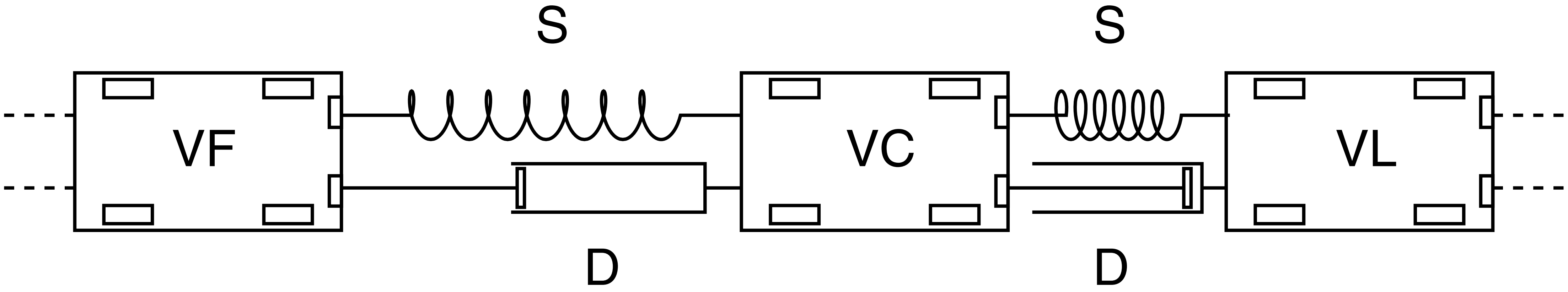
Sensors

- Need sensors for distance and (relative) velocity
- Alternatives: radar, lidar, sonar, and machine vision
- Imaging chips are low cost — as is on-board processing
- Distance: binocular stereo, trinocular stereo, . . .
- Velocity: motion vision methods . . .
- Distance/Velocity: time to contact (TTC)

Time To Contact



suppressing traffic flow instabilities



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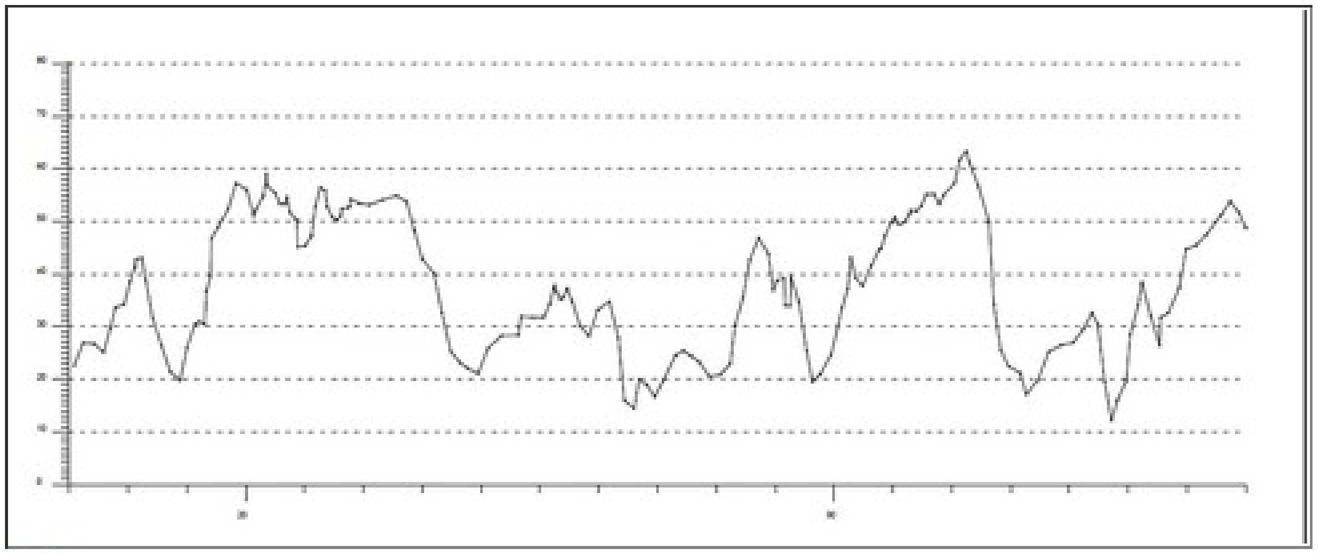
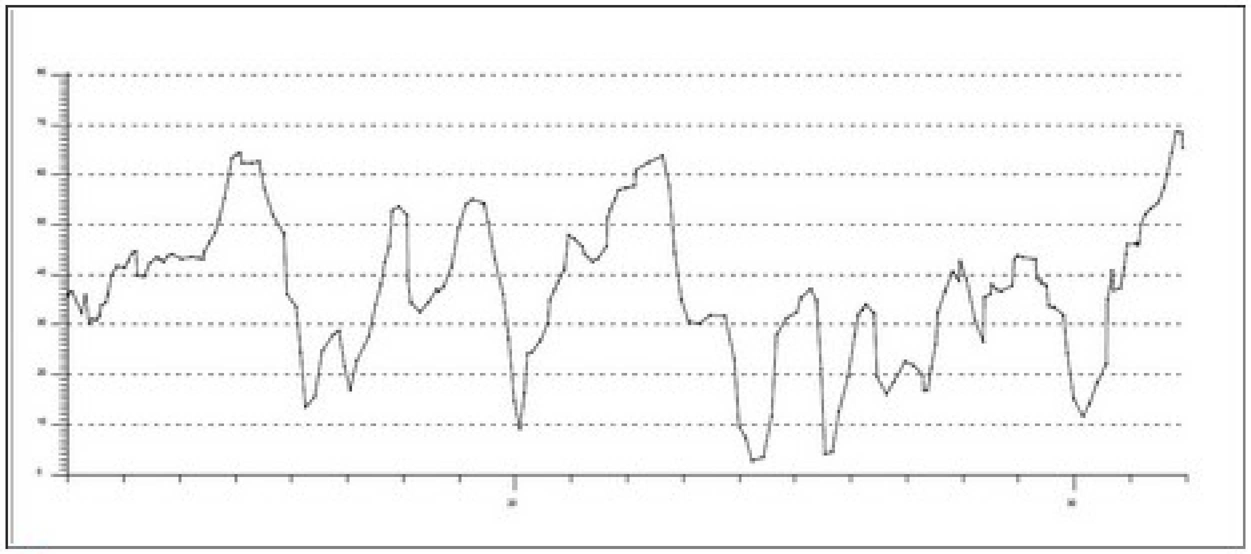
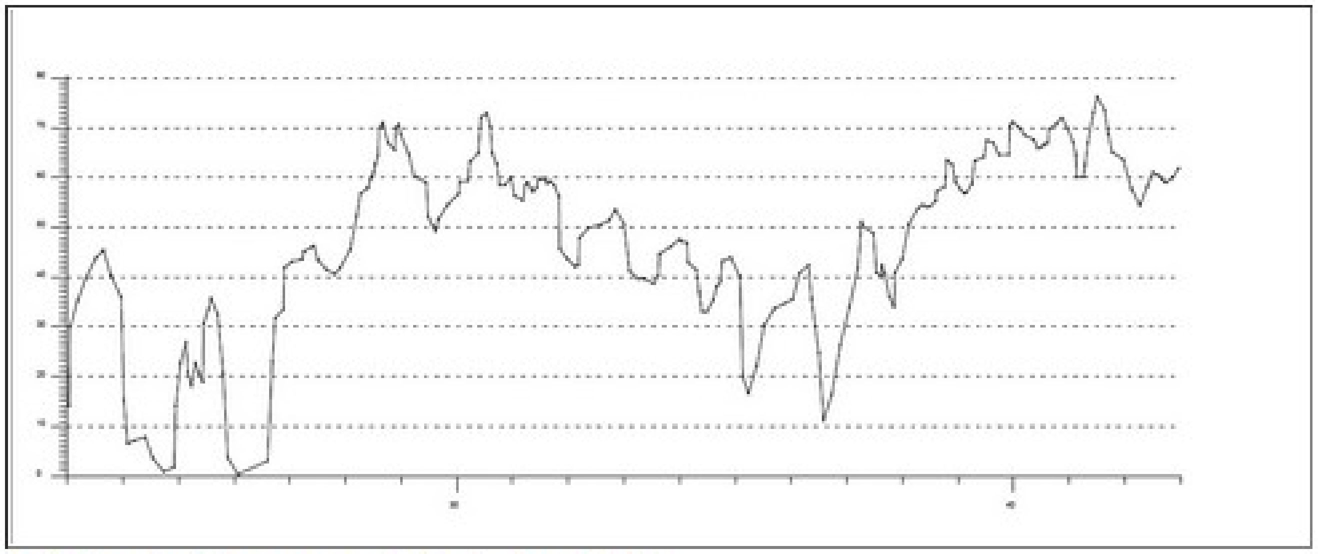


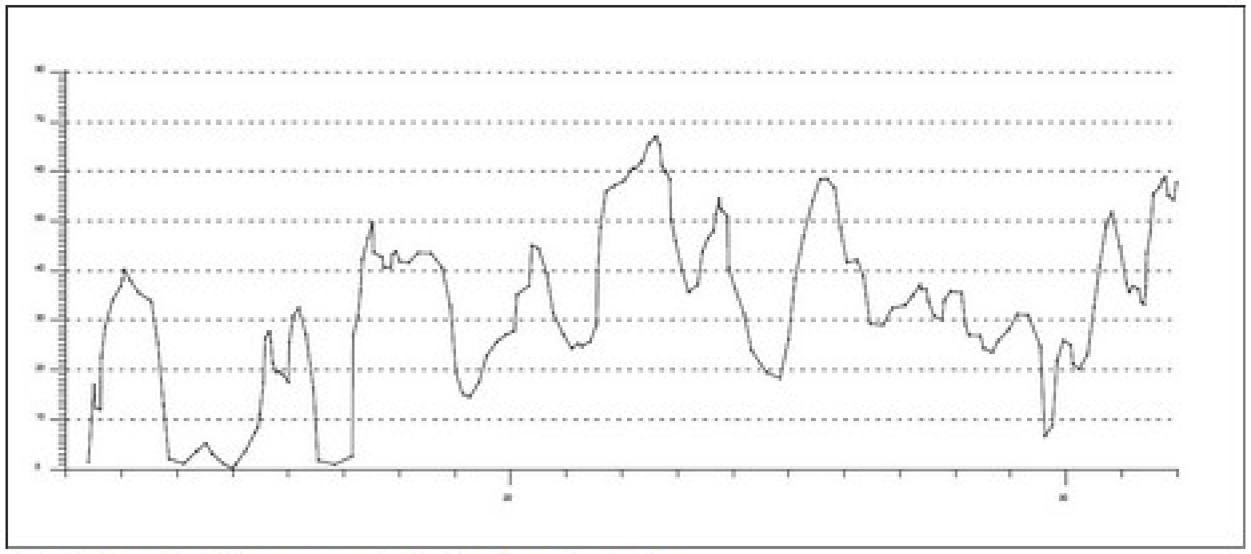
93 North, Boston, 2011 March 31



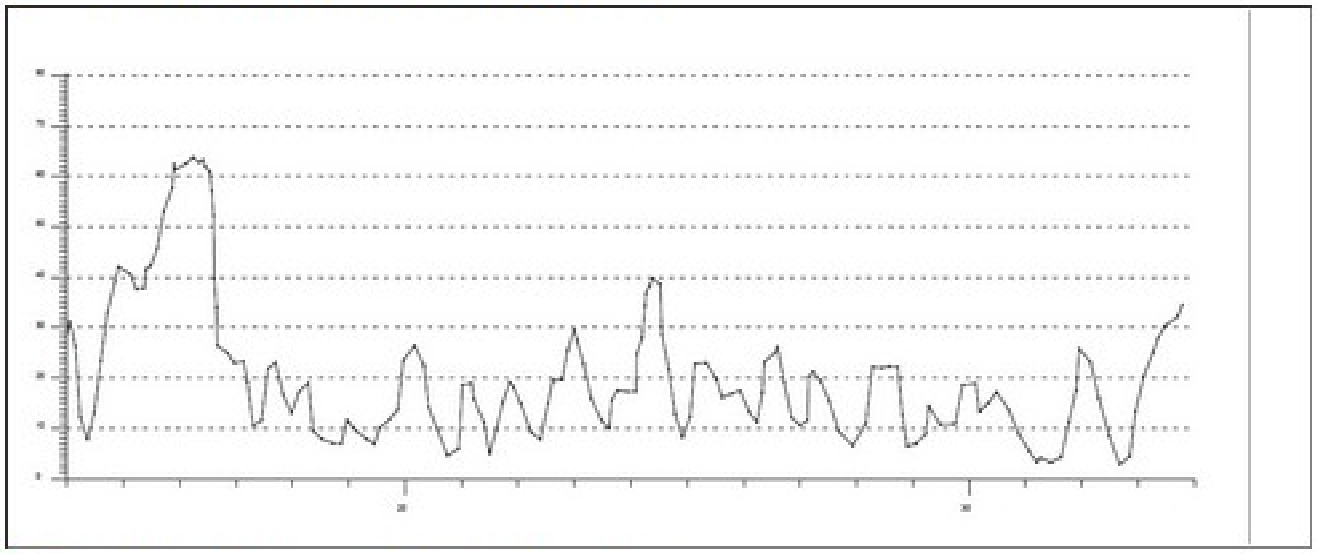
93 North, Boston, 2011 April 14



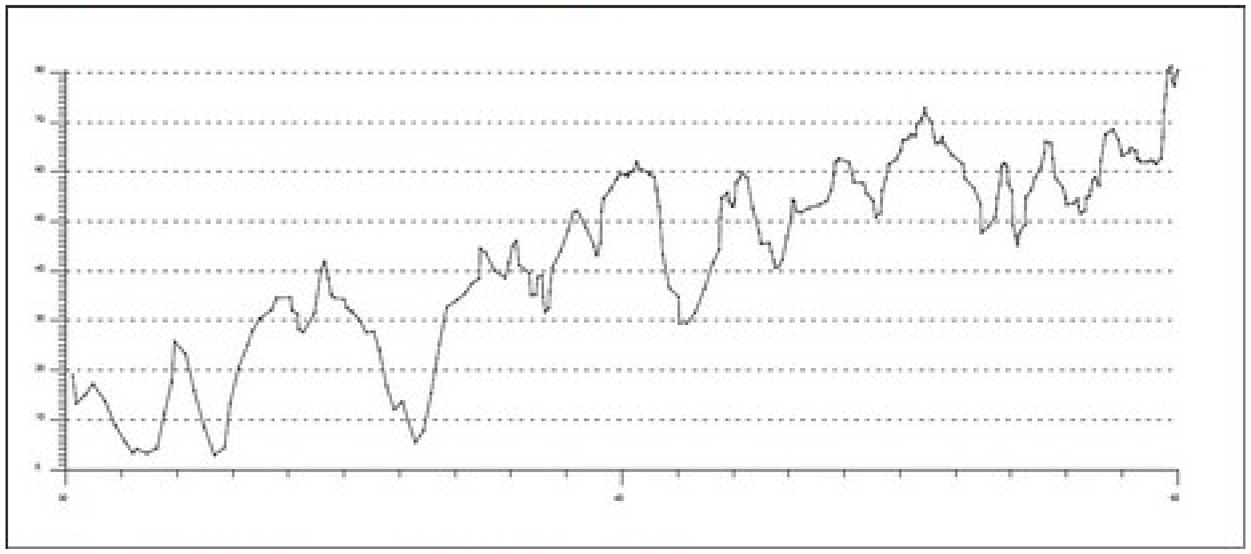
93 North, Boston, 2011 April 21



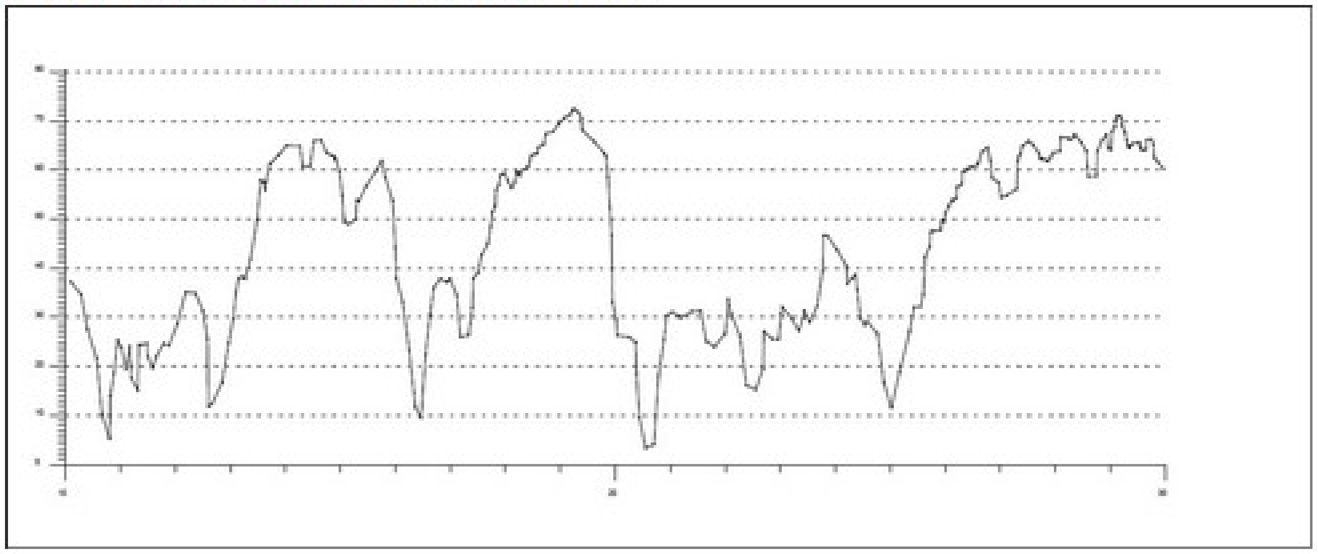
93 North, Boston, 2011 April 28



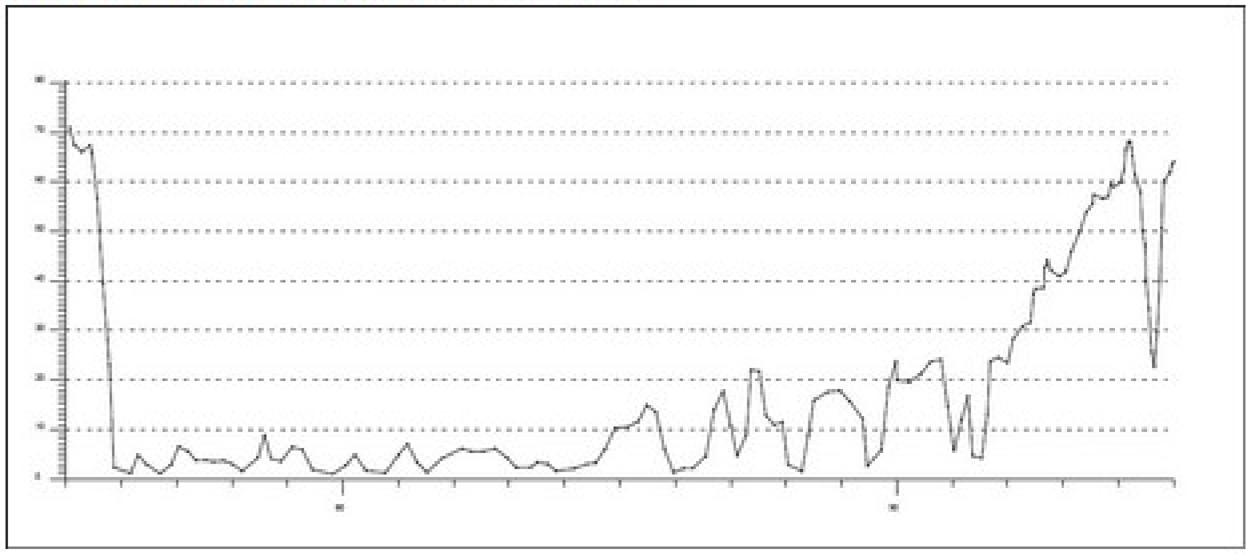
93 North, Boston, 2011 May 12



95 North, Woburn, 2011 May 12



93 North, Boston, 2011 May 19



RT 16 North, Portsmouth, 2011 May 19

Competing Explanations

Many different models predict traffic flow instabilities:

- Cellular automata;
- Differential equations;
- Feedback control models;
- Fluid flow models;
- Particle tracking models;
- Car-following simulation models;

...

What is needed is a method for *suppressing* instabilities

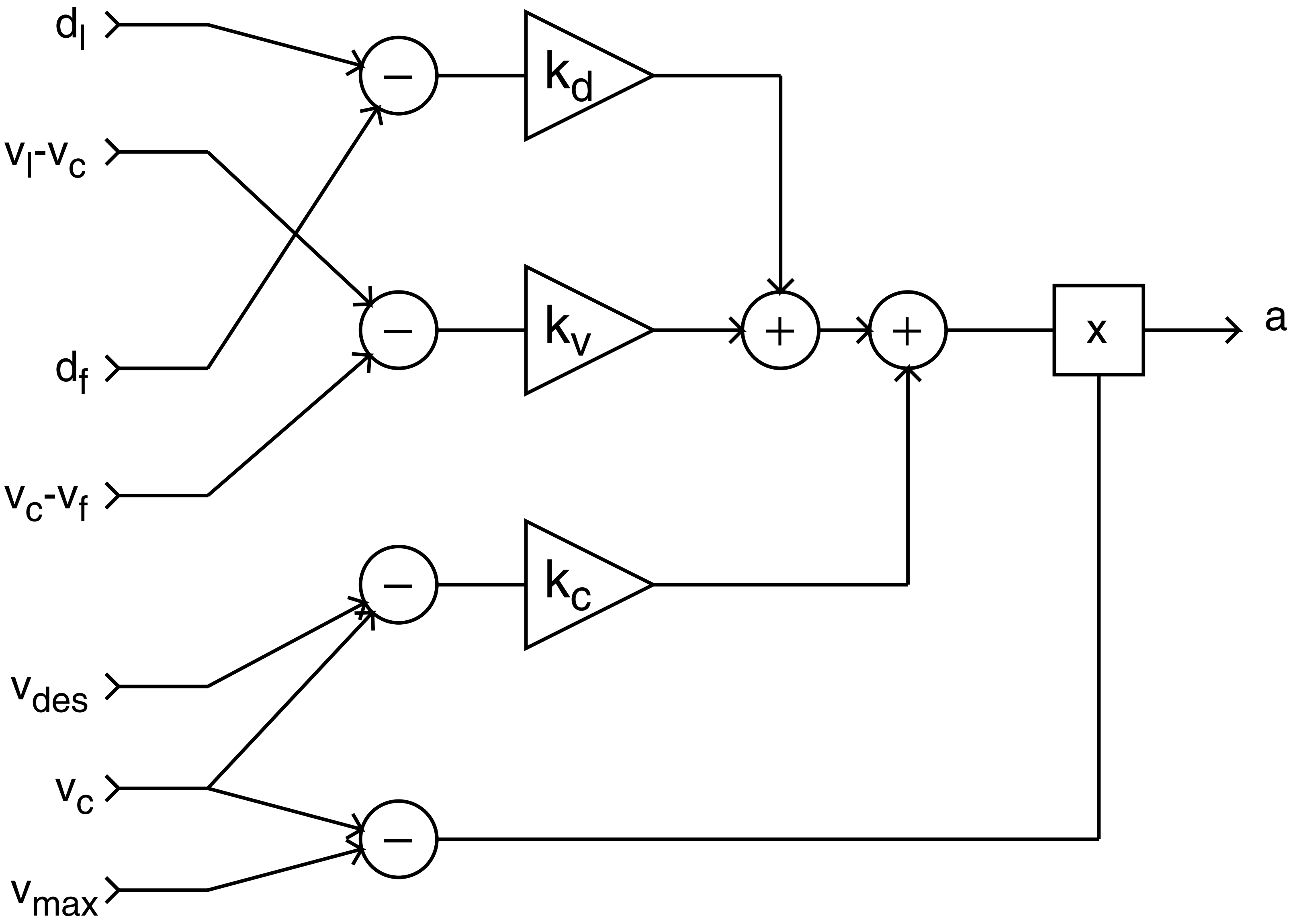
Smooth Flow Analysis

In the absence of instabilities:

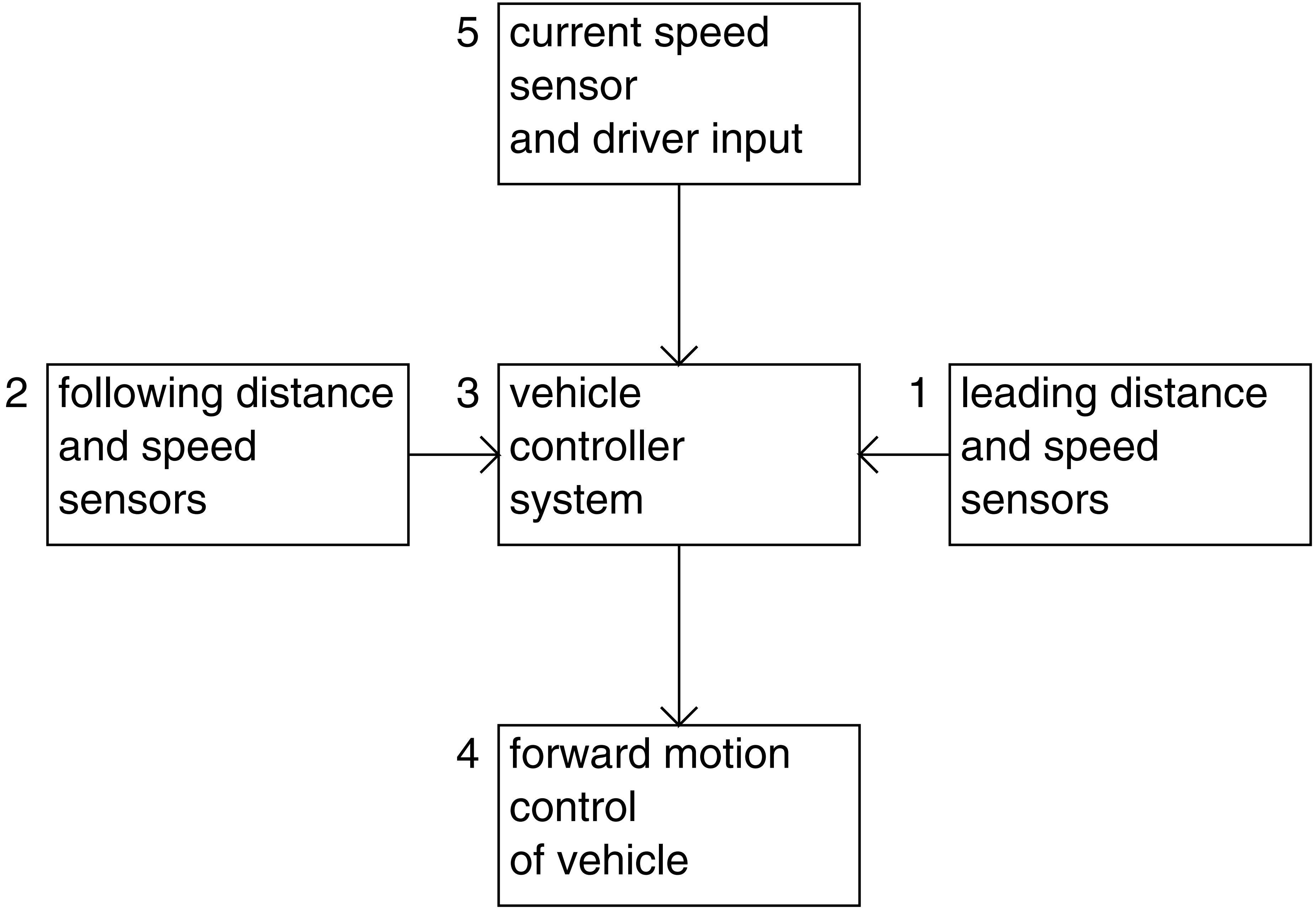
- Safe separation — speed × reaction time: $d = vT$
- Density — inverse of length plus separation: $\rho = 1/(l + d)$
- Throughput — speed × density: $c = v\rho = v/(l + vT)$
- Approaches inverse of reaction time: $c \to 1/T$
- E.g. $T = 1$ sec — c approaches 3600 vehicles per hour

- **In practice, throughput is considerably lower — because flow is *not* smooth**

Illustrative Bilateral Control System



Block Diagram of Bilateral Control System



5 current speed sensor and driver input

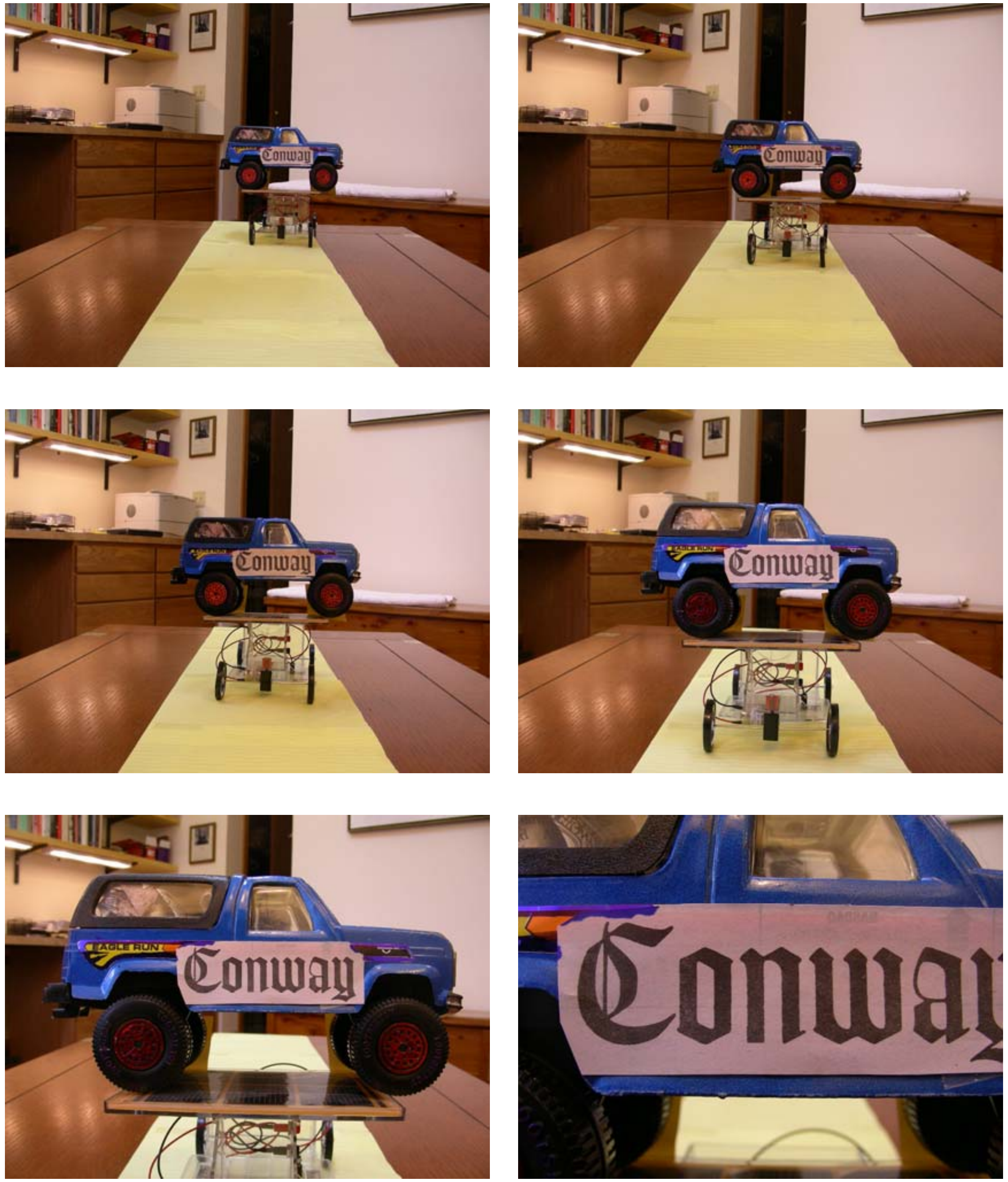
2 following distance and speed sensors

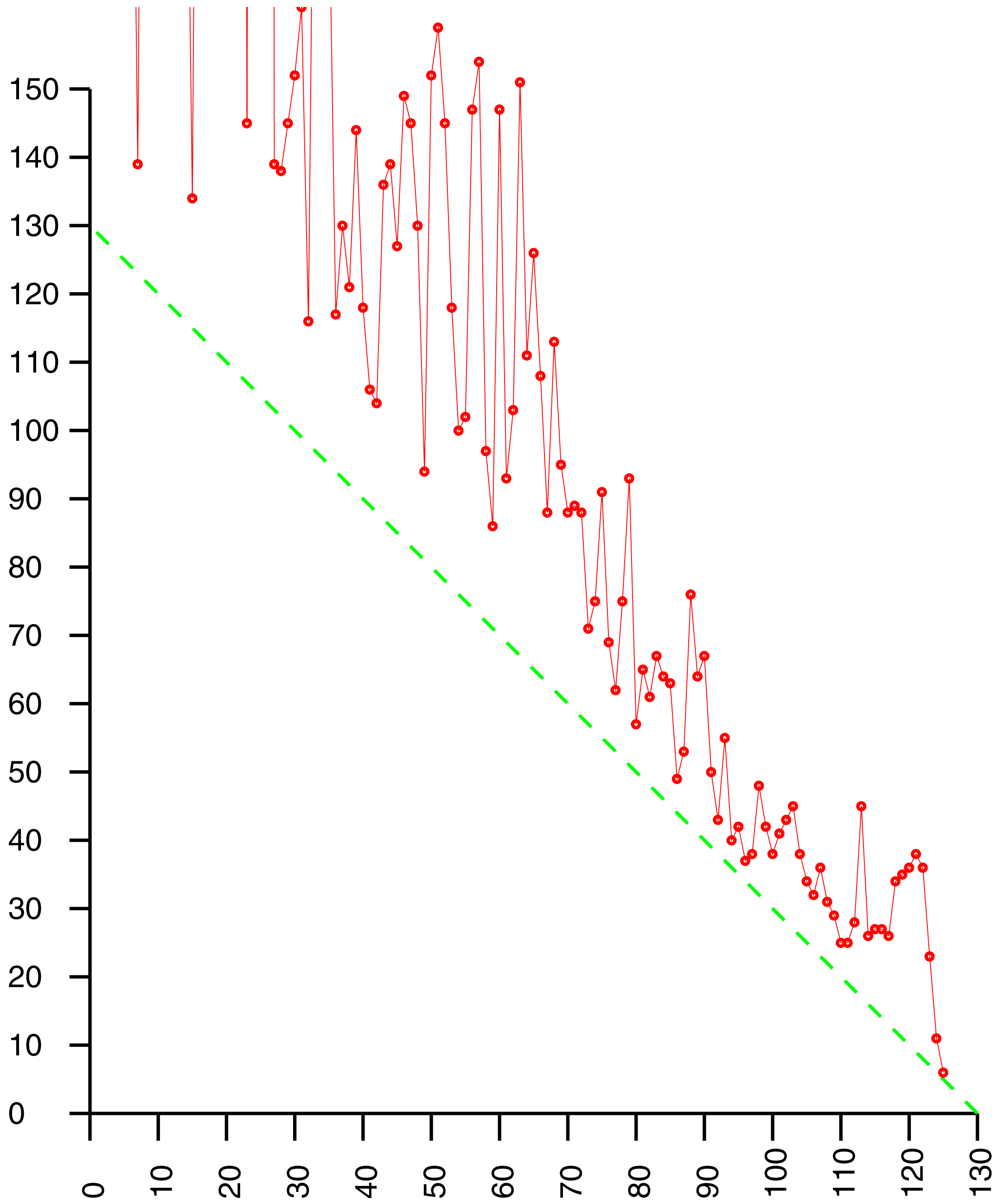
3 vehicle controller system

1 leading distance and speed sensors

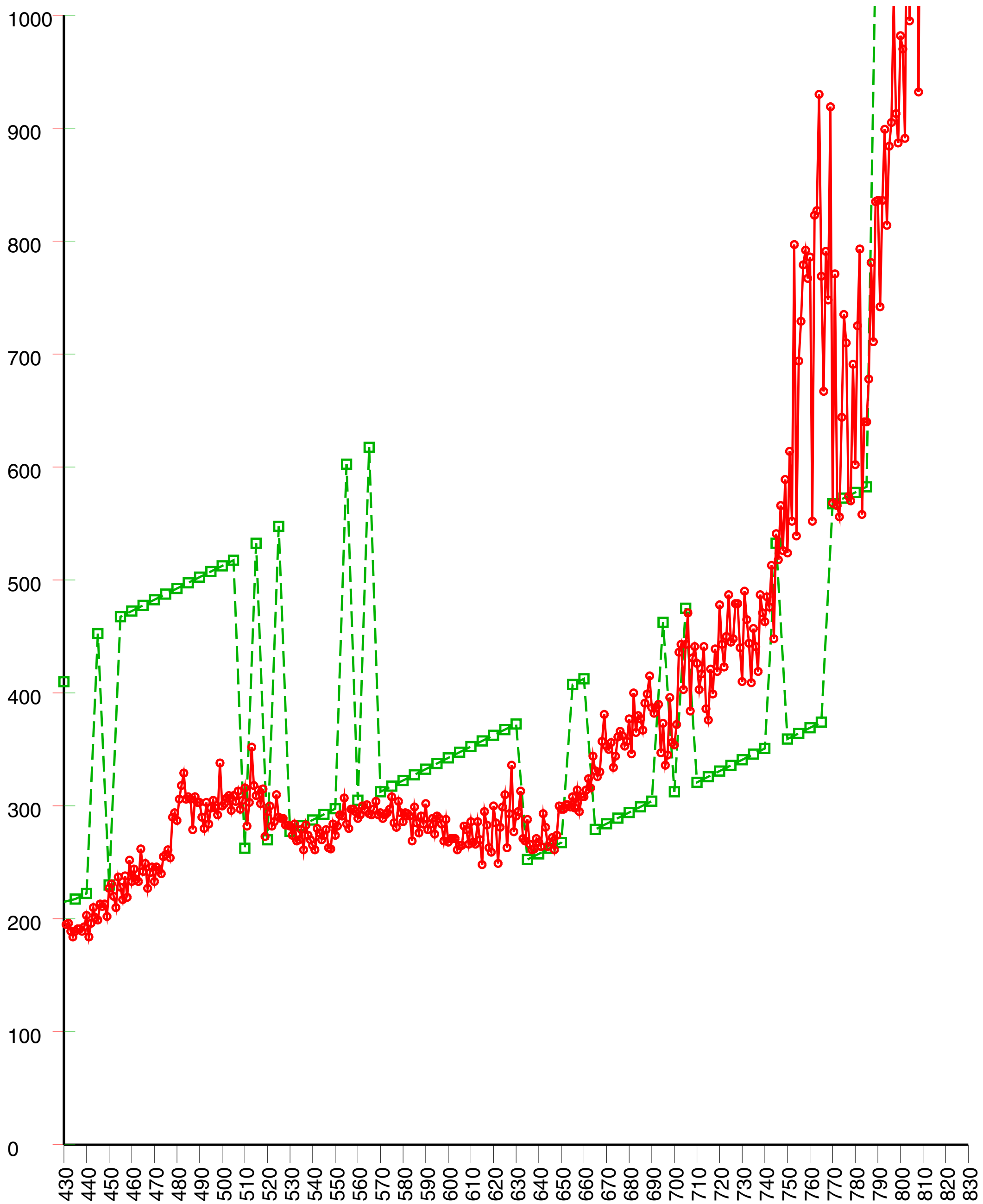
4 forward motion control of vehicle

Time To Contact (time lapse sequence)





Time To Contact (real world sequence)



Problems to solve

- What is the business model?

- What sensors and algorithms? TTC + trinocular stereo?
- Full automation, “modulation” or merely advisory?

- Extend to *mix* of automated and legacy vehicles
- Extend to multiple lanes, exits and entrances etc.

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- What sensors and algorithms? TTC + trinocular stereo?
- Full automation, “modulation” or merely advisory?

- Extend to *mix* of automated and legacy vehicles
- Extend to multiple lanes, exits and entrances etc.

- Explore use of inter-vehicle communication for sensing
- “Optimize” the control scheme