suppressing traffic flow instabilities

Berthold K.P. Horn
Traffic flow instabilities waste energy:

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- 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

- At high flow densities, traffic flow becomes unstable
- Travelling waves of velocity and density fluctuations
- Perturbations are amplified
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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
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 \((H(s))^n\)
Need more than “adaptive cruise control”

- Many explanations for how flow instabilities arise
- For example: Simple car-following model
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- But, few ideas on what to do about it
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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
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 \( v_c - v_f \)
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, acceleration of each vehicle depends on distance and relative velocity of leading and following vehicle.)

For additional details:
- search for Supressing Traffic Flow Instabilities
- or search for bkph traffic
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
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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 $\times$ reaction time: $d = vT$
• Density — inverse of length plus separation: $\rho = 1/(l + d)$
• Throughput — speed $\times$ 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

d_l

v_l-v_c

d_f

v_c-v_f

v_{\text{des}}

v_c

v_{\text{max}}

- k_d

- k_v

+ k_c

\times

a
Block Diagram of Bilateral Control System

1. leading distance and speed sensors
2. following distance and speed sensors
3. vehicle controller system
4. forward motion control of vehicle
5. current speed sensor and driver input
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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- 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