ASSESSING CAUSAL FACTORS IN INDIVIDUAL ROAD ACCIDENTS: COLLECTIVE RESPONSIBILITY IN FREEWAY REAR-END COLLISIONS?

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Sponsored by: ITS Institute

Video Data Collection: John Hourdos, Vishnu Garg, Ted Morris
WHAT CAN WE SAY ABOUT FREEWAY REAR-END COLLISIONS?

Example from a Minnesota accident report:
- Happened on I-94 in downtown Minneapolis
- Happened during the afternoon peak period
- Vehicle 2 rear-ended vehicle 1
- Driver 1 received 'possible injury'
- Driver 2 reported as:
  - ‘Following too closely’
  - ‘Driver inattention/distraction’

More generally, freeway rear-end collisions:
- Often happen during high-demand periods
- Don't often result in fatal or very severe injuries
- Do often result in non-recurring congestion
- Responsibility is usually attributed to rear-ending driver

But is this the whole story?
A DIGRESSION ON ‘CAUSE’?

David Hume: “...we may define a cause to be an object, followed by another, and where all objects similar to the first are followed by objects similar to the second. Or in other words where, if the first object had not been, the second never had existed.”

Stan Baker: “causal factor” is a circumstance “contributing to a result without which the result could not have occurred”

NTSB: “probable cause” is a “condition or event” such that “had the condition or event been prevented...the accident would not occur.”

That is, we say “A caused B” if
(1) A occurred,
(2) B occurred,
(3) if A hadn’t occurred neither would B

Interesting, but how can we test the plausibility of counterfactuals like (3)?
If we are willing to accept:

**Local Laplacean Determinism:**
In principle, it is possible to specify a set of structural equations, and a set of initial variable values, so that a given crash can be ‘exactly’ simulated (Baker, 1975)

**Counterfactual Treatment of Causation:**
The causal effect of some variable is determined by comparing what happened to what would have happened, other things equal, had that variable been set to some different value.

**Probabilistic Treatment of Uncertainty:**
“There is a forceful argument, that is being increasingly accepted, which concludes that the only sensible way to handle uncertainty is by means of probability.” (D.V. Lindley, 1991)

Then
Judea Pearl’s theory of **Probabilistic Causal Models** can be used to answer questions concerning individual accident causation.
Example: Speed as a causal factor
- \( v \) = vehicle speed; \( u \) = other collision variables; \( y \) = \{0 if no collision, 1 if collision\}

Collision leaves evidence \( e \)

**Probability of Necessity:** \( PN = P[y_{v=v^*} = 0 | y=1 \& e] \)

**Computing PN** (Balke and Pearl, 1994):
- **Abduction:** Using Bayes Theorem, compute \( P[v,u | y=1\&e] \)
- **Action:** Set \( v=v^* \)
- **Prediction:** compute \( PN = \mathbb{I}\{u:y(v^*,u)=0\} \ dP[u | y=1 \& e] \)

Computations (relatively) straightforward using Markov Chain Monte Carlo
FREEWAY REAR-ENDING COLLISIONS
GM CAR-FOLLOWING MODEL

Spacing governed by differential equation

\[ \frac{d^2 x_{k+1}(t+T)}{dt^2} = \alpha \left( \frac{dx_k(t)}{dt} \right) \]

When \( \alpha T > 1/2 \), system is ‘asymptotically unstable’

**Note:** Asymptotic instability is a property of a platoon of drivers, not of an individual driver
Brill’s (1972) Kinematic Model

\[ v_k = \text{speed of vehicle } k \]

\[ h_k = \text{following headway of driver } k \]

\[ r_k = \text{reaction time of driver } k \]

\[ a_k = \text{deceleration of driver } k \]
BRILL’S COLLISION CONDITION

\[ v_{k+1} h_{k+1} + \frac{v_k^2}{2 a_k} \geq v_{k+1} r_{k+1} + \frac{v_{k+1}^2}{2 a_{k+1}} \Rightarrow a_{k+1} \geq \frac{v_{k+1}^2}{\frac{v_k^2}{a_k} + 2v_k (h_{k+1} - r_{k+1})} \]

Collision avoided when available stopping distance exceeds required stopping distance

**Note:** \( r_{k+1} > h_{k+1} \) implies, other things equal, \( a_{k+1} > a_k \) i.e. deceleration required by driver \( k+1 \) exceeds that required by driver \( k \)

**Hypothesis:** ‘Long’ reaction times by drivers early in platoon can **cause** collision between vehicles later in platoon.
Data Collection System

- Advanced detection and Surveillance Stations.
  - Designed, assembled and deployed by the ITS laboratory.
Collision on 12/30/2002
COLLISIONS ON I-94

Video cameras placed on high-rise buildings overlooking WB I-94
Video footage of collisions saved
Trajectories of vehicles extracted from video using Videopoint

Trajectories for 7 vehicles, with collision between 6 & 7, December 30, 2002.
**TRAJECTORY MODEL**

\[
x(t) = \begin{cases} 
vt, & t \neq t_0 \\
vt + a(t-t_0)^2/2, & t_0 < t \neq t_0 + v/a \\
v t_0 + v^2/2a, & t > t_0 + v/a 
\end{cases}
\]

Parameterized by vehicle's initial speed \(v\), time when braking began \(t_0\), and braking deceleration \(a\)

Bayes estimates of trajectory model parameters computed using WinBUGS

Example trajectory model fit for vehicle 1
DETERMINING REACTION TIMES AND FOLLOWING HEADWAYS

(1) Speeds \( (v) \), braking decelerations \( (a) \) and braking initiation times \( (t_0) \) estimated from observed trajectories

(2) Reaction times determined as difference between braking initiation times

(3) Following distance determined as location difference when lead vehicle initiated braking
**BAYES ESTIMATES:**
**COLLISION ON 12/30/02**

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<th>Vehicle</th>
<th>$v_k$ (fps)</th>
<th>$h_k$ (sec)</th>
<th>$r_k$ (sec)</th>
<th>$a_k$ (fps$^2$)</th>
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**Note:**
(1) Reaction times tend to exceed following headways,
(2) Minimum necessary decelerations ($a_{k0}$) tend to increase,
(3) Long reaction time on part of driver 3
TESTING FOR CAUSAL FACTORS

Example Counterfactual Test:
If Driver 3's reaction time had been equal to his/her following headway would, other things equal, the crash have been prevented?

(1) Abduction step: Compute posterior distribution for trajectory parameters, using Markov Chain Monte Carlo

(2) Action step: Set constraint r3=h3

(3) Prediction step: Compute PN = P[a07 \( r_3 < h_3 \) < a7 ] (i.e. the probability driver 7's minimum necessary deceleration when r3=h3 is less than his observed deceleration

In this case PN = P[a07 \( r_3 < h_3 \) < a7 ] = 1.0.
COLLISION ON 05/02/03

Bayes Estimates Posterior Means Only

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SUMMARY OF RESULTS FROM COUNTERFACTUAL TESTING

Collision on December 30, 2003:
1. $h_7 = 2.0$ sec $\Rightarrow$ PN $= 1.0$ (had driver 7 maintained a following headway of 2.0 seconds, the collision would not have occurred)
2. $r_3 = h_3$ $\Rightarrow$ PN $= 1.0$ (had driver 3's reaction time been equal to his/her following headway, the collision would not have occurred)

Collision on May 2, 2003:
1. $h_7 = 2.0$ seconds $\Rightarrow$ PN $= 1.0$ (had driver 7's following headway been equal to 2.0 seconds, the collision would not have occurred)
2. $v_6 = 60$ fps $\Rightarrow$ PN $= 1.0$ (had driver 6's speed been 60 fps, the collision would not have occurred)
3. $r_3 = h_3$ $\Rightarrow$ PN $= 1.0$ (had driver 3's reaction time equaled his/her following headway, the collision would not have occurred)

Collision on March 20, 2003:
1. $h_8 = 2.0$ sec $\Rightarrow$ PN $= 1.0$ (had driver 8's following headway equaled 2 seconds the collision would not have occurred)
2. $r_5 = h_5$ $\Rightarrow$ PN $= 1.0$ (had driver 5's reaction time equaled his/her following headway the collision would not have occurred)
CONCLUSIONS

1. In each of the three collisions, actions of colliding drivers were plausible causal factors.

2. In each of the three collisions, relatively long reaction times by earlier (non-colliding) drivers were also plausible causal factors.

3. This suggests that some of the costs associated with certain driving behaviors (close following and/or long reaction times) are external.

4. Which in turn suggests that a high-demand freeway functions as an unmanaged commons, where close following and long reactions are ‘overconsumed’ compared to what would be socially optimal.

5. Reducing the incidence of freeway rear-end collisions would then require an external intervention that moves the level of close following and slow reactions toward socially more optimal levels.
THANK YOU

QUESTIONS?

This presentation draws on material published in: