Modelling Choices of Control Transitions and Speed Regulations in Full-Range Adaptive Cruise Control

Silvia Varotto, Haneen Farah, Tomer Toledo, Bart van Arem, Serge Hoogendoorn
1. Introduction

Control transitions between ACC and manual driving

Driver switches off  System switches off

Microscopic traffic flow models

Control transitions are not modelled

ACC vehicles have an effect on traffic flow efficiency (?)  
(Klunder, et al. 2009; Van Driel & Van Arem 2010)
## 2. Literature review

Xiong and Boyle (2012), Varotto et al. (2017)

<table>
<thead>
<tr>
<th>DIDC to <em>Inactive</em></th>
<th>DIDC to <em>Active and accelerate</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Leader speed &amp; acceleration</td>
<td>Acceleration</td>
</tr>
<tr>
<td>Cut-in anticipation</td>
<td>Time after activation</td>
</tr>
<tr>
<td>Ramps &amp; exits</td>
<td>Ramps</td>
</tr>
<tr>
<td>Driver heterogeneity</td>
<td>Driver heterogeneity</td>
</tr>
</tbody>
</table>
3. Research objectives

- Develop an empirically underpinned modelling framework
- In which conditions do drivers transfer control?
- How does driver behaviour change during these transitions?
- Estimate a driver behaviour model
- Predict the effects of control transitions on traffic flow
4. Data collection

Controlled on-road experiment

Drive as you do in real life and use the system only when you think it is appropriate

- BMW 5 series with full range ACC
- Peak hours, A99 ~ 35.5 km
- 23 participants
4.1 ACC system specifications

- ACC Active (A)
  - Press gas pedal

- ACC Inactive (I)
  - Driver in control (DC)
  - ACC in control (AC)
  - DIAC transition
  - DIDC transition

- System regulation

Target Speed

Release gas pedal

Press gas pedal
4.2 Dataset

- Decrease (AS-) 471
- Increase (AS+) 698

ACC Inactive (I)

ACC Active (A)

ACC Active and accelerate (AAc)

- Driver in control (DC)
- ACC in control (AC)
- DIAC transition
- DIDC transition
- State transition
- System regulation
5. Choice model to manual control

Feeling of risk and task difficulty evaluation: actual level vs. acceptable range

System state and speed regulation choice

- Driver in control (DC)
- Observable choices
- Unobservable choices
- ACC in control (AC)
- Unobservable choices
- No transition
- Control transition
5.1 Risk feeling and task difficulty

Ordered probit model with random thresholds

\[ RFTD_n(t) = \lambda_{\text{DrivBehChar}} \cdot \text{DrivBehChar}(t) + \sigma \cdot \delta_n(t) \]

\[ \text{MinAc}_n = t^L + \tau^L_{\text{DrivChar}} \cdot \text{DrivChar} + \rho^L \cdot \ln[\exp(V_{n}^{\text{Ac}}(t)) + \exp(V_{n}^{\text{AS}+}(t))] + \gamma^L \cdot \phi_n \]

\[ \text{MaxAc}_n = t^H + \tau^H_{\text{DrivChar}} \cdot \text{DrivChar} + \rho^H \cdot \ln[\exp(V_{n}^{\text{Ac}}(t)) + \exp(V_{n}^{\text{AS}^-}(t))] + \gamma^H \cdot \phi_n \]

\( \lambda \) and \( \tau \) are vectors of parameters associated with the explanatory variables;
\( t^L \) and \( t^H \) are the mean lowest and highest risk acceptable;
\( \rho^L \) and \( \rho^H \) are parameters associated with the utility of resuming control;
\( \gamma^L \) and \( \gamma^H \) are parameters associated with the individual specific error term \( \phi_n \sim N(0,1) \);
5.2 System state and speed regulation

Mixed logit models

\[
\begin{align*}
    U_{n}^{AS-}(t) &= 0 + \varepsilon_{n}^{AS-}(t) \\
    U_{n}^{I}(t) &= \alpha^{I} + \beta^{I} \cdot X(t) + \gamma^{I} \cdot \vartheta_{n} + \varepsilon_{n}^{I}(t) \\
    U_{n}^{AS+}(t) &= 0 + \varepsilon_{n}^{AS+}(t) \\
    U_{n}^{AAC}(t) &= \alpha^{AAC} + \beta^{AAC} \cdot X(t) + \gamma^{AAC} \cdot \vartheta_{n} + \varepsilon_{n}^{AAC}(t)
\end{align*}
\]

\(\alpha^{I}\) and \(\alpha^{AAC}\) are alternative specific constants;
\(\beta^{I}\) and \(\beta^{AAC}\) are vectors of parameters associated with the explanatory variables \(X(t)\);
\(\gamma^{I}\) and \(\gamma^{AAC}\) are parameters associated with the individual specific error term \(\vartheta_{n} \sim N(0,1)\);
\(\varepsilon_{n}^{AS-}(t)\), \(\varepsilon_{n}^{I}(t)\), \(\varepsilon_{n}^{AS+}(t)\), and \(\varepsilon_{n}^{AAC}(t)\) are i.i.d. Gumbel – distributed error terms.
## 5.3 Estimation results

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Value</th>
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<tbody>
<tr>
<td>Number of parameters associated with explanatory variables</td>
<td>23</td>
</tr>
<tr>
<td>Number of alternative specific constants and mean thresholds</td>
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<td>Number of drivers</td>
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<td>Number of observations</td>
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<tr>
<td>Final log likelihood</td>
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<tr>
<td>Constant log likelihood (logit)</td>
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<td>Parameters</td>
<td>Estimate</td>
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<tr>
<td>L_SPEED</td>
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<tr>
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<td>L_DA</td>
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<td>B_EXIT_HI</td>
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<td>B_logTIMEA_LAAc</td>
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<tr>
<td>GAMMA_LAAc</td>
<td>0.19</td>
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Feeling of risk and task difficulty evaluation

System state and speed regulation choice
6. Conclusion

**Low risk and task difficulty**
- No experience with ACC
- Patient and Reckless
- Driver heterogeneity

**High risk and task difficulty**
- Experience with ACC
- Patient
- Driver heterogeneity

- **DIDC to Active and accelerate**
  - Time after activation
  - Driver heterogeneity

- **DIDC to Inactive**
  - Ramps & exits
7. Future research

**Choice Model**

*Transition choice*

Discrete/continuous choice of control transitions and speed regulations

**Acceleration model**

*Transition period*

Temporal evolution of driver behaviour characteristics over time
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http://hf-auto.eu/
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s.f.varotto@tudelft.nl