Judging a Car by its Cover: Human Factors Implications for Automated Vehicle External Communication Breakout Session # 2.1

Summary of Key Findings and Lessons Learned

• Attendees received up-to-date information on international projects and standardization activities
• Further understanding gained by attendees of the complexities designing systems to support communication between automated vehicles and other road users (e.g. vulnerable road users, drivers)
• Attendees learned about relevant human factors design heuristics
Breakout Session # 2.1

Recommended Action Items & Research Questions

• Two-Way communications: Can vehicles sense or detect the intent of other road users? Will one way communication be enough (e.g., vehicles display their intent but do not recognize other road user behavior)?
• How much and what information that is displayed to external users (pedestrians, other traffic, etc.) is also displayed to passengers/operators?
  • This would include specialized communications for HAVs intended for use as taxis
• Alerting or communication strategies may extend an event rather than resolve it
  • There are likely situations that don’t require development of additional communication modalities/methods
  • Understanding when to use vehicle movement as communication devices (e.g., highway merging)
Effects of Non-verbal communication cues on decisions and confidence of drivers at an uncontrolled intersection

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Background

• The traffic regulations are sometimes uncertain in situations such as uncontrolled intersections, transition of traffic signals, merging/changing lane, and multi-lane roundabouts.

• Drivers exchange their intentions with other drivers in those situations to arrive at safe and efficient joint actions using various formal and informal non-verbal communication cues that include signals sent by the devices (blinker, brake lights etc.), vehicle behaviors (position, speed, acceleration/deceleration etc.), and driver’s behaviors (eye contact, hand gestures etc.)

• What about automated vehicles (Level 3+) in mixed traffic?
• Automated vehicles are also expected to communicate with other road users.

• First, it is important to understand how current drivers non-verbally communicate with other road users.
Objective and research questions

Objective

To understand effects of non-verbal communication cues on drivers’ decisions and confidence.

Specific research questions

When and how do vehicle behaviors and hand gestures influence drivers’ yielding decisions and confidence at an uncontrolled intersection?

Some expectations and recommendations for automated vehicles will be discussed.
Methods

1. Scenarios

One-on-one interviews were conducted to measure subjective responses to stimuli. The study used straight-cross-path and left-turn scenarios around an uncontrolled intersection where priority rules were officially in force but sometimes uncertain.

- Crossing two roads had the same width and there was no major road.
- Two cars were approaching the intersection and expected to reach the intersection at the same time.
- Car-A was assumed to be driven by the subject.
- Car-B sent various communication cues to the subject.
- The subject officially had priorities to go in SCP and LTP.
Methods

2. Communication cues

The communication cues were various combinations of vehicle behaviors and hand gestures.

Experimental conditions: combinations of vehicle behaviors and hand gestures

<table>
<thead>
<tr>
<th>Vehicle behaviors</th>
<th>Hand gestures</th>
<th>No hand gesture</th>
<th>Stop hand gesture</th>
<th>Go hand gesture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant speed</td>
<td></td>
<td>X (Baseline)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speeding up</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Slowing down</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Stop hand used in all scenarios
Go hand gesture used in SC and SCP
Go hand gesture used in LT and LTP
Methods

3. Rating scales

• Yielding frequency (YF)

  Frequency of yielding in similar situations in subject’s driving experience

<table>
<thead>
<tr>
<th>Never (1)</th>
<th>Rarely (2)</th>
<th>Occasionally (3)</th>
<th>Frequently (4)</th>
<th>Always (5)</th>
</tr>
</thead>
</table>

• Confidence level (CL)

  Confidence about the inferred intention of the Car-B driver.

<table>
<thead>
<tr>
<th>Not confident at all (1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>Perfectly confident (5)</th>
</tr>
</thead>
</table>
Methods

4. Subjects

• A total of 65 subjects with the age of 30 and older (mean age of 57 years) were recruited from the general population of Iowa City.
• The gender was balanced.
• Each subject participated in the experiment either with the scenarios SC and SCP or with the scenarios LT and LTP (N.B. 32 subjects for SC and SCP, and 33 subjects for LT and LTP).
• The order of the two scenarios and the order of the cue conditions within each scenario were counterbalanced to avoid the order effect.

<table>
<thead>
<tr>
<th>Cue conditions</th>
<th>Constant speed</th>
<th>Speeding up</th>
<th>Speeding up + Stop Hand gesture</th>
<th>Slowing down</th>
<th>Slowing down + Go Hand gesture</th>
<th>Scenarios</th>
<th>Number of subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Straight-Cross-Pass</td>
<td>32 subjects</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Left-Turn</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Left-Turn with Priority</td>
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</tr>
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</table>
Methods

5. Experimental procedure

1. The experimenter showed the video of the intersection for calibration of subject’s image of the intersection (only once at the beginning of the experiment).

2. The experimenter verbally explained each scenario and each cue condition to the subject. The priority rule was NOT explained to the subject.

3. For hand gestures, the experimenter demonstrated one of the two hand gestures.

4. A schematic computer animation showing the plan view of the intersection and the two moving cars was presented to the subject.

5. The animation was terminated before the two cars reached the intersection to avoid showing additional cues.

6. The subject rated Yielding frequency and Confidence level.
Situation 1.2.3

- You are driving Car-A.
- Car-B is approaching the intersection from your right and **slowing down**.
- The driver of Car-B send you a **hand gesture**.
- The two cars are likely to reach the intersection at the same time.
- There are no controls (i.e. traffic signs) at the intersection. There is no major road (i.e. roads are equivalent).
Situation 1.3.3

- You are driving Car-A.
- Car-B is approaching the intersection from your right and **speeding up**.
- The driver of Car-B send you a **hand gesture**.
- The two cars are likely to reach the intersection at the same time.
- There are no controls (i.e. traffic signs) at the intersection. There is no major road (i.e. roads are equivalent).
Results

1. Effects of priority rules

Mean ± SD of YFs and CLs with constant speed. Statistical differences were calculated between SC and SCP, and between LT and LTP; *** $p \leq 0.01$, ** $0.01 < p \leq 0.025$, * $0.025 < p \leq 0.05$.

- 87% of the subjects knew the right-car-priority-rule and 99% of the subjects knew the straight-car-priority-rule.

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<th>Scenario SCP</th>
<th>Scenario LT</th>
<th>Scenario LTP</th>
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<td>Effects of priority rules</td>
<td>The effect was insignificant, resulting in high YFs and low CLs.</td>
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Results

2. Effects of vehicle behaviors

Mean±SD of YFs and CLs with constant speed, speeding up and slowing down. Statistical differences were calculated from the constant speed; *** $p \leq 0.01$, ** $0.01 < p \leq 0.025$, * $0.025 < p \leq 0.05$.

Summarized results. ■ indicates a condition where the cues conflict with the effective priority rule.

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<td>Speeding up</td>
<td>-</td>
<td>YF increased.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CL increased.</td>
<td></td>
<td>CL increased.</td>
<td></td>
<td>CL decreased.</td>
</tr>
<tr>
<td>Slowing down</td>
<td>YF decreased.</td>
<td>YF decreased.</td>
<td>-</td>
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3. Effects of hand gestures combined with vehicle behaviors

Statistical differences were calculated from the constant speed and also for additional effects of the hand gestures (indicated in parentheses); *** $p \leq 0.01$, ** $0.01 < p \leq 0.025$, * $0.025 < p \leq 0.05$.

Summarized results. ■ indicates a condition where the cues conflict with the effective priority rule. # indicates a significant additional effect of the hand gesture.

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<tbody>
<tr>
<td>Stop hand gesture + speeding up</td>
<td>YF increased.</td>
<td>YF increased.</td>
<td>CL increased.</td>
<td>CL increased.#</td>
</tr>
<tr>
<td>Go hand gesture + slowing down</td>
<td>YF decreased.#</td>
<td>YF decreased.#</td>
<td>YF decreased.#</td>
<td>YF decreased.</td>
</tr>
<tr>
<td></td>
<td>CL increased.#</td>
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<td>CL increased.#</td>
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Discussion

• Overall, the hand gestures combined with vehicle behaviors showed larger effects than vehicle behaviors alone in the scenarios SC and SCP where the priority rule was ineffective. The combinations modulated subjects’ decisions to yield or go and also gave more confidence to the subjects regardless of the priority side. The vehicle behaviors alone were not sufficient cues to consolidate subjects’ decisions and confidence.

• In the scenario LT, the subjects were confident to yield based on the priority given to the other vehicle, and no additional benefits of Speeding up and Stop hand gesture were found to consolidate subjects’ decision to yield and confidence.
Discussion

- In the scenario LTP, Slowing down gave the subjects more confidence to go, and no additional benefits of Go hand gesture were found to consolidate subjects’ decision to go and confidence.

- The hand gestures showed significant effects to change YFs to accept the cues against the effective priority rule in the scenarios LT and LTP, where the vehicle behaviors alone did not affect YFs.

- The increment of YF against the priority rule by Stop hand gesture in LTP is considered to be a potentially positive effect to improve safety when the other vehicle do not follow the straight-car-priority-rule.

- The decrement of YF against the effective priority rule by Go hand gesture in the scenario LT is considered to be a potentially positive effect to improve efficiency when the other vehicle offers the right of way against the priority rule. The subjects showed low CL in this condition which implied that they were cautious in accepting the offer.
Discussion

Limitation of generalization of the results and remaining factors for future studies

• In practice, drivers need to make decisions within limited time. Such time pressure may influence drivers’ decisions, especially for older drivers with slower cognitive processing.

• This study excluded the effects of visual perception of the cues. In practice, drivers need to perceive the cues in distance and the thresholds of visual perception may affect the effectiveness of the cues.

• The communication cues studied were limited and more cues currently used by drivers need to be explored. For example, drivers use longer distance to an intersection with slower constant speed than necessary to stop as a cue for yielding.

• The effects of the priority rules and the effects of the communication cues may vary depending on the traffic culture.
Discussion: implications for AV external communication

- Automated vehicles are expected to understand cues sent by the other driver to show intention to go such as speeding up (N.B. Stop HG is not a commonly used cue by drivers), and yield to avoid a crash regardless of the priority side.
- Automated vehicles are expected to understand cues sent by the other driver to show intention to yield such as slowing down and Go hand gesture. The automated vehicle can accept the offer and go for traffic efficiency as long as the cues are interpreted with sufficient accuracy.
- When yielding, the automated vehicle is expected to send a signal such as a combination of slowing down and a cue equivalent to Go hand gesture to let the other driver go with confidence.
- When going, the automated vehicle is expected to send a signal such as a combination of speeding up and a cue equivalent to Stop hand gesture to consolidate the other driver’s decision to yield with confidence.
- For enhancement of general traffic safety and efficiency, it is recommended to design behaviors of automated vehicles as communication cues on top of kinematic requirements.
- It may be effective to implement automated vehicles with new signals as communication cues with minimized uncertainty, equivalent to or more effective than the hand gestures used in this study.
Conclusions

- The vehicle behaviors and the hand gestures affected subjects’ yielding decisions and confidence in all the scenarios studied.
- Those communication cues also interacted with the priority rule in the left turn scenarios.
- The hand gestures were especially effective, when combined with vehicle behaviors, to consolidate subjects’ decisions to yield or go with confidence when the priority rule was ineffective (i.e. in the straight-cross-path scenarios).
- The hand gestures were also effective to change the yielding frequency to accept the cues conflicting with the effective priority rule (i.e. in the left-turn scenarios).
- Some expectations and recommendations for automated vehicles were discussed.