Messaging Techniques to Increase Vehicle Spacing at Work Zones

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Introduction

• 650 total work zone crashes occur per year and rear-end collisions (45%) are the most common type of crash in work zones in Iowa\(^1\)

• Rear-end collision contributing factors in work zones\(^2\)
  - Vehicles slowing and stopping – Merging and lane changing
  - Speeding (8% ~ 52%) – All moving vehicle violation fines are doubled and speeding as high as $1,000 in Work zones
  - Tailgating (10% ~ 55%) – Requires a study for counter-tailgating treatments in work zones
    ➢ Smart Work Zone Deployment Initiative (SWZDI)

• Objective
  - Develop messaging techniques that encourage drivers to maintain proper spacing at work zones
  - Develop performance measures related to drivers’ vehicle following behavior

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\(^1\) Work Zone Safety – Work Zone Quick Facts, [https://iowadot.gov/workzone/quick-iowa-facts](https://iowadot.gov/workzone/quick-iowa-facts), Updated 2/2/2022

\(^2\) Assessing Driver Behavior at Back of Queues: Implications for Queue Warning System in Work Zones, InTrans Project 19-686, Center for Transportation Research and Education (CTRE), Iowa State University
Background

• Counter-tailgating treatments

1) Pavement Marking
   - Dot (MnDOT, 2006)
   - Chevron (NSW AU, 2018)

2) In-Vehicle Warning
   - Headway Monitoring & Warning (Mobileye, 2021)

3) Message Sign
   - Fixed signs (MnDOT, 2006)
Methodology

Design Message

- Determine message purpose
  - Existing design?
    - Y: Develop candidate designs
    - N: Existing design?

Safety Graphics Comprehension Testing

- Stage 1: User ratings of candidate designs
  - Good Reaction?
    - Y: Use It
    - N: Discard

- Stage 2: Multiple-Choice Comprehension test
  - Properly understood?
    - Y: Use It
    - N: Discard

- Stage 3: Open-ended Comprehension test
  - Properly understood?
    - Y: Use It
    - N: Discard

Development Messaging techniques

Tailgater Targeting Message Strategy Design

- Data Collecting and Cleaning
  - Triggering
    - Data Collection (Tailgating Detection)
    - Anti-Tailgating

- Determine Tailgating Thresholds
- Verification and Measure Selection
Safety Graphics Comprehension Testing

• Goals:
 ➢ At least 85% correct responses
 ➢ No more than 15% “critical confusion”

• Survey Sites
 ➢ Ames Driver’s License Station (Stage 1)
 ➢ Ankeny Driver’s License Station (Stage 1 – 3)

Stage 1 – User Rating

Stage 2 – Multiple Choice

Stage 3 – Open-End
Safety Graphics Comprehension Testing

- **Participants Statistics**
  - Total number of participants: 247 (Ames: 44, Ankeny: 203)

- **Do you have a Driver license/permit?**
  - Yes: 230, 93%
  - Came to apply: 4, 2%
  - No: 13, 5%

- **Primary Language**
  - English: 228, 93%
  - Spanish: 11, 5%
  - Hmong: 6, 2%
  - Other: 1, 0%

- **Gender**
  - Woman: 140, 57%
  - Man: 102, 41%
  - Non-Binary: 4, 2%
  - Prefer not to answer: 0, 0%
Safety Graphics Comprehension Testing

- Participants Statistics

![Age Groups](chart)

- Hours Driven Groups

![Hours Driven per Week](chart)
Stage 1 – User rating candidate designs

- 8 Graphic signs with message + 12 Dynamic Message Sign
Stage 2 – Multiple-Choice Comprehension test

11. What does this sign mean to you?
- Avoid following too closely behind the car in front of you 44%
- Leave extra space for workers 4%
- Avoid driving too close to temporary barriers
- All of the above 52%
Stage 3 – Open-ended Comprehension test

- **76% Correct (39 of 51)** Ex: “Make sure to leave a few cars length space between you and the car in front of you”
- **16% Partially Correct/Vague (8 of 51)** Ex: “Drive Carefully”
- **8% Incorrect (4 of 51)** Ex: “Leave space between parking”
Study Site

• Construction Site Description
  • Roadway: US 151
  • Construction Start Date: March 14th, 2022
  • Work Zone Note:
    1. The EB Bridge work started on Mar 14, 2022, and last for 9 months
• Data availability:
  1. Video: Installed
  2. Sensor: Installed
• Baseline Data Collection Period : 8/18/2022 ~ 8/31/2022 (2 weeks)
Study Site

2016 AADT: 26,300
Passenger: 22,716 (86%)
Single Unit: 1,200 (5%)
Combination: 2,384 (9%)
Master Plan

• Message Technique Deployment Before & After Comparison
Tailgating Detection Threshold Selection

Individual vehicle data collecting and cleaning (Houston Sensor)
1) Vehicle Speed (Exclude cases Speed < 45mph)
2) Vehicle Headway
3) Vehicle Length
4) Time

Data Aggregation (20-sec period)
1) Count vehicles
2) Calculate average speed
3) Calculate Occupancy
4) Check Tailgating Occurrence (Headway < 1s)

Estimate Thresholds (Binary Logistic Regression Analysis)
1) Labeling Tailgating Indicator (0: Normal, 1: Tailgating)
2) Explanatory Variables
   - Vehicle Counts
   - Average Speed
   - Occupancy

Verification and Selection
1) Compare Prediction Accuracy
2) Selection Proper Measure
Study Site Headway Characteristics

• Headway Histograms (Entire)

![Histogram and Boxplots]

Tailgating Headway Threshold: 1 sec
Binary Logistic Regression Analysis

• Basic Concept
  • “A logistic regression models to estimate an event’s occurrence probability utilizing the linear combinations among explanatory variables (Young et al., 2008)”
  • Probability equation

\[ P = \frac{e^\beta}{1+e^\beta}, \quad \beta = \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k \]

- \( P \): The probability of an event for which the dependent variable \( y \) is 1
  (Assuming \( y \) is a binary variable, 0 or 1)
- \( \beta_0 \): Constant
- \( \beta_n \): Variable \( x_n \)'s coefficient
Binary Logistic Regression Analysis

• Method
  ➢ Stratified sampling method
    ✓ Filtering cases with error values (Negative speed or headway)
    ✓ Normal Situation and Tailgating classification
    ✓ Sampling rate: 1 (Normal Situation) : 1 (Tailgating)
    ✓ The number of cases
      ① Normal Situation: 11,417
      ② Tailgating: 11,417
  ➢ Dividing training set (70%) and test set (30%)
Tailgating Determination Threshold

- BLR Results

1) Occupancy

\[ P = \frac{e^{-3.27+0.51 \times \text{Occupancy}}}{1 + e^{-3.27+0.51 \times \text{Occupancy}}} \]

Threshold \((P>0.5) = 6.41 \approx 7\%\)

2) Traffic Counts

\[ P = \frac{e^{-3.75+1.29 \times \text{Traffic}}}{1 + e^{-3.75+1.29 \times \text{Traffic}}} \]

Threshold \((P>0.5) = 2.91 \approx 3\text{ vehs / 20 sec}\)
Conclusion

• Message sign design
  ➢ Positive and concise message signs are preferable and acceptable
  ➢ Message signs should state a clear object to avoid any confusion

• Tailgating Detection
  ➢ Traffic counts and occupancy can be a performance measure related to drivers’ vehicle following behavior: tailgating

• Next steps
  ➢ Collect traffic data after implementing the message technique in the study site
  ➢ Collaboration with Iowa DOT is required to implement the master plan
  ➢ Check the transferability of the BLR model
Q & A
Appendix A. Survey 1

These are some ideas we had for regular signs to encourage safe following distances in work zones. Which signs best explain that message? Please indicate your reaction to each sign by marking up to three emoji (icons).

1. NO TAILGATING
   - Keep Your Distance
   - Excellent
   - Confusing
   - Boring
   - Inconsistent

2. PREVENT CRASHES
   - Leave Extra Space
   - Excellent
   - Confusing
   - Boring
   - Inconsistent

3. PREVENT CRASHES
   - Stay 10 Car Lengths Apart
   - Excellent
   - Confusing
   - Boring
   - Inconsistent

4. NO TAILGATING
   - Leave Extra Space
   - Excellent
   - Confusing
   - Boring
   - Inconsistent

5. PREVENT CRASHES
   - Stay 200 Feet Apart
   - Excellent
   - Confusing
   - Boring
   - Inconsistent

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Hello! We are looking for ways to discourage drivers from following too closely (tailgating) in work zones. On the next few pages you will see some traffic signs meant to remind drivers to keep a safe following distance. Please tell us your reaction to each sign by selecting up to 3 emoji (icons).

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About this project:
This survey is being done by the Institute for Transportation at Iowa State University. The research is sponsored by the Smart Work Zone Deployment initiative, a coalition of transportation agencies from several states. If you have questions about this project, contact Dr. Jorge Ciriza at 515-294-2201 or Mr. John Shaw at 515-294-5916. Your participation in the survey is voluntary and anonymous. Sorry, there are no prizes or other compensation.

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Iowa State University
Institute for Transportation
Appendix A. Survey 1

Messages on portable electronic signs are usually used in pairs, one screen after the other. Please indicate your reaction to each message set.

BE SAFE DO NOT TAILGATE

NOT TAILGATING

BE SAFE LEAVE EXTRA SPACE

SAFER FOR EVERYONE

MAKE TWO BUMPERS HAPPY

LEAVE EXTRA SPACE

TAILGATERS

CRASHING IS UCHY

THE END IS NEAR

IT MAKES YOU GROUCHY

KEEP YOUR DISTANCE

CRASHES MAKE YOU LATE

DON'T TAILGATE

STAY OUT THEIR TAIL

STAY OFF THEIR TAIL

SPACE IS GOOD

SIMON SAYS

LEAVE EXTRA SPACE

TAILGATE CAUSES CRASHES

STAY CLEAR OF THE REAR

LEAVING EXTRA SPACE?

THANKS!

About You...

Do you have a driver license or permit?

Yes

No

Com to the DMV today to apply for one

What is your primary language?

English

Spanish

Other (please specify)

Which best describes your gender?

Woman

Man

Non-binary

Prefer not to answer

What is your approximate annual income?

Less than $15,000

$15,000 to $30,000

$30,000 to $60,000

$60,000 or more

How many hours do you drive each week?

Less than 5

5 to 10

11 to 20

21 to 40

40 or more

Thank you for your participation!
Appendix A. Survey 2

Signage Understandability Survey

We are evaluating the understandability of several traffic signs. Some you may have seen before, and others are new. For each sign, please PICK ONE OPTION that best describes what the sign means to you.

This survey is being done by the Institute for Transportation at Iowa State University. The research is sponsored by the Iowa Department of Transportation. If you have questions, contact Dr. Jing Dong at 715-334-3032 or [email protected]. Participating in the survey is voluntary and anonymous, so there are no prizes or compensation.

1. What does this sign mean to you?
   - Lanes narrow ahead
   - Overhead construction – watch for falling debris
   - Left lane ending: traffic in left lane should merge into right lane
   - Lanes shifting ahead: expect an S-curve in the left lane

2. What does this sign mean to you?
   - Right turn ahead
   - Work trucks that need access to construction area
   - Be alert for slow trucks entering the roadway
   - Work zone entrance for tour group B on the right

3. What does this sign mean to you?
   - Be alert for trucks entering or leaving the construction area
   - Leave extra space behind the vehicle in front of you
   - Move over if you see workers or work vehicles
   - Drive through the work zone quickly

4. What does this sign mean to you?
   - Work zone speed limit strictly enforced
   - Avoid following too closely behind the car in front of you
   - Leave extra space for workers
   - Parties prohibited at rest areas in the work zone

5. What does this sign mean to you?
   - Blasting zone
   - Overhead construction – be alert for falling debris
   - Broken pavement – be alert for loose stones
   - Unstable hillside – be alert for falling rocks

6. What does this sign mean to you?
   - Lanes narrow ahead
   - Left lane ending: traffic in left lane should merge into right lane
   - Lanes shifting ahead: expect an S-curve in the left lane
   - Construction of a multi-story building in progress – be alert for falling debris

7. What does this sign mean to you?
   - Road user's safety
   - Be safe: do not tailgate

8. What does this sign mean to you?
   - Leave extra space between your vehicle and the one in front of you
   - Leave extra space for workers
   - Parties prohibited at rest areas in the work zone
   - Leave extra space for workers
Appendix A. Survey 3
Appendix B. Tailgating

• Tailgating

➢ “Following a vehicle with insufficient vehicle headway where vehicle headway is the time interval that the two consecutive vehicles passed the same reference point” – (Hutchinson, 2008)

• Example
Appendix C. Counter-tailgating treatments

<table>
<thead>
<tr>
<th>Treatment Type</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement Marking 8) ~ 11)</td>
<td>1) Versatile Applicability</td>
<td>1) High initial costs</td>
</tr>
<tr>
<td></td>
<td>2) Visually effective with proper signs</td>
<td>2) Lane block</td>
</tr>
<tr>
<td>In-Vehicle Warning 12) ~ 17)</td>
<td>1) Faster responses and more effective way</td>
<td>1) In-vehicle Equipment (MPR)</td>
</tr>
<tr>
<td>Enforcement &amp; Education 18) ~ 19)</td>
<td>1) Effective way to change drivers’ tailgating tendency</td>
<td>1) Traffic law have to allow it</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2) Not easy to detect for the enforcement purpose</td>
</tr>
<tr>
<td>Message Sign 9), 20) ~ 21)</td>
<td>1) Flexible strategy</td>
<td>1) Effectiveness variation</td>
</tr>
<tr>
<td></td>
<td>▶ Fixed signs + PDMS</td>
<td>▶ Location, time of day, vehicle type</td>
</tr>
<tr>
<td></td>
<td>▶ Targeting tailgating groups</td>
<td>▶ Framing of messages</td>
</tr>
<tr>
<td></td>
<td>2) No mainline blockage required</td>
<td></td>
</tr>
</tbody>
</table>

1) Versatile Applicability: The pavement marking is adaptable and can be applied in various situations.
2) Visually effective with proper signs: The pavement marking is visually noticeable with the right signage.
1) High initial costs: Initial costs are high for implementing pavement marking.
2) Lane block: Lane blockage may occur during the installation process.
1) Faster responses and more effective way: In-vehicle warning systems respond quickly and effectively.
1) In-vehicle Equipment (MPR): In-vehicle warning systems require specific hardware.
1) Effective way to change drivers’ tailgating tendency: Enforcement and education can change driver behavior.
1) Traffic law have to allow it: The enforcement and education methods depend on the legal framework.
1) Effectiveness variation: Message signs may vary in effectiveness depending on location, time of day, and vehicle type.
2) No mainline blockage required: Message signs do not require blockage of main lanes during installation.
Appendix D. Stage 3 – Open-ended Comprehension test

1. What does this sign mean to you?

94% Correct (47 of 50) Ex: “Left lane ends, merge right,” “Merge from 2 lanes to 1”
0% Partially Correct/Vague (0 of 50)
6% Incorrect (3 of 50) Ex: “Divided highway ahead”

2. What does this sign mean to you?

76% Correct (39 of 51) Ex: “Make sure to leave a few cars length space between you and the car in front of you”
16% Partially Correct/Vague (8 of 51) Ex: “Drive Carefully”
8% Incorrect (4 of 51) Ex: “Leave space between parking”

3. What does this sign mean to you?

74% Correct (37 of 50) Ex: “Entrance point for construction. Gate B.”
20% Partially Correct/Vague (10 of 50) Ex: “Construction area,” “trucks/loaders frequent the area”
4% Incorrect (3 of 50) Ex: “Work ahead expect slower traffic”
Appendix D. Stage 3 – Open-ended Comprehension test

<table>
<thead>
<tr>
<th>Question</th>
<th>Correct Responses</th>
<th>Partially Correct/Vague</th>
<th>Incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. What does this sign mean to you?</td>
<td>98% Correct (49 of 50) Ex: “Ensure there is a good amount of space between my car and the one in front of me”</td>
<td>2% Partially Correct/Vague (1 of 50) Ex: “You might get rear ended”</td>
<td>0% Incorrect (0 of 50)</td>
</tr>
<tr>
<td>5. What does this sign mean to you?</td>
<td>76% Correct (38 of 51) Ex: “The middle lane ends, merging into the right lane”</td>
<td>6% Partially Correct/Vague (6 of 51) Ex: “Merging traffic”</td>
<td>20% Incorrect (10 of 51) Ex: “Right lane exit only,” “I don’t know.”</td>
</tr>
<tr>
<td>6. What does this sign mean to you?</td>
<td>98% Correct (49 of 50) Ex: “Keeping proper space helps prevent accidents”</td>
<td>2% Partially Correct/Vague (1 of 50) Ex: “Drive with caution”</td>
<td>0% Incorrect (0 of 50)</td>
</tr>
</tbody>
</table>
### Appendix D. Stage 3 – Open-ended Comprehension test

#### Question 7
What does this sign mean to you?

| 82% Correct (42 of 51) Ex: “Merge over to the right” |
| 8% Partially Correct/Vague (4 of 51) Ex: “Road change ahead”, “Divider in middle is ending and need to merge right” |
| 10% Incorrect (5 of 51) “The left lane is shifting but maintain it’s own lane while the right lane stays straight” |

#### Question 8
What does this sign mean to you?

| 90% Correct (45 of 50) Ex: “Don’t drive too close to the car in front of you” |
| 8% Partially Correct/Vague (4 of 50) Ex: “Reminder to pay attention” |
| 2% Incorrect (1 of 50) Ex: “Sudden stop” |
Appendix E. Headway Previous Studies

- Headway Thresholds for Safety Purpose

<table>
<thead>
<tr>
<th>Headway Thresholds</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 sec</td>
<td>1) Hutchinson, P. T. (2008)</td>
</tr>
<tr>
<td>1.5 sec</td>
<td>4) Kumar, R. et al. (2014)</td>
</tr>
<tr>
<td>1.2 sec</td>
<td>5) Merrikhpour, M. et al. (2014)</td>
</tr>
<tr>
<td>1.0 sec</td>
<td>6) Evans, L., and P. Wasielewski (1982)</td>
</tr>
<tr>
<td></td>
<td>7) Michael, P.G. et al. (2000)</td>
</tr>
</tbody>
</table>

- In this study, 1 seconds was set as the threshold to determine the tailgating situation, which is most dangerous standard among the safety standards of the existing literature.
## Appendix F. Data Collecting Devices

<table>
<thead>
<tr>
<th>Devices</th>
<th>Wavetronix (Aggregated Traffic Data)</th>
<th>Houston Sensor (Aggregated &amp; Individual vehicle data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>1) Lane 2) Average Speed 3) Vehicle counts by vehicle class 4) Occupancy</td>
<td>1) Lane 2) Speed 3) Headway 4) Vehicle length 5) Vehicle counts</td>
</tr>
<tr>
<td>Aggregation Period</td>
<td>20 sec, 1 min, and 5 min</td>
<td>Individual vehicle data (Aggregating is available)</td>
</tr>
<tr>
<td>Number of installations</td>
<td>Many</td>
<td>Few</td>
</tr>
<tr>
<td>in work zones</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
References

1) Hutchinson, P.T. Tailgating. Safety Centre for Automotive Safety Research, University of Adelaide, Australia, Research Report # CASR046, 2008


5) Merrikhpour M, Donmez B, Battista V. A field operational trial evaluating a feedback–reward system on speeding and tailgating behaviors. Transportation research part F: traffic psychology and behaviour. 2014 Nov 1;27:56-68.


7) Michael PG, Leeming FC, Dwyer WO. Headway on urban streets: observational data and an intervention to decrease tailgating. Transportation research part F: traffic psychology and behaviour. 2000 Jun 1;3(2):55-64.


References


15) W. Barfield, T.A. Dingus (Eds.), Human Factors in Intelligent Transportation Systems, Lawrence Erlbaum (1998)


