The Effects of Restricted Sight Distances on Drivers at Simulated Rural Intersections

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Intersection Sight Distance & Safety

- Restricted sight distances at rural intersections can result in reduced safety
  - Drivers choosing smaller gaps between oncoming vehicles (Yan & Richards, 2010)
- Time to collision/contact (TTC) is a primary motivating factor on driver decisions to cross intersections.
- Drivers' TTC perception is a function of various factors
  - Oncoming vehicle speed (Cavallo & Laurent, 1988)
  - Vehicle distance (Smeets et al., 1996)
  - Tau (Lee, 1976)
- **Hypothesis**: Confidence – Performance mismatch at longer sight distances
  - Distance increases confidence but not performance at rail crossings (Ward & Wilde, 1996)
  - Higher distances result in poor peripheral detection of vehicles on collision courses (Uchida et al., 2001)

Project Goals

- Conduct a simulated driving study to examine intersection visibility and other factors that may influence driver behavior at rural thru-STOP intersections in Minnesota
  - Ensure adequate validity and fidelity of representative simulated rural intersections
- Establish lower and upper-limit for visibility standards at rural intersections by examining driver decision making and behavior (performance, eye tracking, subjective reporting/confidence)
  - Maximize driver safety and behavior around rural thru-STOP intersections through recommended sight distances
  - Minimize cost and labor to ensure clearing and grubbing efforts are efficient

Validating Simulated Intersections

- *7 engineers familiar with rural roadways participated in 2 validation tasks*

1) Sight estimation

Average Sight Distance Estimation: Means (Standard Deviations)			
Actual distances	**400 ft.**	**600 ft.**	**1000 ft.**
Avg. Perceived distances	420 ft. (45 ft)	700 ft. (100 ft)	1020 ft. (205 ft)

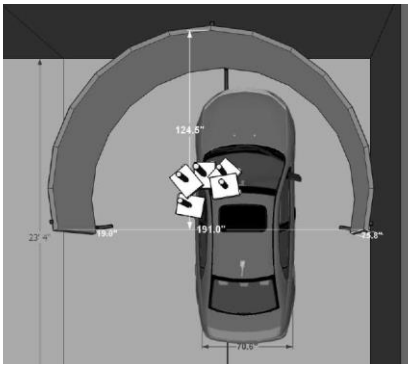
2) Representativeness rating

Average Representative Rating by Distance: Means (Standard Deviations)			
Actual distances	**400 ft.**	**600 ft.**	**1000 ft.**
Avg. Representative Score	4.5 (1.6)	5 (0.8)	5.1 (1.1)

Average Representative Rating by Speed: Means (Standard Deviations)			
Actual speeds	**55 MPH**	**65 MPH**	**75 MPH**
Avg. Representative Score	4.9 (1.0)	4.8 (1.1)	4.8 (1.5)

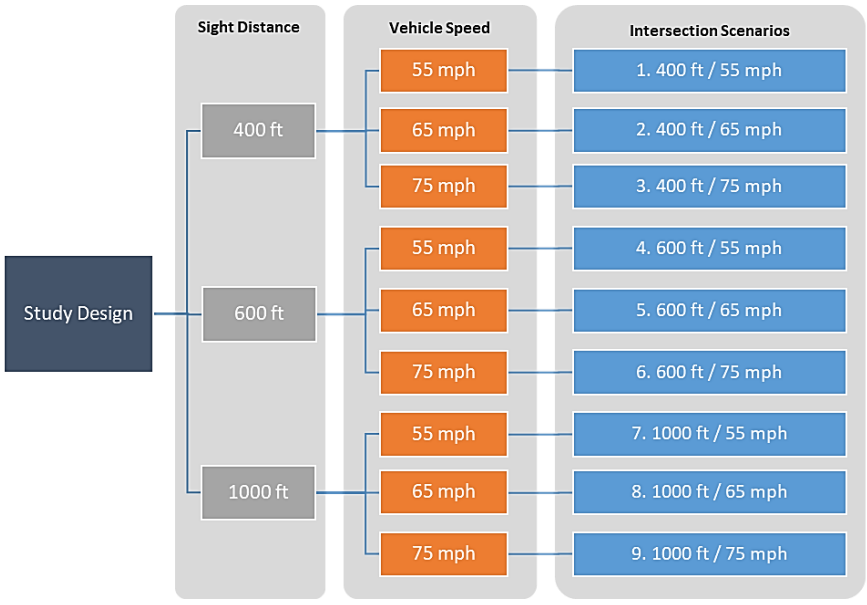
Methods

- 36 participants
  - Mean Age = 27; *SD* = 6.7
  - 17 females and 19 males
  - Range of road type experience (limited rural)
- Simulator
  - RTI Full vehicle cab simulator with motion base
  - 210-degree forward horizontal field of view

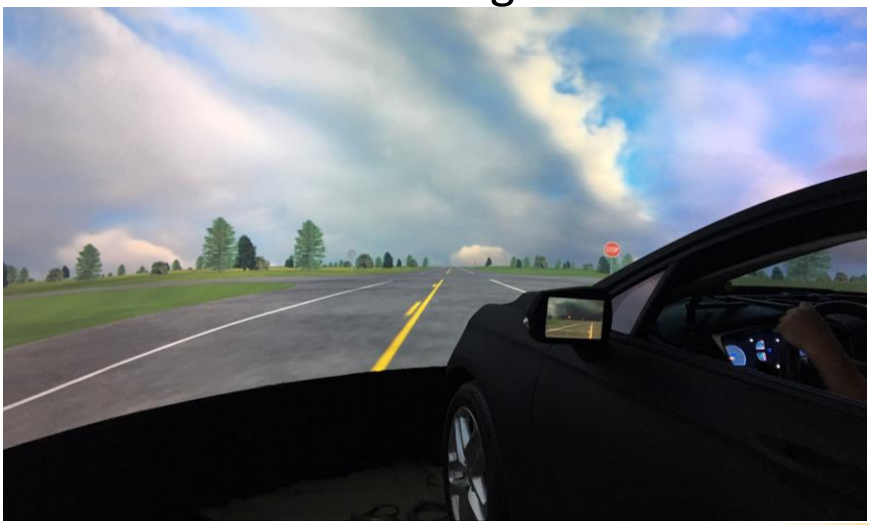


Study #1: TTC Judgment Study

- Drivers were presented with a number of intersection scenarios from minor road perspective
  - View mainline vehicles at 3 sight distances and 3 speeds (i.e., 3 x 3 design)
  - 10 vehicles presented at each intersection
    - 3 sec, 5 sec, 7 sec, 9 sec, and 12 sec time headways
  - Drivers pressed accelerator as soon as they are presented with a gap they felt they could safely cross
  - Provided confidence estimates of their accuracy after each condition
    - 3 questions, 7-pt scale



Practice Drive of Six Intersection Crossings

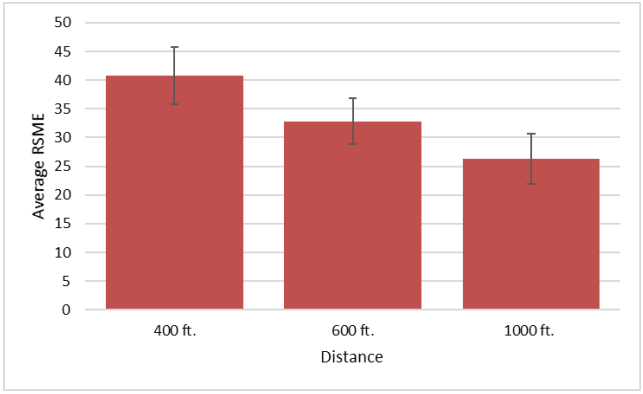


TTC Judgment Study

Measures

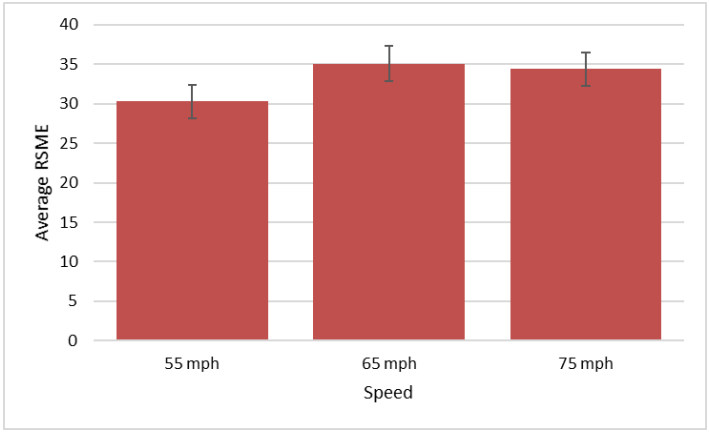
- Subjective Measures for Confidence
  - Rating Scale Mental Effort (RMSE)
    - (Zijlstra, 1993)
  - Perceived task difficulty, task riskiness, anxiety
    - 7 pt. scale, adapted from Ward & Wilde (1996)
- "Objective" Performance Measures
  - TTC
    - Oncoming vehicle to middle of intersection at pedal press
  - Estimated collision rate
  - Head movement count
    - Captured with Go-pro camera

TTC Subjective Results: Mental Workload



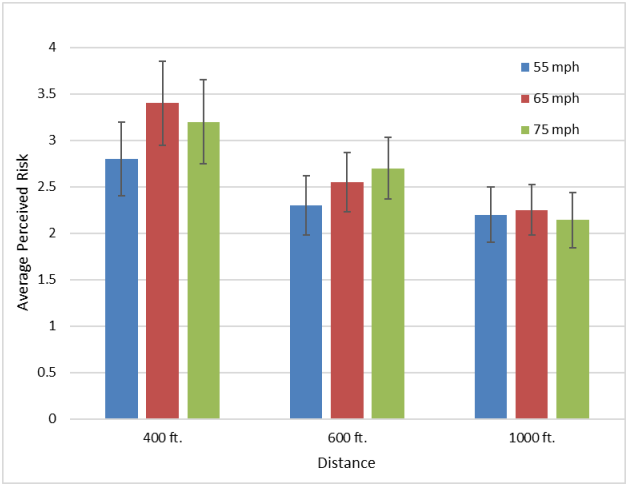
Average RSME for distance.

TTC Subjective Results: Mental Workload



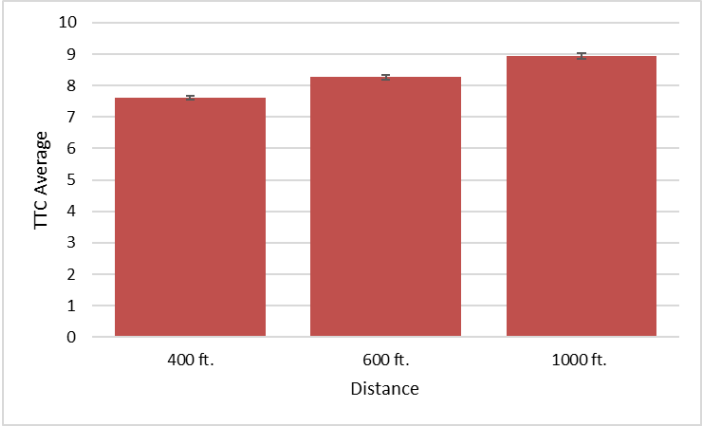
Average RSME for speed

TTC Subjective Results: Risk



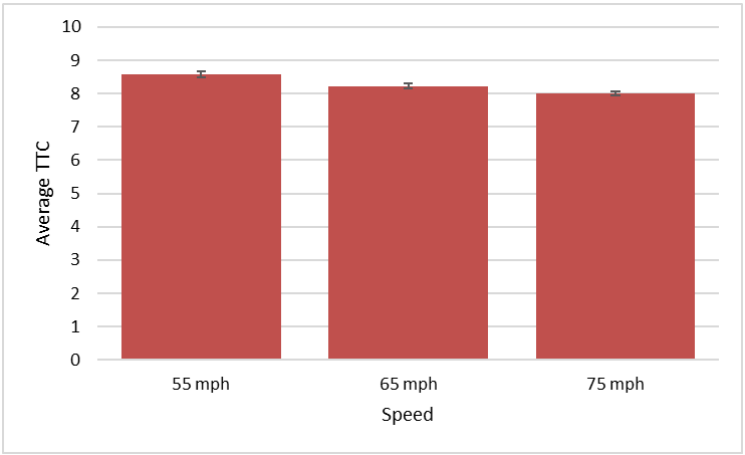
Average Perceived Risk by Speed and Distance

TTC Objective Results: TTC



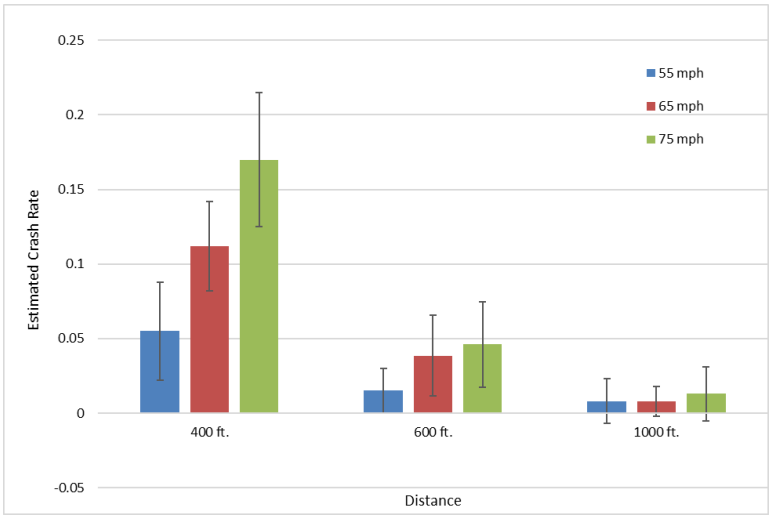
Average TTC for distance

TTC Objective Results: TTC



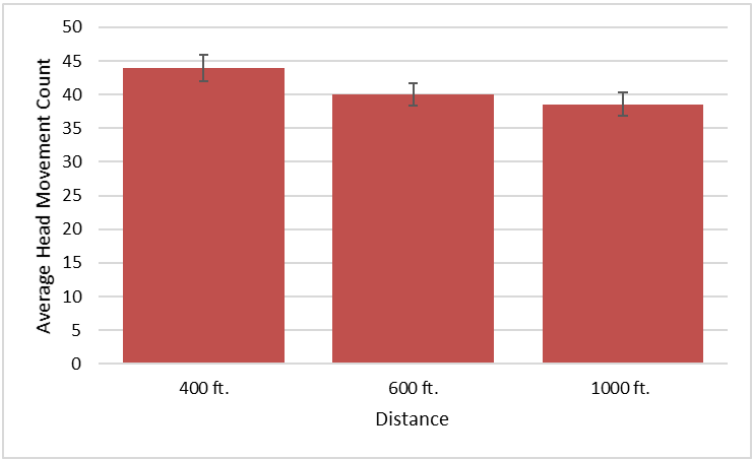
Average TTC for speed

TTC Objective Results: Collision



Estimated crash rate as a function of distance and speed.

TTC Objective Results: Head Movements



Average count of head movements or glances by distance.

TTC Subjective Results Summary

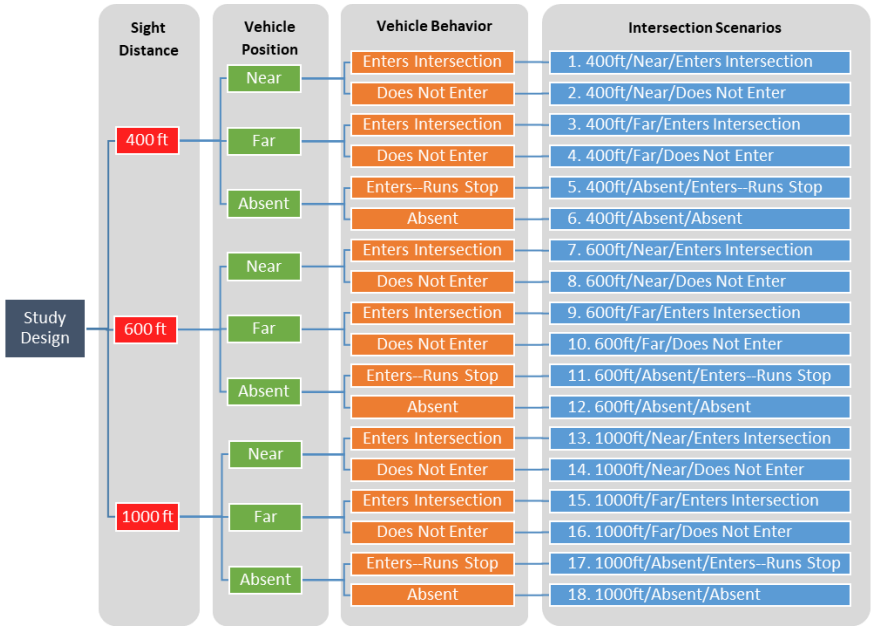
- Participants reported
  - Higher stress for 400 ft. and 600 ft. compared to 1000 ft. sight distances.
  - Lower stress for 55 mph compared to 65 and 75 mph (no differences between 65 & 75).
- An interaction was observed for perceived risk with no differences between speeds reported at the 1000 ft. sight distance
  - Indicating that drivers may become less sensitive to high-speed risks at very long sight distances.

TTC Objective Results Summary

- More head movements under the shortest sight distance condition (i.e., 400 ft.) compared to longer distances
- Final TTC of the accepted gap was shorter and more likely to be estimated as a collision risk (i.e., shorter that 4.5 sec TTC at time of crossing decision) under 400 ft., 600 ft., 65 mph, and 75 mph
- Slower speeds (i.e., 55 mph) and longer sight distances (i.e., 1000 ft.) imposed less stress on drivers and led to drivers accepting fewer but ultimately longer TTC/safer gaps than the faster, shorter sight distance scenarios.

Study #2: Mainline Study

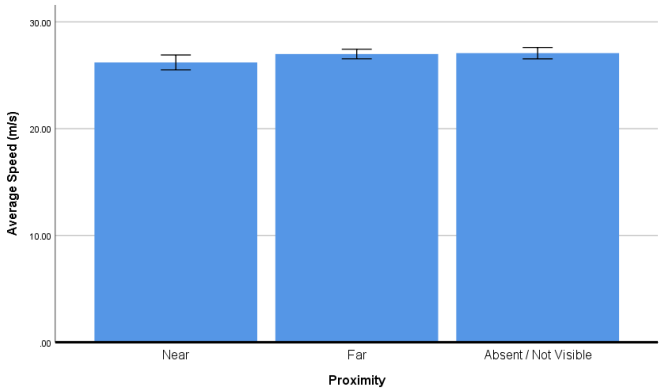
- Drivers were presented with a series of intersection scenarios from mainline road perspective
  - View minor road vehicles at 3 sight distances, 3 stop placements, and 2 behaviors (i.e., 3 x 3 x 2 design)
  - 18 intersections
  - Drivers drove 60 MPH and decreased speed/braked to avoid any collisions



Measures

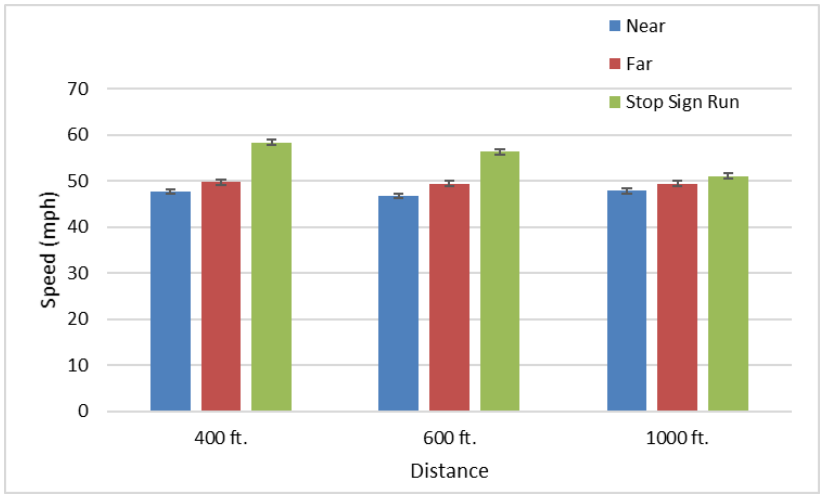
- Subjective Measures for Confidence
  - Unable to assess with previous questionnaires
- "Objective" Performance Measures
  - Average speed and speed deviation
  - Minimum TTC
  - Braking distance
  - Collision rate for intruding vehicle condition

Mainline Results: Speed



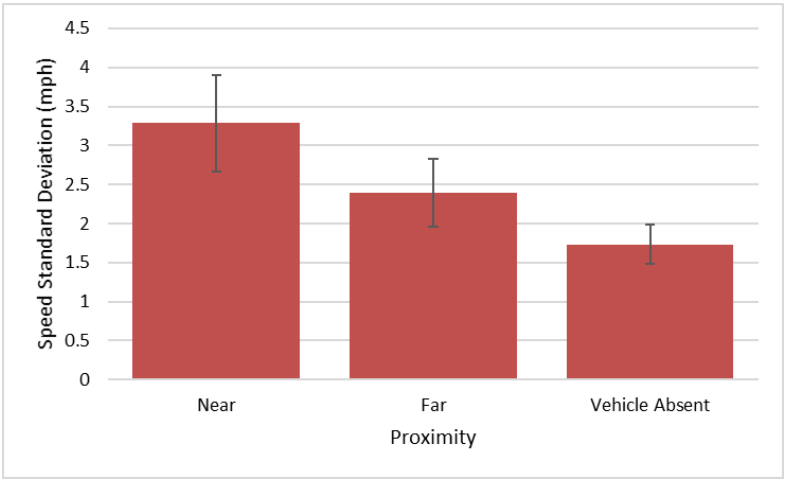
Average speed (m/s) in the 4th quarter mile for stationary vehicles by proximity.

Mainline Results: Speed



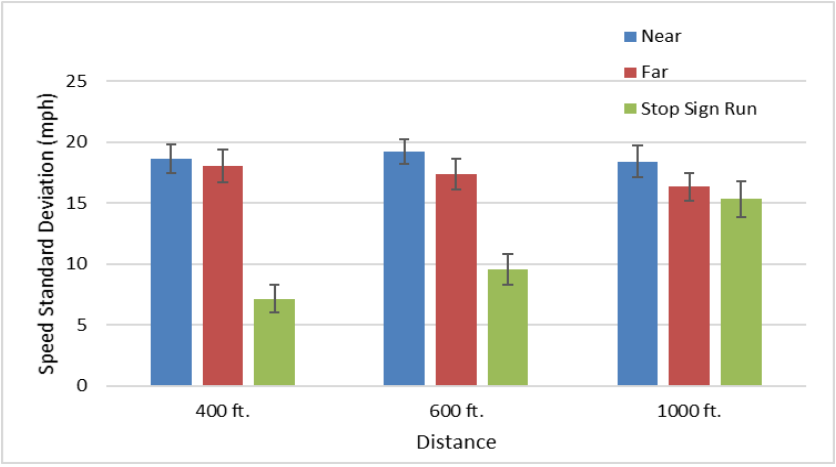
Average speed (mph) for the 4th quarter mile for moving vehicles as a function of distance and proximity.

Mainline Results: Speed Deviation



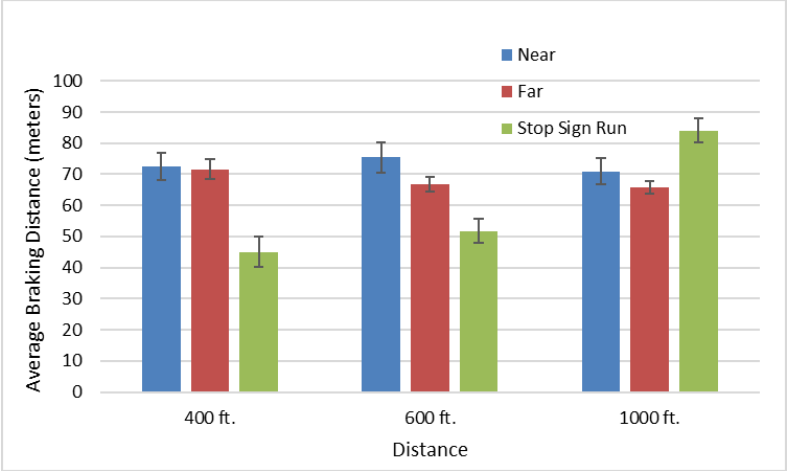
Standard deviation of speed for the 4th quarter mile for stationary vehicles by proximity.

Mainline Results: Speed Deviation



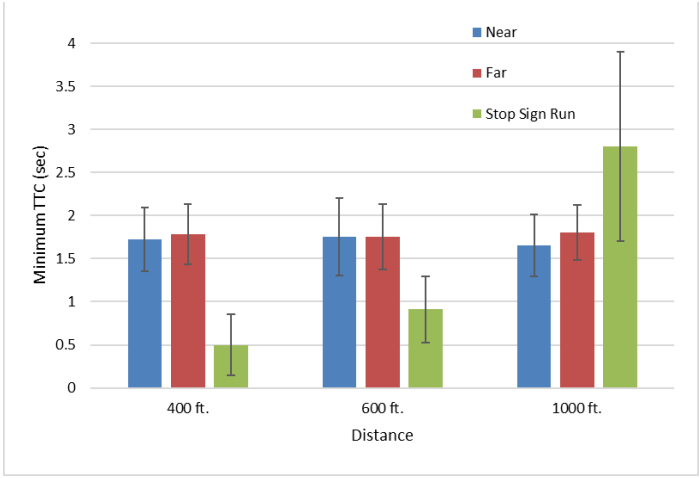
Average standard deviation of speed in the 4th quarter mile for moving vehicles as a function of distance and proximity.

Mainline Results: Braking Distance



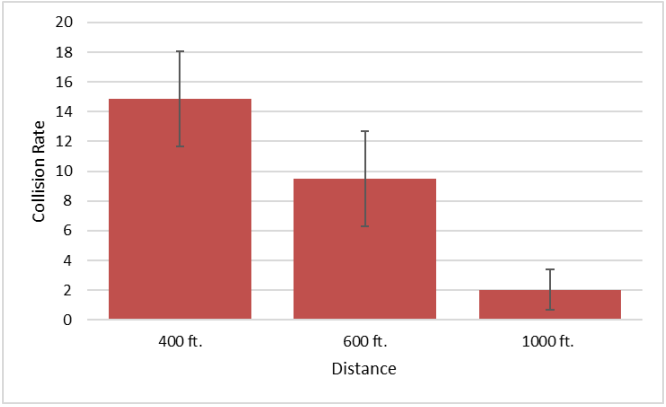
Average braking distance (m) for moving vehicles as a function of distance by proximity.

Mainline Results: Min TTC



Minimum TTC value for moving vehicles as a function of distance and proximity.

Mainline Results: Collisions



Collision rate for the stop sign running condition by distance.

Mainline Summary Results

- Drivers were slower (mean speed and average speed deviation) if a stationary vehicle was stopped near the intersection compared to vehicle stopped far from the intersection or absent.
- Approach speeds did not differ with sight distance changes for stationary vehicles.
- Approach speeds sig. differed by sight distance and vehicle proximity for intruding vehicles.
- The best responsiveness and further back braking to stop sign running vehicle was found with the largest sight distance (1000 ft.)
  - Little to no response at 400 and 600 ft.
- 1000 ft. sight distance with stop sign running vehicles resulted in longer TTCs and significantly fewer collisions compared to 400 & 600 ft.

Overall Summary: Water is Wet

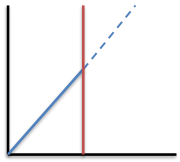
- 1000 ft sight distance and slower crossing speed (i.e., 55 mph) assist drivers on the minor road attempting to cross
  1) lower mental workload, less perceived risk, difficulty, and anxiousness
  2) Lower estimated crash rate, larger TTCs.
- 1000 ft sight distance assists drivers on the main road approaching an intersection, especially when another driver runs the stop sign
  - Better able to react and avoid crashes
- Few significant differences were found at 400 and 600 ft. indicating the safety effect is not realized until approaching 1000 ft.
- Vehicles stopped near the intersection led to slower speeds than when vehicles were placed further away from the intersection,
  - Proximity of a vehicle to the intersection lead to safer driving behaviors by participants travelling on the main road
  - Engineers should consider placing stop lines closer to the intersection

Research Takeaways

- Support for roles of vehicle speed and distance for TTC perception and gap selection
- Potential lower limit of 1000 feet. Upper limit undetermined.
- No support for confidence – performance mismatch hypothesis at longer sight distances
  - For rural intersections, sight distances up to 1000 ft.
  - Perceived risk interaction in TTC Study

Limitations and Future Directions

- Homogenous sample
  - Test teens and older drivers
- Only straight roads
  - Test alternative road geometries (e.g., curved)
- Did not test size arrival effect
  - Test different vehicle sizes
    - (e.g., Levulis, DeLucia, & Jupe, 2015)
- Potential study order effect, contrived scenarios
- Unable to assess confidence for mainline drive
  - Test active driving confidence for sight distances
- Limited distances tested
  - Max at 1000 ft.
  - Hypothesis of mismatched confidence with performance may find support at greater distances



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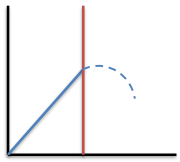

Acknowledgements and References

Acknowledgements

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- Minnesota Department of Transportation
  - LRRB

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QUESTIONS?