Using cognitive bias on Dynamic Message Signs to mitigate speeding

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Top driving behaviors contributing to crashes

Violating traffic laws

- 28% of all traffic fatalities in the U.S. are caused by speeding (National Center for Statistics and Analysis, 2022)
- Speeding is the most common roadway violation (Chaurand et al., 2015) and significantly increases crash risk (Elvik, 2005; IIHS, 2023; Tran et al., 2022)
- Speeding can be mitigated using DMS campaigns, speed cameras, speed display trailers, traffic calming, police enforcement (Hawkins & Hallmark, 2020)

Engaging in distractions

Visual   Manual   Cognitive

- Driving distractions are non-driving activities that cause drivers to divert their attention away from their primary driving task (Trick et al., 2004)
- 9 people in the U.S. die every day due to distracted driving (CDC, 2023)

Aggressive driving

- Aggressive driving includes tailgating, speeding, weaving in and out of traffic, running red lights
- 80% of U.S. drivers state that they were significantly angry, aggressive, and exhibited road rage within the last 30 days (AAA FTS, 2019)
- This behavior can be prevented by remaining calm and considerate of other drivers, keeping a safe following distance, and using turn signals (AAA FTS, 2023)

Context of studies

Three studies evaluating the applicability and effectiveness of psychology in changing behavior

Study 1: pilot study assessing drivers' beliefs about road safety

Study 2: applied results from study 1 in framing DMS messages to nudge drivers to change their behavior

Study 3: applied results from study 2 to an observational study measuring the effectiveness of DMS messages on road safety

Study 1 – pilot addressing drivers’ perception of road safety

Most drivers believe they are safe, and others are the problem

Study overview

Conducted in 2019 with 100 GWA drivers – 10 min online survey to assess drivers’ beliefs about safety

Results

90% of drivers believe they are somewhat/extremely safe and rated only 35% of other drivers the same

Takeaways

- Traditional DMS messages such as “Slow down” would be ineffective because drivers think others are the problem.
- These results suggest that messages should be reframed to focus on the unsafe behaviors of other drivers using *cognitive dissonance* – creating discomfort causing drivers to want to change their behavior to resolve the conflict.

Study 2 - *It’s not me, it’s you (2022)*

DMS messages as a countermeasure to unsafe driving

Review of framing techniques on DMS messages to improve driver safety

Negative-framed messaging

1669 deaths this year on Texas roads

- Messages to provoke negative emotions
- Uses protection motivation theory to increase the probability of acting or changing a behavior to decrease the threat or consequence (Kassens-Noor et al., 2021)
- Drivers subjectively perceive these messages as being most effective in changing their behavior (Kassens-Noor et al., 2021)
- An observational study found increased crash risk when DMS messages displayed consequences such as, crash and fatality statistics (Hall & Madsen, 2022)

Gain-framed messaging

Respected speed limit = less crashes

- Messages to provoke positive emotions by informing drivers of the benefits of safe behavior (Chaurand et al., 2015; Kassens-Noor et al., 2021)
- An observational study found that drivers reduced their speed when this type of message was displayed on DMS (Chaurand et al., 2015)

Non-traditional messaging

May the 4th be with you

- Messages including pop-culture references, rhymes, sports-related
- Drivers subjectively perceived these messages as promoting safe driving (Shealy et al., 2020)

Cognitive dissonance

A psychological phenomenon used to create discomfort causing drivers to change behavior in order to resolve the conflict (Bran & Vaidis, 2020)

- Drivers overestimate their own driving skills and think other drivers are the problem (Williams, 2003)
- Cognitive dissonance has shown to be effective in changing behavior, such as, improving safety compliance during COVID-19 (Pearce & Cooper, 2021)

Cognitive dissonance DMS study methods

Express Lane users are younger drivers with higher degrees and less years of driving experience

Participant demographics

400 GWA drivers participated in the study. Participants were eligible to participate in the study if they had a driver's license and drove on any of our corridors (either GP or ELs)

	Express Lane users	Non-users
Express Lanes (495, 95, 395)	**74% users**	**26% not users**
18 – 88 age	**Average 44 years**	**Average 57 years**
Gender	Men 49% Women 51%	Men 44% Women 56%
Education	Some college or less 32% Bachelors or higher 68%	Some college or less 47% Bachelors or higher 53%
Years licensed	< 5 86% ≥ 5 14%	< 5 92% ≥ 5 8%

Materials and procedures

10-min online survey:

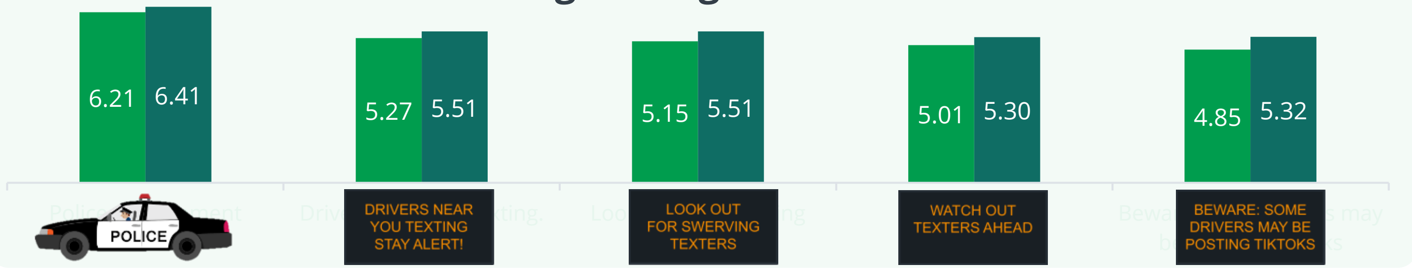
1. **Demographics questions**
   - Age, gender, education level, etc.
2. **Situations causing changes in driving behavior**
   - Crash involvement, children in the vehicle, on-road safety messages, police presence, receiving tickets, etc.
3. **Perception of driving behavior**
   - Rating self versus others' driving behavior using a 5-point Likert scale where 1 = strongly disagree and 5 = strongly agree
4. **Likelihood of signage in changing behavior**
   - Using a 7-point Likert scale where 1 = not likely at all and 7 = extremely likely, drivers rated the likelihood of signage to cause them to obey traffic laws (e.g., following speed limit), avoid distractions (e.g., radio, phone, eating), and remain calm (e.g., controlling stress or anger, safe following distance, avoiding impulsive decisions)
   - DMS signage was framed in terms of cognitive dissonance

Fear of consequences motivates behavior change

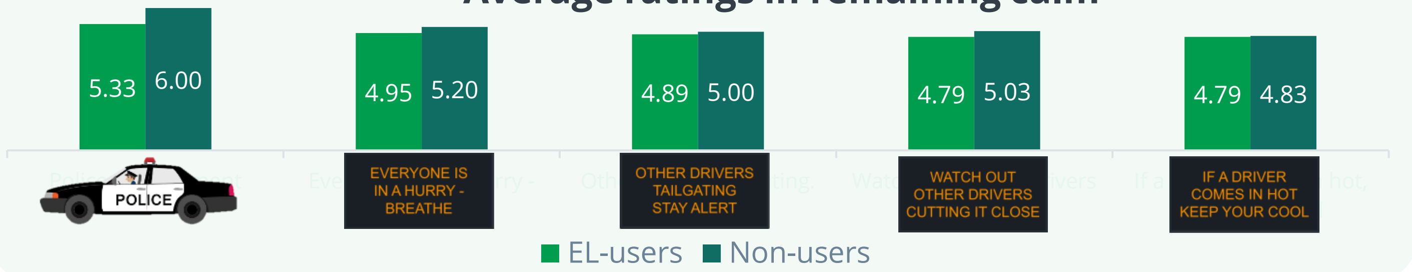
Express Lane drivers had lower ratings in changing behavior, but these differences were not significant

Average ratings in obeying traffic laws

Average ratings in avoid distractions



Average ratings in remaining calm



- All drivers significantly overestimate their driving skills compared to others and non-EL users even more so.
- Police enforcement was rated significantly greater in changing behavior than all the DMS messages, *ps* < .001.
- A speed camera sign was also rated significantly greater in changing behavior compared to the DMS messages for obeying traffic laws, *p* < .001.
- Overall, EL drivers had lower ratings in behavior change for all the signs and police enforcement.

		Express Lane users	Non-users
Obey traffic laws	Self	4.17	4.31
	Others	3.15	3.08
	Difference	1.02	1.23 ▲
Avoid distractions	Self	3.82	3.91
	Others	2.85	2.76
	Difference	0.97	1.15 ▲
Stay calm	Self	4.01	4.18
	Others	3.14	3.14
	Difference	0.87	1.04 ▲

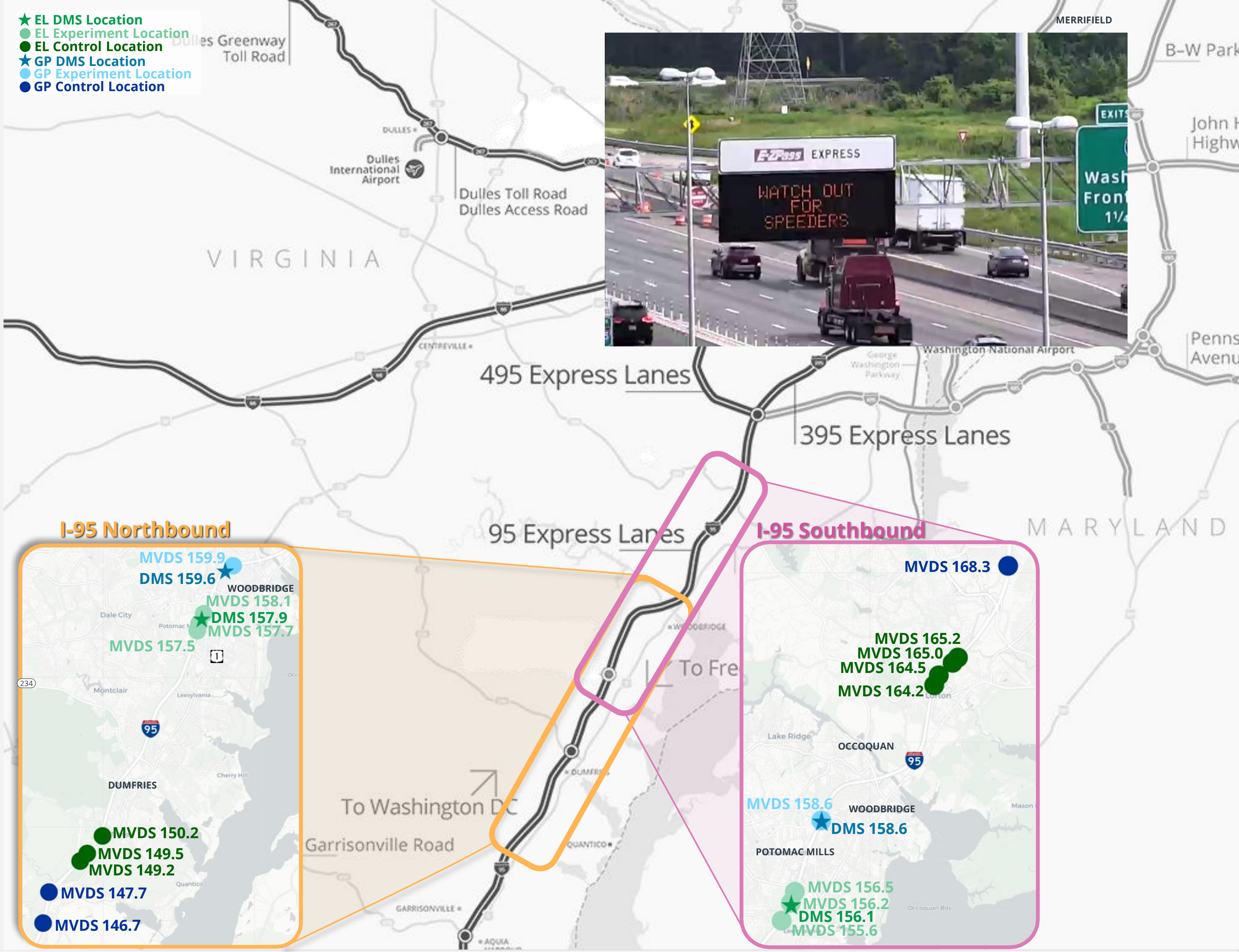
Study 3 – DMS on *Express Lanes and GP (2023)*

Observational study methods

Data were obtained from Microwave Vehicle Detection System (MVDS) sensors on I-95 General Purpose lanes and I-95 Express Lanes. Data were extracted ~0.5 mi before and ~0.5 mi after the DMS.

DMS Message was displayed for 2 weeks and speed behavior was compared to data at the same location 2 weeks prior.

Conditions were control vs. experimental locations. For each DMS, there was a corresponding control location to adjust for confounding variables such as, day of week, congestion, holidays, etc.



Data analysis

Analysis & Cleaning

- The data obtained from the MVDS sensors were divided into four groups by condition (control and experiment) and time period (before and during).
- Any observations where the reported speed or reported volume was equal to zero were removed from the data set.
- To prepare for modeling, the posted speed limit for each sensor location was then added to the data set and the data were split into three additional groups:
  - Tier 0: people traveling less than 10 mph above the posted speed limit
  - Tier 1: people traveling 10-20 mph above the posted limit
  - Tier 2: people traveling 20 or more mph above the posted speed limit
- Finally, the data were separated into three time periods (peak, off-peak, and weekend)

3 Million
Data Points

17
MVDS Sensors

68 mph
Avg Speed

12 Million
Trips

Road	Condition	Speed Limit	Before		During	
			Avg Speed	Avg Daily Volume	Avg Speed	Avg Daily Volume
I-95 EL NB	Control	65 mph	76.0	9,000	76.8	8,000
	Experiment		74.3	12,000	74.8	11,000
I-95 EL SB	Control	65 mph	74.0	21,000	74.3	20,000
	Experiment		72.8	15,000	72.8	14,000
I-95 GP NB*	Control	65 mph	70.7	74,000	70.5	75,000
	Experiment	55 mph	57.2	91,000	55.9	92,000
I-95 GP SB*	Control	55 mph	62.6	103,000	62.6	107,000
	Experiment	60 mph	64.0	68,000	62.6	74,000

*Due to the limited availability of MVDS sensors on the General Purpose lanes, the sensors that were available for the control and experiment locations were in two different speed limit zones.

Models

Two test were used to determine whether the DMS messages were effective in lowering the average speed: the "average speed test" and the "speeder test". The goal of the "average speed test" was to determine whether the interaction between the condition (control vs experiment) and time period (before vs during) impacted speeds among all drivers on the corridor. The goal of the "speeder test" was to determine whether the interaction between the condition and time period impacted speeds among those traveling at least 10 mph above the posted speed limit.

Average Speed Test

The model for the "average speed test" is a A/B test linear model with random effects of the form:

$$S = S_0 + \alpha \, \text{Period} + \beta \, \text{Condition} + \gamma \, (\text{Period} * \text{Condition}) + \delta \, \text{TOD} + \text{random effects}$$

where:

- S is the speed, recorded over a 20-second interval per lane
- S_0 is the intercept
- 'Period' is a categorical variable with values ("before", "during")
- 'Condition' is a categorical variable with values ("control", "experiment")
- 'Period*Condition' is the interaction term
- 'TOD' is a variable describing the time of the day, with values ("peak", "off-peak", "weekend")
- 'random effects' are represented by the lane number of the roadway
- α, β, γ, δ are parameters to be evaluated

Speeder Test

The model for the "speeder test" is a generalized linear model with a negative binomial, of the form:

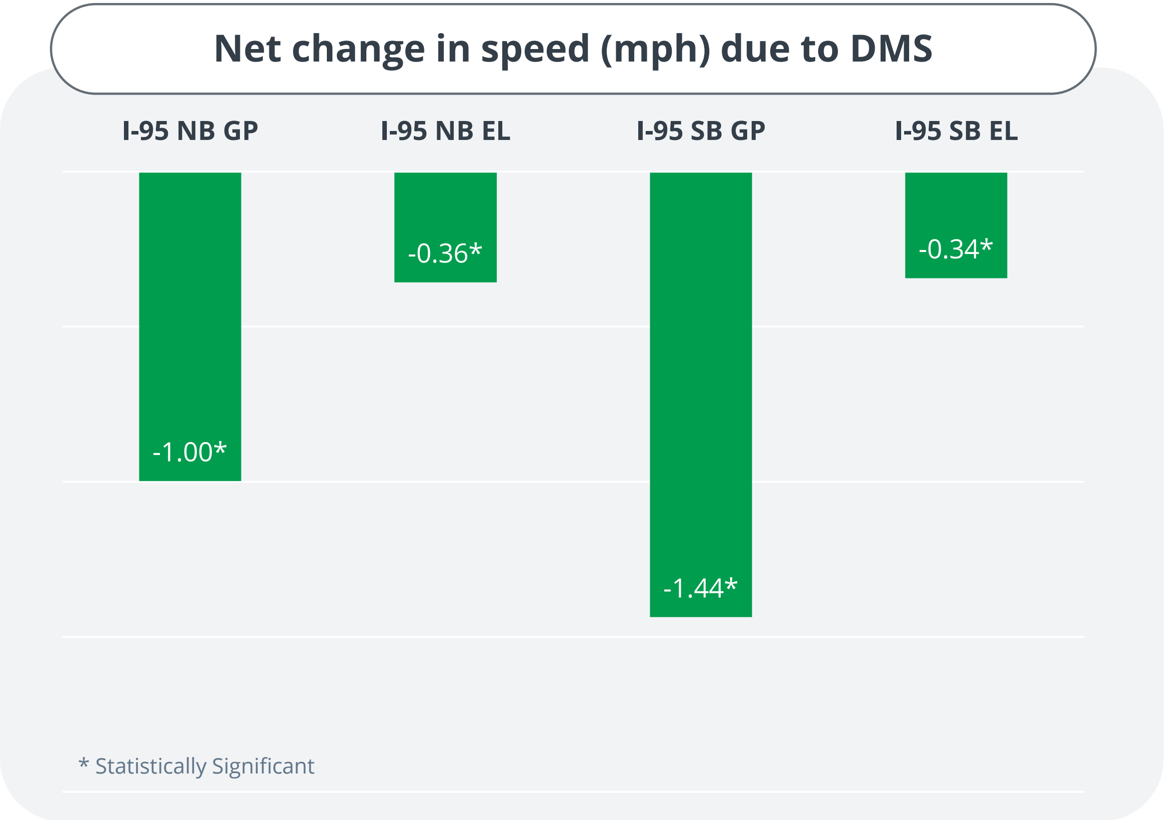
$$V(tier) = S_0 + \alpha \, \text{Period} + \beta \, \text{Condition} + \gamma \, (\text{Period} * \text{Condition})$$

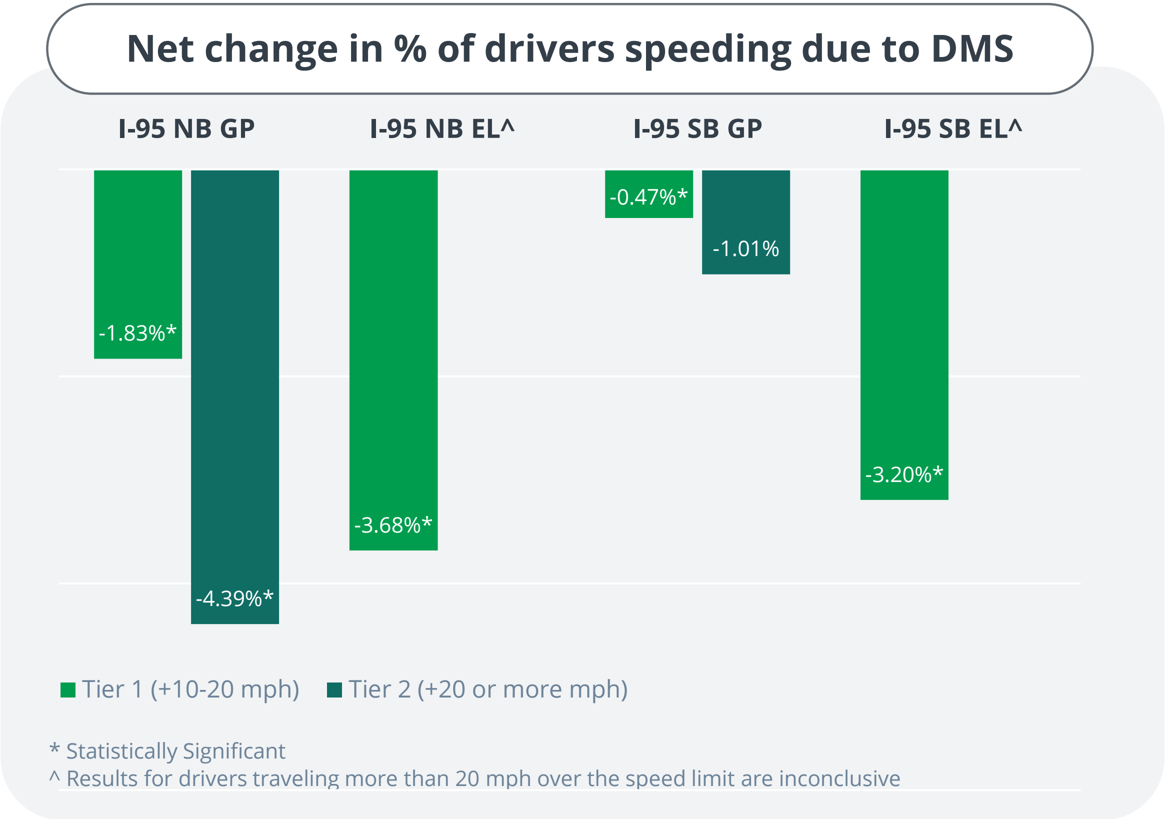
where:

- V is the volume of 'speeders', those vehicles with recorded speed in
  - Tier 1, between 10 mph and 20 mph above posted speed limit, and
  - Tier 2, 20 mph or more above posted speed limit
- S_0 is the intercept
- 'Period' is a categorical variable with values ("before", "during")
- 'Condition' is a categorical variable with values ("control", "treatment")
- 'Period*Condition' is the interaction term
- α, β, γ are parameters to be evaluated

Results

DMS effectively reduced speeds on all I-95 lanes and even more so on I-95 GP lanes





- When compared to the control locations, the DMS message caused drivers to decrease their speed in both directions on all lanes with the greatest reductions occurring on the General Purpose lanes. The small changes in speed on the Express Lanes still suggest improvements in road safety.
- When compared to the control locations, the DMS message also reduced the number of drivers who were already traveling at least 10 mph over the posted limit. The message had a larger impact on drivers traveling 20 mph or more above the posted limit.

Conclusion

Takeaways

Road configuration, data availability, and drivers' characteristics are at the core of the results

Message framing

- Cognitive dissonance messages seem to be effective in mitigating unsafe driving in applied and non-applied settings.
- The effectiveness of these messages on EL drivers and non-users may be attributed to age – cognitive dissonance have a larger effect on older populations (Cooper & Feldman, 2019) – most EL drivers are under 45 years of age (State of the lanes, 2023).
- As expected, drivers reported being most likely to improve their driving behavior to police enforcement and speed cameras though, these are costly and less feasible than posting messages on DMS

Configuration

- Different datasets were used in the analysis and results were not consistent across data sources. MVDS is likely more accurate than RITIS for this study because sample intervals are smaller, and data are more localized.
- Fewer MVDS sensors on GP than EL, and 1-2 more lanes on GP than EL. We found there were larger effects of DMS on speed reduction on the far-left GP lanes.
- Greater speed limit on ELs than GP.
- Areas of narrow shoulders on I-95 ELs – drivers may be less likely to reduce speed because not police enforceable areas.

Driver populations

- EL drivers state that they take the lanes for time savings and greater speed limits – they are less concerned about safety (State of the lanes, 2023).
- Speeding is equally problematic on ELs and GP lanes, but given their motivations, EL drivers may need interventions with more stringent consequences such as, speed cameras or police enforcement.