The Impact of End-of-Green Application on Driver Behavior

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BACKGROUND

During the driving task, the driver is typically exposed to a lot of information, which he is required to process in a relatively short time. This can be sometimes fairly difficult, leading drivers to make their decisions based on a small fraction of available information (*1*). As a result, there are differences between drivers in terms of the way they perceive the environment, and hence, the behavior of each driver in a given situation will be different.

The two main factors influencing the decision whether to cross or stop at a traffic light are the location of the vehicle and the vehicle speed when the traffic light changes from green to yellow. For a driver at a very short distance from the intersection or at a great distance from the intersection, the decision is relatively easy. Decision problems arise when the distance of the vehicle from the stopping line and its speed are such that both decision options seem reasonable and the driver finds it difficult to assess which of them will be the correct decision. Unsuitable decision to stop (when the vehicle's distance from the intersection is less than the distance required for a convenient stop) may require high deceleration in an emergency stop, or stopping beyond the stop line. The result could be discomfort, or even the risk of losing control over the vehicle, as well as the risk of a rear-end accident with a following vehicle. The result of an unsuitable crossing decision (when the vehicle is too far from the stop line) is the risk of an accident with a vehicle entering the intersection from another direction. Hesitation in the situations described above leads to loss of time and increases the chances of unsuccessful implementation of the decision.

This study examines the effect on driver behavior of a recommendation system that alerts drivers at the end of the green light if they need to stop. The experiment is partially within subject, comparing the behavior when warnings are available and the base case without warnings, and partly between subjects, comparing three different configurations of the warning system.
Thirteen males and eleven females with an average age of 26.14 (SD=0.91) participated in the study. All participants were students from the Industrial Engineering and Management Department at Ben-Gurion University of the Negev. Participants were all experienced drivers and had on average 8.26 years of driving experience (SD=1.13).

DISCUSSION

The purpose of this study was to use a driving simulator to evaluate the concept of in-vehicle traffic-signal-stopping advisory system, in terms of its effects on RLR violations, drivers' signal crossing decisions and the intersection efficiency. The novelty of this work with respect to a previous study (9) was to test a recommendation system with different alert timing. Specifically, we evaluated a recommendation system that alerted drivers to stop either 0, 1, or 2 s before the green phase changed to yellow.

The results of this study confirmed our main hypothesis that driving with a recommendation system improves the intersection efficiency and reduces the number of RLR violations. Specifically, the current results have shown that in terms of increasing the intersection efficiency, when driving with a recommendation system compared to driving without a system more drivers decided to cross when they should have crossed the intersection. It was also evident that with a system, drivers performed fewer RLR violations compared to when driving without a system. The current results are consistent with those of (9) and generalize them to systems that not only alert the driver to stop exactly when the green phase change to yellow but also when the alert is initiated 1 or 2 seconds prior to the phase change.

One of the most interesting findings of this work was demonstrated for cases where drivers were driving with a recommendation system, but the alert was not initiated. These cases included target intersections with TTI of 2.5 s where drivers should cross the intersection and therefore an alert was not initiated. In addition, recall that the recommendation system that we evaluated was always accurate and this information was transferred to the participant at the beginning of the experiment. Nevertheless, when looking at the number of crossing cases compared to the number of stopping cases they are almost equal (Figure 2) suggesting that in half of the cases where participants should have crossed the intersection they did not do so and stopped in front of the intersection. On the other hand, for target intersections with TTI greater than 2.5 s, most drivers who were driving with a recommendation system compared to driving without a system made the right decision and stopped. Notably, for target intersections with TTI greater than 2.5 s the recommendation system always triggered an alert to the driver that he should come to a full stop.

A possible explanation for these different patterns of interaction with the recommendation system relies on theories of human machine interaction. That is, according to (*17*), when humans are interacting with automation there could be two main types of behaviors. The first, when the automated system recommends doing something and the operator agrees to act accordingly, meaning that the operator complies with the system. The second, when the automation does not recommend anything and the operator follows and does nothing, meaning that the operator relies on the system. These two types of behaviors are not symmetrical. In our case, participants tended to comply with the recommendation system in cases where it recommended to stop but they did not tend to fully rely on the system where no recommendation was triggered (i.e., for TTI of 2.5 seconds).

Finally, although we examined systems with different alert onset times our results were too ambiguous to come to conclusively determine which configuration is better, and therefore more research is necessary. Nevertheless, the trend of our results with respect to the optimal alert onset configuration suggests that the onset of the alert should be closer to the actual phase change from green to yellow. This suggestion is based on our findings that the only system that yielded no RLR violations was with alert onset time of zero, that is, the alert occurred exactly when the green phase changed to yellow. In fact, this tentative finding contradicts our expectations that drivers would prefer to hear the alert as soon as possible (e.g., 2 s before the green phase changes to yellow). One possible explanation for this counter-intuitive result is that when the alert is provided at the same time as the green changes to yellow, drivers get supportive evidence that they should stop, and therefore we higher compliance rates. On the other hand, when the alert is given to the driver when the light is still green, he or she apparently sees contradicting evidence (i.e., the system tells the driver to stop but the light is still green) and thus the driver's tendency to comply with the system decreases. Again, this is only one possible explanation and there could be others. Future exploration of this issue would therefore be desirable.

IMAGES:

Figure 1- an example of the simulated urban traffic

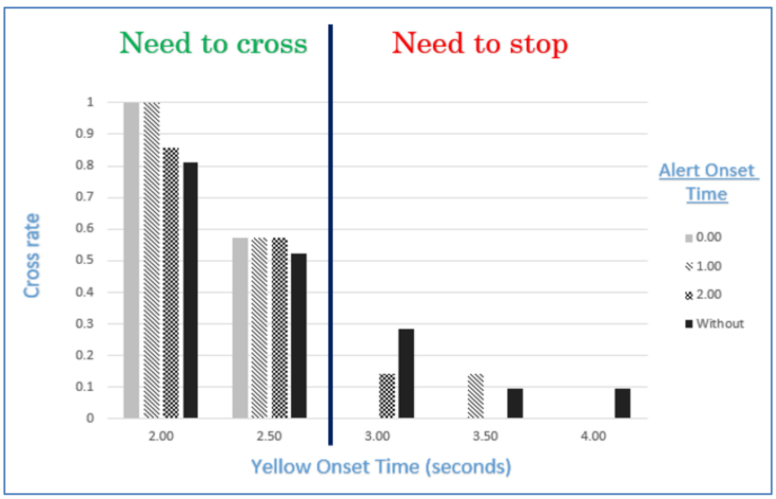

Figure 2- the proportion of drivers who crossed the intersection in the various situations

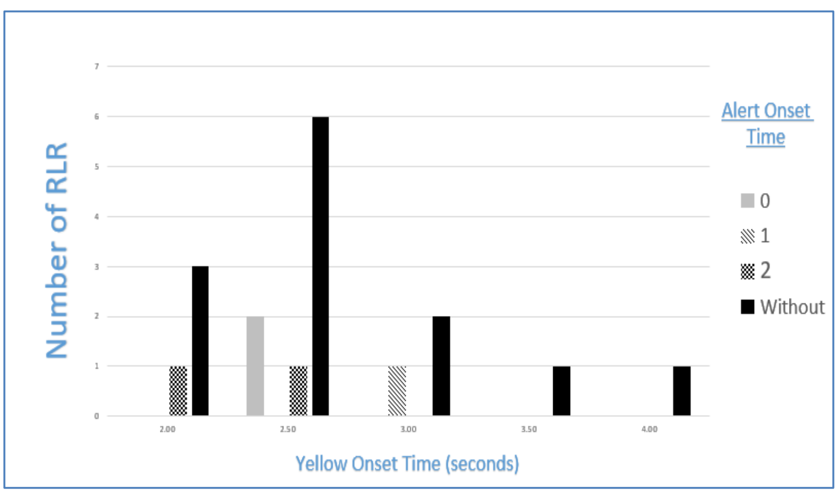

Figure 3- the frequencies of RLR violations in the various situations

REFERENCES

1. Hughes, P. K., & Cole, B. L. (1986). What attracts attention when driving?. *Ergonomics*, *29*(3), 377-391.
2. Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human factors*, *37*(1), 32-64.
3. Liu, C., Herman, R., & Gazis, D. C. (1996). A review of the yellow interval dilemma. *Transportation Research Part A: Policy and Practice*, *30*(5), 333-348.
4. Factor, R., Prashker, J. N., & Mahalel, D. (2012). The flashing green light paradox. *Transportation research part F: traffic psychology and behaviour*, *15*(3), 279-288.
5. Köll, H., Bader, M., & Axhausen, K. W. (2004). Driver behaviour during flashing green before amber: a comparative study. *Accident Analysis & Prevention*, *36*(2), 273-280.
6. Institute of transportation engineers, 2003. http://www.ite.org/
7. Bar-Gera, H., Musicant, O., Schechtman, E., & Ze'evi, T. (2016). Quantifying the yellow signal driver behavior based on naturalistic data from digital enforcement cameras. *Accident Analysis & Prevention*, *96*, 371-381.
8. HSM (2010). Highway Safety Manual. http://safety.fhwa.dot.gov/hsm/, table 14-3.
9. HSM (2010). Highway Safety Manual. http://safety.fhwa.dot.gov/hsm/, table 15-2
10. Retting, R. A., Ferguson, S. A., & Farmer, C. M. (2008). Reducing red light running through longer yellow signal timing and red light camera enforcement: results of a field investigation. *Accident Analysis & Prevention*, *40*(1), 327-333.
11. Høye, A. (2013). Still red light for red light cameras? An update. *Accident Analysis & Prevention*, *55*, 77-89.
12. Lum, K. M., & Halim, H. (2006). A before-and-after study on green signal countdown device installation. *Transportation Research Part F: Traffic Psychology and Behaviour*, *9*(1), 29-41.
13. Chiou, Y. C., & Chang, C. H. (2010). Driver responses to green and red vehicular signal countdown displays: Safety and efficiency aspects. *Accident Analysis & Prevention*, *42*(4), 1057-1065.
14. Bar-Gera, H., Oron-Gilad, T., & Musicant, O. (2013). In-vehicle stopping decision advisory system for drivers approaching a traffic signal. *Transportation Research Record: Journal of the Transportation Research Board*, (2365), 22-30.
15. Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology* (Vol. 52, pp. 139-183). North-Holland.
16. Zuckerman, M. (1994). *Behavioral expressions and biosocial bases of sensation seeking*. Cambridge university press.
17. Wickens, C.D., Clegg, B. A., Vieane, A. Z., & Sebok, A. L. (2015). Complacency and automation bias in the use of imperfect automation. *Human factors*, *57*(5), 728-739.