2003-01-0295

Driving with HID Headlamps: A Review of Research Findings

Michael Sivak, Michael J. Flannagan, Brandon Schoettle, and Go Adachi
The University of Michigan

ABSTRACT

High-intensity discharge (HID) headlamps have several advantages over tungsten-halogen headlamps, including greater light efficiency (lumens per watt) and longer life. However, from the safety point of view, the primary attraction of HID headlamps is that, because they produce more total light, they have the potential to provide more useful illumination to the driver. At the same time, there are concerns with the effects of HID illumination on perception of the colors of important objects and glare to oncoming traffic. This paper reviews research evidence that we have accumulated over the past 14 years concerning the potential benefits and drawbacks associated with the use of HID headlighting. We conclude that the evidence strongly supports the use of well-designed HID headlamps.

BACKGROUND

It is generally acknowledged that current tungsten-halogen low beams do not provide enough illumination for normal driving speeds. It has been estimated that about 45 mph (72 km/h) is the highest speed at which the seeing distance provided by low-beam headlamps is adequate to give drivers time to react to unexpected obstacles (Perel, Olson, Sivak, & Medlin, 1983). Although it is clear that a part of the problem is the tug-of-war between increasing the light for the driver behind the lamps (the seeing light) and decreasing the light for the opposing driver (the glare light), a part of the problem lies in not having enough light to work with. Enter HIDs. For example, a recent study estimated that the HID low beams manufactured for use in the U.S. on 2000 model vehicles provided over twice the useful luminous flux of tungsten-halogen low beams of the same vintage (Sivak, Flannagan, Schoettle, & Nakata, 2002).

BENEFITS OF MORE LIGHT

What do headlamp designers do with this extra light? In the U.S., where the extra light is directed varies, in part, with the optics of the HIDs. In comparison to tungsten-halogen low beams, the first generation of HIDs in the U.S. (for model year 2000 vehicles) tended to provide wider beam patterns regardless of the optics. However, the illumination directed at far distances on the right side of the beam pattern (important for pedestrian visibility) from tungsten-halogens (all were nonprojectors) was surpassed only by projector HIDs; the nonprojector HIDs delivered less light in this part of the beam pattern (Sivak, Flannagan, Schoettle, & Nakata, 2002).

In the same study, we found that HID low beams tended to direct less glare illumination towards oncoming drivers than did tungsten-halogen low beams, with the exception of delivering more glare illumination on right curves (and even there the increase in illumination was only modest). (A recent study by Grimm and Hamm [2001] found that ECE HID low beams also tend to produce slightly less glare light than ECE tungsten-halogen low beams.)

Overall, we concluded that HIDs “hold great promise for improving the nighttime safety of driving by improving the low-beam light distribution. The present analysis indicates that this promise has already been partially met in the first generation of HID lamps on vehicles in the U.S.” (Sivak, Flannagan, Schoettle, & Nakata, 2002, p. i).

In addition to providing more seeing light for detecting important objects such as pedestrians, a wider beam pattern is predicted to decrease the workload required for lane tracking. We evaluated this prediction in a recent field study (Sivak, Flannagan, Schoettle, & Mefford, 2002). In this study, the subjects drove two identical vehicles that were equipped with either HID or tungsten-halogen low beams. The main difference between the two beams was that the HID lamps provided more spread light. Driving performance was evaluated by analyzing steering frequencies. The hypothesis was that the wider beam pattern of HID low beams would be beneficial by reducing the steering effort in the 0.3 to 0.6 Hz (high-frequency) range, which has been used in previous studies as an index of steering-task difficulty (e.g., Blaauw, 1984; McLean & Hoffmann, 1973; Schumann, 2000). The main finding was that the wider HID beam pattern resulted in less effortful steering, as measured by a reduction in the steering frequencies between 0.3 and 0.6 Hz. A tentative implication of this study is that HID headlamps are beneficial to safety, because their wider beam patterns impose less effort on steering performance and consequently they allow more of the limited information-processing resources of drivers to be allocated to other tasks.

PERCEPTION OF COLOR

Perceived color is not an inherent property of an object. The two primary determinants of perceived color are the spectral reflectance of the object and the spectral power distribution of the illuminant. (There are other, secondary, factors, such as the spectral power distribution of the adjacent background and the degree of color normalcy of the observer.) It is the spectral power distribution of HIDs that is of potential concern here: The profile of the spectral power distribution of HIDs, relative to tungsten-halogens, is less continuous and proportionally stronger in the short-wavelength region.

The flip side of emitting more energy in the short-wavelength (blue) part of the visible spectrum is providing less energy in the long-wavelength (red) part—precisely in the most reflective wavelength region of retroreflective red stop signs. Consequently, the color perception of stop signs became the focus for one of the two main concerns with HID headlighting.

As part of our research program, we performed four studies related to the issue of color perception when using HID headlamps. The first, analytical study (Sivak, Simmons, & Flannagan, 1991) evaluated the colorimetric properties of retroreflective traffic signs when illuminated by HID headlamps. Two aspects were investigated: (1) colorimetric shifts of individual sign materials when illuminated by HID as opposed to tungsten-halogen light sources, and (2) colorimetric separations of the red sign material from the yellow, orange, and brown sign materials when illuminated by HID light sources. Spectral reflectances of 14 sign materials and spectral power distributions of seven HID headlamps (along with a tungsten-halogen headlamp) were used to derive the CIE tristimulus values for the sign materials. These values were then transformed into the CIELAB space—a perceptually uniform color space. On the negative side, the results of the analyses indicate that the magnitude of the colorimetric shift increased with increasing correlated color temperature of the light source. On the positive side, the resulting colorimetric separations of red from yellow, orange, and brown for the HID light sources also tended to increase with increasing correlated color temperature.

The second of our studies on color perception with HIDs was a photometry study (Flannagan, Sivak, Gellatly, & Luoma, 1992b), designed to compare the magnitudes of the shifts in chromaticity of stop signs illuminated by HID and tungsten-halogen headlamps to the range of chromaticities of stop signs under tungsten-halogen headlamps. A stratified sample of 25 in-use stop signs was selected. Stratification was by sign material, age, and the compass direction faced by the legend side of the sign. The chromaticities of these signs were measured in the field under both tungsten-halogen and HID illumination. The shifts between the chromaticities of the signs when they were illuminated with HID as opposed to tungsten-halogen light sources were in the direction of orange, and they were moderate relative to the range of chromaticities under the tungsten-halogen source. We concluded that, although the sizes of the shifts should not be interpreted as indicating a problem with color rendering by HID headlamps, they were not small enough to allow us to dismiss the possibility of a problem on the basis of colorimetric data alone.

The third study in this series was a laboratory investigation (Sivak, Flannagan, Gellatly, & Luoma, 1992), designed to experimentally address the consequences of colorimetric shifts of red sign materials in different colorimetric directions. Subjects were shown individual color samples under controlled lighting conditions. Their task was to indicate, on each trial, whether the sample color was acceptable for stop signs. Additionally, at the end of each experimental session, subjects were asked to select a single, most appropriate color for stop signs from among 16 simultaneously presented color samples. An implicit assumption underlying this study was that subjective preference is related to performance: stimuli that are closer to the most preferred stimulus lead to better performance in terms of measures such as percent correct identification, reaction time, etc. Although direct evidence confirming this assumption does not exist, there is some indirect evidence. Stimulus-response situations that are compatible with the population stereotype lead to shorter reaction times than situations that are incompatible with the population stereotype (Kantowitz & Sorkin, 1983). There were two main findings of this study. First, there was an overwhelming agreement among the subjects concerning the most appropriate red color for stop signs out of the 16 colors presented—a particular saturated red. Second, observers were differentially sensitive to colorimetric shifts in different directions from this most appropriate color. From among the directions of colorimetric shift that were tested in this study, subjects were most sensitive to hue shifts towards orange (generally in the same direction as the shift that was obtained in the above-mentioned photometry study of in-use stop signs), while they were relatively insensitive to saturation shifts towards pink.

The fourth, and final study on color perception with HID illumination evaluated drivers' impressions after in-traffic experience with both types of illumination, with an emphasis on color appearance of stop signs (Sivak, Flannagan, Traube, Battle, & Sato, 1994). In the first of two tasks, subjects drove (or rode) for half an hour on a variety of roads in a car equipped with either HID or tungsten-halogen low beam headlights with similar beam patterns. Instructions did not mention color appearance. The second task involved a direct comparison of the two types of headlamps. In this task, the subjects were instructed to pay attention to the color appearance of stops signs and other objects prior to a 7-minute drive through a residential area. The main finding from the first task was that subjects who experienced HID headlamps did not report more (or fewer) spontaneous negative comments on color appearance of stop signs and other objects than did subjects who experienced tungsten-halogen headlamps. In the direct comparison in the second task, there was also no evidence of problems with color appearance of stop signs or other objects when using HID headlamps. These findings suggest that the colorimetric shifts resulting from using HID lamps might not be of sufficient magnitude to cause a problem in actual driving.

In summary, these four studies suggest that (1) HID headlamps result in colorimetric shifts of the red stop-sign materials towards orange, (2) observers in a laboratory setting are sensitive to such shifts, but (3) observers in actual driving are not sensitive enough to raise concerns with these shifts. Thus, we conclude that color rendition with HIDs seems adequate for the practical needs of driving.

GLARE

In the formal study of glare, a major distinction has been made between the extent to which glare stimuli diminish a person's objective ability to see (often referred to as disability glare) and the extent to which glare stimuli evoke reports of subjective discomfort (often referred to as discomfort glare). The mechanisms of disability glare are relatively simple and well understood, having to do with aspects of the eye itself. The mechanisms of discomfort glare, although they often appear to be quite systematic, are more complicated and less well understood, involving not just physiological aspects of the eye but also how people think about stimuli. People's subjective reactions to glare stimuli depend on many aspects of the stimulus situation and of their past experience—for example, the difficulty of a concurrent task (Sivak, Flannagan, Ensing, & Simmons, 1991) or the range of stimuli presented in a certain context (Olson & Sivak, 1984). From the safety point of view, of course, disability glare is of primary concern. However, the limiting factor in practice is often discomfort glare: If people complain enough, the industry and/or the government will take action.

As indicated above, current HID low beams tend to direct *less* light towards oncoming drivers than do tungsten-halogen low beams. This has been shown for the low beams in the U.S. (Sivak, Flannagan, Schoettle, & Nakata, 2002) as well as in Europe (Grimm & Hamm, 2001). Nevertheless, drivers (especially in the U.S.) continue to complain about glare from HID headlamps. What is it about HID headlamps that drivers find objectionable? There are several possible reasons, including physiological or psychological reactions to the different spectral power distribution, greater source luminance (because of generally smaller illuminated surface areas), unintended illumination reaching oncoming drivers on vertically uneven roadways (because of sharper vertical gradients), and sheer novelty. We will discuss the available research evidence concerning the effects of spectral power distribution and illuminated surface area.

SPECTRAL POWER DISTRIBUTION

A series of our studies has addressed the issue of possible differences in discomfort glare from HID and tungsten-halogen headlamps as a function of spectral power distribution. The first two were laboratory studies (Flannagan, Sivak, Ensing, & Simmons, 1989; Flannagan, Sivak, & Gellatly, 1991). These studies used nearly monochromatic stimuli rather than actual headlamps. They suggested that, in the range of luminance that is characteristic of night driving, discomfort glare ratings are strongly influenced by rod photoreceptors, and that the scotopic luminous efficiency function might lead to better predictions of discomfort ratings than the more standard photopic luminous efficiency function.

The following study (Flannagan, Sivak, & Gellatly, 1992a) was performed in an outdoor, static situation that was comparable in terms of lighting to a meeting between two cars on an unlighted, two-lane road. Subjects' ratings of discomfort glare indicated that HID lamps were more glaring than tungsten-halogen lamps when the two types of lamps produced equal photopic lux values at the subjects' eyes. We quantified the effect in terms of the difference in log photopic lux levels that would be necessary to produce equal discomfort glare ratings. That difference turned out to be about 0.22, corresponding to a factor of 1.66. This difference was in the same direction as, but much larger than, a predicted difference based on the assumption (prompted by the laboratory data on monochromatic stimuli) that scotopic photometry would predict discomfort glare responses. The predicted difference in log photopic lux values was only 0.037 (corresponding to a factor of 1.09).

The next field study (Flannagan, Sivak, Battle, Sato, & Traube, 1993) replicated the difference between and HID and tungsten-halogen lamps that we observed in the previous study. (The obtained difference between the lamps in log photopic lux levels that would be necessary to produce equal discomfort glare ratings was 0.165 log units, meaning that photopic lux for tungsten-halogen lamps would be 1.46 times greater than for HID lamps when discomfort glare was equal.) Furthermore, the results indicated that the difference between the lamps is not reduced by several explicit manipulations of context and experience. Specifically, the magnitude of the difference between the effects of the two lamp types was not affected by the type of headlamp (HID or tungsten-halogen) used on the car in which observers sat while viewing the glare stimuli, nor by whether the HID lamps and tungsten-halogen lamps were presented in the context of headlamps that had been filtered to produce strongly saturated colors.

The most recent of our studies on glare with HID headlamps (Flannagan, 1999) dealt with both discomfort and disability glare in a laboratory setting. Consistent with the two field studies, the HID lamps produced more discomfort. Importantly, however, disability glare (measured by determining the luminance threshold for detecting a pedestrian silhouette presented near the glare source) was unaffected by lamp type. This important finding (of no effect of lamp type on disability glare) was later closely replicated by another laboratory (Bullough, Fu, & Van Derlofsky, 2002).

In summary, our research evidence from five studies is consistent concerning increased discomfort glare from bluish light of HID headlamps, as compared to more yellowish light from tungsten-halogen headlamps. Our best estimate is that for the two types of lamps to produce equal level of discomfort, tungsten-halogen lamps would need to be about 1.5 times as intense as HID lamps. Importantly, however, there is no evidence that HID lamps lead to more disability glare than do tungsten-halogen lamps.

SIZE OF THE ILLUMINATED AREA

Previous research has shown that the same amount of illuminance tends to be more discomforting when it comes from a smaller apparent source (e.g., Sivak, Simmons, & Flannagan, 1990; Alferdinck & Varkevisser, 1991, Manz, 2001; but see Flannagan, 1999). In other words, the evidence suggests that discomfort glare is influenced by the luminance of the light source. Consequently, if HIDs are smaller, the increased discomfort could partly be explained by their higher luminance.

We evaluate the hypothesis that the increased discomfort glare from HID headlamps on the road is partly a consequence of their smaller illuminated surface area in a recent study (Schoettle, Sivak, Flannagan, & Adachi, 2002). A sample of 20 tungsten-halogen lamps and 17 HID lamps for model year 2000 vehicles in the U.S. was examined. The illuminated surface area was determined using a modified version of an ECE method for evaluating the illuminated surface of signaling devices. The main finding was that the HID low beams generally had smaller illuminated surface areas than did the tungsten-halogen low beams. For example, the median area of the HID lamps was 1.8 times smaller than the median area of the tungsten-halogen lamps. This finding suggests that the smaller illuminated area is one reason for drivers reporting more discomfort from HID lamps. An implication is that the increased discomfort from HID lamps could be reduced by increasing their illuminated surface area.

DRIVER PREFERENCES

We examined driver preferences for HID versus tungsten-halogen low beams in two studies. The first study (Sivak, Flannagan, Traube, Battle, & Sato, 1994), which focused on color perception with HID lamps (see above), involved two driving tasks. In the first (unalerted) task, subjects drove for about 30 minutes with either HID or tungsten-halogen lamps without specific instructions about the purpose of the study. In the second (alerted) task, subjects drove with each type of lamp for 7 minutes after receiving specific instructions to pay attention to the color appearance of stop signs and other objects. The main finding of relevance here is that subjects who had the relatively extended (30-minute) driving exposure to HID lamps in the first task overwhelmingly preferred them to tungsten-halogen lamps in the head-to-head comparison of the second task. However, this preference for HID lamps was not present for those subjects that drove with the tungsten-halogen lamps in the first task, and thus did not have the relatively extended exposure to HID lamps.

The second study (Sivak, Flannagan, Schoettle, & Mefford, 2002), which focused on driver steering performance (see above), also asked subjects about their headlamp preferences. The general method was similar to the previous study. However, in this study each subject had a 30-minute drive with each of the two types of headlamps in the first (unalerted) part. Analogous to the results in the previous study, when the subjects were not primed before driving to pay attention to the headlamps in the first task, they did not show, as a group, preference for either type of lamp. However, when they were told to pay attention to the headlamps in the second task, they overwhelmingly preferred the HID lamps.

Overall, the results of these two studies suggest that drivers strongly prefer HID headlamps, provided that (1) they have relatively extended driving exposure to them, and (2) they are primed to pay attention to headlamp performance.

SUMMARY AND CONCLUSIONS

More seeing light is needed to make night driving safer. For example, a recent analysis (Sullivan & Flannagan, 2001) indicates that approximately 2,300 pedestrians are killed in the U.S. annually because of drivers' inability to see at night. In combination with the conclusion that current low-beam headlamps do not provide sufficient seeing distance for common highway speeds (Perel Olson, Sivak, & Medlin, 1983), this suggests that improved headlighting would probably have substantial safety benefits. HIDs, with their greater luminous flux, could make a difference. A recent photometric analysis (Sivak, Flannagan, Schoettle, & Nakata, 2002) indicates that positive changes from tungsten-halogen to HID illumination are already present in some of the first-generation HID low beams in the U.S.

Two traditional concerns with HID headlamps—color perception and glare—have been studied extensively. Color-perception changes with HID illumination do occur, but they are unlikely to be of substantial magnitude to cause a problem in actual driving. Increased discomfort (subjective) glare with HID headlamps has been well documented in numerous studies. However, there is no evidence that HID illumination causes increased disability (objective) glare. The increased discomfort glare with HIDs is due, in part, to the different spectral power distribution and smaller illuminated surface area (both of which are modifiable to some extent).

Drivers overwhelmingly prefer HID over tungsten-halogen low beams on their own vehicles. However, this preference is evident only if they are given a relatively extended driving experience with HID lamps, and are told to pay attention to headlighting.

There is potential for improving the seeing part of the beam pattern with HID light sources, stemming primarily from having more light available. The concurrent increase in discomfort glare should not deter us from trying to provide more seeing light and, thus, better overall vision for drivers.

ACKNOWLEDGMENTS

Appreciation is extended to the members of the University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety for support of this research. The current members of the Program are: AGC America, Autoliv, Automotive Lighting, Avery Dennison, BMW, DaimlerChrysler, DBM Reflex, Denso, Exatec, Federal-Mogul, Fiat, Ford, GE, Gentex, General Motors, Guardian Industries, Guide Corporation, Hella, Honda, Ichikoh Industries, Koito Manufacturing, Labsphere division of X-Rite, Lang-Mekra North America, LumiLeds, Magna International, Mitsubishi Motors, Nichia America, North American Lighting, OSRAM Sylvania, Pennzoil-Quaker State, Philips Lighting, PPG Industries, Reflexite, Renault, Samlip, Schefenacker International, Solutia Performance Films, Stanley Electric, Toyota Technical Center USA, Valeo, Vidrio Plano, Visteon, 3M Personal Safety Products, 3M Traffic Control Materials.

Information about the Industry Affiliation Program is available at: http://www.umich.edu/~industry/

REFERENCES

1. Alferdinck, J.W.A.M. & Varkevisser, J. (1991). *Discomfort glare from D1 headlamps of different size* (Report No. IZF 1991 C-21). Soesterberg, The Netherlands: TNO Institute for Perception.
2. Blaauw, G.J. (1984). *Car driving as a supervisory control task*. Soesterberg, The Netherlands: Institute for Perception TNO.
3. Bullough, J.D., Fu, Z., & Van Derlofsky, J. (2002). *Discomfort and disability glare from halogen and HID headlamp systems* (SAE Technical Paper Series No. 2002-01-0010). Warrendale, PA: Society of Automotive Engineers.
4. Flannagan, M.J. (1999). *Subjective and objective aspects of headlamp glare: Effects of size and spectral power distribution* (Report No. UMTRI-99-36). Ann Arbor, MI: The University of Michigan Transportation Research Institute.
5. Flannagan, M.J., Sivak, M., Battle, D.S., Sato, T., & Traube, E.C. (1993). *Discomfort glare from high-intensity discharge headlamps: Effects of context and experience* (Report No. UMTRI-93-10). Ann Arbor, MI: The University of Michigan Transportation Research Institute.
6. Flannagan, M., Sivak, M., Ensing, M., & Simmons, C.J. (1989). *Effect of wavelength on discomfort glare from monochromatic sources* (Report No. UMTRI-89-30). Ann Arbor, MI: The University of Michigan Transportation Research Institute.
7. Flannagan, M.J., Sivak, M., & Gellatly, A.W. (1991). *Joint effects of wavelength and ambient luminance on discomfort glare from monochromatic and bichromatic sources* (Report No. UMTRI-91-42). Ann Arbor, MI: The University of Michigan Transportation Research Institute.
8. Flannagan, M.J., Sivak, M., Gellatly, A.W., & Luoma, J. (1992a). *A field study of discomfort glare from high-intensity discharge headlamps* (Report No. UMTRI-92-16). Ann Arbor, MI: The University of Michigan Transportation Research Institute.
9. Flannagan, M.J., Sivak, M., Gellatly, A.W., & Luoma, J. (1992b). *Ranges of stop sign chromaticity under tungsten-halogen and high-intensity discharge illumination* (Report No. UMTRI-92-17). Ann Arbor, MI: The University of Michigan Transportation Research Institute.
10. Grimm, M. & Hamm, M. (2001). ECE headlamp performance status and potential for improvement. In, *Proceedings of the Conference on Progress in Automobile Lighting* (pp. 348-354). Darmstadt, Germany: Darmstadt University of Technology.
11. Kantowitz, B. & Sorkin, R.D. (1983). *Human factors*. New York: Wiley.
12. McLean, J.R. and Hoffmann, E.R. (1971). Analysis of drivers' control movements. *Human Factors*, *13*, 407-418.
13. Manz, K. (2001). The influence by size of headlamp on discomfort glare. In, *Proceedings of the Conference on Progress in Automobile Lighting* (pp. 618-634). Darmstadt, Germany: Darmstadt University of Technology.

14. Olson, P.L. & Sivak, M. (1984). Discomfort glare from automobile headlights. *Journal of the Illuminating Engineering Society*, *13*, 296-303.

15. Perel, M., Olson, P., Sivak, M., & Medlin, J.W. (1983). *Motor vehicle forward lighting* (SAE Technical Paper Series No. 830567). Warrendale, PA: Society of Automotive Engineers.

16. Schoettle, B., Sivak, M., Flannagan, M.J., & Adachi, G. (2002). *The illuminated surface areas of HID and tungsten-halogen headlamps in the U.S.* (Report No. UMTRI-2002-32). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

17. Schumann, J. (2000). *Post-mounted delineators and perceptual cues for long-range guidance during night driving* (Report No. UMTRI-2000-42). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

18. Sivak, M., Flannagan, M.J., Ensing, M., & Simmons, C.J. (1991). Discomfort glare is task dependent. *International Journal of Vehicle Design*, *12*, 152-159.

19. Sivak, M., Flannagan, M.J., Gellatly, A.W., & Luoma, J. (1992). Subjective preferences for the red color of stop signs: Implications for the design of high-intensity discharge headlamps. *Color Research and Application*, *17*, 356-360.

20. Sivak, M., Flannagan, M.J., Schoettle, B., & Mefford, M.L. (2002). *Driving performance with and preference for HID headlamps* (Report No. UMTRI-2002-3). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

21. Sivak, M., Flannagan, M.J., Schoettle, B., & Nakata, Y. (2002). *Performance of the first generation of HID headlamps in the U.S.* (Report No. UMTRI-2002-14). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

22. Sivak, M., Flannagan, M.J., Traube, E.C., Battle, D.S., & Sato, T. (1994). Evaluations of in-traffic performance of high-intensity discharge headlamps. *Lighting Research and Technology*, *26*, 181-188.

23. Sivak, M., Simmons, C.J., & Flannagan, M.J. (1990). Effect of headlamp area on discomfort glare. *Lighting Research and Technology*, *22*, 49-52.

24. Sivak, M., Simmons, C.J., & Flannagan, M.J. (1991). Colours of retroreflective sign materials when illuminated by high-intensity-discharge headlamps. *International Journal of Vehicle Design*, *12*, 284-295.

25. Sullivan, J. M., & Flannagan, M. J. (2001). *Characteristics of pedestrian risk in darkness* (Report No. UMTRI-2001-33). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

CONTACT

Michael Sivak, Ph.D.
The University of Michigan
Transportation Research Institute
2901 Baxter Road
Ann Arbor, MI 48109-2150, U.S.A.
e-mail: sivak@umich.edu