UMTRI-2007-46 NOVEMBER 2007

BENEFITS OF HEADLAMP LEVELING AND CLEANING FOR CURRENT U.S. LOW BEAMS

MICHAEL J. FLANNAGAN
MICHAEL SIVAK
BRANDON SCHOETTLE

UMTRI
UNIVERSITY OF MICHIGAN
TRANSPORTATION RESEARCH INSTITUTE

BENEFITS OF HEADLAMP LEVELING AND CLEANING FOR CURRENT U.S. LOW BEAMS

Michael J. Flannagan
Michael Sivak
Brandon Schoettle

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

Report No. UMTRI-2007-46
November 2007

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-2007-46		

4. Title and Subtitle	5. Report Date
Benefits of Headlamp Leveling and Cleaning for Current U.S. Low Beams	November 2007
	6. Performing Organization Code 302753
7. Author(s) Flannagan, M.J., Sivak, M., and Schoettle, B.	8. Performing Organization Report No. UMTRI-2007-46
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A.	10. Work Unit no. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

The Affiliation Program currently includes Alps Automotive/Alpine Electronics, Autoliv, Bendix, BMW, Bosch, Chrysler, Com-Corp Industries, Decoma Autosystems, Denso, Federal-Mogul, Ford, GE, General Motors, Gentex, Grote Industries, Hella, Honda, Ichikoh Industries, Koito Manufacturing, Lang-Mekra North America, Magna Donnelly, Muth, Nissan, North American Lighting, Northrop Grumman, OSRAM Sylvania, Philips Lighting, Renault, SABIC Innovative Plastics, Siemens VDO Automotive, Sisecam, SL Corporation, Stanley Electric, Toyota Technical Center USA, Truck-Lite, Valeo, Visteon/ACH, and 3M Personal Safety Products. Information about the Affiliation Program is available at: http://www.umich.edu/~industry/

16. Abstract

The goal of this study was to examine whether the recent changes in the sharpness of the vertical gradient in U.S. low beams have changed the importance of headlamp leveling and cleaning systems. The study consisted of three parts. In the first part, we collected new data on dynamic distributions of pitch angles for a passenger car, a minivan, and an SUV in actual traffic. In the second part, we applied the new dynamic pitch data (combined with recent static pitch data) to representative low-beam patterns to estimate the changes in the benefits of leveling systems. These estimates were made for a comprehensive combination of static and dynamic sources of misaim; additional analyses would be necessary to determine the relative benefits of leveling systems that address selected sources of misaim. Three sets of photometric data were used in the analysis: market-weighted 1997 and 2004 tungsten-halogen beam patterns, and a representative 2004 HID beam pattern. In the third part, we applied a previously derived model for the effects of dirt on the three beam patterns to estimate the changes in the benefits of cleaning systems. In both sets of analyses, the effects on both visibility and glare were considered. The results indicate that (1) the importance of headlamp leveling systems for U.S. low beams has recently increased substantially for tungsten-halogen and especially HID lamps, and (2) the importance of headlamp cleaning systems has stayed approximately the same.

17. Key Words	18. Distribution Statement
headlamps, low beams, leveling, cleaning, visibility, glare	Unlimited

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
None	None	18	

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:

Alps Automotive/Alpine Electronics
Autoliv
Bendix
BMW
Bosch
Chrysler
Com-Corp Industries
Decoma Autosystems
Denso
Federal-Mogul
Ford
GE
General Motors
Gentex
Grote Industries
Hella
Honda
Ichikoh Industries
Koito Manufacturing
Lang-Mekra North America
Magna Donnelly
Muth
Nissan
North American Lighting
Northrop Grumman
OSRAM Sylvania
Philips Lighting
Renault
SABIC Innovative Plastics
Siemens VDO Automotive
Sisecam
SL Corporation
Stanley Electric
Toyota Technical Center, USA
Truck-Lite
Valeo
Visteon/ACH
3M Personal Safety Products

Contents

Introduction

Leveling and cleaning systems for headlamps are common in Europe. Indeed, the Economic Commission for Europe (ECE) regulations require manual leveling systems for all headlamps; automatic leveling systems and cleaning systems are required for low beam headlamps with lights sources that produce at least 2,000 lumens (ECE, 2006). (See Dorleans (1992) and Bahnmüller (1997) for overviews of leveling and cleaning systems, respectively.) The primary rationale for the use of headlamp leveling systems in Europe has been the desire to control the increase in glare that occurs with headlamps aimed too high. Analogously, although lens dirt has negative effects not only on glare (because of light scattering) but also on visibility (because of light filtering), it is the glare control aspect that is often emphasized with headlamp cleaning systems.

In contrast to the situation in Europe, leveling and cleaning systems are not required in the U.S. There are two main reasons for this state of affairs. First, the U.S. regulations, in contrast to the ECE regulations, traditionally emphasized visibility; glare control was secondary. Second, the traditional U.S. low-beam patterns, produced by sealed beams, had a relatively soft cut-off (vertical gradient). Thus, vertical misaim with such headlamps had less severe consequences than with ECE headlamps that have sharper gradients.

However, low-beam headlighting in the U.S. has recently undergone major changes. First, there was the introduction in the late 1990s of visual/optical aiming. Second, there has been an increased usage of projector lamps. Third, HID headlamps have appeared on vehicles. All three of these factors contributed to sharper vertical gradients (Sivak, Schoettle, & Flannagan, 2004). Consequently, the present study was designed to quantify how the benefits of leveling and cleaning systems have changed recently for U.S. low beams.

This study consisted of three parts. In the first part, we collected new data on dynamic distributions of pitch angles for a passenger car, a minivan, and an SUV in actual traffic. In the second part, we applied the new dynamic pitch data (combined with recent static pitch data) to market-weighted 1997 and 2004 tungsten-halogen low-beam patterns and a representative 2004 HID low-beam pattern. This was performed to estimate the changes in the benefits of leveling systems for both visibility and glare. In the third part, we applied a previously derived model for the effects of dirt on the three beam patterns to estimate the changes in the benefits of cleaning systems.

In-traffic vehicle pitch

Background

In a recent study, we comprehensively analyzed the effects of the 10 most important factors on the performance of low-beam headlamps (Sivak, Flannagan, & Miyokawa, 1998). Based on the results of this analysis, we concluded that vertical aim is overwhelmingly the most important factor.

There are two broad sources of vertical misaim: static and dynamic. Static sources have their influence even when a vehicle is not moving. They include, for example, incorrect initial aim, damage, and vehicle load (occupants, cargo, and fuel). The most recent survey of the static aim of U.S. vehicles in use found that the standard deviation of vertical aim was 0.65° (Copenhaver & Jones, 1992). (Previous U.S. studies of Olson and Winkler (1985) and Hull et al. (1972) obtained standard deviations of 0.9° and 0.8°, respectively.)

Dynamic sources of vertical misaim occur while moving. They include, for example, acceleration/deceleration, aerodynamics, and road irregularities. As shown by Ishikawa and Kobayashi (1993) and Huhn (1999), acceleration tends to produce greater effects (1.0° and 1.23°, respectively) than deceleration (-0.7° and -0.63°, respectively). (The *g* levels were not specified in these two studies.) Speed has a more moderate effect. For example, Olson and Winkler (1985) found that the effect at 88 km/h was 0.08°.

In this part of the study, we measured dynamic effects on headlamp aim (by monitoring vehicle pitch) for three vehicles types: sedan, minivan, and SUV. The dynamic influences involved were typical accelerations/decelerations, speed, and road irregularities encountered during test drives on a route over public roads in Ann Arbor, Michigan. Dynamic effects were measured under two levels of a static influence: vehicle load (minimum or full).

Method

Loads. Two load conditions were tested: minimum load (only a 150-pound [68-kg] driver), and full load. For each vehicle, the full load was enough to bring it to approximately its gross vehicle weight rating. The loads included the same driver as in the minimum condition, plus 150 pounds [68 kg] of bagged sand in each passenger position and 100 pounds [45 kg] of bagged sand in the trunk or rear cargo area. The number of passenger positions, in addition to the driver, were 4 four for the sedan and 6 each for the minivan and SUV.

Route. The same 24-km route was used for all runs. The route included rural, expressway, and residential sections. All runs were driven by the same driver.

Vehicles. Three vehicles were used: a sedan (1992 Honda Accord), a minivan (2002 Dodge Grand Caravan), and an SUV (2002 Ford Explorer).

Instrumentation. Vehicle pitch was measured throughout the test drives at 100 Hz by means of a pair of laser range finders mounted near the front and rear bumpers.

Results

Mean pitch by vehicle and load is presented in Figure 1. The main findings are as follows: (1) The differences in mean pitch by vehicle class are not major, and (2) the differences between the two load conditions across the three vehicle classes averaged 0.83°. The corresponding standard deviations are shown in Figure 2. The main finding is that standard deviation of pitch does not vary substantially with vehicle class or load.

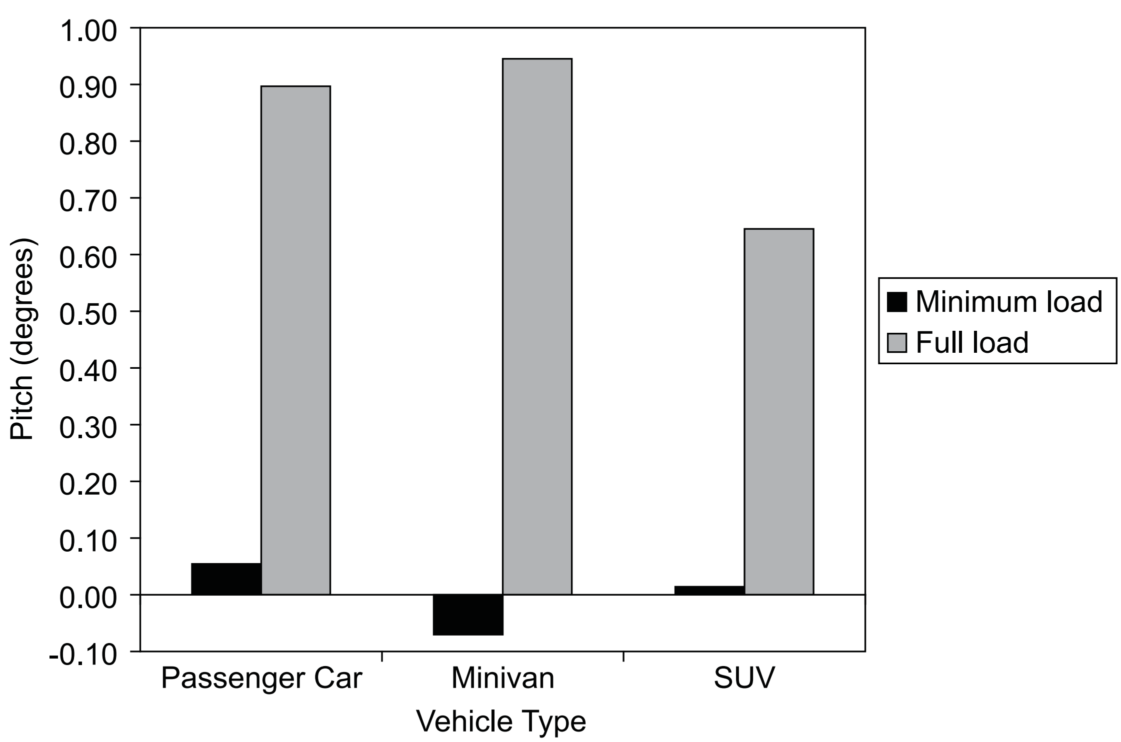

Figure 1. Mean pitch by vehicle and load.

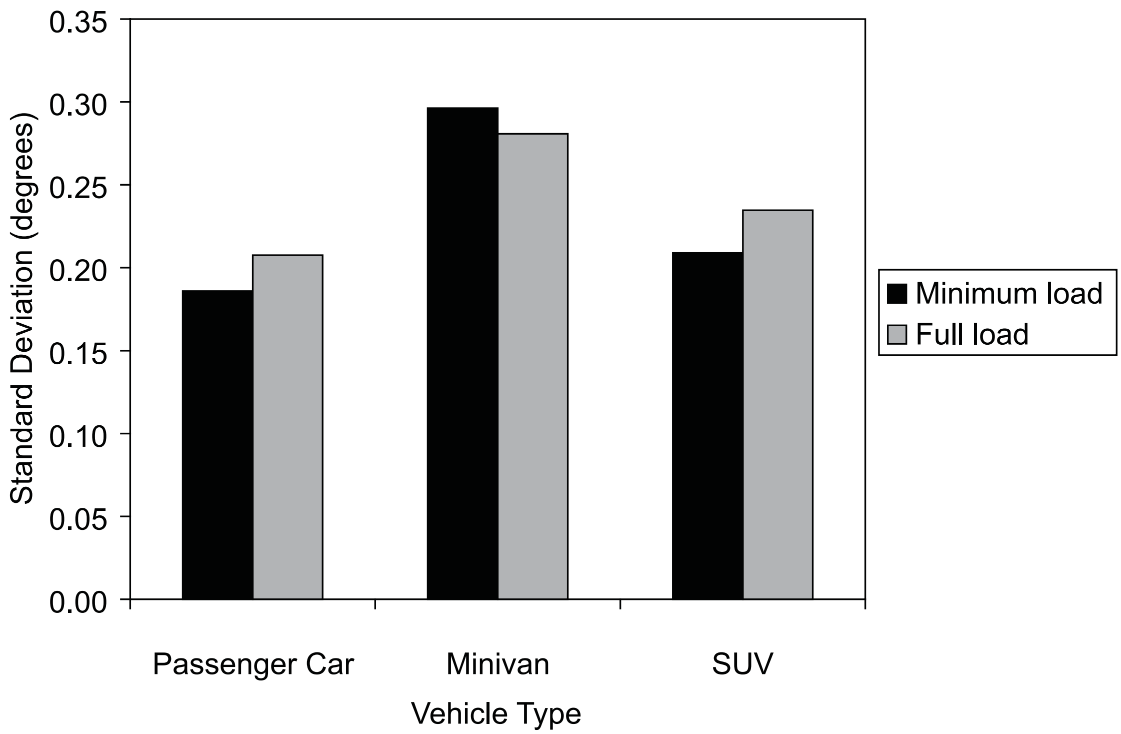

Figure 2. Standards deviation of pitch by vehicle and load.

Figure 3 presents vehicle pitch as a function of speed for one of the six conditions tested (SUV, minimum load). As is evident from Figure 3, the variability of pitch tended to be greater at speeds of less than about 50 km/h than at higher speeds. (The pattern of results was similar for the other five conditions.) Figure 4 presents standard deviation of pitch by speed (averaged across the six conditions).

The effect of load on mean pitch was similar for all three vehicles. The mean change in pitch from the minimum load to full load was +0.83°. However, given that the average vehicle occupancy for passenger cars in the U.S. is only 1.57 persons (Bureau of Transportation Statistics, 2007), it is not surprising that a recent, large study of 768 vehicles (Copenhaver & Jones, 1992) found the mean static headlamp aim to be very close to 0 (+0.04°) when vehicles in normal use were sampled and measured with their loads of occupants, cargo, and fuel in place.

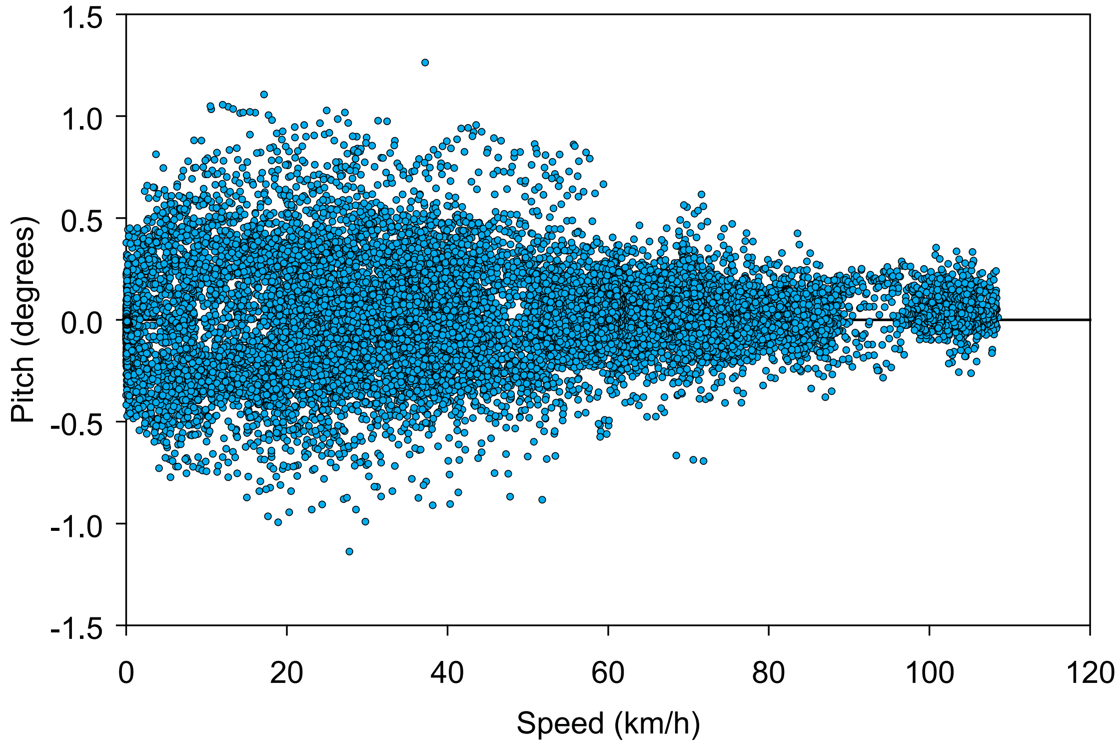

Figure 3. Pitch as a function of speed.

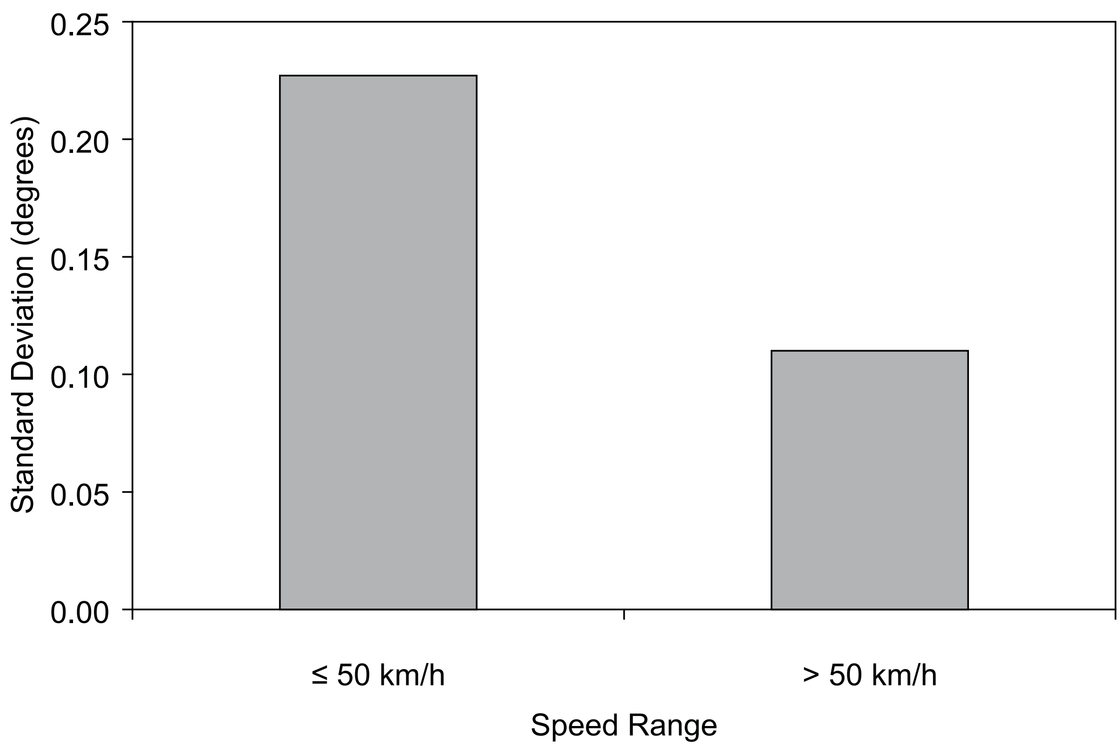

Figure 4. Standard deviation of pitch by speed.

Benefits of headlamp leveling

Approach

To estimate the benefits of leveling systems, we calculated the amount of light directed toward representative visibility and glare test points when the lamps were correctly aimed and when they were misaimed at two standard deviations of vertical aim.

Standard deviation of vertical aim

To estimate the combined static and dynamic standard deviation of pitch, we used the static standard deviation obtained by Copenhaver and Jones (1992) for a wide variety of vehicles and loads (0.65°), and the dynamic standard deviation for speeds of 50 km/h or less from the preceding section of this report (0.23°). The combined standard deviation (0.69°, rounded to 0.7°) was derived by taking the square root of the sum of the squares of each standard deviation. This way of combining the standard deviations assumes that the static and dynamic effects are independent random variables, as is probably appropriate for estimating the overall level of misaim for a large population of vehicles. For example, the combined standard deviation of vertical aim as estimated here would probably characterize the distribution of aims one would experience in a large number of encounters with oncoming vehicles in the course of a night drive.

Headlamp samples

The 1997 tungsten-halogen sample. A total of 23 lamps, manufactured for use on the 23 best-selling 1997 model year light vehicles, were in this sample (Sivak, Flannagan, Kojima, & Traube, 1997). The 23 vehicles constituted 45% of all vehicles sold during that year. None of the lamps was visually/optically aimable.

The 2004 tungsten-halogen sample. A total of 20 lamps, manufactured for use on the 20 best-selling 2004 model year light vehicles were in this sample (Schoettle, Sivak, Flannagan, & Kosmatka, 2004). The 20 vehicles constituted 39% of all vehicles sold during that year. Most of the lamps (91%) were visually/optically aimable.

The 2004 HID sample. This sample consisted of 5 lamps for the 5 best-selling vehicle models that offered HID low beams in that model year either as standard or optional equipment (Sivak, Schoettle, & Flannagan, 2004). All of the lamps were visually/optically aimable.

Test points

We used two standard test points for our analysis (FMVSS, 2006): a visibility test point on the right side (0.6° down, 1.3° right), and a glare test point on the left side (0.5° up, 1.5° left). In each case, we used a reasonably worst case scenario of misaim: For the visibility test point, we applied the misaim that corresponded to two standard deviations of pitch down, while for the glare test point the misaim corresponded to two standard deviations of pitch up. The median (50^{th} percentile) luminous intensities were used in the analyses.

Results

Table 1 shows the consequences of misaiming the lamps two standard deviations of vehicle pitch down on luminous intensities at 0.6° down, 1.5° right. The results indicate that (1) for the tungsten-halogen lamps, the misaim resulted in a larger reduction for the 2004 low beams (93%) than for the 1997 low beams (91%), and (2) for the 2004 lamps, the misaim resulted in a larger reductions for the HID low beams (97%) than for the tungsten-halogen low beams (93%).

Table 1
Median luminous intensity directed toward 0.6° down, 1.3° right (a visibility test point) from 1997 and 2004 U.S. low beams when aimed nominally and when misaimed two standard deviations of vehicle pitch down.

Lamps	Aim		Change
	Nominal	1.4° down	
1997 T-H	15,976 cd	1,413 cd	-91%
2004 T-H	19,365 cd	1,337 cd	-93%
2004 HID	28,090 cd	944 cd	-97%

Table 2 shows the consequences of misaiming the lamps two standard deviations of vehicle pitch up on luminous intensities at 0.5° up, 1.5° left. The results indicate that (1) for the tungsten-halogen lamps, the misaim resulted in a larger increase in luminous intensities for the 2004 low beams (952%) than for the 1997 low-beams (518%), and (2) for the 2004 lamps, the misaim resulted in a larger increase in luminous intensities for the HID low beams (2,433%) than for the tungsten-halogen low-beams (952%).

Table 2
Median luminous intensity directed toward 0.5° up, 1.5° left (a glare test point) from 1997 and 2004 U.S. low beams when aimed nominally and when misaimed two standard deviations of vehicle pitch up.

Lamps	Aim		Change
	Nominal	1.4° up	
1997 T-H	911 cd	5,628 cd	+518%
2004 T-H	932 cd	9,808 cd	+952%
2004 HID	700 cd	17,733 cd	+2,433%

A comparison of the data in Tables 1 and 2 highlights the magnitude of the misaim problem. Specifically, the luminous intensity directed toward the glare test point when the low beams are misaimed by two standard deviations up is *greater* than the luminous intensity directed toward the visibility point tested when the low beams are misaimed by two standard deviations down. While this effect was present for all three sets of lamps tested, the magnitude of the effect was greatest for the 2004 HID lamps, followed by the 2004 tungsten-halogen lamps, and the 1997 tungsten-halogen lamps.

Benefits of headlamp cleaning

Background

In a recent study, we evaluated changes in the light output of low-beam headlamps as a function of dirt accumulated during a 482-km route, representing a 10-day period of driving for a typical U.S. driver (Sivak, Flannagan, Traube, Kojima, & Aoki, 1996). The route was traversed on three separate occasions, under each of the following environmental conditions: summer while dry, summer while wet, and winter with road salt. The relationship between the luminous intensities for dirty and clean headlamps proved to be well described by linear models. The fact that linear models provide good approximation implies that the effect of dirt can be modeled by two parameters: a slope (quantifying the degree of proportional reduction in the luminous intensity throughout the beam pattern), and an intercept (quantifying the amount of superimposed uniform intensity throughout the beam pattern). The linear model for the most severe condition (winter with road salt) is presented in Equation 1.

$$\text{luminous intensity}_{\text{dirty}} = 0.72 \text{ x luminous intensity}_{\text{clean}} + 112 \qquad (1)$$

The slope of Equation 1 is primarily dependent on the amount of the deposited dirt, while the intercept is governed primarily by the total light output. Consequently, Equation 1, based on the data from tungsten-halogen lamps, needs to be modified for use with HID lamps by adjusting the intercept for the increased light output. To do so, we calculated the ratio between the estimated total light outputs of the median 2004 HID lamps in our sample and the tungsten-halogen lamp used by Sivak et al. (1996). This ratio turned out to be 1.33. (In both cases, we estimated the total light output by calculating the sum of the luminous intensities in the central area—20° left to 20° right, 5° up to 5° down.) Consequently, we multiplied the intercept in Equation 1 by 1.33 to obtain an intercept applicable to HID lamps. The result of those calculations is Equation 2.

$$\text{luminous intensity}_{\text{dirty}} = 0.72 \text{ x luminous intensity}_{\text{clean}} + 149 \qquad (2)$$

Approach

To estimate the benefits of cleaning systems on visibility and glare, we applied Equation 1 (for the tungsten-halogen lamps) and Equation 2 (for the HID lamps) to the luminous intensities in Tables 1 and 2, and then compared the "dirty" to "clean" values.

Results

The results are shown in Tables 3 and 4. The main finding is that the percentage differences between the dirty and clean luminous intensities were similar for the low beams in the three samples.

Table 3
Effects of dirt on the median luminous intensity directed toward 0.6° down, 1.3° right (a visibility test point) from 1997 and 2004 U.S. low beams when aimed nominally and when misaimed two standard deviations of vehicle pitch down.

Lamps	Aim					
	Nominal			1.4° down		
	Clean	Dirty	Change	Clean	Dirty	Change
1997 T-H	15,976 cd	11,615 cd	-27%	1,413 cd	1,130 cd	-20%
2004 T-H	19,365 cd	14,055 cd	-27%	1,337 cd	1,075 cd	-20%
2004 HID	28,090 cd	20,374 cd	-27%	944 cd	829 cd	-12%

Table 4
Effects of dirt on the median luminous intensity directed toward 0.5° up, 1.5° left (a glare test point) from 1997 and 2004 U.S. low beams when aimed nominally and when misaimed two standard deviations of vehicle pitch up.

Lamps	Aim					
	Nominal			1.4° up		
	Clean	Dirty	Change	Clean	Dirty	Change
1997 T-H	911 cd	768 cd	-16%	5,628 cd	4,164 cd	-26%
2004 T-H	932 cd	783 cd	-16%	9,808 cd	7,174 cd	-27%
2004 HID	700 cd	653 cd	-7%	17,733 cd	12,917 cd	-27%

Both test points had *decreases* in luminous intensity with dirt. Given Equation 1, only the points of tungsten-halogen low beams that have the clean luminous intensity of less than 400 cd would have *increases* with dirt. (At 400 cd, the proportional decrease due to the slope of 0.72 is the same as the uniform increase due to the constant of 112.) The analogous tipping point for HID low beams, based on Equation 2, is 539 cd.

Conclusions

The goal of this study was to examine whether the recent changes in the sharpness of the vertical gradient in U.S. low beams have changed the importance of headlamp leveling and cleaning systems.

The study consisted of three parts. In the first part, we collected new data on dynamic distributions of pitch angles for a passenger car, a minivan, and an SUV in actual traffic. In the second part, we applied the new dynamic pitch data (combined with recent static pitch data) to representative low-beam patterns to estimate the changes in the benefits of leveling systems. These estimates were made for a comprehensive combination of static and dynamic sources of misaim; additional analyses would be necessary to determine the relative benefits of leveling systems that address selected sources of misaim. Three sets of photometric data were used in the analysis: market-weighted 1997 and 2004 tungsten-halogen beam patterns, and a representative 2004 HID beam pattern. In the third part, we applied a previously derived model for the effects of dirt on the three beam patterns to estimate the changes in the benefits of cleaning systems. In both sets of analyses, the effects on both visibility and glare were considered.

The results indicate that (1) the importance of headlamp leveling systems for U.S. low beams has recently increased substantially for tungsten-halogen and especially HID lamps, and (2) the importance of headlamp cleaning systems has stayed approximately the same.

References

Bahnmüller, G. (1997). Progress in development of headlamp cleaning systems. In, *Proceedings of the Conference on Progress in Automotive Lighting* (pp. 43-48). Darmstadt, Germany: Technical University of Darmstadt.

Bureau of Transportation Statistics (2007). *National transportation statistics 2007*. Washington, D.C.: U.S. Department of Transportation.

Copenhaver, M.M. and Jones, E. (1992). *Measurement of headlamp aim and the electrical and photometric performance characteristics of rear lighting systems* (Report No. DOT HS 807 930). Washington, D.C.: National Highway Traffic Safety Administration.

Dorleans, G. (1992). *Headlamp levelling devices* (SAE Technical Paper Series No. 932000). Warrendale, PA: Society of Automotive Engineers.

ECE [Economic Commission for Europe]. (2006). *Uniform provisions concerning the approval of vehicles with regard to the installation of lighting and light-signaling devices* (Regulation No. 48). Geneva: United Nations.

FMVSS [Federal Motor Vehicle Safety Standards] (2006). Standard No. 108: Lamps, reflective devices, and associated equipment. In, *Code of Federal Regulations, Title 49*. Washington, D.C.: Office of the Federal Register.

Huhn, W. (1999). Influence of dynamic car parameters on lighting. In, *Proceedings of the Conference on Progress in Automotive Lighting* (pp. 412-419). Darmstadt, Germany: Technical University of Darmstadt.

Hull, R.W., Hemion, R.H., and Cadena, D.G. (1972). *Guidelines for improving the stability of headlamp aim* (Report No. DOT HS 800 739). Washington, D.C.: National Highway Traffic Safety Administration.

Ishikawa, M. and Kobayashi, S. (1993). *Auto-levelling projector headlamp system with rotatable light shield* (SAE Technical Paper Series No. 930726). Warrendale, PA: Society of Automotive Engineers.

Olson, P.L. and Winkler, C.B. (1985). *Measurement of crash avoidance characteristics of vehicles in use* (Technical Report No. UMTRI-85-20). Ann Arbor: The University of Michigan Transportation Research Institute.

Schoettle, B., Sivak, M., Flannagan, M.J., & Kosmatka, W.J. (2004). *A market-weighted description of low-beam headlighting patterns in the U.S.: 2004* (Technical Report No. UMTRI-2004-23). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M., Flannagan, M.J., Kojima, S., and Traube, E.C. (1997). *A market-weighted description of low-beam headlighting patterns in the U.S.* (Technical Report No. UMTRI-97-37). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M., Flannagan, M.J., and Miyokawa, T. (1998). *Quantitative comparisons of factors influencing the performance of low-beam headlamps* (Technical Report No. UMTRI-98-42). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M., Flannagan, M.J., Traube, E.C., Kojima, S., and Aoki, M. (1996). *Effects of realistic levels of dirt on light distribution of low-beam headlamps* (Technical Report No. UMTRI-96-10). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M., Schoettle, B., and Flannagan, M.J. (2004). *Recent trends in the performance of tungsten-halogen and HID low beams in the U.S.* (Technical Report No. UMTRI-2004-25). Ann Arbor: The University of Michigan Transportation Research Institute.