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16. Abstract

This study evaluated changes in the light output of rear signal lamps as a function of dirt accumulated during a 482-km drive, representing a 10-day amount of driving for a typical U.S. driver. The complete route was traversed on three separate occasions, under each of the following environmental conditions: dry, wet, and snowy/salty. Luminous intensity measurements were obtained for all U.S. and European test points. Photometry for each of two stop lamps was performed twice after the completion of each drive: first "as is" and then after cleaning.

The results indicate that dirt deposits tended to cause the light output to decrease at the points tested. The reductions in the light output were greater for the driver-side than the passenger-side lamps under the wet and snowy/salty conditions, but smaller under the dry condition. The reductions after the dry drive were all less than 8%. However, after the wet and snowy/salty drives reductions of more than 25% occurred at several test points, with a maximum reduction of 37%. The greatest percentage reductions occurred for the points at and near the optical axes of the lamps, which had the highest original intensities, and at which maintaining adequate intensity is presumably most important. A theoretical analysis of the changes caused by dirt indicates that this is the pattern of results that will usually occur.

A full evaluation of the significance of the effects of dirt that are quantified in this report should be done in the context of other factors that affect signal-lamp intensity, such as vehicle voltage control and lamp design. It may also be important to measure more fully the range and distributions of dirt conditions in the real world. However, the present results demonstrate that, within the range of common weather conditions, dirt can cause reductions of signal-lamp intensity that are large enough to be of concern, especially for the relatively important positions at and near the optical axes of signal lamps.

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Contents

Introduction

Dirt deposits on lenses of vehicle lamps have two major effects: a reduction in the total amount of transmitted light, and an increase in scattered light. For headlamps, the net effect of these two processes is that, for those parts of the beam pattern where most of the light is directed (generally below horizontal), there is a reduction in light, while for those parts where, by design, light is kept to a minimum (generally above horizontal), there is an increase in light (e.g., Sivak, Flannagan, Traube, Kojima, and Aoki, 1996). In contrast, rear signal lamps are not designed to minimize light output in any particular direction. Consequently, it is not clear whether dirt on rear signal lamps will lead to a mixture of increases and decreases in light output, or only to decreases. We are not aware of any published data on the effects of dirt on light output of rear signal lamps.

This study evaluated changes in the light output of stop lamps as a function of dirt accumulated during a 482-km route, representing a 10-day amount of driving for a typical U.S. driver. The complete route was traversed on three separate occasions, under each of the following conditions: dry, wet, and snowy with road salt. Photometry for each of two stop lamps was performed twice after the completion of each drive, first “as is” and then after cleaning. Photometric information was obtained for all current U.S. and European test points.

Although only stop lamps were measured, it is reasonable to assume that the results would be applicable to all standard (low-mounted) rear signal lamps, including those that signal presence/tail, turn, and backup. On the other hand, the results might not be applicable to high-mounted stop lamps, because their greater mounting height (and frequent location behind the rear window) might result in less accumulation of dirt.

Method

Test vehicle and lamps

A midsize car was used in this study. The car was equipped with its original rear lamps. On each side of the vehicle there were two laterally adjacent stop/tail lamps, a turn signal lamp, and a backup lamp.

The photometry was performed on the outboard-mounted stop/tail lamp on each side. The lamps had a red outer lens and a clear inner lens with a replaceable two-filament bulb (No. 2057) and a parabolic reflector. During the photometry the stop filament was energized at 12.8 V. The effective illuminated area (the lens size) was 165 mm wide by 85 mm high, with a 850 mm center-to-ground distance. Center-to-center lateral separation between the two lamps was 1360 mm.

Test route

The test route was the same as the one used in our previous study on the effects of dirt on the light distribution of low-beam headlamps (Sivak et al., 1996). The route was approximately 482-km long. It included roads in the southern and central portions of the lower peninsula of the state of Michigan. The surface of the route was asphalt (67%), concrete (30%), and unpaved (3%). In terms of the road type, the route included rural two-lane roads (53%), limited-access multi-lane highways (39%), and city streets (8%).

Test conditions

The test route was driven three times, each time during daylight hours on a work day. The first drive took place on March 6, 1997 on a snowy and cold day. Snow had fallen on the entire route within the previous 24 hours. During 37% of the route, active snow was falling. Most of the route was heavily salted. Approximately 73% of the route involved snowy or wet pavement (presumably with salt), 11% was “damp and salty,” and 16% was “dry and salty.” The level of salt on the roads varied, but it was visible on the road surface for all dry sections of the route.

The second drive took place on April 23, 1997 on a generally sunny and cool day. No precipitation occurred during the drive, and the pavement was dry throughout.

The third and final drive took place on May 8, 1997 on a rainy and cool day. There was active precipitation on 86% of the route, with an additional 4% of the route having wet roads but no active precipitation.

Test equipment

The measurements were made in a photometry lab, using a goniometer. The distance from the lamp to the measuring screen was 30 m.

Procedure

Changes in weather and road condition were recorded during the test drives. Because the temperature of the lens is likely to influence the nature of dirt deposits, the lamps were switched on and off using the following schedule repeated five times: 64 km on, 32 km off. The lamps were switched on so that the lenses would be at a relatively high temperature characteristic of those times, during nighttime and low-visibility driving, when the headlamps (and thus also the rear lamps) are normally switched on.

The lamps were cleaned at the beginning of each drive. At the end of the test route, the lamps were removed from the vehicle. After they had been measured in the "dirty" condition, they were cleaned and measured a second time.

Prior to photometry, the lamps were placed in stands built specifically for the style, shape, and model used in the study, and attached to the goniometer platform. Lamps were measured at all 19 U.S. and European test points. Both measurements (dirty and clean) of one lamp were taken before the other lamp was measured.

Evaluation of the effects of the changes in light output

A decrease in the light output will result in a decrease in the effectiveness of rear signal lamps, especially under difficult environmental conditions such as bright sunlight or the presence of competing visual stimuli (e.g., Mortimer, Moore, Jorgeson, and Thomas, 1973; Schmidt-Clausen, 1986; Sivak, Flannagan, Olson, Bender, and Conn, 1986; MIRA, 1988; Sayer, Flannagan, and Sivak, 1995). The magnitude of the effect will depend on a variety of factors, such as the measure of interest (e.g., reaction time, proportion of missed signals, or conspicuity), ambient illumination, luminous intensities of the other rear lamps, etc. For example, the study by MIRA (1988) evaluated the effects of intensity of stop lamps on the detectability of stop signals. The stop lamps in the condition of interest were presented with presence lamps set at 7 cd. During a daytime condition, a change in the luminous intensity of stop lamps from 66 cd to 32 cd (about a 50% reduction) resulted in an increase in reaction time from 1.04 s to 1.51 s, and an increase in the percentage of missed signals from 7.5% to 23.8%. On the other hand, during a nighttime condition, the same change in luminous intensity produced no effects on either reaction time or missed signals.

To evaluate the practical importance of light output, a nonzero criterion has to be established. For this study we selected a change of 25% as such a criterion. This selection was based on a finding by Huey, Dekker, and Lyons (1994) that subjects required signal lamp intensity to differ by 25% to be noticeably different.

Results and Discussion

Luminous intensities with clean lenses

The luminous intensities at the 19 test points after the lenses were cleaned (for each of the two lamps following each of the three test drives) ranged from 14.4 cd to 67.9 cd. As indicated above, all measurements were made for the outboard of the two stop lamps on each side of the vehicle. Assuming that the inboard stop lamps (which were not measured) would provide the same output as the outboard lamps, the cleaned stop lamps on the test vehicle (after each drive) met the U.S. regulations (Office of the Federal Register, 1996) for two-compartment stop lamps.

Comparison of luminous intensities with clean and dirty lenses

The means and ranges of the differences in luminous intensities after each of the three drives are shown in Table 1 for each lamp. The actual differences at each test point are listed in Table 2. As is evident from the information in Tables 1 and 2, the differences after the dry drive were negligible. On the other hand, the differences after the wet and snowy/salty drives were substantial, exceeding 25% at several of the test points, with a maximum reduction of 37%. All of the differences after the latter two drives were reductions in output.

Table 1
Means and ranges of the percentage differences in luminous intensities between "clean" and "dirty" measurements after each drive. The calculations involved subtracting the (generally higher) "clean" luminous intensities from the corresponding (generally lower) "dirty" luminous intensities.

Drive	Left lamp		Right lamp	
	Mean	Range	Mean	Range
Dry	0	-1, +1	-5	-7, -3
Wet	-26	-33, -14	-17	-22, -10
Snowy/salty	-30	-37, -14	-26	-35, -13

Table 2
Percentage differences in luminous intensities between "clean" and "dirty" at each test point. In each cell, the first entry is for the left lamp, and the second entry is for the right lamp. Entries in bold indicate changes of at least 25%.

Dry

	20L	10L	5L	V	5R	10R	20R
10U			+1/-4		+1/-5		
5U	+1/-7	0/-7		+1/-7		0/-6	0/-4
H		0/-6	0/-4	0/-6	0/-5	0/-5	
5D	0/-6	0/-6		-1/-5		0/-5	-1/-4
10D			0/-3		0/-4		

Wet

	20L	10L	5L	V	5R	10R	20R
10U			-20/-13		-23/-11		
5U	-24/-13	**-28**/-19		**-30**/-19		**-31**/-18	-24/-14
H		**-30**/-22	**-31**/-19	**-33**/-21	-23/-20	**-33**/-21	
5D	-24/-14	**-26**/-21		**-29**/-22		**-27**/-20	-21/-17
10D			-15/-10		-14/-11		

Snowy/salty

	20L	10L	5L	V	5R	10R	20R
10U			**-25**/-18		**-25**/-17		
5U	**-30**/-23	**-33/-32**		**-35/-32**		**-34/-29**	-24/-22
H		**-36/-34**	**-36/-34**	**-37/-35**	**-37/-34**	**-36/-32**	
5D	**-28**/-21	**-32/-28**		**-33/-31**		**-32/-29**	-19/-23
10D			-16/-13		-14/-15		

The reductions in the light output were greater for the left lamp than for the right lamp both after the wet drive (mean reductions of 26% vs. 17%) and after the snowy/salty drive (30% vs. 26%). However, the pattern was reversed after the dry drive (0% vs. 5%). One speculative explanation for these results is as follows. When the roadway is wet (because of either rain or snow), spray from overtaking traffic (and to a lesser degree from oncoming traffic) results in more dirt deposits on left lamps than on right lamps. On the other hand, when the roadway is dry, there is probably more dirt on the right side of the lane of travel on a two-lane roadway (due to the crown of the road). (The directions of these effects would be reversed for left-hand traffic.)

"Clean" luminous intensity as a predictor of "dirty" luminous intensity

For each test drive and each lamp we regressed "dirty" luminous intensities on corresponding "clean" luminous intensities (cf., Sivak et al., 1996). The relationships between intensities of clean lamps and dirty lamps were well described by linear models (all r^2 values were greater than .98). The fact that linear models provide a good fit implies that the effects of dirt can be separated into two components that can be quantified by two parameters: a proportional reduction in the luminous intensity throughout the beam pattern (quantified by a slope) and additional light superimposed uniformly throughout the beam pattern (quantified by an intercept).

An example of a scatter plot of "dirty" versus "clean" luminous intensity for one lamp (left) and one environmental condition (snowy/salty) is shown in Figure 1, along with the best-fitting linear model. The slope of this equation (0.57 or 57%) is an estimate of the proportional reduction in luminous intensity throughout the beam pattern, presumably caused by both absorption and scattering. The intercept of this equation (4.0) is an estimate of the amount of a superimposed intensity (in cd) throughout the beam pattern, presumably caused by scattering. In other words, the regression equation suggests that after the snowy/salty drive for the left lamp the dirt deposits reduced luminous intensity at each test point to 57% of the original value, and that this reduction was partially offset by a superimposed uniform addition of 4.0 cd throughout the beam pattern.

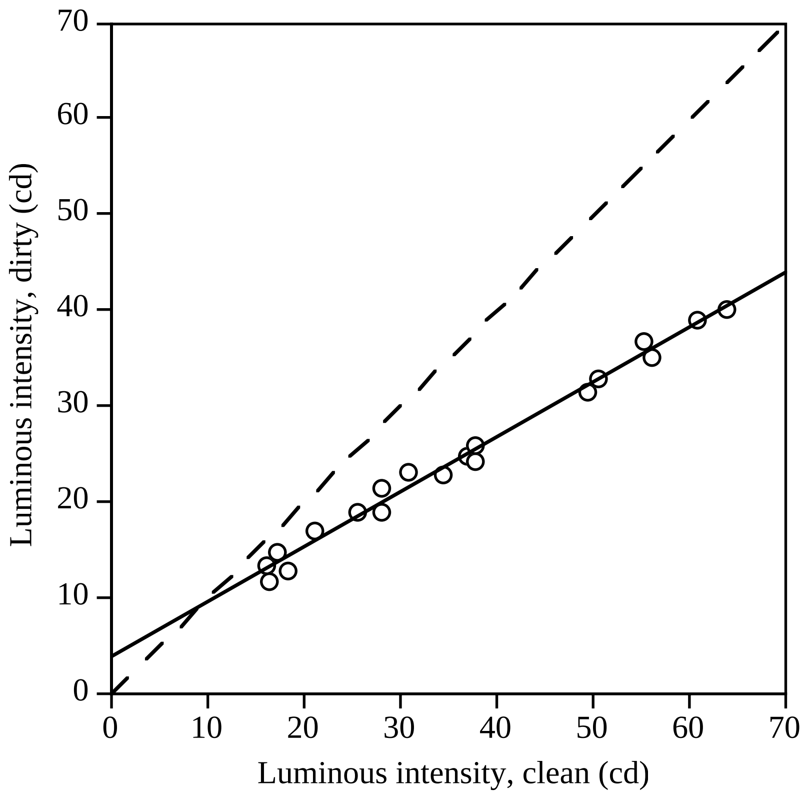

Figure 1. The relationship between the "clean" and "dirty" luminous intensities for the left lamp after the snowy/salty drive. The solid line is the best-fitting linear model ($y = 0.57x + 4.0$). For comparison, the dashed line shows where points would fall if luminous intensities were unaffected by dirt ($y = x$).

To the extent that linear models provide good descriptions of the relationships between "clean" and "dirty" luminous intensities, we can estimate which levels of intensity will increase because of dirt and which will decrease. Using the best-fitting linear equations, we calculated the *pivot* intensities. Luminous intensities of clean lamps that are smaller than the corresponding pivot intensity would be expected to increase due to dirt, because at these intensity levels the uniform intensity increase is greater than the proportional decrease. On the other hand, the luminous intensities that are greater than the pivot intensity would be expected to decrease, because at these intensity levels the uniform intensity increase is smaller than the proportional decrease. (Points with luminous intensities equal to pivot intensity should remain unchanged.) The specific calculation involved solving the regression equation ($y = ax + b$) for $y = x$. The pivot intensity for the example shown in Figure 1 (the left lamp after the snowy/salty drive) proved to be 9.4 cd.

Table 3 lists the parameters of the best-fitting linear equations and the corresponding pivot intensities for the two environmental conditions that showed substantial effects of dirt (i.e., the wet and snowy/salty drives).

One potentially interesting aspect of the existence of pivot points (evident graphically in Figure 1), is that, in terms of a percentage reduction, dirt will have the most effect on the brightest test points and the least effect on the dimmest test points. Using the example in Figure 1 (the left lamp after the snowy/salty drive), a point that is 60 cd when clean is predicted to lose 36%, while a point that is 20 cd when clean is predicted to lose 23%.

Table 3
The parameters of the best-fitting linear equations and the corresponding pivot intensities for the wet and snowy/salty drives.

Drive	Lamp	Slope	Intercept (cd)	Pivot intensity (cd)
Wet	Left	0.62	3.2	8.6
Wet	Right	0.76	1.9	7.7
Snowy/salty	Left	0.57	4.0	9.4
Snowy/salty	Right	0.60	4.1	10.2

Comparison of the effects of dirt on rear signal lamps and headlamps

Both the present study and our recent study on the effect of dirt on the light output of low-beam headlamps (Sivak et al., 1996) used the same route. Although the environmental conditions in the two studies were also the same nominally (dry, wet, and snowy/salty), there were some differences. The dry drive in the present study was done in the spring, whereas the dry drive in the headlighting study was done during the summer, with more insects present in the air. (Although, even if the number of insects had been equal for the two studies, they presumably would have had less effect on rear lamps than on front lamps.) Furthermore, the wet drive in the present study included a higher proportion of active rain and wet roadways. Finally, the snowy/salty drive in the present study was partly during active snowfall, whereas the snowy/salty drive in the headlighting study was performed a day after a snowfall. Although it is important to keep the environmental differences in mind, it is nevertheless instructive to compare the results of the two studies.

Decreases vs. increases in light output. For rear signal lamps, the only practically significant changes in light output were decreases. This is probably because the distribution of light from the signal lamps was more uniform than the distribution of light from the headlamps. As a consequence of the more uniform distribution, all of the measured "clean" luminous intensities for the signal lamps were greater than the corresponding pivot luminous intensities (for example, see Figure 1). In contrast, the effect of dirt on headlamps resulted in both decreases and increases, with increases generally confined to light above and near the horizontal.

Magnitudes of the decreases. After the dry drives, the decreases were greater for the headlamps than for the rear lamps. This is probably a consequence of the fact that the presence of insects in the air has a greater effect on the cleanliness of the headlamps than on the cleanliness of the rear lamps. (There were also more insects present during the headlighting drive.) After the wet drives, the decreases in the output of rear lamps were somewhat greater than those of the headlamps. Finally, after the snowy/salty drives, the magnitudes of the peak decreases were comparable.

Summary

This study evaluated changes in the light output of rear signal lamps as a function of dirt accumulated during a 482-km drive, representing a 10-day amount of driving for a typical U.S. driver. The complete route was traversed on three separate occasions, under each of the following environmental conditions: dry, wet, and snowy/salty. Luminous intensity measurements were obtained for all U.S. and European test points. Photometry for each of two stop lamps was performed twice after the completion of each drive: first "as is" and then after cleaning.

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A full evaluation of the significance of the effects of dirt that are quantified in this report should be done in the context of other factors that affect signal-lamp intensity, such as vehicle voltage control and lamp design. It may also be important to measure more fully the range and distributions of dirt conditions in the real world. However, the present results demonstrate that, within the range of common weather conditions, dirt can cause reductions of signal-lamp intensity that are large enough to be of concern, especially for the relatively important positions at and near the optical axes of signal lamps.

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