VEHICULAR LIGHTING SYSTEMS FOR TWO-LANE RURAL HIGHWAYS

G. E. Meese

In this attempt to express the state of the art, we will direct our attention primarily to headlighting and a condensed history of domestic progress to 1970 (Fig. 1).

Through World War I the development of the motor vehicle industry was much the same in Europe and Great Britain as it was in North America. However, since 1917, distinct differences in the political, social, economic, and geographic environments have led to very rapid expansion of the industry in the United States and Canada, while growth has been seriously retarded overseas (1, 2). Therefore, until very recently, the automobile has existed in a grossly different environment in the United States and Canada as compared with the rest of the world. Domestically, we have been experiencing serious vehicular traffic congestion in both urban and rural areas since the middle 1920s, whereas in Europe most citizens, until recently, have used other forms of transportation such as bicycles. This has resulted in a distinct difference in philosophy in the design of headlighting systems. Broadly, it might be stated that, because of the low vehicle population and the great preponderance of cycle and pedestrian traffic in Europe, great emphasis was placed on very low levels of headlight glare. Priority was given to the development of fixed overhead lighting, and in urban areas vehicles were prohibited by law from using headlights. Conversely, on the open highway at night, there was little or no traffic and, consequently, little restriction on the luminous intensity of the high beam. The result was a 2-beam system: a low-glare, low-visibility, low beam; and a high-candlepower, long-range high beam that could legally develop up to 300,000 candelas.

In the United States, because most street and highway traffic has consisted of automobiles, a greater tolerance developed for the brightness of headlights, and designers could therefore place more emphasis on providing better illumination for when cars meet. Good street lighting was not as extensive as in European cities, and, with our greater traffic density, vehicles drove in the cities with low beams lighted. Also, because nighttime suburban and rural traffic was relatively heavy, particularly on weekends near urban centers, there was a great need for good low beams. Conversely, this same traffic density caused a continuing public clamor against high output, clear-road beams, which would annoy oncoming drivers at great separation distances. As a result, when the original sealed-beam headlighting system became nationally standardized in 1939, the Uniform Vehicle Code (National Committee on Uniform Traffic Laws and Ordinances) established a limit of 75,000 candelas for the total high beam, and this has been enforced by the states ever since.

It is interesting to note that since the mid-1950s Europeans have experienced very rapid growth in motor vehicle sales and use, and increasingly they have been encountering many of the same types of lighting problems that were faced in this country years ago. They have recognized the need for better illumination when cars meet and have made some improvements in the design of their lower beams. Also, with the advent of the tungsten-halogen regenerative-cycle lamp bulbs, more cars are achieving total high-beam intensities approaching 200,000 candelas. This has caused growing concern about public annoyance created by these more powerful sources.

Figure 1. Automotive headlight history.

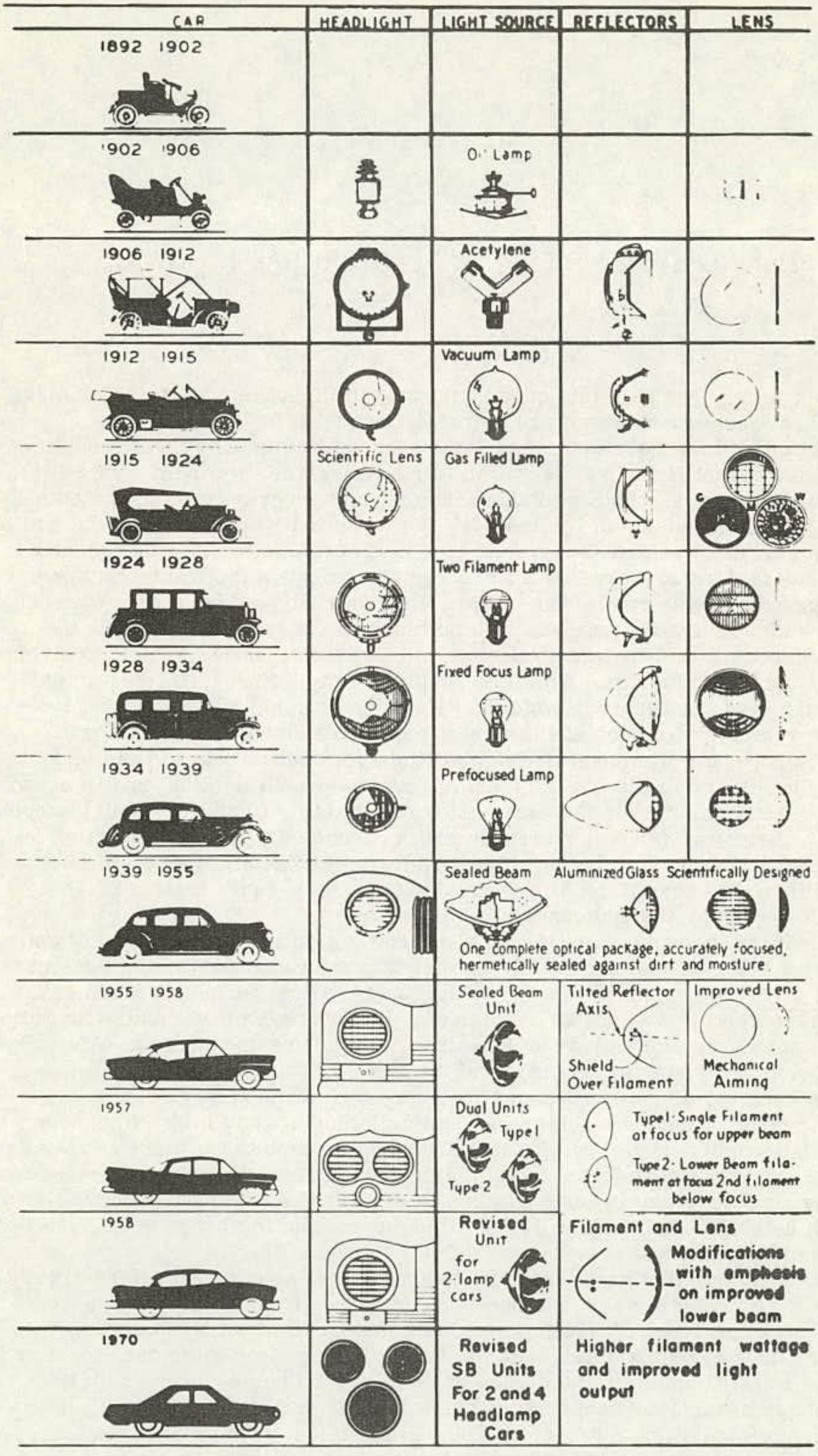


Figure 2 shows the lighting problem during the encounter of 2 vehicles on a straight, level, 2-lane highway (3, 4, 5). To obtain acceptable seeing distances in one's lane of travel, one must develop relatively high intensity just below the horizontal and just to the right of the oncoming driver. This would seem to suggest that the low-beam pattern has almost "knife-edge" cutoffs at the top of the beam to keep the eyes of the oncoming driver relative in darkness. Such a beam would, of course, be less than ideal for a clear road, where the highest intensity should be directed down the center of the road for distant seeing but with enough light in lateral and vertical spread to accommodate curves and hills.

In the United States, the light patterns for the upper and lower beams have been achieved with a parabolic reflector having 2 filaments in close relation to the focal point (Fig. 3). By its orientation, the upper filament can supply downwardly directed light for a low beam and the other light for a high beam. A frontal lens, having a complexity of elements for spreading and bending particular groups of light rays from the reflector, distributes the light to serve the needs of both beams. By using the full reflector for both beams, the greatest amount of light is gathered for each beam but at the sacrifice of a very sharp cutoff at the top of the low beam.

If sharpness of cutoff is the prime criterion, there are many possible optical approaches that can be used to achieve it. Foremost has been the Graves "anti-dazzle" system as used by European manufacturers (Fig. 4). It presents a reasonable compromise among adaptability to repetitive manufacturing techniques, system efficacy, and cost. This last item is very important in terms of overall public benefit. Gated elliptical systems as well as other more complex systems, usually involving objective lenses, can do a fine job of focusing a sharp cutoff pattern down the highway. As shown in Figure 5, these systems involve several optical elements that contribute to greater variances in manufacture, and costs become very high in terms of value received. These systems are generally in the 10 to 30 percent range of useful light output.

In the Graves "anti-dazzle" approach, the parabola of revolution would pick up from 55 to 65 percent of filament lumens, but to achieve the sharp cutoff for the low beam almost the entire lower half of the reflector is purposely blocked by the filament shield. This reduces the efficacy to the order of 35 percent or less. With our domestic sealed-beam designs, the reflectors pick up from 50 to 62 percent of the generated lumens, and almost all of this is directed into the beam. Because of simplicity, manufacturing cost is lower, and uniformity among lamps is considerably greater.

One of the most sophisticated attempts to solve the problem of providing abundant light ahead without bothering the oncoming driver is that advanced by Evan P. Bone in the late 1930s. This consists of a gated elliptical system somewhat like the one shown in Figure 5. In this case, the gate is replaced with a movable mask that can move laterally and be brought across the gate area. This causes a shadow to move across the beam from the left and, in fact, can block the entire beam if desired. A separate objective lens system and "photosensor" determine the presence of the headlights of an oncoming car and cause the mask to move in from the left just to the point where the oncoming car is in shadow. The remainder of the highly intense beam continues to light the highway ahead. As the oncoming car approaches the point of meeting, the mask slowly recedes to the left but always keeps that car in the shadow. Once past, the mask is dormant and the full beam shines ahead.

Advances in sensors and electronics have improved, and the "Auto Sensa" has become the most recent example of this approach with prototypes manufactured in Great Britain. As with most sensor-operated devices, they react to predetermined stimuli but are unable to "anticipate" or accommodate all of the myriad situations found in the normal highway environment. As a result, cost benefits are difficult to reconcile.

In any system where an attempt is made to develop both the symmetrical upper beam and the nonsymmetrical lower beam from the same optical system, compromises must be accepted in lighting performance (6). It is for this reason that the 4-headlight system was introduced in the United States in 1957. Two sealed-beam units were designed and used expressly for the lower beam, and the other 2 were designed for the upper beam. A second off-focus filament in each low-beam lamp is operated along

Figure 2. Vehicle encounter lighting problem.

Figure 3. Parabolic reflector.

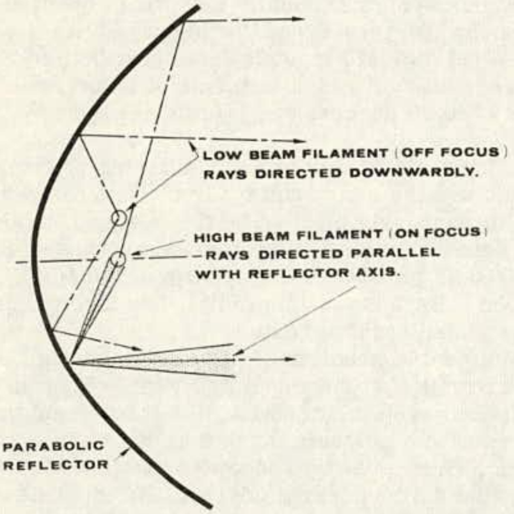


Figure 4. Graves "anti-dazzle" system.

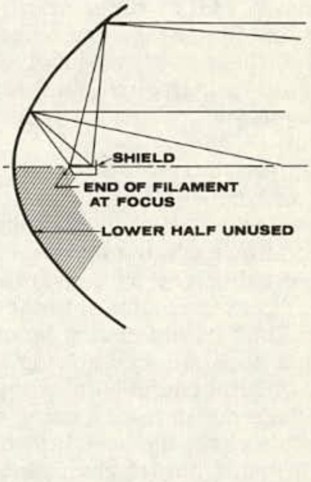


Figure 5. Gated elliptical system.

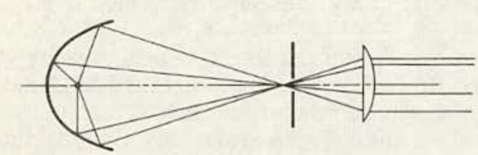
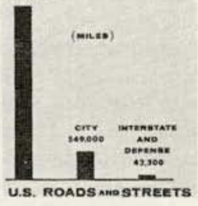


Figure 6. U.S. highway and street mileage.



with the upper-beam lamps to supplement the overall light output. This separation of function is also used to some extent in Europe, not only with an array of 4 separate headlight units but also with 2 separate lamp bulbs and reflecting systems contained behind 1 lens plate at each side of the car in nonsealed assemblies.

Roads are not straight and level, and vehicles are not stable mounting platforms for precision light projection devices. The best laboratory designs for headlights face serious problems in the practical world (7). Normal undulations of the vehicle due to uneven road surfaces cause beams to rise and fall. Lamps having a sharp cutoff will present to oncoming drivers very abrupt changes in brightness that tend to be annoying (8, 9, 10). On the other hand, lamps having a soft cutoff present changes that are less sharp. Similarly in seeing ahead, on undulation, the sharp cutoff will approach and recede rapidly on the roadway surface ahead of the vehicle. This is not as obvious or annoying with the soft cutoff.

Other investigators have noted that, during dynamic vision tests, the soft cutoff seems to aid in revealing obstacles at greater distances ahead (7, 8, 9). With the sharp cutoff, as the vehicle proceeds, obstacles are not revealed until they suddenly appear in the beam as they change from an unlighted, below-threshold state to a lighted state. On the other hand, with a softer gradient at the top of the beam, the eye seems able to apprehend the obstacle at a lower level of contrast and hence at a greater distance.

Headlight aim on the vehicle constitutes the greatest single source of variance in performance (11). Even with perfect aim, however, we are confronted with a change in attitude from the unloaded to the fully loaded state of more than a degree on certain standard-sized American cars. It becomes impossible to aim the lamps with a single setting that will accommodate such a broad range, but fortunately the extreme is rarely reached.

In U. S. practice the lamps are designed for 0.4 deg lower than ideal aim when the vehicle is unloaded. The assumption is that, with average loading, beams will approach the nominally best attitude for highway driving. For prolonged use with very heavy loads, it is assumed that the driver will re-aim the lamps. In Europe there appears to be no official recognition of loading allowance in standards and regulations.

Changes in load present more of a problem with a sharp cutoff low beam than with a soft cutoff. Also, smaller cars with short wheelbases generally present greater deflections from no-load to full load. As a result, there has been considerable interest in Europe in the development of schemes for manually adjusting the aim of headlights from within the vehicle and also automatic devices intended to maintain the aim of the headlights with respect to the highway, regardless of vehicle loading. Many designs and patents have emerged, but these must be precision mechanisms. When one considers that they must be supported in the front-end sheet metal of the vehicle body and work successfully for the life of the vehicle, one must question their practicality. In this location the mechanisms are most vulnerable to body damage, mud, salt, water, and icing conditions. At least one of these devices is now being installed in a European car, and it will be interesting to evaluate its performance in service.

There are also total vehicle leveling systems that are related to the vehicle suspension system. In these, ride, performance, handling, and other objectives are sought, and headlight leveling becomes an ancillary benefit. Because they become an inherent part of the basic vehicle, reasonably good maintenance in service should be expected. However, the attendant cost necessitates careful evaluation in terms of real public benefit.

In considering a headlighting system, one must also take into account the highway system within which it must perform. Although great strides have been made worldwide in highway construction and most notably with the Interstate system in the United States (1), the driving situation, as it affects headlighting, has not changed greatly since the 1930s. Some may take exception to this statement and cite the limited-access highway where average speeds are high and drivers are assumed to be overdriving their headlights. However, surveys show a 7-mph higher average speed on such highways, and I submit that drivers are far safer and there is relatively less need for headlight improvement here than on the ordinary bidirectional highways of the country. Please note that I did not say that better headlighting is not needed, but simply that, for the same reason that drivers are safer in daytime, there is less opportunity for unexpected trouble to appear at night on limited-access highways.

Of the total of 3,710,000 miles of streets and highways in 1969, 549,000 miles were in municipalities and only 29,638 miles were Interstate highways (Fig. 6). Also in 1969, the miles driven on rural roads just about equaled urban mileage—526 billion to 544 billion. Of this total of 1,070 billion, less than 200 million miles were driven on Interstate roads. Obviously the hazards are far more numerous and the need for better headlighting much greater on these millions of miles of streets and highways carrying bidirectional traffic, particularly because so few of these miles have even mediocre fixed highway lighting.

The need exists and the technical problems persist. The clear road is of little concern to the optical designer other than the allowance by the vehicle designer of enough electrical power and enough "real estate" on the front end to mount lamps of adequate size. But with regard to the meeting situation, we are still trying to find better ways of lighting the lane ahead without blinding oncoming or immediately preceding drivers.

During the 1960s, because of the feeling that motorists were overdriving their low beams on Interstate highways, improvement was attempted by experimentally interjecting a third beam between the low and high. Purpose was not well defined, but it fell into 2 general categories. First, it was thought that a beam similar to the high beam was needed but with a sharp cutoff latterly to restrict high candlepower from crossing the median toward oncoming traffic. One new lamp would supplement the low beam but provide sufficient illumination for 70-mph driving. Second, some researchers felt that light from this type of lamp would be too annoying, entering the rear windows and mirrors of preceding cars. This group suggested instead that this lamp (to supplement the low beam) should be little greater in glare than an existing low-beam lamp but have as high output as possible at and just below horizontal. Such a design was felt to be more useful in that it could even be used to improve seeing in most meetings on normal bidirectional roads.

Both of these "schools of thought" were advanced as modifications to the 4-headlight system. The inboard lamp on the driver's side would provide the intermediate beam. This leaves only the inboard lamp on the curb side to generate the very intense portion of the high beam for clear-road vision far ahead. Although this beam can be used only a minimal amount of driving time, high performance is needed because it is the sole source of light when the car is alone on the open highway.

Variations of these approaches are currently under consideration. The 3-beam concept seems to have appeal, but there is a very real human-factors question concerning the ability of the average (and less than average) motorist to understand and properly use each beam. There are also attempts to improve the 2-beam system, and headlight and car manufacturers are working on this problem. Whether these approaches can be evaluated properly, and whether improvement can be sufficient to justify a new standard, remains to be seen.

Unfortunately, the subject is politically extremely volatile. Many seeing-distances studies show that greater amounts of light projected ahead with the accompaniment of rather large increases in glare will net greater seeing distances in certain meeting situations. What these studies have not measured is the subjective reaction to the increased glare. Although it appears that the public will accept some modest glare increase to permit better seeing performance, there is little definitive information available (12). Hemion at the Southwest Research Institute made a good survey, but much confirming data are needed from highway tests before any major changes in glare limits are made. Should regulatory bodies move in this direction and exceed the nebulous public tolerance level, serious repercussions could result and we could find ourselves in a situation similar to the chaotic 1920s and 1930s with "glare wars" between motorists. Having been a driver during this period, I can readily understand how the emotions of affected drivers can quickly be felt in state and federal legislatures, not to mention the "press," and real public benefit would be doubtful.

I believe that the greatest need in the face of urban growth and increased vehicle density is improved visibility of oncoming vehicles. It is obvious that, because of economics, the majority of rural and urban travel will continue to be made on bidirectional, essentially 2-lane roadways. Although refined optical systems, beam modes, and leveling devices may offer some small improvement, only polarized headlighting offers the advantage of the use of a clear-road high-intensity beam that does not bother drivers as they approach each other in a meeting situation. The advantages and disadvantages of polarized headlighting were first studied in depth between 1939 and 1948 (13, 14). Jehu of the British Road Research Laboratory examined problems of introduction in 1963, and since 1968 considerable work has been done in Sweden by Erickson of the Institute of Optical Research and Johansson and Rumar of the University of Uppsala, which has evoked much interest in Europe. Also during the last 4 years, Hemion of the Southwest Research Institute has conducted a thorough investigation of the subject on behalf of the Federal Highway Administration and under the guidance of R. N. Schwab (15). Problems of available power, wiring, and switching are less critical now than 20 years ago although some deterrents remain. Undoubtedly the biggest is the fact that the polarized headlight system will work well only if all cars are properly equipped. This implies an extended transition period during which cars become equipped, either through normal attrition or with the use of conversion kits or both.

Before we move into such a program, with its great economic impact, more knowledge of anticipated public acceptance and use is needed. The large-scale testing programs that have been proposed will require federal sponsorship. This is currently under consideration by the National Highway Traffic Safety Administration. The system holds promise for more comfortable, safer nighttime travel, but we need more research on the tolerance level of drivers to headlight glare.

This subject is far more complex than the basic points that have been presented. Adverse weather, accumulation of dirt, and depreciation from any number of causes must be recognized. Merrill Allen of the University of Indiana has attempted to quantify the effect of pitting and scratching of glass windshields and lamp lenses. Many researchers have been working on the development of headlight cleaning devices, and standards have been written for implementation in Sweden and perhaps for Europe. These and many more are items worthy of serious consideration, but we still face the fundamental task of finding a way to adequately illuminate the road ahead without annoying other highway users.

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DISCUSSION

Philip Maurer

As Meese has well indicated, automotive lighting is a complex subject that goes far beyond the simple task of designing a set of lamps that project an arbitrary selected beam pattern ahead of the car. In addition to the strictly physical design factors involved, there are other parameters that have to be considered, such as the design of the rest of the automobile, highway design, physiological and psychological considerations grouped under the broad title of human factors, and cost-benefit ratio.

I agree with Meese's analysis of how the American and European beams developed differently. Each, when seen in its own locale, seems to be fairly well suited to the driving task but when mixed show a decided contrast. European lighting experts admit that the U.S. system seems to be very satisfactory here but appears very glaring when observed in Europe among a great majority of cars equipped with European beams. It is interesting to note that, as European rural expressway night traffic increases, Europeans are beginning to have doubts about the 300,000-candela maximum for high beams. At the same time, we in the United States are thinking about increasing our 75,000-candela maximum. Perhaps we will meet somewhere in between.

It is also noteworthy that Sweden, after extensive testing, is beginning to favor the U.S. low beam; however, because of the high tourist car interchange with the rest of the continent, Sweden feels that it cannot make such a change alone.

Aim

I would like to point out that the importance of good headlight aim cannot be stressed enough. A great deal of emphasis has been put on this subject by some states and by the automotive companies. The inspection and regulation of headlight aim is accomplished by state-owned or state-licensed inspection stations in those states that have an inspection program. Automotive manufacturers are exploring various ways to further ensure proper aim on all cars. Mandatory state inspection should ensure maintenance of such aim in service as well as rule off the road some of the "baling wire wonders" that are still seen on the roads of states that do not have mandatory inspection.

Load Levelers

The need for a load adjustment device for headlights is being discussed in European lighting circles, and we may see a legal requirement there in the future. Such a need is not as great in the United States because our low beams are less annoying when raised slightly, our larger, longer wheelbase cars do not change level as much either statically or dynamically as do European cars, and our load factor is much lower. Because of these factors, neither headlights nor full-car load levelers seem to have a good cost-benefit ratio for general use, although one U.S. luxury car already has a full-car automatic load leveler as standard equipment.

The simplest method of headlight leveling control that is being considered is a manually operated device, e.g., a lever that would tilt the headlights and have positions for "1 to 3 passengers," "4 to 6 passengers," and "heavy load." Knowing something of the psychology of the average motorist, I fear most controls would be set according to the driver's opinion of his best seeing condition and then would be left there through all kinds of loading.

Three-Beam System

I agree with Meese that, although we may sometimes overdrive our headlights on limited-access superhighways, the risk is minimal because the road is generally clear of unexpected obstacles. A few years ago we had much discussion about a so-called "turnpike beam," and I was one of the first to point out that what we really need, as dictated by accident records, is an intermediate beam usable on 2-lane country roads. As Meese mentioned, considerable work is being done in this area by both industry and government, and our next step in headlighting improvement may well be in that direction.

Control of such a 3-beam system is of paramount importance. The present foot switch no longer meets the requirements of ease of control, understandability, and ease of reaching any beam quickly. It appears that a hand-operated control of some sort would be a better answer.

I think that Meese is overly concerned about glare acceptance because a properly designed intermediate beam may have only slightly more glare than our present lower beams and because there is always the option of signaling an offending driver to switch to his lower beam. I would agree that considerable cooperative testing between the National Highway Traffic Safety Administration (NHTSA) and the automotive and lighting industries should be conducted before an "across-the-board" change is made.

Polarized Headlighting

I differ with Meese somewhat on his assessment of polarized headlighting. In my opinion, although it has some good theoretical advantages, there are still many unanswered questions that make its future use at least questionable. I took part in both the 1946-47 Automobile Manufacturers Association's (AMA's) evaluation and the 1971 evaluation at Southwest Research Institute, and my conclusion is that there has been very little progress in the interim. In fact, in several areas we are worse off today than we were in 1947; e.g., windshields are curved and raked backward more, and rear windows are made of tempered glass with its stress concentrations. Both of these conditions cause depolarization with accompanying glare.

Because of the high optical losses in polarized lighting, it probably becomes impractical to equal or exceed current high-beam output in seeing light returned to the driver, so open road improvement may not be achieved with the system used in these 2 tests unless some further breakthrough is achieved. Furthermore, it appears that the best polarizing material available in large enough quantities for high production use deteriorates rapidly at the elevated temperatures to be expected in high-output lamps.

One European manufacturer is reported to have achieved considerably higher efficiency in a new system based on the application of Brewster's law. Either plane or circular polarized light can be produced. Such work needs to be carefully evaluated.

Besides the system experimented with in this country, which polarizes only the upper beam, there have been proposals for polarizing only the lower beam, for polarizing both the upper and lower beams, and for polarizing only a meeting beam of a 3-beam system.

A few of the problem areas that have not been resolved are as follows:

1. Street lighting effectiveness is reduced;
2. Glare to pedestrians and cyclists is excessive;
3. Glare through side windows must be controlled at intersections where cars are approaching on side roads;
4. Polarized headlights do not cause any atmospheric glow when approaching the top of a hill, thus giving no advance warning;
5. The problem of introduction of polarized lighting and intermix with present lighting is very complicated and must be given a great deal of further study; and
6. The added current consumption will necessitate larger generators on some cars, which becomes a cost and space problem.

I have not enumerated all the problems, but my point is that polarized lighting is not ready for large-scale testing. First, we must better determine an optimum system, and, if possible, this should be done in cooperation with European standard-making organizations, or we will again find ourselves with mismatched headlight systems of even less compatibility than today's.

When we look at these difficulties, we can see that it probably will be several years before polarized headlighting could be considered for use. In the meantime, we should endeavor to improve our present system such as by converting to a 3-beam system.

Headlight Cleaning Devices

Headlight cleaning device standards are being seriously worked on in Europe, and it appears that the use of headlight cleaners will be mandatory overseas. Such devices have been offered for sale in this country as an extra-cost option but without much success. I am sure that both NHTSA and the industry will be watching this development in Europe closely because a good reliable headlight cleaner could certainly help visibility under the most adverse conditions.

AUTHOR'S CLOSURE

I would like to thank Maurer for his discussion of my paper, which admittedly constitutes only a brief overview of a very complex and difficult lighting problem area. The questions with respect to the practicability of polarized headlighting require some further clarification.

It is a fact that the excessive sloping and contouring of windshield glass tends to cause depolarization, which can be accommodated to some extent by proper orientation of the basic plane of polarization.

It is not an impractical matter to overcome the light losses inherent in polarization. As indicated in the body of the report, clear-road lighting systems are in existence today that develop up to 300,000 candelas. Reducing the intensity of such systems by polarization would still net usable illumination that is considerably in excess of that allowed by current domestic regulations. The point that is missed in this criticism is that, when cars having polarized systems meet, visibility distance remains close to that of clear-road conditions. In addition, our experience with polarizing materials has shown that they are readily capable of withstanding the temperatures of "high-output" lamps. Work is continuing on bonding materials, which also indicates compatibility.

System design details concerning number of beams and which sources to polarize can be readily solved through national or, preferably, international convention and standardization.

I know of no serious proposal that includes the use of a fixed polarizing screen that would remain in the line of view during daytime driving or driving under lighted city streets and highways. Therefore, I foresee no reduction in street lighting effectiveness.

Pedestrians and cyclists are subject to severe glare from present high beams. Under polarization, the wearing of simple polarized half-spectacles could increase comfort.

Glare through side windows can be annoying at intersections, particularly if one is attempting to make a left turn across the beam of a car intersecting from the left. If the driver is wearing spectacles, however, this presents no problem. Attention to design of the visor or polarizing screen fixed to the car could alleviate this momentary condition.

The statement concerning atmospheric glow is invalid when one considers that it is not present in daytime driving nor is it present under clear atmospheric conditions at night. Regardless of the lighting system used, motorists should stay on their own side of the road and be cautious of blind curves and hills.

From the appraisals of the past 35 years, I see no serious problems with regard to the introduction of polarized lighting and its intermix with current lighting systems. However, this is merely an opinion, and the consideration of introduction and intermix is a necessary part of any program.

Added current consumption and larger generators have not seemed to present any problem when the object has been that of supplying air-conditioners, window lifts, and other useful accessories; therefore, these objections hardly seem insurmountable.

I agree with Maurer that further investigation of this subject should be done on an international basis because the benefits can be best realized under international standardization of the fundamental elements of the system. With respect to the complaint that there has been little progress since the 1946-47 AMA evaluation, I find it unfortunate that no contributions have been forthcoming from the vehicle manufacturers. I can see no other remotely practicable means for accomplishing a significant improvement in visibility. The other avenues for improvement using ordinary light can yield only minimal increments in an area where major gains are needed.