UMTRI-2001-35

A WORLDWIDE PERSPECTIVE ON FUTURE AUTOMOBILE LIGHTING

Kåre Rumar

November 2001

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Report No. UMTRI-2001-35
November 2001

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-2001-35		

4. Title and Subtitle	5. Report Date
A Worldwide Perspective on Future Automobile Lighting	November 2001
	6. Performing Organization Code 302753
7. Author(s) Rumar, K.	8. Performing Organization Report No. UMTRI-2001-35
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 Adac Plastics, AGC America, Autoliv, Automotive Lighting, Avery Dennison, BMW, Coherix, Corning, DaimlerChrysler, Denso, Donnelly, Federal-Mogul Lighting Products, Fiat, Ford, GE, Gentex, GM NAO Safety Center, Guardian Industries, Guide Corporation, Hella, Ichikoh Industries, Koito Manufacturing, Lang-Mekra North America, LumiLeds, Magna International, North American Lighting, OSRAM Sylvania, Pennzoil-Quaker State, Philips Lighting, PPG Industries, Reflexite, Renault, Schefenacker International, Stanley Electric, TEXTRON Automotive, Valeo, Vidrio Plano, Visteon, Yorka, 3M Personal Safety Products, and 3M Traffic Control Materials.

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

16. Abstract

Past work in vehicle lighting has focused primarily on the needs of the developed world. The goal of this study was to analyze how our understanding of lighting needs might be affected if the perspective was widened to the entire world, including the developing countries.

Each year, worldwide traffic fatalities are increasing, with the vast majority of the increase occurring in the developing countries. These countries have 40% of the motor vehicles, but suffer 86% of all traffic fatalities. The primary safety problem in the developing world is collisions between vehicles and pedestrians. Furthermore, the crash rate is approximately three times higher in nighttime traffic than during the daytime. The crash type most overrepresented in darkness is pedestrian collisions, with a three to seven times greater fatality risk than during the daytime. Worldwide, an estimated 200,000 pedestrians are killed in night traffic each year. Over 90% of these fatalities occur in developing countries. A number of other nighttime crash types are also overrepresented, but causes other than darkness are more involved (e.g., alcohol, and fatigue).

Analyses based on the limited information that is available were made of the crash and traffic situations in which automobile lighting plays a critical role and where an improvement in automobile lighting would increase safety. Results showed obvious differences between developed and developing countries. The large number of pedestrians killed in developing countries in night traffic is the major safety difference. This study suggests and evaluates improvements in automobile lighting that would reduce this safety problem in darkness for the world in general and for the developing countries in particular. Some other potential improvements of automobile lighting and other countermeasures are also discussed.

17. Key Words	18. Distribution Statement
Night traffic, headlights, signal lights, visibility, development, fatalities, pedestrians, developing countries	Unlimited

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
None	None	52	

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:

Adac Plastics
AGC America
Autoliv
Automotive Lighting
Avery Dennison
BMW
Coherix
Corning
DaimlerChrysler
Denso
Donnelly
Federal-Mogul Lighting Products
Fiat
Ford
GE
Gentex
GM NAO Safety Center
Guardian Industries
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Ichikoh Industries
Koito Manufacturing
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Reflexite
Renault
Schefenacker International
Stanley Electric
TEXTRON Automotive
Valeo
Vidrio Plano
Visteon
Yorka
3M Personal Safety Products
3M Traffic Control Materials

Additional thanks go to Michael Flannagan and Michael Sivak for their helpful suggestions during the preparation of this report.

CONTENTS

1. SCOPE OF THIS STUDY

The development of automobile lighting (headlighting as well as signal lighting), like the development of other automobile components, has aimed to solve the problems arising through the development of road traffic. The technological development at the time has been a limiting factor in this process (Moore, 1998; Moore & Rumar, 1999).

Initially, the main problems were making automobile lighting reliable. In the next stage, handling, performance, and maintenance characteristics were emphasized. As traffic increased, roads became paved, speeds increased, and technology advanced, lighting also became more sophisticated and technically advanced. Cars were designed and produced mainly in the developed world. Consequently, automobile components were also adapted to the conditions typical of the developed world. Such conditions include, for example, well educated and gradually older drivers and car owners; paved, wide, and well marked and signed roads; regular maintenance and control of vehicle condition; frequent qualified service stations; passenger cars dominating the traffic picture; few pedestrians and bicyclists along rural roads; and good road lighting along streets and roads with heavy traffic. The car-producing countries dictated the standards for automobile lighting based on these conditions. (Presently, automobile lighting systems and components are not frequently produced by the car manufacturers themselves, but by lighting suppliers.)

Statistically, the higher the motorization level in a country, the less dangerous each car is, because level of motorization mirrors the country's economic situation. Furthermore as the economy improves, a number of general conditions improve as well, including the quality of the road network, vehicle condition, driver education, and health care. All these and other factors, including vehicle lighting, contribute to reducing the fatality rate per vehicle. Figure 1 illustrates the basic relationship between the level of motorization and fatality rates throughout the world. The regression line is based on a large number of both developed and developing countries. African countries are normally found in the upper left, Asian countries in the central region, and North American and West European countries in the lower right of the figure.

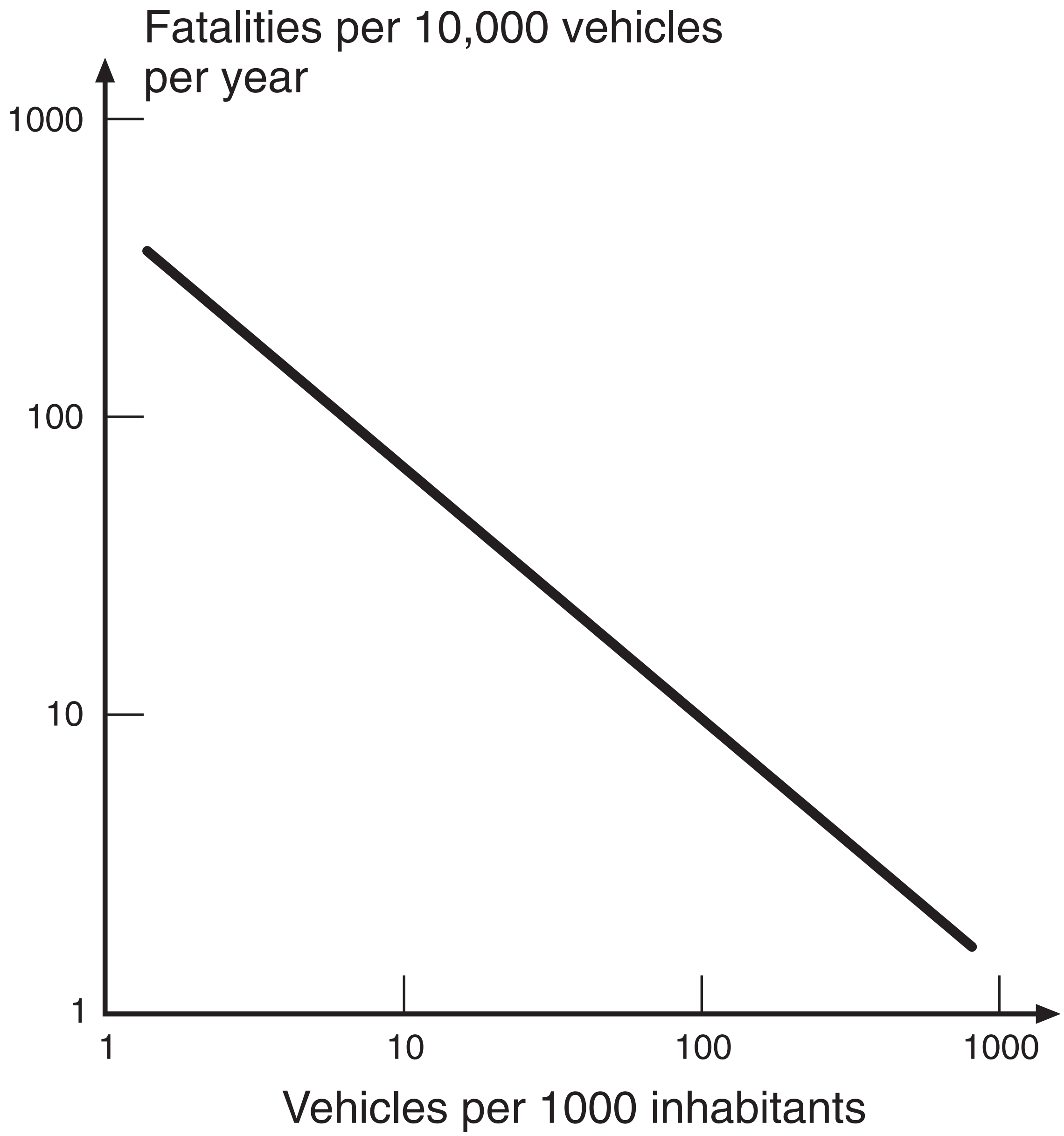

Figure 1. General relationship between level of motorization and fatalities per vehicles, based on data from developed and developing countries (Jacobs and Hutchinson, 1973; VTI, 2001).

Some vehicle manufacturers have made efforts to produce vehicles especially for countries in the developing world. These vehicles have been stripped of more advanced features and luxury components. They are much sturdier and less sophisticated than the corresponding models marketed in developed countries, but their lighting characteristics still fulfill basic international regulations. Most likely, the production volumes for such vehicles are so small that the price is not lower than that of standard cars, which would explain why this idea has never really caught on. Other specialized vehicles have been built in developing countries, often two- and three-wheelers, under names such as bajajs, bemos, and mikrolets in Indonesia (Dimitriou, 1993). Information about their lighting characteristics is not available.

Presently, two automobile lighting standards dominate the world, the UN/ECE and the North American. Efforts have been made to harmonize these two slightly different sets of requirements (Moore, 1998; Moore & Rumar, 1999). But both of these standards are written for conditions typical of the developed world. This is especially true for the current efforts in advanced (adaptive) frontal lighting (Rumar, 1997; GTB, 2001) and advanced rear lighting.

The goal of this study is to investigate desirable directions of future automobile lighting developments, by considering accident statistics and expected number of automobiles throughout the whole world—not just in the developed countries. Should this perspective in any way change the development presently in progress?

The study starts by specifying the objectives of automobile lighting (Section 2) and continues with an analysis of the characteristics of the main factors determining nighttime visibility (Section 3). Sections 4 and 5 discuss the negative effects of impaired nighttime visibility. Section 6 describes the present and likely future distribution of vehicles worldwide, while Section 7 describes the present development trends in automobile lighting. Section 8 covers specific crash and traffic characteristics in the developing world. Section 9 analyzes the overall findings and provides recommendations. Finally, Chapter 10 draws conclusions about the potential effect of various measures and of the possibility of implementing them.

2. THE OBJECTIVES OF AUTOMOBILE LIGHTING

The three major objectives of automobile lighting are to improve driver visual performance in darkness, to improve vehicle conspicuity in specific conditions, and to facilitate communication between road users. Of these, improving visual conditions in the darkness is the primary purpose. The overall risk of driving at night is substantially greater than that of driving during daylight, and automobile lighting is designed to reduce this increased risk.

Drivers state that their main problem in night traffic is seeing the road far ahead of them (Walraven, 1980), and the consequent insufficient ability to prepare for what is going to happen in the immediate future. However, analyses of fatal crashes carried out in the U.S. paint a different picture. Crashes that are most over-represented in darkness, as compared to daytime traffic, are collisions between automobiles and pedestrians, not single vehicle crashes (Sullivan & Flannagan, 1999). That study distinguished between nighttime and darkness by analyzing crashes during the transition to and from daylight saving time. The rationale was that, at least in the highly developed countries such as the U.S., driving behavior is strongly governed by the clock and not by light.

There are strong confounding factors behind the general risk increase in nighttime traffic as compared to daytime traffic. Not only is the general ambient illumination much lower, but drivers are also more likely to be fatigued and intoxicated. The driver population at night is also different from the daytime driver population: At night, there are more young, inexperienced drivers and more male drivers (higher risk), but also more experienced professional drivers (lower risk). A large proportion of the collisions between vehicles and animals occurs at night. These and other factors influence the traffic risk at night. Automobile lighting can only modify the effect of darkness by improving driver visibility conditions.

Pedestrians are also more frequently intoxicated at night. (That is in fact one of the reasons for them not to take the car but to walk.) Studies show that it is much more dangerous to be a drunk pedestrian in darkness than in daytime. Probably the unpredictable behavior of the drunk pedestrian is much more dangerous when visibility is limited as is the case in darkness. In the same way it was found that speed is more critical in darkness when visibility is limited. The risk of a pedestrian collision increases with increasing speed (Sullivan and Flannagan, 2001).

Seeing (detection) distance in night traffic is a function of five factors (see Figure 2): visual performance of the observer, illumination characteristics (fixed street lighting and vehicle lighting), characteristics of the targets to be seen (vertical and horizontal), characteristics of light signals (stationary and mobile), and characteristics of the transmission media (in the vehicles and the atmosphere). To improve seeing distances in night traffic, we have to change one or more of these factors (Rumar, 1975). Short seeing (detection) distances lead either to low safe speeds or a high probability for collisions.

Conspicuity (the ability to be seen) of road users or targets is, to a large extent, the other side of the coin. Contrast, size, position, and motion are the most important variables. Poor conspicuity leads to late detection, which in turn leads to critical situations. Daytime running lights are a good example of a vehicle lighting function that enhances vehicle conspicuity (Rumar, 1980).

Vehicle lighting is used for communication in the sense that vehicle lighting signals inform other road users about the intentions and actions of the driver. This is more important in night traffic than in daytime traffic considering the much poorer visual situation at night, which reduces the available stimuli and increases interpretation possibilities. Inefficient vehicle signals lead to a higher probability of misinterpretations or misunderstandings between road users, which in turn increases the probability of collisions. No direct studies of the relation between vehicle signal light characteristics and crash rate have been undertaken. However, there are several indirect studies indicating that this is an important safety factor (e.g., the positive effect of center high mounted stop lights [CHMSL], and the reduced reaction times of good signal lights as compared to poor or degraded signal lights [Moore & Rumar, 1999]).

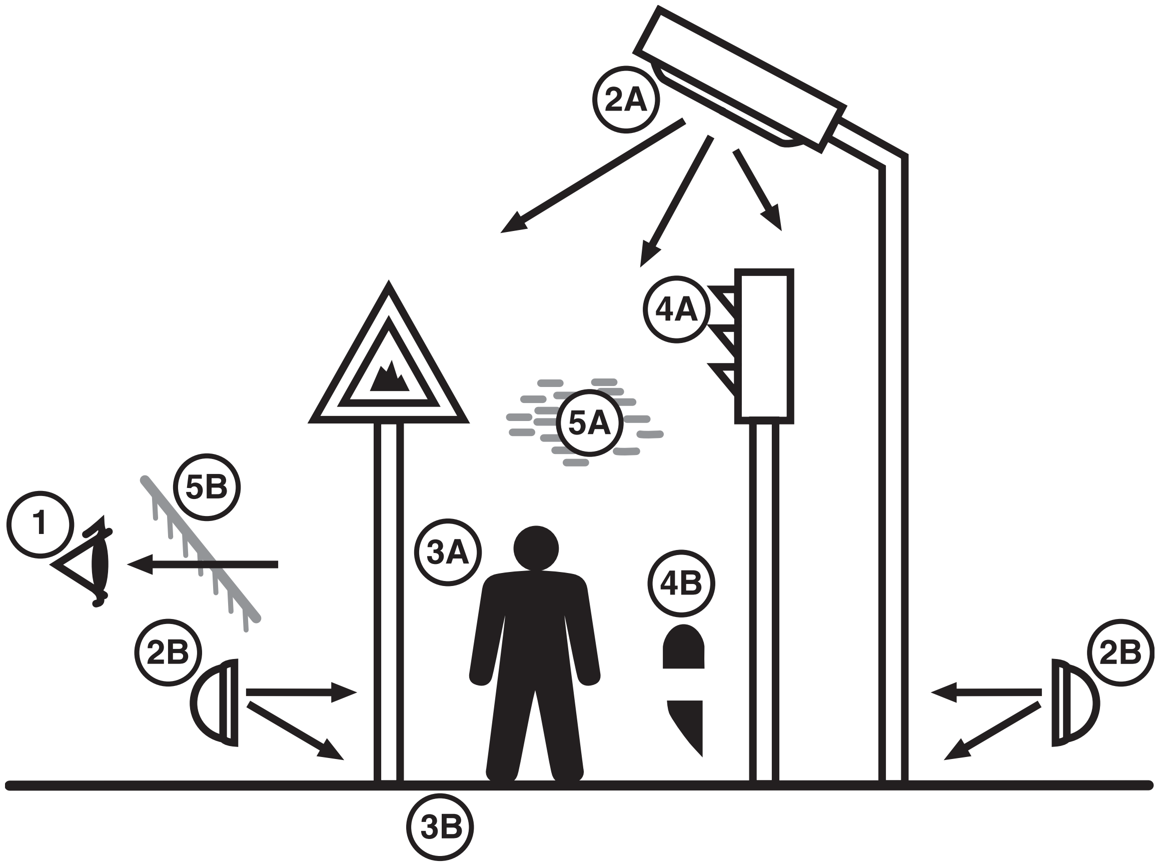

Figure 2. The five primary factors influencing the visibility conditions in night traffic (Rumar 1975):

1. Visual performance
2. Artificial illumination (light sources)
    - A. Vertical illumination (road lighting)
    - B. Horizontal illumination (vehicle headlights)
3. Visual targets
    - A. Vertical targets (other road users, signs, obstacles)
    - B. Horizontal targets (road surface, road markings)
4. Signal lights
    - A. Stationary signals (traffic signals, railway signals, road-work signals,)
    - B. Dynamic signals (vehicle signal lights, vehicle emergency lights)
5. Optical media
    - A. Atmosphere (clear, haze, fog, snow, rain, smoke)
    - B. Vehicle optical media (windows and mirrors: clean, tinted, dirty, scratched)

3. THE FIVE FACTORS DETERMINING VISIBILITY IN NIGHT TRAFFIC

3.1. Human visual sense

Human vision seems to have developed for daytime conditions. The general illumination levels in night traffic with headlights, however, are only a fraction of the illumination during daylight (at 100 m about 0.01% of daytime illumination). At those low levels of illumination, the eye does not function very well. The contrast sensitivity is low and the glare sensitivity is high. Both of these effects work to reduce visibility, especially of low contrast targets. The eye has an impressive capacity to adapt to changing situations, but in nighttime traffic the illumination is both low and uneven with glaring lights in the visual scene. Several efforts have been made to improve visual performance under the traffic illumination levels prevalent in darkness. However, so far neither optical filters nor various types of drugs have shown any real positive effect. Therefore, the only way to improve visibility seems to be to change any of the other relevant factors.

Leibowitz, Owens, and their colleagues (Leibowitz & Owens, 1977; Leibowitz, Owens, & Tyrell, 1998) suggest that drivers' visual performance in night driving is based on two rather separate functions: guidance and recognition. Recognition is seriously impaired in driving at night, while guidance is less impaired. They suggest that because of these separate effects, drivers tend to overdrive their visibility.

3.2. Artificial illumination

The second component with a potential for visibility improvement is an artificial illumination source intended to replace the sun. There are two such sources: stationary street lighting and dynamic vehicle headlights.

Good street lighting with average luminance levels above 1 cd/m^2 is a fairly good substitute for daylight, although the illumination is still much lower than what the sun can offer (about 0.1% of daytime illumination), and only marginally better than headlight illumination. Still, many studies report that serious crashes, especially pedestrian fatalities, are reduced by about 50% when good street lighting is introduced in areas where there was no stationary lighting (CIE, 1992). However, because of installation and operating costs, countries often establish minimum traffic volumes below which street lighting is not installed, and different quality levels of street lighting for various traffic and road conditions. Poor countries have lower quality requirements and higher traffic-volume limits for installation than rich countries.

As stated above, at the distances needed for acceptable vision, automobile headlights can offer even less light than street lighting. Furthermore, the degradation of headlights as well as signal lights due to dirt, corrosion, condensed water, scratches, low voltage, etc. is considerable even in rich countries. However, it is probably even more serious in poor countries with generally older equipment and less frequent and efficient maintenance.

The visual conditions offered by high beams are normally acceptable. The main problem in developed countries is that high beams cannot be used very often due to oncoming traffic. This situation may be different in developing countries. Another problem is that due to excessive glare: strong high beams may create longer dimming distances and thereby short visibility distances for both drivers (Rumar, 2000).

The major problem is the low-beam system (Rumar, 1995). The present low-beam system is a compromise between good illumination and low glare. Therefore, visibility distances—even with the most modern light sources—are quite limited. In optimal situations, visibility distances of about 80 m to dark obstacles are offered during low-beam meetings (Rumar, 1997). Such short distances are not enough for the present speeds of about 100 km/h on rural roads. And in realistic conditions, these distances are halved. Several improvements have been proposed (Rumar, 1997; GTB, 2001). In the 1970s, the concept of a midbeam was proposed both in Europe and the U.S. (Rumar, 1997). This is still a feasible potential improvement. Most of the other suggestions are, however, more complicated and still in the prototype phase. They have been tested in some developed countries, but are presently not intended for developing countries.

In 1936, Land (1968) proposed using polarized headlights as a radical way to increase front illumination without increasing glare. This concept has been extensively tested and found to be feasible (Johansson & Rumar, 1970), although it normally requires special legislation activities. In the 1990s, there was some hope that ultraviolet headlights and fluorescent targets would be feasible possibilities. These ideas have been abandoned as a general solution, but could still be a possibility for specific situations.

Nonvisual systems such as infrared, radar, and ultrasound are currently being tested to improve visibility in darkness, fog, and snow. One of the major problems with such systems is that the visual scene must be presented to the driver without taking attention away from the scene ahead. Though these ideas may be feasible in the future, they are not particularly suitable for developing countries because of their complexity and cost.

Front fog lamps must reduce light above the cutoff in order to lessen backscattering in foggy conditions. At the same time, they must have increased illumination below the cutoff to penetrate the fog and offer the driver at least an acceptable visibility of the road and its outline. Present fog-lamp regulations are not sufficient from these two points of view, but efforts are underway to improve these regulations (GTB, 2001). Furthermore, there are substantial national differences between the regulations concerning the usage of front fog lamps. In some countries, using fog lights and headlights simultaneously is forbidden, while in other countries such usage is accepted.

Some lamps, such as backup lamps for long and heavy trucks and buses, are generally inadequate. The regulations are made for passenger cars and the effective lamp intensity on heavy and long vehicles is quite low (partly because of the low nominal intensity, and partly because of the voltage drop between the battery and lamps often more than 20 m away (Sivak et al., 1994)). Drivers of these vehicles often have to make reversing maneuvers in dark and narrow situations. They need good backup lamps more so than drivers of passenger cars.

3.3. Visual targets

There are two major types of visual targets: vertical targets (such as signs and other road users) and horizontal targets (such as the road and road markings). Unless treated with retroreflective materials, both types of targets reflect only a fraction of the incident automobile illumination. Consequently, the contrast between the targets and their background is low. The low reflectance, combined with the fact that human contrast sensitivity in the situations of interest is low, is the main reason for the short visibility distances. Detection distances to dark obstacles are often around 40 m, and visibility of the road and road markings (if not reflectorized) is normally even shorter due to the more unfavorable retroreflective geometry. Visibility distances of that size are too short for driving in darkness at speeds above 50 km/h.

One solution to this problem would be to increase vehicle front illumination, provided that it can be done without increasing the glare (e.g., by the use of polarized headlights). Another solution would be to increase contrast. That is feasible by the use of retroreflective materials on the visual targets. Good retroreflective materials on the targets will increase visibility of vertical targets in low beam illumination from about 40 m to about 160 m (Johansson & Rumar, 1968; Rumar, 1974; Olson & Sivak, 1983; Leibowitz et al., 1998); in other words, from unacceptable to just acceptable. With high beams, the visibility improvements obtained by retroreflective materials would be from about 200 m to about 800 m. Visibility with good retroreflective materials would be roughly four times greater than with dark targets.

Retroreflective materials on horizontal targets, such as road markings, will approximately double their visibility: On low beams, the improvement would be from about 30 m to about 60 m and on high beams from about 50 m to about 100 m (Rumar & Marsh, 1998). In both cases, the visibility would thus be approximately doubled. For horizontal targets, rain, wetness, and dirt create special problems that are difficult to solve. Raised pavement markers and roadside delineators would increase visibility by factors of two and four, respectively, compared to traditional road markings. They would also considerably reduce problems in wet conditions.

3.4. Signal lights

Automobile signals and traffic signals are a problem in broad daylight conditions, but normally not in dark conditions (Rumar, 1975) because of the reduced contrast in daylight situations (Moore & Rumar, 1999). However, a necessary requirement for efficient functioning in darkness is that the signals are operational. Studies show that malfunctions of, or failure to use, automobile signal lights (e.g., turn signals) are quite common, about 50% (Mortimer et al., 1974; Mortimer & Domas, 1974).

Signal lights play an important role, both day and night, in conditions with reduced visibility because of atmospheric disturbances such as fog, falling snow, thick smoke, and dust. Rear fog lights are a good example of such a special signal light. Rear position lights/rear fog lights are the only automobile signal lights that have two intensities. Two or more intensities, depending on the ambient illumination and visibility, should be required for all signal lights (Moore & Rumar, 1999).

Rear-end collisions are overrepresented in darkness (Moore & Rumar, 1999). This indicates that the rear lighting system does not offer the following driver sufficient information to avoid hitting a slow or stopped vehicle in night traffic.

3.5. Optical media

There are two general types of optical media: man-made and natural. Man-made media include the glass or plastics in windows and rearview mirrors. The only thing we can do about this factor is to make front windows as clear as possible and not too angled. Some windows and rearview mirrors sometimes are made with a tint to reduce unnecessary heat and glare.

The natural media causing problems are mainly fog, rain, and snow. Special fog lamps have been developed for this purpose (see Section 3.2).

4. THE SAFETY CONSEQUENCES OF REDUCED VISIBILITY

As indicated above, drivers generally consider the lack of road visibility the most negative effect of night driving as compared to daytime driving. From a societal point of view, the most serious negative consequences are fatalities and serious injuries. However, as discussed above, in the U.S. the main consequence of reduced visibility at night is an increase in collisions between vehicles and pedestrians (Sullivan & Flannagan, 1999).

The reason for this discrepancy between the individual perspective and the societal perspective is probably the fact that the driver has continuous feedback about the road visibility (Rumar & Marsh 1998), but almost no feedback about the poor visibility of unprotected road users such as pedestrians (Rumar, 1986). Pedestrians, at least in the developed world, are low probability events on roads in darkness. It has even been argued that if we could give the driver the same road visibility at night as in daytime driving, the risk increase for pedestrians would be even higher because the driver would then increase speed as a consequence of improved road visibility (Leibowitz et al., 1998).

In general, the highest risk of a severe injury is from collisions between motor vehicles and unprotected road users, with single vehicle crashes and head-on collisions a close second and third, respectively (SIKA, 2000).

The increase in the risk for automobiles hitting pedestrians at night is five to seven times higher as compared to corresponding daytime collisions (Sullivan & Flannagan, 1999). The risk increase is higher the higher the speed limit of the road. The increase in the risk for hitting other unprotected road users, such as bicyclists, is also high. At night, there are proportionally many more collisions between vehicles and animals, and many more single vehicle crashes (GES, 1999). The results from Sullivan and Flannagan (1999), however, seem to indicate that the overrepresentation of single vehicle crashes is an effect of alcohol and fatigue rather than darkness. The overrepresentation of animal crashes is a consequence of reduced visibility, alcohol, and fatigue, and but the primary reason is the increased exposure of animals at night. This crash type does not generally have very serious consequences for the car occupants. However, for some large types of animals, like moose, camel, and cows (which may weigh as much as 500 kg), animal crashes are serious, especially in many African countries.

At first glance, rear-end crashes appear not to have very serious consequences. There are no apparent major injuries in many of such crashes. However, recent research has shown that rear-end crashes often cause whiplash injuries to the neck and brain, which frequently cause life-long suffering (Moore & Rumar, 1999).

Collisions between cars and pedestrians are well documented to be the primary safety problem in darkness. However, for other crash types, the information is not available to make a substantiated ranking. In developing countries, most roads have a low standard concerning curvature, and surface, and little if any retroreflective marking; bicycles are not well equipped with lighting and retroreflective materials; and animals are much more frequent in roadways.

In summary based on the limited information available, we postulate that during darkness the following types of crashes are the most overrepresented and serious (in the order presented):

1. Collisions between vehicles and pedestrians
2. Single vehicle crashes
3. Collisions between vehicles and bicycles
4. Collisions between vehicles and animals
5. Rear-end collisions between vehicles

5. OTHER CONSEQUENCES OF INADEQUATE AUTOMOBILE LIGHTING

As indicated above, reduced seeing distances lead to reduced mobility because of the necessary lower speeds. Other effects are increased discomfort and stress on drivers due to the difficult visual tasks. For instance, if the headlights are inadequate, road signs and road markings will not be sufficiently visible and legible. This may lead to difficulties both in keeping on the road and in navigating. Combined, these negative effects of reduced visibility may lead to increased costs for the individual as well as the society—of special importance in poor countries. To date, the development of vehicle front lighting has placed too much weight on comfort, at the cost of safety, with the main criterion being to limit glare and not to maximize visibility.

6. WORLDWIDE DISTRIBUTION OF MOTOR VEHICLES

To be able to discuss the future development of worldwide automobile lighting, it is important to estimate the current and future distributions of vehicles in various parts of the world. Future development of automobile lighting should be based partly on the problems that the lighting design ought to reduce or eliminate. But these problems might look different in various parts of the world, where infrastructure, travel patterns, traffic characteristics, drivers, crash statistics, weather, climate, ambient illumination, education, economy, etc. may vary considerably.

The present (1996) distribution of vehicles in six regions of the world is shown in Table 1 (AAMA, 1998). As shown in Table 1, the majority of automobiles are in the rich, developed countries. However, the trend is that the rate of increase of cars is slowing down in industrialized areas such as North America, Western Europe, Oceania, and Japan (see Figure 3). It is increasing rapidly in Asia, and more slowly in Africa and South America. In the world as a whole, the number of cars is now proportionally increasing more rapidly than the number of persons.

Table 1
Distribution of vehicles (passenger and commercial vehicles) in different parts of the world in 1996 (AAMA, 1998).

Region	Number (millions)	Percentage
North and Central America	237.0	35.0
Europe	244.0	36.0
Asia	130.8	19.0
South America	29.8	4.5
Africa	16.4	2.5
Oceania	13.0	2.0
Total	**671.0**	**100.0**

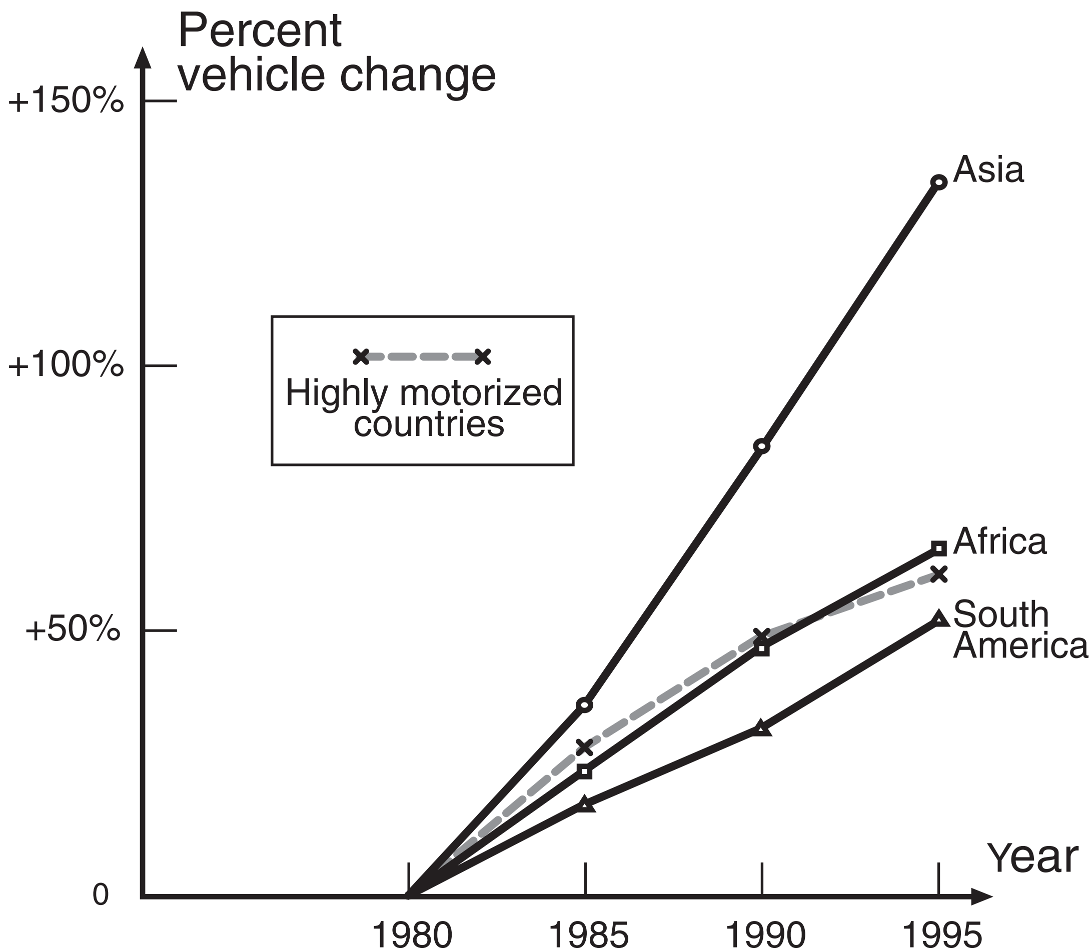

Figure 3. Proportional change in number of vehicles in different regions of the world, using the situation in 1980 as the baseline (AAMA, 1998). (Compare with Figure 4.)

7. PAST TECHNICAL DEVELOPMENTS IN AUTOMOBILE LIGHTING

Both automobile headlighting and signal lighting originally developed more by experience than by research. However, during the second half of the last century, it was gradually based more on systematic research (Moore 1998; Moore & Rumar, 1999). The conditions for which lighting has been developed have usually been representative of the traffic situations in North America and Europe and not of the traffic situations in the developing world.

Typical examples of lighting engineering trends include the development of adaptive headlighting and signal lighting (GTB, 2001). These systems rely, to a large extent, on sophisticated sensors and advanced optical systems. They are comparatively complicated and, although their performance could be good, the cost is high, the reliability is uncertain, and the maintenance requirements are unknown.

Considering that the future increase in traffic fatalities is likely to come exclusively from developing countries and that the proportional increase of automobiles is also larger in the developing world, more consideration should be given to the situation in the developing world. Current development of modern automobile lighting shows an opposite tendency—to introduce more complex designs that require frequent control and adjustment. The needs in developing countries are to a large extent different. Here simple, sturdy, reliable equipment is needed, as well as longer life and better lighting performance under extreme conditions.

Automobiles are one of the most internationally traded objects, which is one of the main reasons why automobile requirements and standards are comparatively harmonized in the world. Although there are two main automobile lighting standards in the world, the differences between these standards are not very large and in most cases it is possible to make one design that meets both standards. It would be very awkward for industry, national authorities, and consumers to have two truly different standards. Therefore, the goal should be to find a development strategy that could be accepted worldwide, both in highly motorized countries and in countries with less developed motorization.

But will it be feasible to find a technical design strategy for future automobile lighting that would be good both for highly motorized and newly motorized countries? If not, we either have to weigh the various demands against each other or produce two separate automobile lighting systems—one for the developed world and one for the developing world. Or we might accept the present worldwide lighting system and try to find other means to improve visibility conditions in night traffic in developing countries by modifying the lighting system within this framework. Another alternative would be to modify other factors (see Section 3) rather than automobile lighting itself, for instance a more frequent and efficient use of retroreflective materials.

8. THE SITUATION IN DEVELOPING COUNTRIES

Because of the difficulties in finding reliable crash statistics from developing countries in general, and night crash statistics in particular, this section is divided into two parts: crash statistics, and traffic characteristics. Information from both of these sources is then used as a basis for the analysis.

In 1995, the International Commission on Illumination (CIE) created a special Technical Committee (TC 4-37) to analyze traffic lighting needs in developing countries. The task of this committee is to set up a framework for standards for road transport lighting (automotive lighting, road lighting, and environmental lighting) in developing countries based on CIE standards. As far as is known the committee has thus far dealt mostly with road lighting. There is no report or draft report available yet on this work.

8.1. Crash statistics

Currently, about 1.17 million people are killed in motor vehicle crashes per year (World Health Organization, 1999). (The figure varies somewhat depending on the source.) Over 85% of all road traffic fatalities occur in developing countries or in countries in transition, in spite of the fact that only 40% of all motor vehicles are in those countries. Road crashes affect mainly the young, mobile population. Of all road crash fatalities, 67% occur to persons under 45 years of age. Only 10% occur to retired persons (Jacobs et al., 2000; World Bank, 2001).

The general trend of road traffic fatalities in the world is illustrated in Figure 4. As is evident from Figure 4, fatality problems are increasing rapidly in Asia, probably primarily because of the rapid motorization in this area. The increase in Africa and Latin America is somewhat slower. In the highly motorized countries, the fatality problem is gradually being reduced, partly due to countermeasures and partly to a smaller increase in the number of automobiles.

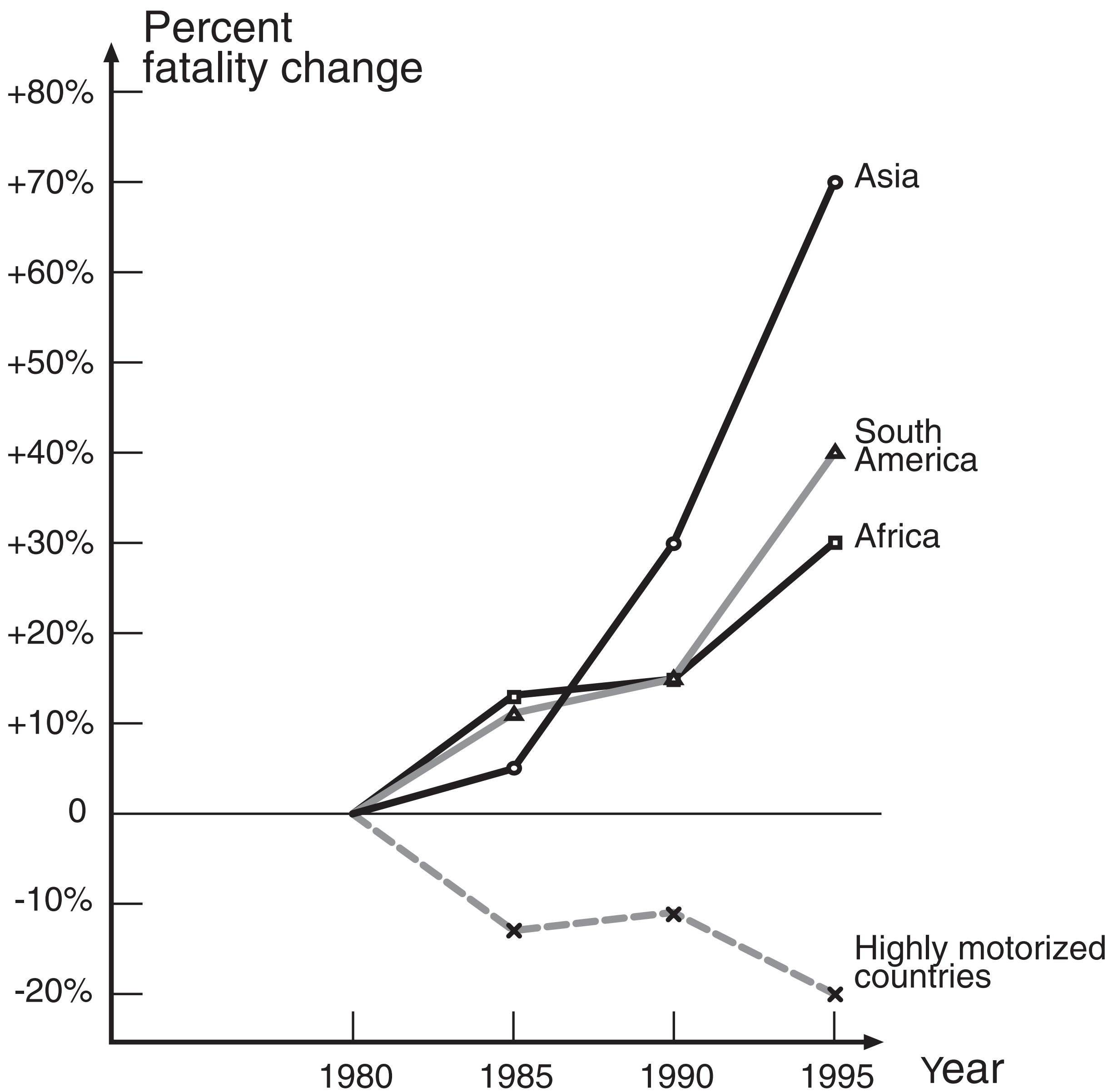

Figure 4. Proportional change in traffic fatalities in different regions of the world, using the situation in 1980 as the baseline (World Bank, 2001). (Compare with Figure 3.)

The road traffic fatality problem in the world is increasing over time, with the entire increase occurring in the developing world. Presently, road traffic crashes are the ninth most frequent cause of death in the world, and ninth most frequent cause of Disability Adjusted Life Years (DALYs). Based on the present development, the World Health Organization (World Health Organization, 1999) has estimated that by the year

2020, road traffic crashes will have climbed to be number six on the list of death causes and number three (!) on the list of Disability Adjusted Life Years.

In Section 5 it was stated that the most serious crash types in night traffic are collisions between cars and pedestrians, single vehicle crashes, collisions between cars and bicycles, collisions between cars and animals, and rear-end collisions. To what extent do these crash types appear in developing countries?

Detailed statistics on nighttime crashes are difficult to obtain for most developing countries. The proportion of night traffic in a country normally increases with the level of motorization. Therefore, the proportion of night traffic is normally higher in developed countries. Furthermore, the available statistics also show that the proportion of collisions between cars and pedestrians, and the proportion of pedestrian fatalities per population, is much higher in developing countries (Downing et al., 1993; Jacobs & Kirk, 1996; Sayer & Palmer, 1997; Mohan & Tiawari, 2000). In developed countries, pedestrian traffic fatalities are generally between 15 and 20%. In African countries, the corresponding proportion is more than 40% and in Middle Eastern countries it is more than 50% (see Table 2).

Table 2
Pedestrians killed in different parts of the world as percentage of all traffic fatalities (Downing et. al., 1993).

Region	**Number of countries included**	**Pedestrians killed as percentage of all fatalities**
Europe/USA	14	20
South East Asia	4	29
South America	1	31
Asia	3	42
Africa	9	43
Caribbean	3	44
Middle East	5	51

In developing countries, the general tendency is that the proportions of persons killed during the day and night are similar, while in well-developed countries, day fatalities are substantially larger than the night fatalities (IRF, 2000; UN, 2000). The reasons for this may be that in developing countries there is a greater exposure of pedestrians, less developed traffic control and road lighting, more alcohol and driver recklessness, less separation between vehicles and vulnerable road users, and less adequate vehicle lighting. However, the relative importance of these and other factors is difficult to establish.

The proportion of injury accidents that occur at night, on the other hand, show no systematic differences (25 to 35%) between developed and developing countries (IRF, 2000). But the proportion of pedestrians killed at night compared to day is higher in developed countries (about 50% (ECMT, 2000) as compared to about 30% in developing countries (Downing et al., 1993)). This difference in proportion is probably partly because developed countries (in contrast to developing countries) have solved many of their pedestrian daytime problems, and partly because the exposure of pedestrians during daytime traffic is so large in developing countries. But it seems safe to conclude that the number of pedestrians killed or seriously injured in night traffic is considerably higher in the developing countries than in the developed countries.

In fact, if the percentages mentioned above are applied to the existing fatality figures for pedestrians in night traffic in developed and developing countries, the result is that over 90% of all pedestrians killed in night traffic in the world annually are killed in developing countries.

In some Asian countries with many motorized two wheelers (e.g., in Malaysia and Indonesia), over 50% of the persons injured in road traffic are drivers or passengers of motorcycles or equivalent vehicles (Jacobs & Kirk, 1996).

As discussed above, a vehicle is much more dangerous in the developing than in the developed countries (see Figure 1). The fatality risk per vehicle in the worst developing countries is, in fact, about 200 times higher than the corresponding risk in the best developed countries. We also know that a vehicle is more dangerous at night. Unfortunately, due to lack of data, we can separate neither the risks between day and darkness nor between urban and rural areas. The proportions of nighttime and daytime single vehicle crashes, collisions between cars and bicyclists, collisions between cars and animals, and rear-end collisions in developing countries are not known.

Massie and Campbell (1993) showed that the difference in the crash risk between day and night is much greater for young drivers than for middle-aged or old drivers. This finding has an interesting implication for developing countries because their populations are substantially younger than in developed countries. However, as pointed out earlier, factors other than darkness play an important role in night traffic risks (e.g., alcohol and fatigue).

Consequently, there are a number of direct and indirect indications from crash data that the road safety situation in darkness is different between countries with different levels of motorization. Now let us look at possible differences in traffic conditions.

8.2. Traffic characteristics

Traffic patterns are very different in various parts of the world. In many Asian countries for instance, the proportion of two wheelers among motorized vehicles is very large, sometimes over 50% (Mohan & Tiawari, 2000; VTI, 2001), while in developed countries it is normally below 10%. In many of the Eastern European countries, the proportion of heavy vehicles is often 15 to 20% (VTI, 2001). In most developing countries the number of pedestrians on the roads is very high. However, we do not know how high it is.

The high number of pedestrian fatalities in the developing world has been mentioned earlier. One of the reasons is that there are more pedestrians on the roads, walking five times longer distances (Khisty, 1993). Two important questions are whether these pedestrians were killed in urban or rural areas, and whether they were walking along the road or crossing the road. The limited data available seem to indicate that a large proportion of the pedestrian causalities occurred when pedestrians tried to cross the road and that this happened to a large extent in the rural areas (Sayer & Palmer, 1997). This is very different from the situation in the developed world where only about 20% of the pedestrian causalities occur in rural areas (Downing et al., 1993).

The control and condition of vehicles also vary widely over the world. In the highly motorized countries, there is often a compulsory annual vehicle inspection or vehicle checks along the roads. Most service stations are qualified and equipped to carry out fairly complicated repairs. In developing countries, vehicles tend to be older, and drivers do not or cannot maintain them so well. Strict regular vehicle inspection and roadside checks are unusual. The conditions of the roads, the common overloading, and the climate are putting much strain on the lighting components. Lighting equipment is one of the more sensitive components of an automobile and therefore tends to degrade fairly quickly. Misaimed headlights, bulbs not working, and broken lenses are common in the developing world.

In the developed world, the misaiming of headlights is probably the most common deficiency, along with burned out lamps and general degradation. It is not known which is the most frequent and serious lighting deficiency in developing countries. Burned out lamps or otherwise nonfunctioning lamps probably come first, followed by misaiming and general degradation. Misaiming should be more serious with headlamps with sharp cutoff (e.g., ECE) than with headlamps with a softer cutoff (e.g., U.S.). Considering that commercial vehicles are more common both in traffic and in collisions in developing countries, and that commercial cars are often overloaded, there should be a natural tendency for headlamps to be aimed too high. From a pedestrian safety point of view, this is probably much better than having them aimed too low, which is often the case in the western world (Cobb, 1990).

In the developing world, the motorization level is lower and the proportion of commercial vehicles is larger. Furthermore, they are driven longer distances each year. It is no surprise that commercial vehicles are very often involved in traffic crashes in developing countries, often in over 80% of crashes (Jacobs & Kirk, 1996; Mock et al., 1999). However, the frequent involvement of commercial vehicles in crashes has a positive implication for remediation, because, vehicles owned by businesses and their drivers may be amenable to more control as well as to information and education.

Road networks also differ considerably in various parts of the world. In highly motorized countries, they are well developed with a high proportion of paved roads, well-developed road signing and marking systems, and road lighting along high volume roads and some motorways. In the less motorized countries, most roads are still gravel and the signing and marking systems are limited (VTI, 2001).

Data indicate that pedestrians walking against (facing) traffic have a lower risk of being hit than those walking with their back towards traffic (Downing at al., 1993; Sayer & Palmer, 1997). This is an argument for educating pedestrians how to walk along the road both in darkness and in daytime. An even more important topic for education is teaching pedestrians why and how they should wear retroreflective materials.

Finally, drivers in the developing world are different from those in the developed world. Generally, they do not have the education and experience of the drivers in the developed world. Traffic education is very limited and driver education, training, and examination are generally of a low standard. The illiteracy rate is high, often 10 to 50 % (VTI, 2001). The emergency and health care in developing countries is far from the standard in the developed world (Masheswari & Mohan, 1988). The number of persons per physician is often over 5,000 in developing countries, while it is normally below 500 in developed countries (VTI, 2001).

Which of these differences could be of importance for nighttime traffic? The following twelve differences in developing countries seem to be of primary importance for traffic crashes and automobile lighting:

1. More pedestrians on and along the roads
2. Limited use of retroreflective materials, both on road users and on and along the road
3. Motor vehicles older and more degraded, and lighting equipment in worse condition
4. Drivers less considerate to unprotected road users (Jacobs et al., 1981; Jacobs & Sayer, 1984)
5. Roads not paved and lacking road markings
6. Few and low quality road and street lighting installations
7. Education of drivers and other road users lower, and behavior less predictable (Jacobs, 1982)
8. More two wheelers in traffic (especially in Asia)
9. Proportionally more commercial vehicles
10. Road signing less developed
11. A much younger population
12. Underreporting of crashes generally higher, and probably especially higher during nighttime

9. ANALYSIS OF FINDINGS

We will start by analyzing the general driver visibility situation in the world as a whole. What are the most serious and most frequent visibility problems that drivers encounter in darkness? Next, we will analyze the situation in developing countries, and finally we will discuss changes in automobile lighting and other possible countermeasures.

9.1. General visibility problems

Visibility distances to dark obstacles are most probably both the most frequent and the most serious visibility problem facing drivers in night traffic. An uncomfortable question is whether we in the developed world value comfort (limited glare) so much that we accept killing a number of people in order not to cause discomfort. We know that visibility could be improved at the price of increased glare (Flannagan et al., 1996). But the regulations (especially those for the ECE) are very concerned with limiting the glare.

In daylight, visibility is only limited by physical obstacles and is normally several hundred meters. To be called minimally safe, the visibility distances should at least exceed 100 m, and preferably about 150 m. In reality detection distances on low beams are normally below 100 m and often shorter than 50 m. It is this situation that explains the high risk for pedestrians and, to some extent, bicyclists of being hit by a car in darkness. (Bicyclists are, however, better equipped with lighting and retroreflective materials.) This situation also explains why good road lighting reduces crashes by about 50%.

Seeing the road itself seems to be the second largest visibility problem in darkness (Rumar & Marsh, 1998). However, in the developed world, roads are equipped with at least some retroreflective markings, which substantially reduce this visibility problem. In developed countries, it is primarily in rain that the road visibility problem is still serious.

This situation explains to some extent the higher risk for single vehicle crashes in night traffic. However, more important reasons are probably alcohol and fatigue. In reality, these factors obviously interact to further increase the risk. We have reasons to believe that single vehicle crashes in darkness are more overrepresented in developing countries than in developed countries.

Collisions between vehicles and animals are also overrepresented in night traffic. However, this is probably more an effect of increased exposure than of reduced visibility.

The increased risk for rear-end collisions in darkness can probably be attributed to inadequate rear lighting systems. The present signaling is inadequate to convey to other motorists in darkness changes in speed and distance (Moore & Rumar, 1999). One of the reasons for this situation is that the accepted design is to have only one intensity level for each signal light (except rear fog lights), in spite of the fact that the level of ambient illumination varies considerably.

A special rear-end problem occurs in fog situations, both in daylight and in darkness. The fog situation creates visibility problems concerning the roads and obstacles on them. The special front fog lights are not efficient enough to both reduce the backscattering of the front headlights and to penetrate the fog tin order to give drivers some visibility ahead.

Consequently, vehicle lighting worldwide should be improved in at least four aspects: low beams, high beams, front fog lights, and rear lighting. Efforts are underway to harmonize both low beams and high beams (GTB, 2001). These new light distributions would improve, but not solve, the problems. Other efforts are in progress to make low beams adaptive to the situation in terms of curvature, load, road condition, bad weather, speed, etc. If implemented, these new headlights will improve the visibility situation further, but not entirely solve it. The visibility distances offered would still be too short.

Development has also started to make the signaling system, primarily the rear lighting system, more adaptive to the situations in which it is used.

9.2. The developing world

The mechanism of seeing in traffic—the way in which driver-vision, headlights, and signal lights work in darkness—should be identical in all parts of the world, as are human visual capabilities. But as indicated above, the traffic situations differ in many aspects. Are any of these differences so large or so important that they change the weight of the factors or the functioning of the system described in Section 3?

The most important differences in the developing world are the higher percentage of pedestrians and (to some extent) two wheelers, the lower education of drivers, the lower level of maintenance of the vehicles, and the lower quality of the roads.

The higher proportion of pedestrians and bicyclists is an argument for increasing illumination on low beams, at least along the near (right or left) road side where the unprotected road users are most frequent and are most at risk. The third-beam concept (a beam in between high and low beams) would address this problem. Such midbeams were suggested both in Europe and in USA in the 1970s. The intention at that time was to design a beam for usage on motorways or other multilane, limited-access roads. These beams offered considerably more light on the near road side. But crash statistics indicate that the highest injury risk in general, and for pedestrians in particular, is on two-lane roads. Maybe the concept of a midbeam could be revitalized but now with a slightly different purpose: to improve safety (particularly pedestrian safety) on two-lane rural roads.

Auxiliary lamps with that working principle have been produced and sold in developed countries (Rumar, 1997). Such an increase of illumination along the near roadside would preferably also cover a larger angle to the side to help drivers see unprotected road users not directly on the road. However, if illumination along the near road side is increased markedly, it would create increased glare for oncoming drivers, especially in curves. This would reduce visibility for drivers of vehicles that are not equipped with stronger headlights.

There is some evidence that there are considerable differences between the pedestrian collisions in the developing and developed world. In the developed world, most pedestrian collisions occur in urban areas, and pedestrian collisions in rural areas occur between cars and pedestrians walking along the road. In the developing countries, pedestrian collisions primarily occur in rural areas and mainly involve pedestrians crossing the road. This implies that more illumination along the near side of the road would not improve the situation very much. The illumination should cover the road in front as well as both sides of the road. Auxiliary front fog lamps would improve the situation. Another way would be to raise the aiming of low beams by, say, 0.5°. The drawback with that proposal is that accurate aiming is a problem in itself in developing countries. Such a high aim of the low beams would require accurate and frequent aiming.

Another way of increasing headlight illumination is to use more intense light sources. To begin with, halogen bulbs should replace incandescent bulbs. Furthermore, it may be a good idea to introduce high-intensity discharge (HID) lamps in developing countries, though to date these more intense light sources have been typically used for the upper-level luxury cars. An additional advantage with HID lamps is much longer life, but the drawback is a higher price and more complicated construction.

A solution to the problem with an adequate light distribution in headlamps could be to install intelligent (adaptive, advanced) headlights, which take road and oncoming traffic into consideration (Rumar, 1997; Sullivan & Flannagan, 1999). But such a solution does not, at least at this stage, appear to be good for developing countries because it would introduce a more complex and consequently more sensitive system, instead of making the systems more simple and robust. Introducing polarized headlights, which are not as technically sophisticated or complex, would be a better solution, though they would require a well-planned transition period and new legislative measures.

The high proportion of pedestrians and two wheelers could, however, also be taken as a strong argument for equipping all pedestrians and two wheelers with retroreflective materials. The effect of such an action would be much greater than an improvement to automobile headlights. However, the problem remains of how to equip a large proportion of pedestrians and two wheelers with retroreflective materials. Experience shows that a totally voluntary system is not feasible. It might be best achieved by integrating the material with some other necessary equipment, such as shoes, tires for two wheelers, or spokes or rims for bicycles.

A special problem in countries with a high proportion of motorcycles is that automobile headlights are considerably stronger than motorcycle headlights (low beams as well as high beams), which creates glare problems for drivers of the two wheelers. It would be difficult to solve that problem by modifying the automobile headlamp light distribution, which would need to be more controlled and reduced along the far road side, especially since the roads in developing countries are far from straight. Again, a possible solution would be polarized headlights.

The lower education level of drivers in developing countries could be taken as an argument to relieve drivers of some of their manual tasks. In night traffic, the special manual tasks of the driver are limited to switching on and off the lights, switching between high and low beams at appropriate moments, and switching on and off front and rear fog lights. All these tasks could be made automatic. Such concepts have been tested and exist in some vehicles. If that type of design works well, it would be an advantage for both developed and developing countries. According to recent informal information, India has introduced automatic switching between high and low beams because of extensive misuse of high beams. The question is whether these steps could be done both simply and effectively. Experience so far does not support such an idea, except for the switching the lights on and off when starting and stopping the vehicle.

Automatic on and off switching of lights has been tested extensively in connection with the introduction of daytime running lights (DRLs). With such a solution, DRLs would be of particular benefit for developing countries. According to accident studies, the road users benefiting most from DRLs are unprotected road users, the main target group in developing countries. The main reason for this reduction in daylight collisions is probably that the vulnerable road users detect the approaching car in their visual periphery better because of the higher contrast. Experiments support this hypothesis (Rumar, 1980). The question then is if DRLs would be accepted, considering the increased fuel consumption and the decreased life of light sources.

Another, more simple idea, based partly on the lower level of driver education and partly on the lower level of vehicle maintenance in the developing countries, would be to reduce the control and maintenance requirements on lighting equipment as far as possible. The fact that service stations are less frequent and less equipped in developing countries also supports such an idea. The maintenance requirements include replacing burned out bulbs, to re-aiming headlamps when necessary (often after switching bulbs), cleaning lighting lenses, and replacing worn out, cracked, corroded, or otherwise malfunctioning lamps or parts of lamps. Actions to reduce the need for such maintenance include using long-life bulbs (preferably lasting the life of the vehicle), making the lamps sturdy and rigid, making headlights self-aiming or in no need of aiming, and making cleaning automatic. Sealed beam headlamps with long-life filaments, or even HID and LED signal lamps, would not fully solve the problems, but would be beneficial.

The efficiency of LEDs is reduced in the high temperatures common in developing countries. Presently, the testing requirements specify 25˚ C, while in some of the developing countries temperatures over 50˚ C are common, which could reduce efficiency by about 50%. This problem could be solved by specifying requirements at about 55˚ C and reducing the voltage in conditions with lower temperatures (Jenkins, 2001).

Automatic cleaning of headlights (and signal lights) is feasible but, as with many of the other proposals, would introduce new components and thereby reduce total reliability. Polarized headlights would eliminate both the need for switching between high and low beams and the aiming of low beams. But they would introduce new problems at the same time as solving others.

The lower quality of the roads is probably more critical in darkness than in daytime because in daylight, when visual cues are redundant, the guidance is quite good. In darkness, however, when the visual scene is poor, good artificial illumination or artificial information, such as reflectorized road markings and road signs, are more important. Such information could be considerably enhanced by a more frequent and systematic use of good retroreflective materials. That would probably be more effective from a safety point of view than stronger headlight illumination. The only counterargument is that the guidance part of the visual performance must not be too good in relation to the recognition part because that might lead to drivers overdriving their detection distances (see Section 3.1).

9.3. Should automobile lighting be modified worldwide?

For safety reasons some automobile lighting characteristics should be changed worldwide, in developed and developing countries. The following functions seem to require substantial improvement:

1. A low-beam system offering substantially longer visibility distances (preferably greater than 150 m)
2. A front fog lighting system with less backscattering and improved transmission characteristics
3. A signal-lamp system with adaptive intensities
4. A rear-lighting system with more differentiated and dynamic signal characteristics

The most urgent of these improvements is a better low-beam system, as the major risk increase in darkness occurs for pedestrian collisions because drivers on low beams do not detect pedestrians far enough in advance to stop. Currently, about 200,000 pedestrians are killed in night traffic in the world each year. Over 90% of these fatalities occur in developing countries. Traffic volumes and safety problems in developing countries will probably increase faster than effective countermeasures will be introduced. Consequently, time is a critical factor here. Further delays in modifying vehicle lighting will cause many fatalities.

Unfortunately, there are few direct crash data to base proposed countermeasures on, but a number of indirect arguments concerning differences in night traffic between developing and developed countries are available to support this view. It would be technically and economically easier to introduce possible countermeasures in the developing world because the vehicle population is still relatively small.

The crash type in developing countries that seems to differ most from the crash situation in developed countries is pedestrian collisions. The situation in night traffic in developing countries is in this respect not different from the daytime crashes. In other words, pedestrians are the largest fatality group in developing countries in darkness as well as in daytime. Other large safety problems in darkness are single vehicle crashes and, in countries where two wheelers are common, crashes between vehicles and two wheelers. There are also indications that crashes between vehicles and animals are a considerable safety problem in darkness in many developing countries (VTI, 2001). However, not many hard data support the statement that these crash situations are especially pronounced and different in developing countries in darkness. Most of the arguments are based on indirect information.

Another argument for focusing future improvements of safety in traffic in darkness on automobile lighting is that the major increase in automobile and traffic volumes is going to take place in developing countries and countries in transition. More vehicles will be exported to developing countries, though for many years to come the majority of vehicles will still be in traffic in the developed countries.

Let us assume that the traffic situation in developing countries is, indeed, different from what is typical of developed countries; that could be an argument for having two different lighting systems. However, the arguments for different lighting systems have to be very strong because of trade, business, and user needs for a worldwide automobile standard. It would seem that we lack such strong arguments.

Consequently, two lighting standards are not justified. However, the standard should be broad enough to encompass slightly different designs to be used in developing countries. The differences would be primarily in making the versions for the developing countries simpler and less sophisticated, more reliable and easy to handle, more sturdy and durable, and with longer life. Also, for instance, aiming of beams could be different even if beam patterns would be identical.

In some aspects, automobile lighting in developing countries should represent the minimum version of what the worldwide standard requires. But it should not degrade from that level but maintain its performance even in difficult situations. However, fairly new applications should also be introduced in some circumstances. For example, rear fog lights could be worth introducing in countries where fog is frequent. (It is interesting to note that China has recently introduced compulsory rear fog lights.)

Signal lights are not a problem in darkness, but in broad daylight and in reduced visibility conditions such as fog. Therefore, the intensity of the signal lights should be adaptive to the ambient illumination and to general visibility conditions (Moore and Rumar, 1999). The larger proportion of unprotected road users in developing countries could be an argument for developing vehicle signals that are better adapted to the needs of vulnerable road users. The main disadvantage of present signal lights from the perspective of cyclists, motorcyclists, and pedestrians is that they are situated too low to be conspicuous in many situations where the unprotected road user is parallel to the vehicle. The lights should be placed higher (e.g., turn signals should be on the top of the A-pillar and brake lights and rear turn lights at the top of the rear of the car [compare CHMSL]). The light sources in signal lights should be the reliable and low-energy consuming LED, provided the efficiency is good enough in the climate in question. According to van den Berg (2001), LEDs with intensity high enough for any signal lamp will be on the market shortly.

A key question is how a measure with big potential for visibility improvement, but which is difficult to implement, should be weighted against a measure with a smaller effect but a larger probability of being implemented (e.g., more retroreflective materials to improve pedestrian visibility versus a better headlighting system). Another equally difficult weighting problem is between polarized headlights and improved low beams. Retroreflective materials and polarized headlights would easily triple detection distances. Improved headlighting would probably, in the best case, increase pedestrian detection distances by about 50%. But, it is difficult to make pedestrians wear retroreflective materials, and it is difficult to introduce polarized headlights. An improved low-beam system would be more likely to be quickly introduced on a general level.

One way to solve the weighting problem could be to apply different measures with different time perspectives. The first thing to do could be to convince pedestrians that certain behavioral patterns would reduce accident risks in darkness (e.g., walking against the traffic). The second step could be to convince pedestrians and cyclists to wear retroreflective materials and to make these materials readily available. Both of these actions would require some time to implement. The third thing to do in a longer perspective could be to improve vehicle lighting—primarily headlighting. Here an improved low beam could be a first step, followed by polarized headlights. But it could also be possible to go directly for polarized headlights.

9.4. Could visibility in darkness be improved by means other than automobile lighting?

There is little hope of achieving improvements of visual performance in traffic darkness. Drugs and filters have not been able to improve visual performance. Electronic vision enhancements (e.g., radar, IR) are possible, but these solutions are sophisticated, complicated, expensive, and thus very much the opposite of what we want in developing countries.

Increased use of street lighting would solve many of the visibility problems in darkness. It is, however, the cost of implementing and maintaining street lighting that prevents it from being a general solution in the normally poor developing countries.

Treating visual targets offers an obvious potential solution. If equipped with good retroreflective materials, their visibility would increase much more than could be achieved with modified headlights. The problem is marking all road users (primarily pedestrians and two wheelers), curves, roads, signs, animals, etc. Especially important is that the vertical visual targets be equipped with retroreflective material. In other words, the retroreflectorization should not be limited to the horizontal road scene, as the part of visual performance that is seriously degraded in darkness (recognition) needs more help than the part that is not equally impaired (guidance).

The optical media are generally not different in developed and developing countries. However, because of the large percentage of unpaved roads and frequent fires, smoke, and dust in developing countries rear fog lights might prove especially helpful. Insects are more common in developing countries, and thus there would be benefits from more reliable and durable windshield wipers and headlight cleaners.

10. CONCLUSIONS

Current automobile lighting is based primarily on the road and traffic situations typical of the developed world. This study investigated what direction future automobile lighting should take, based on a worldwide perspective that takes developing countries into consideration. The majority of road traffic fatalities occur in developing countries or in countries in transition, and that is where an increase of traffic fatalities will occur in the future. The most serious safety concern during darkness involves pedestrian collisions.

In the future, the vast majority of all automobiles will still be driven in developed countries. However, the future increase of automobiles will take place in developing countries and in countries in transition.

Unfortunately, accident statistics of developing countries do not permit any detailed analysis of crashes that occur in darkness. The availability and the reliability of the statistics are inadequate. Therefore much of the analysis here was based on indirect information concerning traffic situations, vehicle populations, driver characteristics, and roads in developing countries.

In order to develop well-substantiated proposals for changes to the traffic system that would improve safety in traffic during darkness, considerable amounts of new information are required in the following areas:

- Crash statistics concerning day/night, urban/rural, lighted/dark, pedestrian/cyclist/motorcycle/car/heavy vehicles, commercial/private vehicles
- Exposure data concerning the above
- Vehicle characteristics, especially those concerning attributes and condition of lighting
- Behavioral data concerning drivers, pedestrians, and other road users during darkness

The present analysis shows that in the developing countries the following situations require special actions to improve nighttime visibility conditions:

1. More pedestrians on and along the roadways
2. Limited use of retroreflective materials, both on road users and on and along the road
3. Motor vehicles older and more degraded, and lighting equipment in worse condition
4. Drivers less considerate to unprotected road users
5. Roads not paved and lacking road markings
6. Few and low quality road lighting installations
7. Education of drivers and other road users lower and behavior less predictable
8. More two wheelers in traffic (especially in Asia)
9. Proportionally more commercial motor vehicles
10. Road signing less developed
11. A much younger population

Most of the recommended actions concern automobile headlights, while some specific situations would require special designs of automobile signal lights. However, most of the visibility improvements in traffic in darkness could probably be solved in a more cost-effective way by more extensive and systematic use of retroreflective materials. The question is how realistic it is to expect that a majority of pedestrians will wear retroreflective materials. Other potential improvements involve lower speed limits during night traffic, as well as driver training, education, and information.

It is difficult to establish precisely what effects these proposals would have on safety. Thus, the following three tables rate each proposal by potential effectiveness and ease of implementation, using a three-point scale for each criterion.

Tables 3A and 3B summarize critical visibility situations and suggested solutions related to *nighttime visibility* problems *worldwide*. Because the main difference between daylight traffic and traffic in darkness is the sharply increased risk for pedestrians, most of these general proposals aim to reduce this risk. Table 4 shows the corresponding situations relevant to *signal lighting worldwide*.

Tables 3A and 3B
Lighting (3A) and nonlighting (3B) countermeasures for nighttime visibility problems worldwide. The potential effectiveness and ease of implementation of these countermeasures are rated on three-point scales, where ★★★ corresponds to the highest potential effectiveness and easiest implementation.

Table 3A
Lighting countermeasures.

Traffic/crash situation	Countermeasure	Potential effectiveness	Ease of implementation
General	Improved low beams	★★	★
	Adaptive headlamps	★★	★★
	Midbeam	★★	★
	Polarized headlamps	★★★	★
	Front fog lamps	★	★
Back up crashes	Improved backup lamps	★	★★

Table 3B
Nonlighting countermeasures.

Traffic/crash situation	Countermeasure	Potential effectiveness	Ease of implementation
General	Systematic use of retroreflective materials	★★★	★★
	Training and education	★	★★
	Lower speed limits during nighttime	★★	★
	Short-wave detection beams (e.g., IR, NIR, radar)	★★	★

Table 4
Countermeasures for vehicle signaling problems worldwide. The potential effectiveness and ease of implementation of these countermeasures are rated on three-point scales, where ★★★ corresponds to the highest potential effectiveness and the easiest implementation.

Traffic/crash situation	Countermeasure	Potential effectiveness	Ease of implementation
General	LED light sources for signal lights	★	★★
	Novel rear-signaling functions	★★	★★
	Day/night signal intensities	★★	★

Tables 5A and 5B provide a corresponding summary for situations relevant to *nighttime visibility problems* of particular importance in *developing countrie*s. Again, reducing the risk of pedestrian collisions in darkness is the primary goal of these proposals. Table 6 shows the corresponding situations relevant to *signal lighting* in *developing countries*.

Tables 5A and 5B
Headlighting (5A) and nonlighting (5B) countermeasures for nighttime visibility problems of particular importance in developing countries. The potential effectiveness and ease of implementation of these countermeasures are rated on three-point scales, where ★★★ corresponds to the highest potential effectiveness and the easiest implementation.

Table 5A
Lighting countermeasures

Traffic/crash situation	Countermeasure	Potential effectiveness	Ease of implementation
General	Special lighting regulations, more illumination	★★	★
	More reliable, longer life, less maintenance	★★★	★
	HID lamps	★★	★
	Higher low-beam aiming	★★	★
	Automatic switching of headlights	★★	★★
	Sealed-beam lamps	★★	★★
	Soft cutoff	★	★★
Pedestrian and cyclist collisions	Stronger road side illumination	★	★
	Two front fog lamps	★★	★★
Glare to two-wheel vehicles	Control glare	★	★
Single vehicle crashes	Stronger illumination	★	★
Collisions with animals	Stronger illumination	★	★
Backup crashes	Improved backup lamps	★	★★

Table 5B
Nonlighting countermeasures.

Traffic/crash situation	Countermeasure	Potential effectiveness	Ease of implementation
General	Systematic use of reflective materials	★★★	★★
	Improved training and education	★	★★
	Stricter vehicle inspections of personal vehicles	★	★★
	Stricter vehicle inspections of commercial vehicles	★★	★★
	Training and education of professional drivers	★★	★★
Pedestrian and cyclist collisions	Reflectorization of pedestrians and cyclists	★★★	★★
Single vehicle crashes	Improved road markings	★★	★★
Collision with animals	Reflectors for domestic animals	★	★★

Table 6
Countermeasures for vehicle signaling problems of particular importance in developing countries. The potential effectiveness and ease of implementation of these countermeasures are rated on three-point scales, where ★★★ corresponds to the highest potential effectiveness and the easiest implementation.

Traffic/crash situation	**Countermeasure**	**Potential effectiveness**	**Ease of implementation**
General	Special lighting regulations	★	★
	More reliable, longer life, less maintenance	★★★	★
	Daytime running lights	★★	★★
Interaction with unprotected road users	Signal lights placed higher on the vehicle	★★	★★
Rear-end crashes in poor visibility	Rear fog lights	★★	★★

Most of the suggestions above are not supported by hard scientific data such as experimental studies or reliable crash statistics. Therefore, before introducing any of them, they need to be further substantiated and evaluated.

The problems and countermeasures common worldwide (Tables 3A, 3B, and 4) are the most important to solve from a safety point of view. Problems and counter measures that are more specific to developing countries (Tables 5A, 5B, and 6) have second priority. In both cases, improved pedestrian safety in darkness is the main problem. The problems and measures more specific to the developed world (not explicitly listed) get third priority.

Road traffic causes about 1.17 million fatalities worldwide each year (World Health Organization, 1999), and this figure increases every year. The future increases will depend on the situation in the developing world. About 15% of all traffic fatalities occur in the developed world (World Bank, 2001), where about 20% of the road fatalities are pedestrians (Downing et al., 1993) and about 51% of the pedestrian fatalities occur in darkness (ECMT, 2000). About 85% of all road traffic fatalities occur in developing countries (World Bank, 2001) and about 65% of these fatalities are pedestrians (World Bank, 2001). About 30% of the pedestrian fatalities in the developing world occur in darkness (Downing et al., 1993).

Although these numbers are only approximate, they permit an initial estimate of the magnitude of the problem of pedestrian deaths in darkness worldwide. A calculation based on these figures implies that about 200,000 pedestrians are killed worldwide in night traffic every year! If we assume that the pedestrian risk at night is about four times the risk during the daytime, we conclude that about 75% of these fatalities could have been saved if visibility at night had been as good as during daylight.

We will not solve this problem overnight, and we will not solve this problem with a silver bullet (i.e., with one single countermeasure). Improving pedestrian safety in traffic in darkness requires implementing many of the above proposed countermeasures, some (such as information and education) immediately, others (such as pedestrian reflectorization) fairly soon, and some (such as improved headlighting) in a somewhat longer time frame. But all of these activities have to start now.

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