THE STUDY OF BRIGHTNESS LEVELS OF HEADLIGHTS OF OPERATING VEHICLES IN SRI LANKA

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ABSTRACT

Driving an automobile is primarily a visual task, and vision contributes as much as 90% of the information required to drive (Alexander and Lunenfeld 1990). At night time, the required visibility level of roadway is created artificially by vehicle headlights or street lighting or both. Illuminating roadway using vehicle headlight is the most common method at night time driving, but too much light and improper lighting may result in glare, which causes visual discomfort and a diminished ability to see the roadway. In another way, insufficient light causes problems for drivers to see the information needed or potential hazards in the roadway.

There are many different kinds of headlight systems in operating vehicles (imported from various manufactures of various countries in various time periods) in Sri Lankan roads including the oldest systems and the most upgraded systems. Generally, a halogen headlamp system which is commonly found in Sri Lankan roads is expected to be performed well for about 10 years in normal conditions. But the percentage of older vehicles more than 10 years is higher in Sri Lankan roads.

Different organizations all around the world have introduced regulations on vehicle headlights not only for the vehicle manufactures but also for the drivers. Comparisons show that the current Sri Lankan regulations have not been updated to address the issues. Even though the road surfaces have been improved so that encouraging drivers to drive faster, other factors have not been considerably improved. Therefore, introducing of the new regulatory system should be considered to control this vast variety and mitigate the risk and un-comforting condition. The intention of this research is to identify brightness levels of operating vehicles in Sri Lankan roads based on Federal Motor Vehicle (USA) regulations which may helpful in above discomfort circumstances.

The experimental brightness levels of headlights were measured by simulating the testing arrangement at a work station free for night time. The readings were taken in terms of “Lux” and maximum and minimum levels of brightness were identified.

The results of field tests revealed that the majority of operating vehicles has less brightness levels compared with the minimum brightness level specified in the Federal Motor Vehicle Regulation. Vehicles older than five years were failing to produce a sufficient intensity for low beam operation compared to the FMVSS limitation. Further, it was revealed that the most headlights of operating vehicles are miss-aimed and illuminate unnecessary regions which cause inconvenience to the drivers of oncoming vehicles.

Also, it was revealed that the driver's attention to the maintenance of the headlight system of their own vehicle is very poor.

Finally, this research suggests introducing regulations to minimize or mitigate adverse effects of headlights by periodically evaluating headlight systems of operating vehicles based on a proper regulator system in Sri Lanka.

Key words: Headlight, High beam, Low beam, Illumination

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LIST OF ABBREVIATIONS

FMVSS	Federal Motor Vehicle Safety Standards
UNECE	United Nations Economic Commission for Europe
CMVSS	Canada Motor Vehicle Safety Standard
LHS	Left Hand Side
RHS	Right Hand Side
GRE	Group Rapporteurs Eclairage
US	United States
UN	United Nations
HPSV	High Pressure Sodium Vapor
HID	High intensity Discharger

1 INTRODUCTION

Headlights play the most important part in illuminating the roadway at nighttime driving. It is expected to illuminate enough the roadside information, potential hazards, pedestrians, animals and let others on the road know where you are while not disturbing the eyes of drivers of oncoming vehicles. Most countries have established regulations to formalize the use of vehicle headlights. It's not only the usage, but also maintaining the headlight system is also important as per to function properly, that they expected to be function at brand new condition. Current Sri Lankan vehicle regulation does not address headlight usage effectively. There is growing public concern related to various aspects of headlight glare associated with nighttime driving. The complaints are here more frequently regarding improper headlights in operating vehicles in Sri Lankan roads. Too bright headlights and less bright headlights are commonly observed and they create uncomfortable and dangerous circumstances.

1.1 Background of the Study

The quality of output light of a headlamp system of an automobile is assessed by brightness level, aim of the beam and color of the beam. Vehicle manufacturers are regulated to produce a quality headlight system by relevant regulation such as UNECE regulations. The headlamp system of an automobile should be checked while it is operating, to maintain the expected quality. Federal Motor Vehicle Safety Standards (FMVSS) have separate chapter of regulation on vehicle headlights; FMVSS-108 regulations related to lamps, reflective devices, and associated equipment of automobiles administered by the United States Department of Transportation's National Highway Traffic Safety Administration. Canada's analogous regulation is called Canada Motor Vehicle Safety Standard 108 (CMVSS 108), and is very similar to FMVSS 108. Those lighting standards are very complex and are difficult to interpret even for specialists due to the complexity of the subject. But referring related literatures, the allowable maximum and minimum light output of a headlamp system can be extracted.

The quality of output light of a headlamp system may be changed with time passes due to various reasons like oxidization of lances, physical damages of lenses and bulbs, varying of supply voltage and many more. Many developed countries have introduced regulations to

check and correct the light output of vehicles, even the old vehicle population is very low in those countries. It is a must to update the Sri Lankan regulations to fulfill same aspects because the variation of quality of output light is too high. People have less attention on maintaining of headlamp systems, even though the vehicles are very old. Also, people tend to use low quality productions in replacing of damaged parts of headlight system. The greatest issue is that there is no guarantee even on a brand new vehicle of some manufactures. Therefore, introducing a regulatory system to local condition is vital at the current situation.

The majority of the Sri Lankan road network is consists of two-way two-lane roads lead through rural areas which street lighting is less like to present, though road surfaces have been improved recent past so that drivers are encouraged to drive faster. Roadway geometry can be complex and less carriageway width may present and oncoming traffic is more likely to be closer to a driver's line of sight. It is commonly observed that the access to the roadway is less restricted and pedestrians can be closer to the traveling vehicle. Traffic signs and road markings are less like to present in secondary roads and the un-even road surfaces make the conditions worse. With all above factors, poor discipline of the drivers and adverse weather condition which are common in Sri Lankan context can increase the risk at night time driving.

1.2 Objective

The objectives of this study are to;

- Identify the international standards on headlamp systems
- Evaluate the current brightness level of the headlights in operating vehicles in Sri Lanka
- Analyze the brightness levels comparable with international standard limits
- Propose recommendations regarding brightness level

2 LITERATURE SURVEY

Research and studies on regulations on headlamp systems of automobiles have been carried out since the first noticeable improvement, in the U.S. occurred in 1906 when acetylene headlamps appeared. Headlamp technologies have been developed remarkably with the help of findings of research and studies. Many countries have upgraded their regulations on headlamp systems simultaneously and various international organizations have established separate bodies to act on this particular subject, such as GRE (Group Rapporteurs Eclairage) established by the UN.

2.1 History of the headlamp regulation

The first lighting regulation was adopted in the state of Massachusetts in U.S. on October 27, 1915 (Devine, 1921, p. 507):

This regulation provided that wherever there was not sufficient light on the highway to make all substantial objects visible for a distance of at least 150 feet (45.7m), the lamps which a motor vehicle was required to display, should throw sufficient light ahead to make clearly visible any such object within the specified distance. They provided further that any light thrown ahead or sidewise should be so directed that no dazzling rays should at any time be more than 3.5ft (1.1m) above the ground 50ft (15m) or more ahead of the vehicle, and that such light should be sufficient to show any substantial object 10ft (3m) on each side 10ft (3m) ahead of the vehicle.

Along with technical product developments, standards and regulations were also being written. In 1918, the first joint IES (Illuminating Engineering Society) and SAE (Society of Automotive Engineers) specification relating to the optical performance of headlamps was developed. Perhaps the first documented study of headlamp performance was done in 1920 (Devine, 1921). Thirty headlamps were obtained and photometered in a test laboratory developed for the state of Massachusetts. These headlamps were then used in road tests to compare laboratory photometry with on-road performance.

Another early study was conducted by engineers at GE Nela Park in Cleveland (Magdsick and Falge, 1921). Observers determined the amount of light in various parts of the beam pattern that “would satisfy the driver from the standpoints of safety and afford a reasonable

degree of convenience in operating the car" (p. 483). This was a thorough and comprehensive study conducted in the city and country roads, and in different weather conditions. The study also included comments regarding the legislative activities in several states of U.S. During the decade of 1920-1930, inspection stations were established in various states of U.S., with the requirement that drivers of vehicles to obtain a certificate indicating the headlamps were properly aimed, had sufficient light output, and did not cause excessive glare.

The early developments regarding vehicle headlamps were similar in the U.S. and Europe. Bulbs, lighting components, and beam patterns were essentially the same (Devaux, 1970; Meese, 1972; Maurer, 1980). However, in the 1920s two different approaches to automotive lighting began to appear.

(1) Primary emphasis: Develop as much light as possible to maximize seeing ahead of the vehicle. Secondary emphasis: Consider the other driver and try to do something to minimize glare. (U.S. Philosophy)

(2) Primary emphasis: Do whatever is necessary to minimize glare in the other driver's eyes. Secondary emphasis: Try to make sure there is available light to drive. (European Philosophy)

Before 1924, all headlamps generated a single beam pattern, best described as a spot beam resembling today's high beam. In the middle twenties the first two-beam system was developed (Moore, 1958). The two-filament automotive bulb was invented, which enabled a high- and low beam pattern to be created in one headlamp assembly

By the middle 1930s, many states of U.S. had lighting regulations intended to control glare. Creative inventors had developed diffusers, intensity reducers, masks, etc., in an attempt to deal with glare. In 1940 the maximum intensity per vehicle was raised from 50,000cd to 75,000cd (Oliver, 1980).

Headlamp beam patterns were different in the U.S. and Europe. Lighting engineers, lighting manufacturers, and vehicle manufacturers organized a series of tests to try and develop a common beam pattern (deBoer, 1955; deBoer, 1956; Kazenmaier, 1956; Devaux, 1970). These tests were the origin of the "Groupe de Travail-Bruxelles" 1952 (GTB)—an international group of experts from the light source, lighting-device, and vehicle manufacturers.

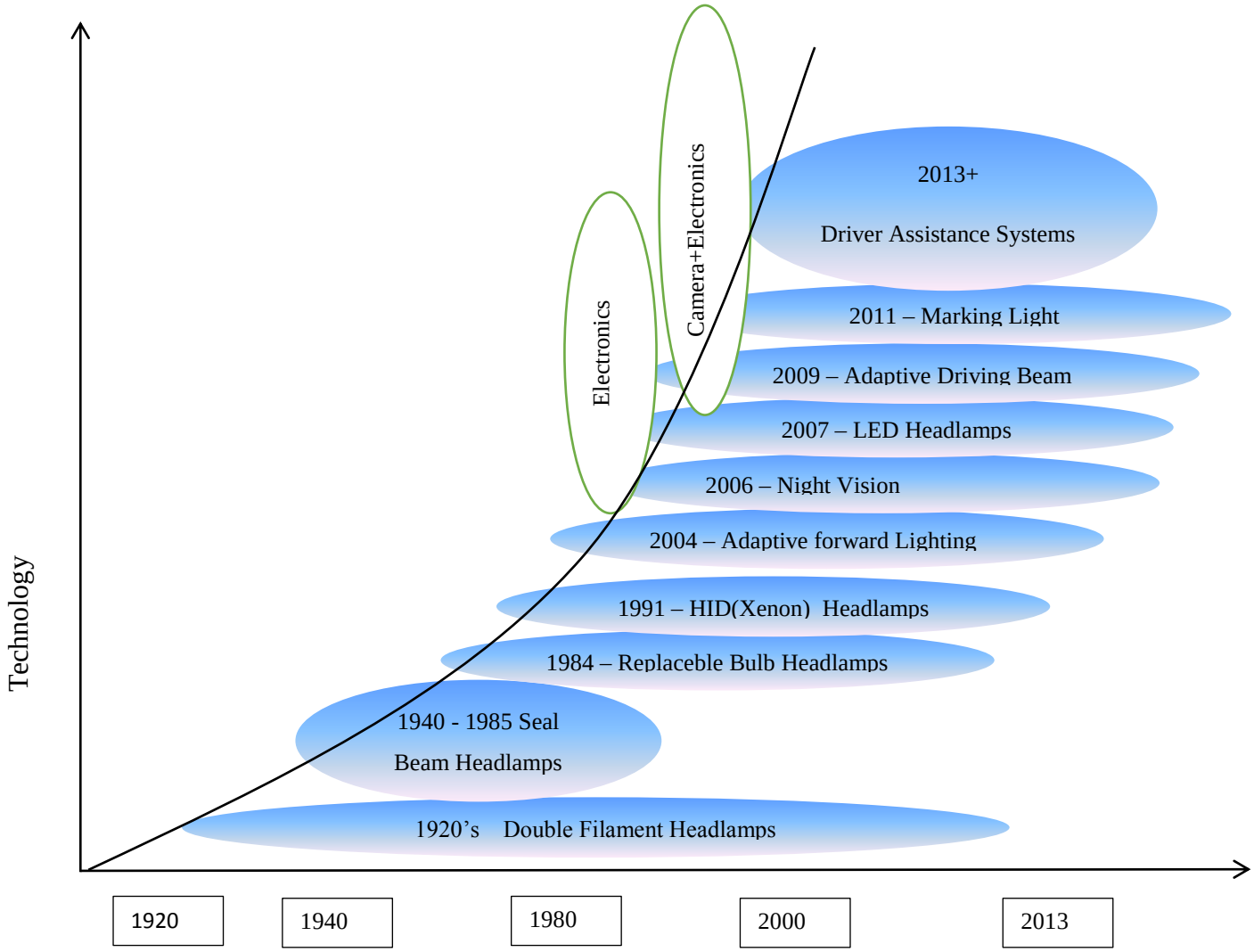


Figure 2-1 Development of Headlamp Technology

Source: Headlamp History and Harmonization, David W. Moore

2.2 Relationship between glare and driving performance

Transport Lighting Group, Lighting Research Center, New York (John Van Derlofske, John D. Bullough, Peping Dee, Jie Chen and Yulio Akashi)

Typical "glare illuminance" of oncoming headlights, range from 0 to 10 lux in normal driving conditions. Bhise et al. cite research stating that 0.1lx at the eye is the threshold for glare, when the illuminance begins to become uncomfortable. An illuminance of 1 to 3 lux is

sufficient to cause drivers to flash their own headlights to signal to oncoming drivers. A value of 3 to 10 lux is close the illuminance at which discomfort becomes unbearable.

2.2.1 Spectrum

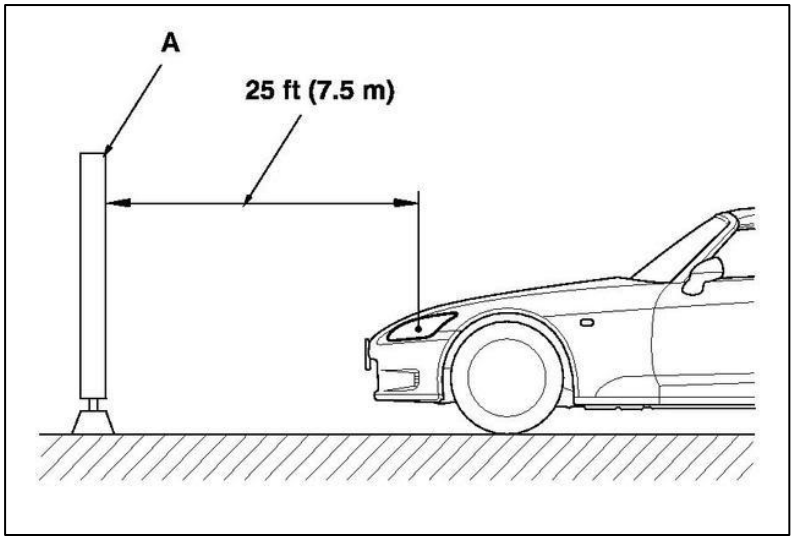
It has been found that source spectrum has little effect on disability glare. This is not surprising since disability glare is a foveal effect, where sources matched for photo-pic illuminance will produce similar effects. Spectrum does; however, appear to play an important role discomfort glare under nighttime driving conditions. This is a phenomenon that has been appreciated since at least the 1930s, when it was reported that discomfort glare was caused more by "Blue" than by "Yellow" light. The effect of spectrum on discomfort glare for nearly monochromatic, highly perceived as less glaring (from a visual comfort perspective) than green or blue sources. For nominally white light sources, such as halogen and HID headlamps, a series of studies has confirmed that typical HID headlamps, viewed in an oncoming situation, result in greater discomfort than typical halogen headlamps.

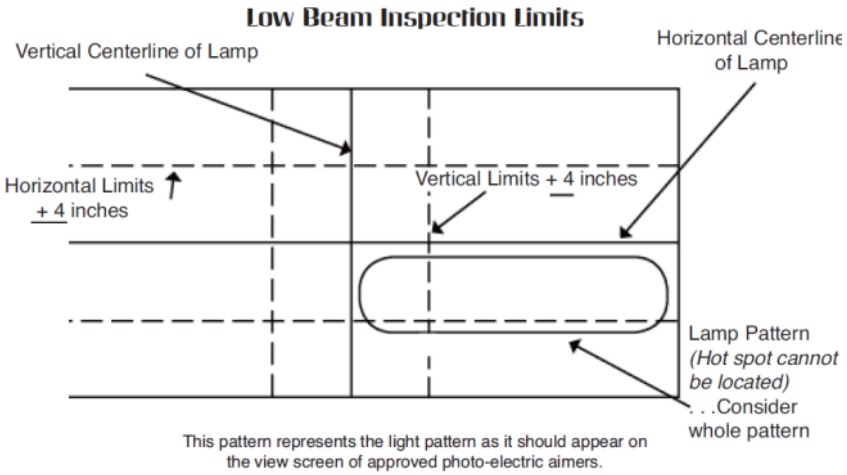
2.2.2 Size of Headlamp

The effect of headlamp size on disability glare has not been studied in great detail. Flannagan compared glare sources subtending 0.3 and 0.6 degrees and found no difference between them in terms of disability glare. More research has been conducted on the effects of source size on discomfort glare. It appears the effect of size is small, when compared to that of the illuminance produced at the eye. Alferdinck and Vakevisser investigated a large range of source sizes (From 0.0006 to 0.15 degrees) and showed that the maximum difference in discomfort attributable to size was equal to about 1 De Boer unit. Flannagan found no effect of size when going from 0.3 to 0.6 degrees, while another study using the same sizes showed a very small effect of size.

2.2.3 Method followed

This study had three primary components: for a constant glare source spectra and source size, glare was measured for different illuminances at the eye, for a constant glare illuminance at the eye and source size, glare was measured with three different glare source spectra: HID, Halogen and Blue-filtered halogen, for a constant illuminance at the eye and a constant spectra, glare was measured for different light source sizes. Subjects were seated in a black 1995 mercury Tracer and performed a tracking task cognitively similar to driving.





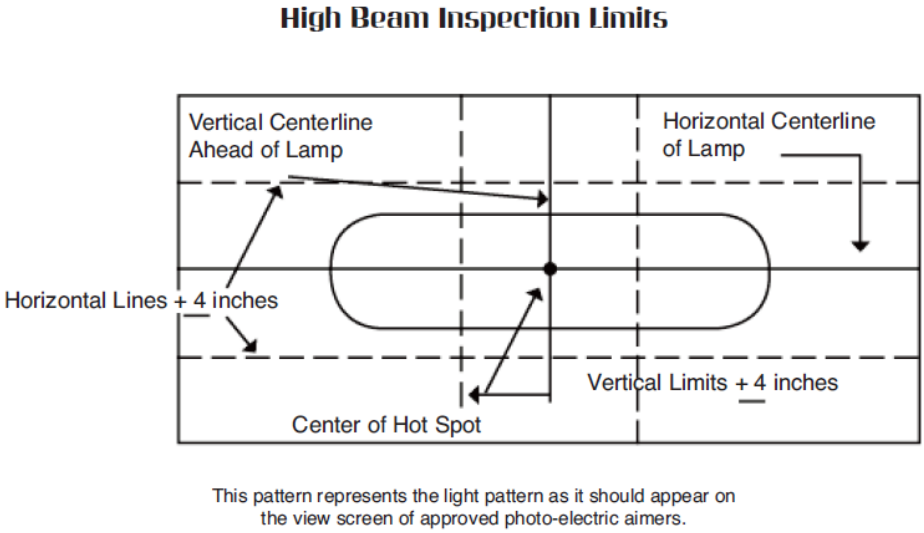


Figure 2-2 Instrumental setup followed in finding relation between glare and driving performance

Source: "Relation between Glare and Driving Performance" by Transport Lighting Group

2.3 Vehicle equipment and inspection regulations, Department of Transportation, Commonwealth of Pennsylvania (PUB-45)

Sub-chapter E - Passenger Cars and Light Trucks, 175.66. Lighting and Electrical Systems

This regulation chapter describes the overall regulations related to lamps of Passenger cars and Light trucks covering areas such as condition of Lamps and Switches, Lighting Standards, headlamp System, Total Candlepower, Other Required Lamps, Illumination, Except headlamps, Fog Lamps, and Auxiliary driving Lamps, Condition and Position of Lamps, Ornamental Lamps, Back-Up Lamps, Registration Plate Lamp, Antique Vehicle Lighting Exemption and Battery Fastening.

This regulation states clearly the intensity limitation for operating vehicles (Passenger cars and Light trucks) in the state of Pennsylvania.

The headlamp low beam minimum candle power shall not be less than 15,000.

The headlamp high beam minimum candle power shall not be less than 20,000

The total candlepower for head lamps and auxiliary lamps shall not exceed 150,000.

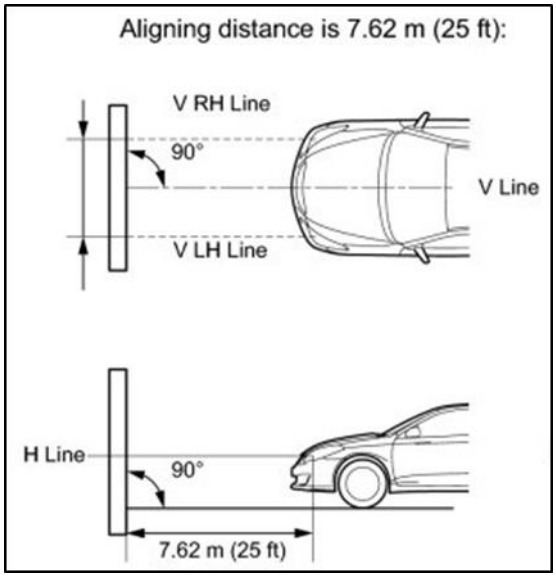


Figure 2-3 Headlight aiming screen at 25 feet and inspection limits

Source: Vehicle Equipment and Inspection Regulations, Commonwealth of Pennsylvania

2.4 United Nations UNECE Regulation for vehicle manufactures, Regulation No. 113

This regulation chapter provides uniform provisions concerning the approval of motor vehicle headlamps emitting asymmetrical passing beam or a driving beam or both and equipped with filament, gas discharge light sources or LED modules

Test Point/Line/Zone	Position in grid in angular degrees		Required illumination in Lux at 25m	
	Vertical	Horizontal	Minimum	Maximum
1	0.86 D	3.5 R	4	20
2	0.86 D	0	8	-
3	0.86 D	3.5 L	4	20
4	0.50 U	1.5 L and 1.5 R	-	1.08
6	2.00 D	15 L and 15 R	2	-
7	4.00 D	20 l and 20 R	1	-
8	0	0	-	1.92
Line 11	2.00 D	9 L to 9R	3	-
Line 12	7.00 U	10 L to 10 R	-	1.08
Line 13	10.00 U	10 L to 10 R	-	1.08
Line 14	10 U to 90 U	0	-	1.08
15	4.00 U	8.0 L	0.1	1.08
16	4.00 U	0	0.1	1.08
17	4.00 U	8.0 R	0.1	1.08
18	2.00 U	4.0 L	0.2	1.08
19	2.00 U	0	0.2	1.08
20	2.00 U	4.0 R	0.2	1.08
21	0	8.0 L and 8.0 R	0.1	-
22	0	4.0 L and 4.0 R	0.2	1.08
Zone 1	1U/8L-4U/8L-4U/8R-1U/8R-0/4R-0/1R-0.6U/0-0/1L-0/4L-1U/8L		-	1.08
Zone 2	>4U to <10U	10L to 10R	-	1.08
Zone 3	10U to 90U	10L to 10R	-	1.08

D - Under the H-H line U - Above the H-H line

R - Right of the V-V line L - Left of the V-V line

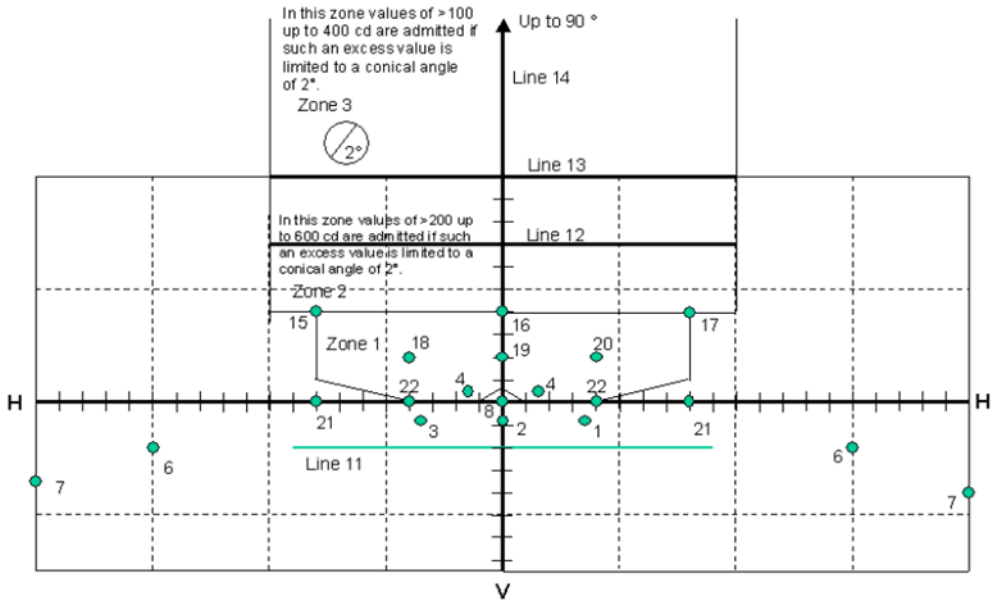


Figure 2-4 Measuring Screen, test points and related illumination limits

Source: UNECE Regulation for Vehicle Manufactures, Regulation No. 113

2.5 OFFICIAL MANUAL FOR VEHICLE INSPECTION, State of Rhode Island, USA

Motor Vehicle Safety and Emission Control Division,
HEADLAMPS

References: 31-24-1 thru 31-24-52

Every inspection station shall inspect headlamps according to the following

Requirements:

While the vehicle is in the inspection bay check the headlamps of the vehicle. You will not be required to check the exact aim of the headlamps but you will be expected to reject the headlamp aim if the aim is noticeably off center. The headlamps shall be of a "type approved" by the Division of Motor Vehicles. No modifications are allowed that will change the original design or performance of any lamp. Every headlamp shall be mounted at a height of not more than 54" nor less than 24" from the center of the headlamp above the level surface upon which the vehicle rests. The headlamp or headlamps on every motor vehicle, motorcycle, or motor scooter shall be of a type which shall emit a clear white light. The use of colored or tinted lenses is prohibited. Headlamp shields, doors or other devices are

allowed provided the light from the lamp is not obstructed or changed in any manner when in use. Every motor vehicle other than a motorcycle shall be equipped with at least two (2) headlamps, with at least one (1) headlamp on each side of the front of the motor vehicle, they shall be of equal intensity, and controlled by a high/low beam switch. Every motorcycle or motor-driven cycle shall be equipped with at least one (1) and not more than two (2) headlamps.

Cause for rejection:
1. Any headlamp beam of light that is noticeably off center.
2. Any vehicle headlamp or devices that fail to meet any of the requirements of this regulation.

Supplying and fixing steel fence erected using 25"x25" steel box bars of 4mm thickness at the edge.

2.6 Vehicle inspection guidance, North Carolina

19A NCAC 03D .0533 LIGHTS

(a) Headlights shall conform to the requirements of G.S. 20-129(b) and (c). Headlights shall not be approved if:

(1) There are not at least two headlamps (at least four on dual headlamp systems which require four units) on all self-propelled vehicles except that motorcycles and motor driven cycles need only one.

(2) The lens produces other than a white or yellow light.

(3) Any lens is cracked, broken, discolored, missing, or rotated away from the proper position, or any reflector is not clean and bright.

(4) The high beam-low beam dimmer switch does not operate properly or the high beam indicator light does not burn on vehicles manufactured after January 1, 1956.

(5) Lights can be moved easily by hand, due to a broken fender or loose support, or if a good ground is not made by the mounting.

(6) Foreign materials (such as shields, half of lens painted) are placed on the headlamp lens that interferes with light beam of lamp.

(7) Lights are improperly aimed. (A light testing machine or light testing chart shall be used to determine this.)

(8) Lights project a dazzling or glaring light when on low beam

Requirements as to headlamps and auxiliary driving lamps.

(a) The headlamps of motor vehicles shall be so constructed, arranged, and adjusted that, except as provided in subsection (c) of this section, they will at all times mentioned in G.S. 20-129, and under normal atmospheric conditions and on a level road, produce a driving light sufficient to render clearly discernible a person 200 feet ahead, but any person operating a motor vehicle upon the highways, when meeting another vehicle, shall so control the lights of the vehicle operated by him by shifting, depressing, deflecting, tilting, or dimming the headlight beams in such manner as shall not project a glaring or dazzling light to persons within a distance of 500 feet in front of such headlamp. Every new motor vehicle, other than a motorcycle or motor-driven cycle, registered in this State after January 1, 1956, which has multiple-beam road-lighting equipment shall be equipped with a beam indicator, which shall be lighted whenever the uppermost distribution of light from the headlamps is in use, and shall not otherwise be lighted. Said indicator shall be so designed and located that when lighted it will be readily visible without glare to the driver of the vehicle so equipped. For purposes of this section, the term "motorcycle" shall not include auto-cycles. Auto-cycles shall be subject to the requirements under this section for motor vehicles.

(b) Headlamps shall be deemed to comply with the foregoing provisions prohibiting glaring and dazzling lights if none of the main bright portion of the headlamp beams rises above a horizontal plane passing through the lamp centers parallel to the level road upon which the loaded vehicle stands, and in no case higher than 42 inches, 75 feet ahead of the vehicle.

(c) Whenever a motor vehicle is being operated upon a highway, or portion thereof, which is sufficiently lighted to reveal a person on the highway at a distance of 200 feet ahead of the vehicle, it shall be permissible to dim the headlamps or to tilt the beams downward or to substitute therefore the light from an auxiliary driving lamp or pair of such lamps, subject to the restrictions as to tilted beams and auxiliary driving lamps set forth in this section.

(d) Whenever a motor vehicle meets another vehicle on any highway it shall be permissible to the beams of the headlamps downward or to substitute therefore the light from an auxiliary driving lamp or pair of such lamps subject to the requirement that the tilted headlamps or auxiliary lamp or lamps shall give sufficient illumination under normal atmospheric conditions and on a level road to render clearly discernible a person 75 feet ahead, but shall not project a glaring or dazzling light to persons in

front of the vehicle: Provided that at all times required in G.S. 20-129 at least two lights shall be displayed on the front of and on opposite sides of every motor vehicle other than a motorcycle, road roller, road machinery, or farm tractor

2.7 Motor Vehicle Safety Inspection Manual, Safety Division, Virginia State Police

19VAC30-70-140 52 Headlamps; Except Motorcycles.

A. Inspect for and reject if:

1. Any motor vehicle is not equipped with headlamps of an approved type. The headlamps must be marked with the headlamp manufacturer's name or trademark, and DOT. If the headlamp bulbs are replaceable, the headlamp lens must be marked with the headlamp light source type (bulb) for which it was designed and the bulb must match the lens code.
2. Headlights are not of the same approved type (Halogen, HID, etc.) except sealed beam headlamps. At least two headlamps are required.
3. In any headlamp the lens is cracked, broken, discolored, or rotated away from the proper position, or the reflector is not clean and bright.
4. Moisture or water buildup in headlamp is such that it affects the aiming pattern.
5. Headlamps omit light other than white. Light tints of color may be acceptable if the headlamp and headlamp bulbs are marked as required.
6. Bulbs are not of an approved type and marked with all of the following: light source type, the manufacturer's name or trade mark, and DOT. NOTE: Approved headlamp bulbs: HB1, HB2, HB3, HB3A, HB4, HB4A, HB5, H1, H3, H7, H8, H8B, H9, H9B, H11, H11B, H11C, H13, H13C, H15, HIR1, HIR2. 53 Approved headlamp bulbs that require ballast: 9500, D1R, D1S, D2R, D2S, D3R, D3S, D4R, D4S, D5S, D7S, D8S. Approved headlamp ballasts must be marked with the light source type (bulb) and DOT. The bulb type marked on the ballast must match the marking on the headlamp lens.
7. Any filament or bulb in headlamps fails to burn properly or headlamps are not at the same location or configuration as designed by manufacturer. (Location and type of headlamps can be found in subsection E of this section.)
8. Wiring is dangling or connections are loose; or if proper filaments do not burn at different switch positions; or if switches, including foot or hand dimmer, do not function properly and are not convenient to the driver.
9. Foreign material is placed on or in front of the headlamp lens or interferes with the beam from the lamp. No glazing may be placed over or in front of the headlamps unless it is a part of an approved headlamp assembly.

a. Reject if vehicle has wire, unapproved lens or plastic covers, any other materials that are not original equipment or any colored material placed on or in front of the headlamps.

b. Vehicles registered as street rods may have clear, rigid plastic or glass headlamp lens covers in front of sealed beam units to replace original manufacturer's equipment.

EXCEPTION: A clean impact film known as Headlight Savers produced by Grand Prix Motoring Accessories may be applied to the headlight lens to absorb impact of rocks, etc.

10. Lamps can be moved easily by hand due to a broken fender or loose support, or if a good ground is not made by the mounting.
11. Headlamps, auxiliary driving lamps and front fog lamps are not mounted so that the beams are aimable and the mounting does not prevent the aim of the lighting device from being disturbed while the vehicle is operating on public roads. All lamps shall be securely mounted on a rigid part of the vehicle.
12. A headlamp visor is over two inches long unless part of the original body design.
13. The high beam indicator in the driver's compartment does not burn when the high beam is on or does not go off when the low beam is on. (Vehicles not originally equipped with an indicator are not required to comply unless sealed beam headlamps have been installed.)

B. Aiming the headlamps.

1. Headlamps shall be checked for proper aim by using an optical headlamp aimer on every motor vehicle inspected, except vehicles with on-board aimers. Headlamp aim on vehicles with on-board aimers shall be checked by visually examining the leveling device mounted either on or adjacent to the headlamp. Reject the vehicle if the leveling device shows the headlamp adjustment to exceed indicated specifications. NOTE: Driving lamp and fog lamps must be aimed using the optical aimer, according to instructions in 19VAC30-70-160 I 10 i and 11 g (2).
2. Headlamps are not aimed within the following tolerances using the optical aimer.

a. The center of the hot spot of all single element high beam lamps is set more than four inches up or down from the horizontal centerline or more than four inches to the left or right from the vertical centerline.

b. The left edge of the lamp pattern of any low beam lamp or any combination or multi-element lamp is more than four inches to the left or right of the vertical centerline or the

top edge of the lamp pattern is more than four inches above or below the horizontal centerline when checked on low beam.

C. Optical aimer.

1. Approved optical headlamp machines shall be used to properly aim all headlamps, except vehicles with on-board aimers. Optical aimers must be properly calibrated and used in the manner recommended by the manufacturer. The optical headlamp machine must be aligned to the vehicle in accordance with the manufacturer's specifications.
2. When aiming headlamps, first look for the type of lamp, which will be found embossed on the lens. The type determines which aiming requirements must be followed for the optical aimer.
3. All low beam or combination/multi-element headlamps must be set by aiming the lamp pattern with the lamps set on low beam. NOTE: If attempting to align a composite or sealed beam lamp with a high and low beam within the same housing, align only the low beam. If aligning a four lamp system with high and low beams in separate housings, it may be necessary to cover the low beam while aligning the high beam, if all four lamps are on at the same time.
4. Pattern should be aimed so that the left edge does not extend to the left or right of straight ahead, and the top of the pattern should be even with the horizontal. Pattern "A" represents the light pattern as it should appear on the view screen of the approved aimer when checking the low-beam pattern on a single element headlamp or a combination multi-element headlamp.
5. All VOL and VOR headlamps will be aimed as follows: To properly aim a combination multi-element or low-beam VOL or VOR headlamp assembly, the headlamp pattern should be aimed on low beam only

   Letters marked on the headlamp cover should properly identify VOL and VOR headlamps. NOTE: VOL and VOR headlamps will normally have only one adjustment, which will be for the vertical aim only. The horizontal aim should be disregarded, as the horizontal aim is preset at the factory.
6. All single element high beam headlamps shall be set by aiming the center of the hot spot with the lamps set on high beam.
7. Aim straight ahead-center of the hot spot should be centered with the vertical and horizontal centerlines. Pattern "B" represents the light pattern as it should appear on the view screen of the approved aimers.

8. When lamp pairs are mounted horizontally, the low beam lamp must be on the outer side and when mounted vertically, the low beam lamp must be at the higher position in the pair.
9. The four headlamp system must be wired so that only the lower beam lamp will burn when the light beams are depressed. When switched to high beams, both high beam and low beam may burn. The "F" type halogen headlamp 1986 (LF-UF) of the four headlamps system will function in the following manner: system must be used so the low beam does not burn with the high beam.

D. Headlamps on vehicles used for snow removal. Approved auxiliary headlamps may be mounted above the conventional headlamps. (These lamps must be in compliance with this section in its entirety, subdivision 7 of 19VAC30-70-150, and 19VAC30-70-170.) E. Inspect for and reject if:

1. Lamps are not an approved type as previously indicated in section A 6.
2. Lamps are not mounted in a manner that will permit proper aiming.
3. Lamps are mounted so as to obstruct the driver's vision.
4. The auxiliary headlamp circuit does not contain a switch that will deactivate the primary headlamp system when the auxiliary headlamps are in use.
5. Auxiliary headlamps are not aimed in accordance with the provisions of subdivision B 2 of this section.
6. Headlamps are not wired in accordance with the provisions of subdivision C 8 of this section. NOTE: Light patterns shown in the following diagram will be displayed on the most recently approved light machines produced by Hopkins and Symtech Corporations.

2.8 Federal Motor Vehicle Safety Standard 108

Federal Motor Vehicle Safety Standard 108 (FMVSS 108) regulates all automotive lighting, signaling and reflective devices in the United States. Like all other Federal Motor Vehicle Safety Standards, FMVSS 108 is administered by the United States Department of Transportation's National Highway Traffic Safety Administration.

Canada's analogous regulation is called *Canada Motor Vehicle Safety Standard 108* (CMVSS 108), and is very similar to FMVSS 108. The primary differences are:

- CMVSS 108 requires daytime running lamps on all vehicles made since 1 January 1990, while FMVSS 108 permits but does not require DRLs

- CMVSS 108, through an adjunct called CMVSS 108.1, permits European headlamps, while FMVSS 108 prohibits them.

Both standards differ markedly from the UN (formerly "European") standards used in most other countries worldwide, not only in technical provisions, terminology, and requirements, but in format: each European standard deals with only one type of lighting device, while the single U.S. and Canadian standards regulate all lighting and reflective devices.

Summarizing the FMVSS 108, it can be identified that Upper/High beam minimum 20,000 and maximum 75,000 candela. Lower beam minimum 8,000 and maximum 20,000 candela.

2.9 Measuring light

2.9.1 Luminous intensity, the Candela

A light source is a device that converts some form of energy (eg, electricity) into light. Suppose, then, that there is a point source of light energy. The light energy radiates away from the source. When the luminous energy flowing through a steradian is equal to 1/683 watts, then the luminous intensity is one candela. The modifier luminous is important, because it implies that the measurement of radiant light energy is made with a filter that weights the energy as would a human eye, giving more weight to green and less to red and purple. The factor 1/683 aligns this definition with an earlier definition, which was based on a standard candle. Therefore, a candle radiates approximately 1/683 luminous watts through each steradian solid angle. Or, put another way, it would take 683 candles4 to radiate one luminous watt through a steradian. As in the definition of steradian, it does not matter where this measurement takes place. The amount of light energy flowing through each steradian is a constant.

2.9.2 Luminous power: Lumens

The total luminous power in lumens flowing out of a source is equal to the product of the luminous intensity in candela times the radiating angle in steradians. Example: One candela radiating through 1 steradian emits one lumen. Running this backward through the definition of candela, this is a luminous power of 1/683 watts. One candela radiating in all directions emits 4π lumens. It’s useful to picture that the number of lumens flowing out of a source is a measurement of the total luminous power in watts of the source.

2.9.3 Luminance: Candela per square meter

Consider that the luminous energy from the previous point source intersects with some surface such as the envelope of a bulb or the frosted Plexiglas's surface of a sign. This surface then becomes an extended (area) source of light. The brightness of this surface is proportional to the luminous intensity of the source, in candela, and inversely proportional to the area. The measure of this brightness is the luminance in candela per square meter.

2.9.4 Illuminance: Lux

When lighting a room or the pavement under a street lamp, we are concerned with the light level on that surface, or the illuminance. Light level is measured in lux. The technical definition of one Lux is one Lumen per square meter. Lumens are a measure of the available lighting energy, and Lux is the brightness after that energy is spread over a surface. For an analogy, consider painting a surface: The total light energy in lumens corresponds to the amount of paint in the can. The illuminance in lux corresponds to the amount of paint per unit of surface area, the thickness of the paint. For example, lighting a living room with one sixty-watt bulb gives a low level of brightness on the room surfaces. The luminance of both these sources is exactly the same, the light output in lumens is exactly the same, but the illuminance is different. A lux meter takes a photometric measurement of illuminance, that is, one that compensates for the color sensitivity of the eye and corresponds to the human perception the amount of light falling on a surface. For a given fixed source, the illuminance decreases with distance according to the inverse square law. As the distance doubles, the illuminance decreases by a factor of 2 squared, or 4.

2.9.5 Summary

Suppose that a light source produces a luminous intensity of **I** candela. One candela radiates one lumen through one steradian. If the source is omnidirectional, then the total radiation angle is 4π steradians, Then the total light energy (luminous flux) flowing out of the source is $4\pi I$ lumens. At some distance d from the source, this energy flows through a surface equal to the surface area A of a sphere with a radius of d meters. Then the illuminance $\mathbf{E_d}$ in lumens per square meter (lux) at distance **d** is:

$$\mathbf{E_d = 4\pi I/A = 4\pi I/4\pi d^2 = I/d^2}$$

Rearranging equation to solve for **I**, the luminous intensity, we have:

$$\mathbf{I = E_d d^2} \text{ candela.}$$

3 MEASURING BRIGHTNESS OF HEADLAMPS OF OPERATING VEHICLES IN SRI LANKA

3.1 Introduction

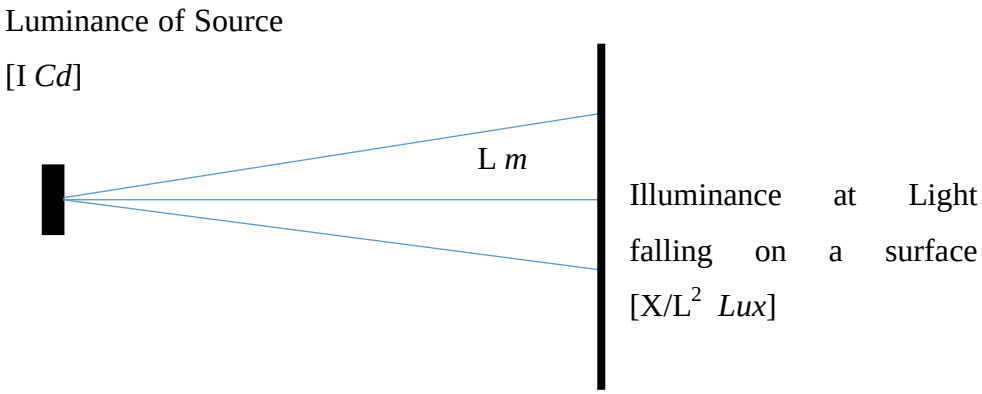
As per the main objectives of this research, understanding the deviation of brightness levels of headlights of operating vehicles in Sri Lanakan roads is very important to the research outcomes. This evaluation will probationary reveal the facts causing inconvenience light outputs from operating vehicles.

According to the findings of the literature review, first a suitable regulation was selected as the base reference after a careful study. As this research is dealing with brightness level of headlamps, it is necessary to select a guideline which clearly indicates the brightness intensity with testing procedures. The Vehicle Equipment and Inspection Regulations of Commonwealth of Pennsylvania have clearly stated the brightness limitations for operating vehicles.

The headlamp low beam minimum candle power shall not be less than 15,000.

The headlamp high beam minimum candle power shall not be less than 20,000.

The total candlepower for head lamps and auxiliary lamps shall not exceed 150,000.



Illuminance E[*lx*] = Luminance of Source I[*Cd*] / Measuring Distance^2 [*m*^{2}

Table 3-1 Calculated Minimum and Maximum values(In Lux) as per FMVSS and Pennsylvanian Standards

		FMVSS 108		Pennsylvania PUB 45	
		Luminance of Source	Illuminance at 25'(7.62*m*)	Luminance of Source	Illuminance at 25'(7.62*m*)
Low Beam	Minimum	16,000*Cd*	275.56*lx*	15,000*Cd*	258.33*lx*
	Maximum	40,000*Cd*	688.89*lx*	-	-
High Beam	Minimum	40,000*Cd*	688.89*lx*	20,000*Cd*	344.45*lx*
	Maximum	150,000*Cd*	1291.67*lx*	150,000Cd	-

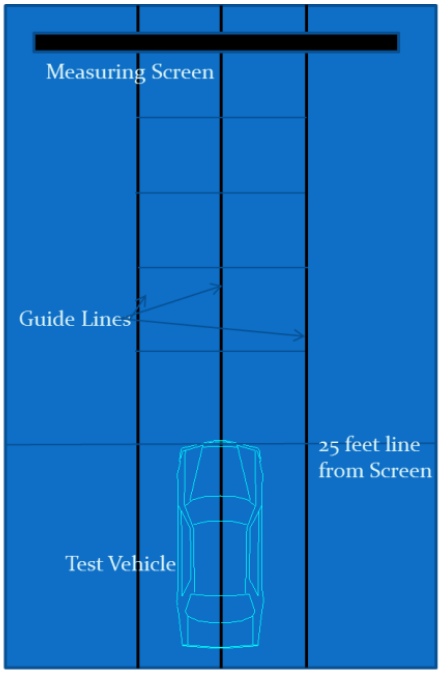
3.2 Location and setup

Location: - A work station free for night time under the Gampaha fly-over

Ground Surface: - Prepared leveled surface using Concrete paving slabs

Surrounding: - Open at three Sides, Small Building at the other side, Closed at top by concrete beams

Setup: - A Vertical Black Screen supported by a concrete column of the building, 25 feet line from Screen, Guidelines for vehicle maneuver



3-1 Marking guidelines and preparing ground surface

3-2 Marking guidelines and preparing ground surface

Equipment :- A Digital Lux Meter, Steel tape, Torch, Digital camera

Figure 3-3 Equipment used in field tests.

3.2.1 Lux meter

Lux meters, sometimes called light meters, measure the intensity of illumination as distinguished by the human eye. This value does not correlate to an objective value of energy radiated or reflected, as different wavelengths within the visible spectrum are perceived with varying sensitivity by the eye, and lux meters evaluate light intensity in consideration of this variable. Most lux meters are handheld devices and are easily transported to the job site.

Articulated and tethered photo detectors may require both hands to optimally position the photo detector and the module, but they also provide measurement flexibility. Some handheld models may include a stand or mounting structure, such as a tripod.

Digital Lux meter

Range : 0 – 200,000 Lux

Accuracy

≤ 10,000 Lux , ±(4%+10word)

≥ 10,000 Lux , ±(5%+10word

Repeatability : ±2%

Power Supply : 9V Battery

Operating Temperature : 0 ºC – 40 ºC

Figure 3-4 Operating instructions of the Lux meter

3.3 Test procedure

- First, the test vehicle is maneuvered into the guidelines and stopped at the 25 feet line as per the front face of the headlamps is situated at exactly 25 feet in front of the screen.
- Then, the Primary details are recorded following the Data entry sheet.
- Next, the headlight low beam operation is started in “Zero”(0) position and kept 1 minute to settle down.
- Next, the cutoff line should be identified (If available) and mark it on the screen.
- Illuminance intensity measurements are taken at each 100mm intervals in two rows; first on the Cutoff line and then in a line 100mm below the Cutoff line.
- Finally, the beam pattern is switched to the high beam position and measure the highest intensity.

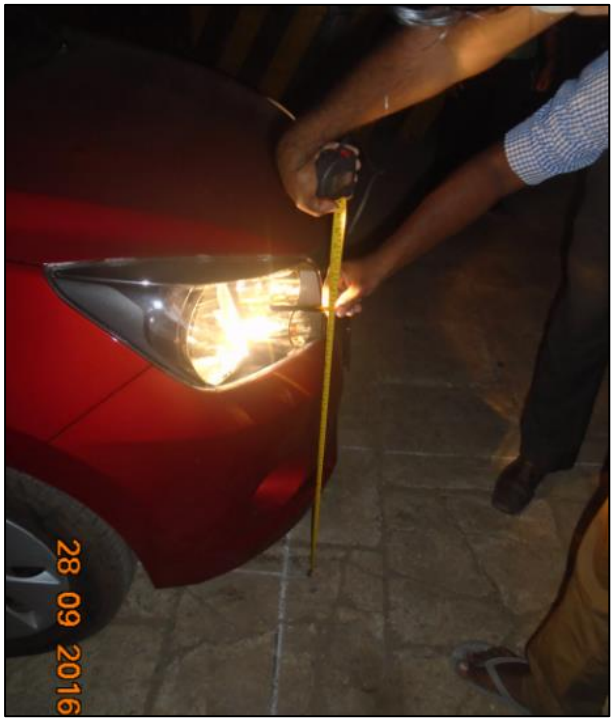


Figure 3-5 Recording primary details.

Figure 3-6 Measuring illuminance intensities using Lux meter

Table 3-2 The list of test vehicles

Test No	Vehicle Manufacturing Year	Vehicle Model
Test 1	2006	Toyota Hilux
Test 2	2006	Isuzu Dump Truck
Test 3	2011	Toyota Aqua
Test 4	2004	Nissan TIDA
Test 5	2011	Bajaj Discover
Test 6	2009	Hero Honda Pleasure
Test 7	2015	Suzuki Maruti Cellerio
Test 8	2001	Piagio Three Wheeler
Test 9	1992	Toyota CR21
Test 10	2002	Suzuki Swift
Test 11	2014	Toyota Axio Hybrid
Test 12	2011	Toyota Prius
Test 13	1996	Isuzu Dump Truck
Test 14	2003	Bajaj Three Wheeler
Test 15	1996	Toyota Corolla
Test 16	2000	Nissan FB15
Test 17	1997	Toyota Corolla 110
Test 18	2015	Suzuki Maruti Alto
Test 19	2014	Suzuki Maruti Alto
Test 20	2014	Honda Fit
Test 21	2011	Toyota Prius
Test 22	2003	Nissan N16
Test 23	2012	Toyota Aqua
Test 24	2013	Toyota Prius
Test 25	2002	Toyota corolla
Test 26	2007	Mazda Axela
Test 27	2006	Toyota Vits
Test 28	2015	Micro Panda
Test 29	2001	Toyota Corolla
Test 30	2009	Toyota Hilux Pick-Up
Test 31	2011	Bajaj Three Wheeler
Test 32	2015	Toyota Premio
Test 33	2014	Suzuki Wagon R
Test 34	2008	Suzuki Maruti Alto
Test 35	2003	Toyota Corolla 121
Test 36	2005	Honda Fit Area
Test 37	2007	Nissan March

3.4 Test results

Field tests were carried out according to the above procedure and the results were recorded using Data entry sheet No: 1 (Annex 1) and Data entry sheet No: 2 (Annex 2).

3.4.1 Sample result 1: Test 3

Vehicle category – Passenger Car Head Light technology - HID

Vehicle Model – Toyota Aqua Manufacturing Year - 2011

Table 3-3 Test result values obtained(In Lux) after Test 3

452	452	475	460	528	522	505	505	305	283	285	328	368	400	414	382	420	487	487	366	345
466	497	521	532	530	526	524	512	485	422	356	333	329	330	331	345	404	444	469	461	468
L1000	L900	L800	L700	L600	L500	L400	L300	L200	L100	0	R100	R200	R300	R400	R500	R600	R700	R800	R900	R1000

Figure 3-7 Photograph of low beam operation Test No:3 , The cutoff line can be clearly observed

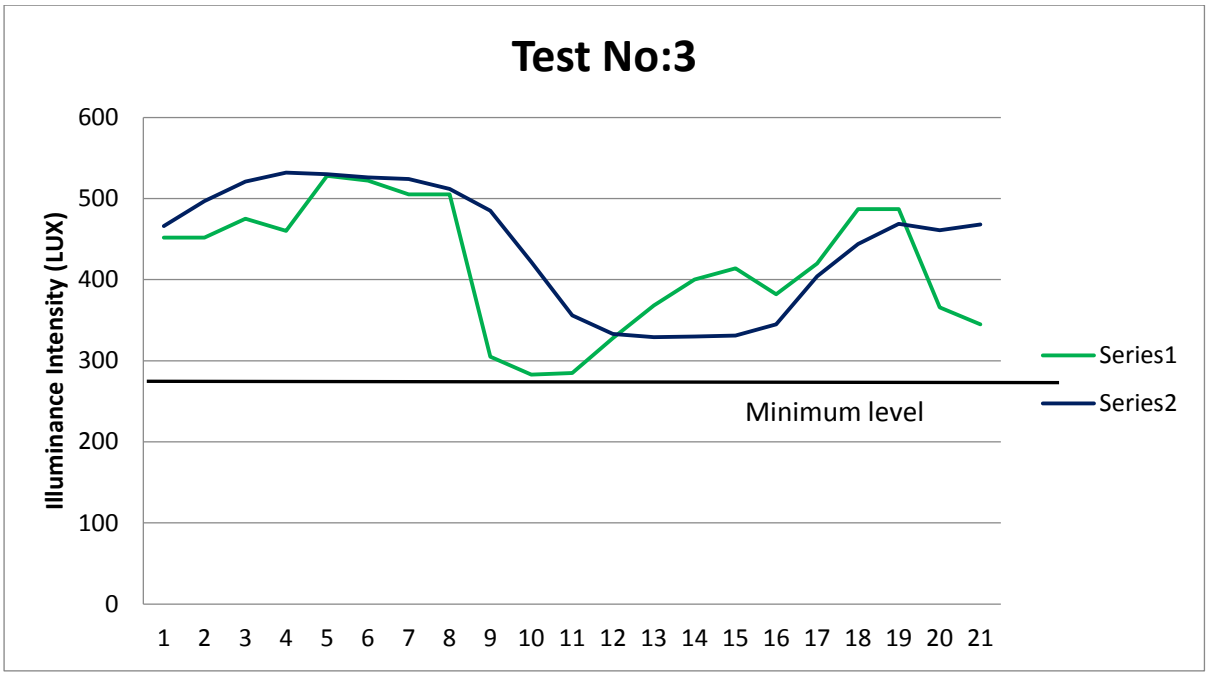


Figure 3-8 Illuinance intensity distribution of headlight in low beam operation:Test 3

Average illuminance intensity at the Cutoff line (500mm) = 418lx

Average illuminance intensity at the 400mm line = 442lx

Illuminace intensity range at the Cutoff Line – 283lx to 528lx

Illuminance intensity range at 400mm line – 329lx to 532lx

According to the FMVSS standards, the range of illuminance intensity for low beam operation

Minimum	16,000*Cd*	275.56*lx*
Maximum	40,000*Cd*	688.89*lx*

Therefore, the headlight system of this vehicle is operating within the FMVSS specified range.

3.4.2 Sample result 2: Test 4

Vehicle category – Passenger Car Head Light technology - Halogen

Vehicle Model – Nissan TIDA Manufacturing Year - 2004

Table 3-4 Test result values obtained (In Lux) after Test 4

Table 3-4Test result values obtained(In Lux) after Test 4

186	172	146	117	85	85	82	92	85	83	91	100	100	117	126	124	120	108	90	62	44
176	182	166	175	191	195	188	172	159	150	148	144	147	162	160	160	188	208	211	197	185
L1000	L900	L800	L700	L600	L500	L400	L300	L200	L100	0	R100	R200	R300	R400	R500	R600	R700	R800	R900	R1000

Figure 3-9 Photograph of low beam operation Test No:4 , The cutoff line is slightly unclear and illuminance intensity is low by visual inspection.

Average illuminance intensity at the Cutoff line (500mm) = 105lx

Average illuminance intensity at the 400mm line = 174lx

Illuminace intensity range at the Cutoff Line – 44lx to 186lx

Illuminance intensity range at 400mm line – 144lx to 208lx

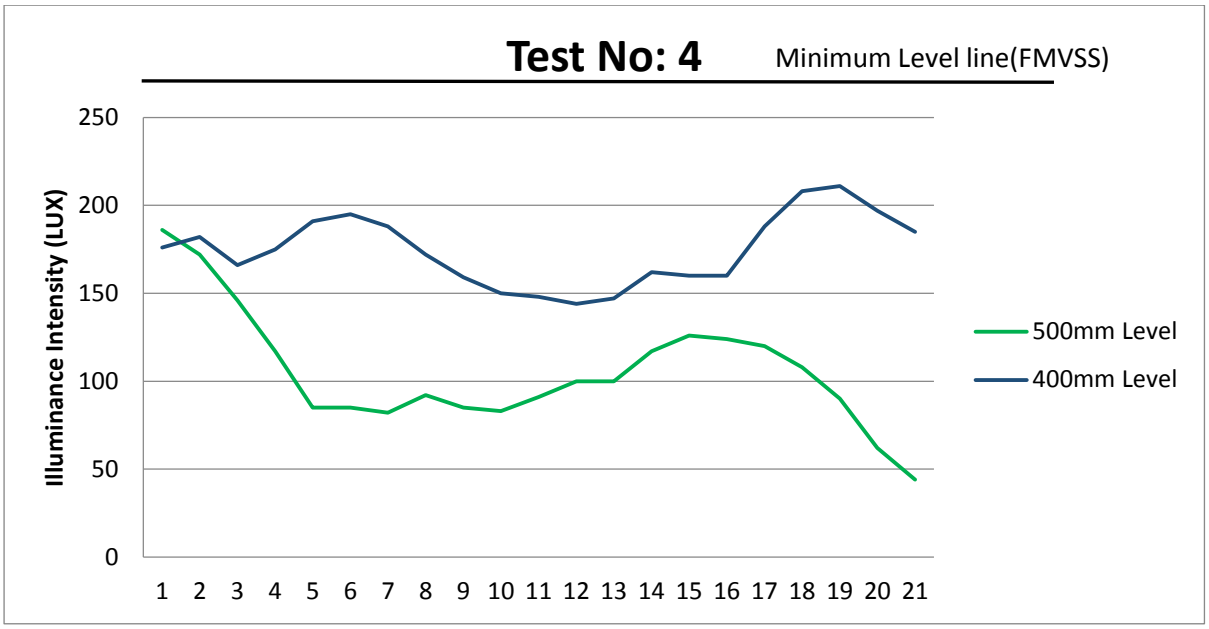


Figure 3-10 Illuinance intensity distribution of headlight in low beam operation:Test 4

This headlight system emits a low beam having a low intensity, well below to the FMVSS specified minimum level.

Insufficiency of intensity of the low beam was also confirmed by the visual inspection and the driver's statement of the vehicle. In the discussion with the driver, it was revealed that this headlight system was not repaired or maintained for a long time. The outer lenses of both head lamps were moderately oxidized.

3.5 Observations

During the field tests, it was observed that the brightness intensity of head light systems in operation has a clear connection with the manufacturing year and origin of the vehicle. All headlight systems of vehicles that not older than five (5) years were within the specified range except the Suzuki Maruti models. Further, it was also observed that properly maintained headlight systems of older vehicles than five (5) years also were within the specified range. However, there were only a few numbers of vehicles which had properly maintained headlight systems.

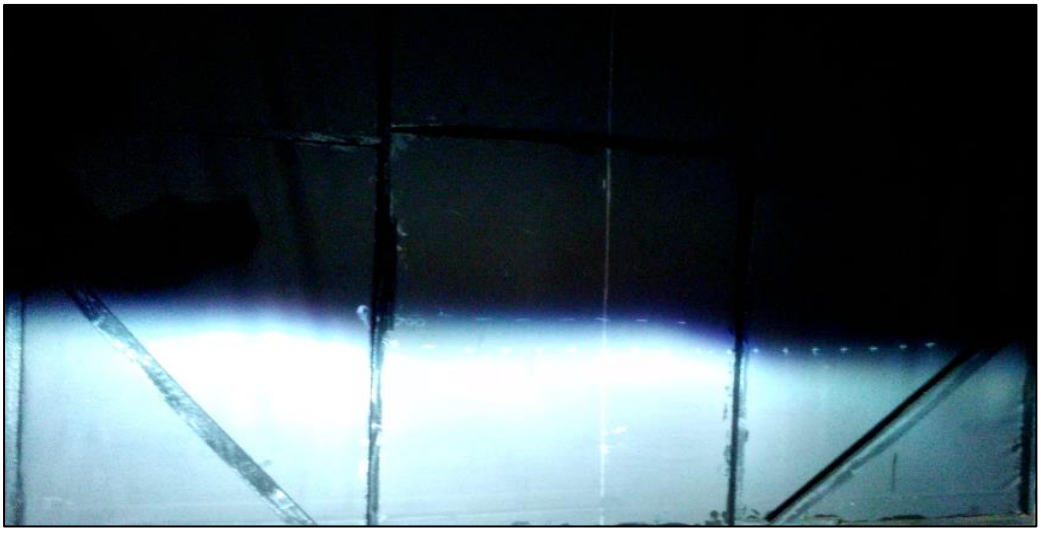


Figure 3-11 Clear cutoff line and higher brightness emitting Test No 32

Headlight systems which have HID bulbs create a brighter light outputs and clear cutoff line on the screen. As a general observation, it was observed that drivers/vehicle owners had very slight attention on their vehicle's headlight system. Number of vehicles which had oxidized headlight systems was high. Most of older vehicles had problems of aiming of the low beam and drivers/vehicle owners didn't know that. Considering all test results, the hot spot area can be identified as Figure 3-14, at just below the horizontal centerline at LHS

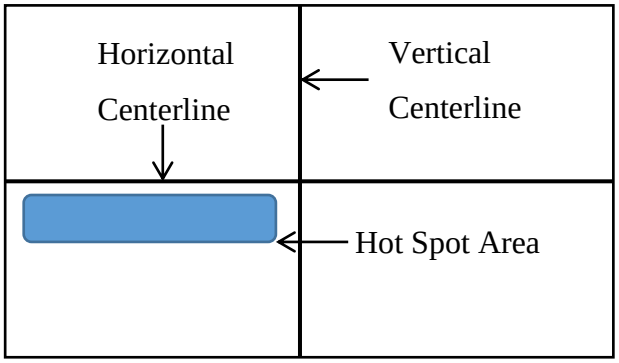


Figure 3-12 Hot Spot area

Figure 3-13 Light distribution of Test No 10, Total beam distribution has lowered due to poor aiming

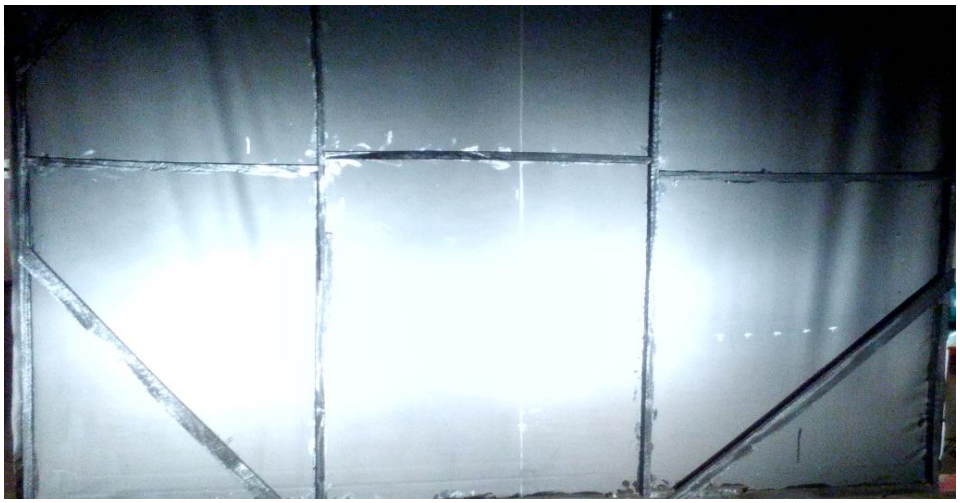


Figure 3-14 Light distribution of Test No 2,Scattered beam due to poor aiming

Figure 3-15 Light distribution of Test No 6, Poor llumnance intensity and Poor aiming

Figure 3-16 Light distribution of Test No 9, VeryPoor llumnance intensity and Very Poor aiming, Recently faced with an accident.

Figure 3-17 Low beam distribution of pattern of 2 stroke three wheeler

Figure 3-18 Low beam distribution of pattern of Disel three wheeler

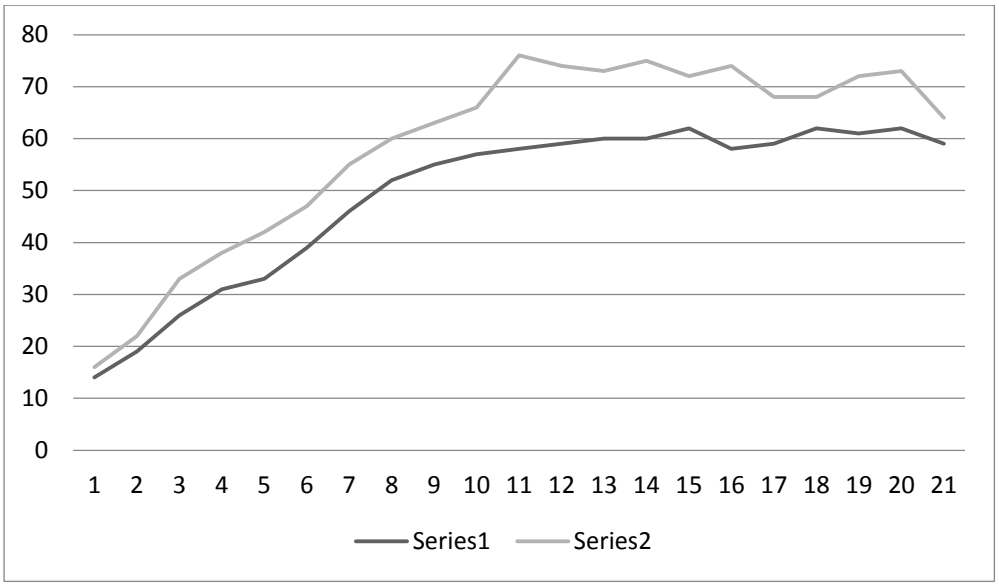


Figure 3-19 Low beam distribution pattern of Test No:8, Hot spot area found at above from the horizontal centerline RHS

4 SUMMARY AND ANALSIS OF EXPERIMENTAL RESULTS

4.1 Specification Requirements

Federal Motor Vehicle Standards and Specification regulates all automotive lighting, signaling and reflective devices in the United States. Like all other Federal Motor Vehicle Safety Standards, FMVSS 108 is administered by the United States Department of Transportation's National Highway Traffic Safety Administration. FMVSS 108 is a complex set of standards and experts have simplified as follows.

FMVSS 108

		Luminance of Source	Illuminance at 25'(7.62*m*)
	Minimum	16,000*Cd*	275.56*lx*
Low Beam	Maximum	40,000*Cd*	688.89*lx*
	Minimum	40,000*Cd*	688.89*lx*
High Beam	Maximum	150,000*Cd*	1291.67*lx*

4.2 Comparison of brightness levels of operating vehicles in Sri Lanka with FMVSS standards.

The results obtained from field tests were checked with the minimum and maximum levels of headlight brightness. Figure 4.6 shows the average illuminance intensities of each test results obtained from the low beam operation condition with the minimum level line.

According to the test results, no vehicle is producing a low beam passing the maximum specified level (688lx). Only ten (10) vehicles were able to pass the minimum specified level out of thirty seven (37) vehicles. All these were passenger cars manufactured within last 5 years.

According to the test results, three wheelers showed no specific beam distribution pattern or exact cutoff line.

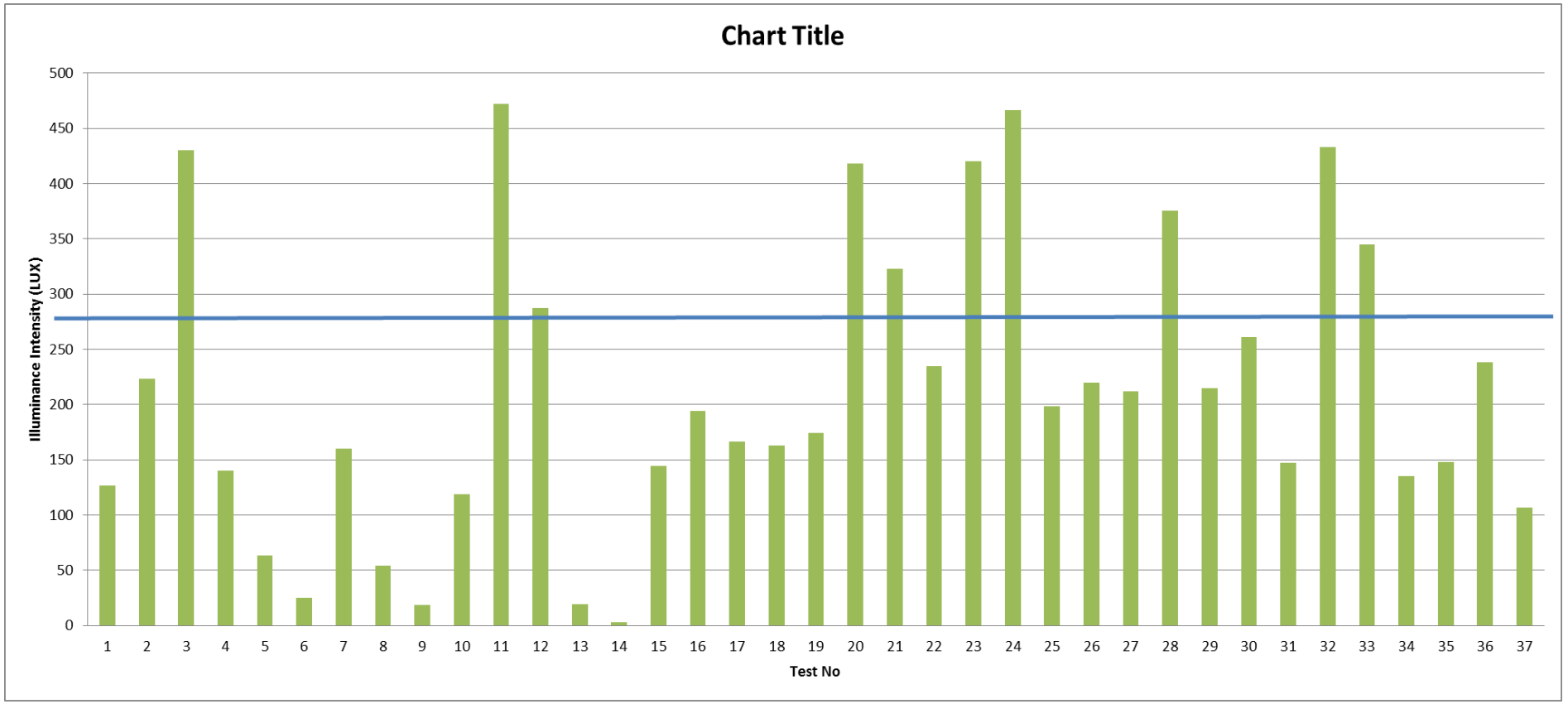


Figure 4-1 Comparison of brightness levels of all test vehicles in with FMVSS standards.

4.3 Illuminance intensity variation with manufacturing year of vehicle

In the observation of test results, it was clearly identified a relationship of manufacturing year of the vehicle with illuminance intensity. Every vehicle made in or after 2011 is producing a low beam passing the FMVSS minimum level except Suzuki Maruti models (Alto & Cellirio). There were thirty (30) passenger cars, among the test vehicle list. Figure 4-2 shows the illuminance variation with manufacturing year of passenger cars.

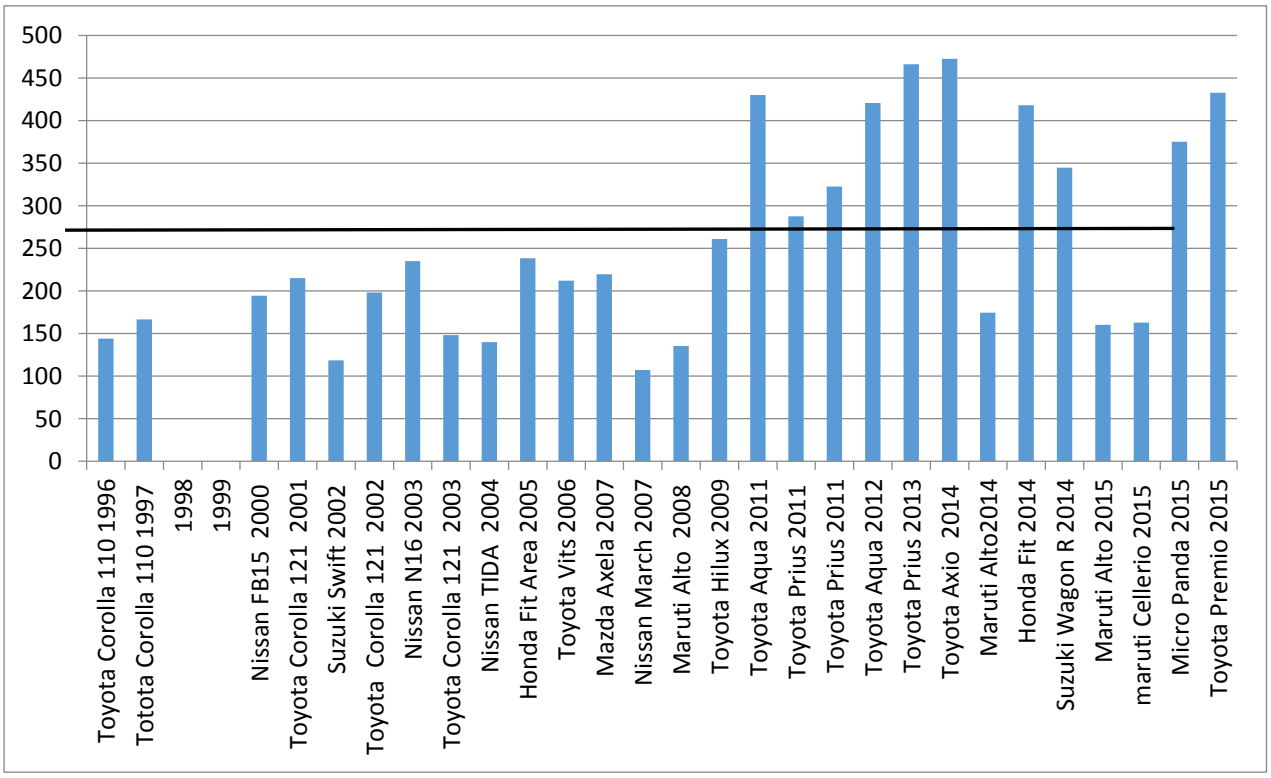


Figure 4-2 Average Illuminance intensity arranged in order by manufacturing year of passenger cars.

67% of tested vehicles have a lower brightness comparing to the minimum FMVSS brightness level. Headlights of "Suzuki Maruti" model emit a comparatively low bright beam. Most of other newly manufactured cars have used HID bulbs while these Suzuki Maruti models use Halogen bulbs. Although these are newly manufactured cars, the aiming was not accurate and a sharp cutoff line was not appeared in low beam operation. This type of low beam operation could cause visual inconvenience to the divers of oncoming vehicles and other road users.

5 CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS

5.1 Conclusions

According to the field test results analysis, it can be concluded that illuminance intensity of low beam in majority as 67% of passenger cars have low brightness over standard intensity limitation.

It can be also concluded that, only the newly manufactured (on year 2011 or after) vehicles have an acceptable brightness in low beam operation. However, even the newly manufactured vehicles of some identified vehicle models do not produce required brightness in low beam operation.

Further, it can be also concluded that, poor aiming of headlamp system is the major reason for creating inconvenience by low beam operation for drivers of oncoming vehicles.

5.2 Recommendations

Introduce new regulations on brightness limits with aiming limitation for both low beam and high beam of operating vehicles in Sri Lanka.

Establish a proper regulatory mechanism to oblige vehicle owners to carryout necessary periodic maintenance and repairs of the headlight systems of their vehicles as to produce a standard brightness and aiming accuracy in specified time intervals and soon after an accident.

Educate vehicle users, maintenance technicians and other relevant parties regarding the importance of carrying periodic maintenance of headlight system and keep their headlight within the standards.

Establish a new mechanism to verify the brightness levels and aiming quality of headlight systems of importing vehicles.

Further studies are highly recommended on both illuminance intensity and aiming of headlight systems of operating vehicles in Sri Lanka.

5.3 Suggestions

There were only 30 headlight systems for passenger cars were tested in this study. The accuracy of results can be achieved by increasing the sample size.

The study may be carried out for other vehicle categories such as Motorcycles, Three-wheelers, Buses, Light trucks etc. The results would help to find more accurate conclusion about the headlight systems of operating vehicles in Sri Lankan Roads.

Headlights are more critical in rainy and foggy environmental conditions. Different environments could be created and tested to find-out the effect of adverse weather on headlights.

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