Design and manufacturing of a setup for the testing and evaluation of a motor vehicle's front fog lamps in an environment recreating fog effects

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EXAMIANTION COMMITTEE

We hereby recommend that the dissertation prepared under supervision by Dr. Sami Ur Rahman Shah titled: "Design and manufacturing of a setup for the testing and evaluation of a motor vehicle's front fog lamps in an environment recreating fog effects" be accepted in partial fulfillment of the requirements for the award of B.E Mechanical Engineering degree.

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ABSTRACT

The main aim of the project was the design and manufacturing of a laboratory setup capable of testing and evaluating a vehicle's front fog lamps per rigorous engineering standards. Furthermore, the need was to design benchmark experiments to be used while evaluating fog lamps. One of the main requirements was to have a laboratory setup free from the interference of external light. For this purpose, a frame made of steel pipes was constructed, and covered with water-proof nylon (a parachute fabric). This setup provided us a testing rig free from external light interference and environmental factors. Within this setup, two different types of experiments were conducted. The first one was related to the beam patterns of sample lights, and the analysis of how a certain beam pattern relates to the performance of the luminaire in real-life settings. The second experiment was related to the recreation of the effects of fog using a net constructed of jute ropes. This net served as an attenuating medium through which some of the light passed, and some of it was reflected. The data obtained by this experiment was compared with previous tests conducted by our partner team in real fog conditions on the M-1 in Kala Shah Kaku, Pakistan. Finally, conclusions were drawn about the performance of different sample lights, and recommendations were made to further develop and broaden the scope of the endeavor.

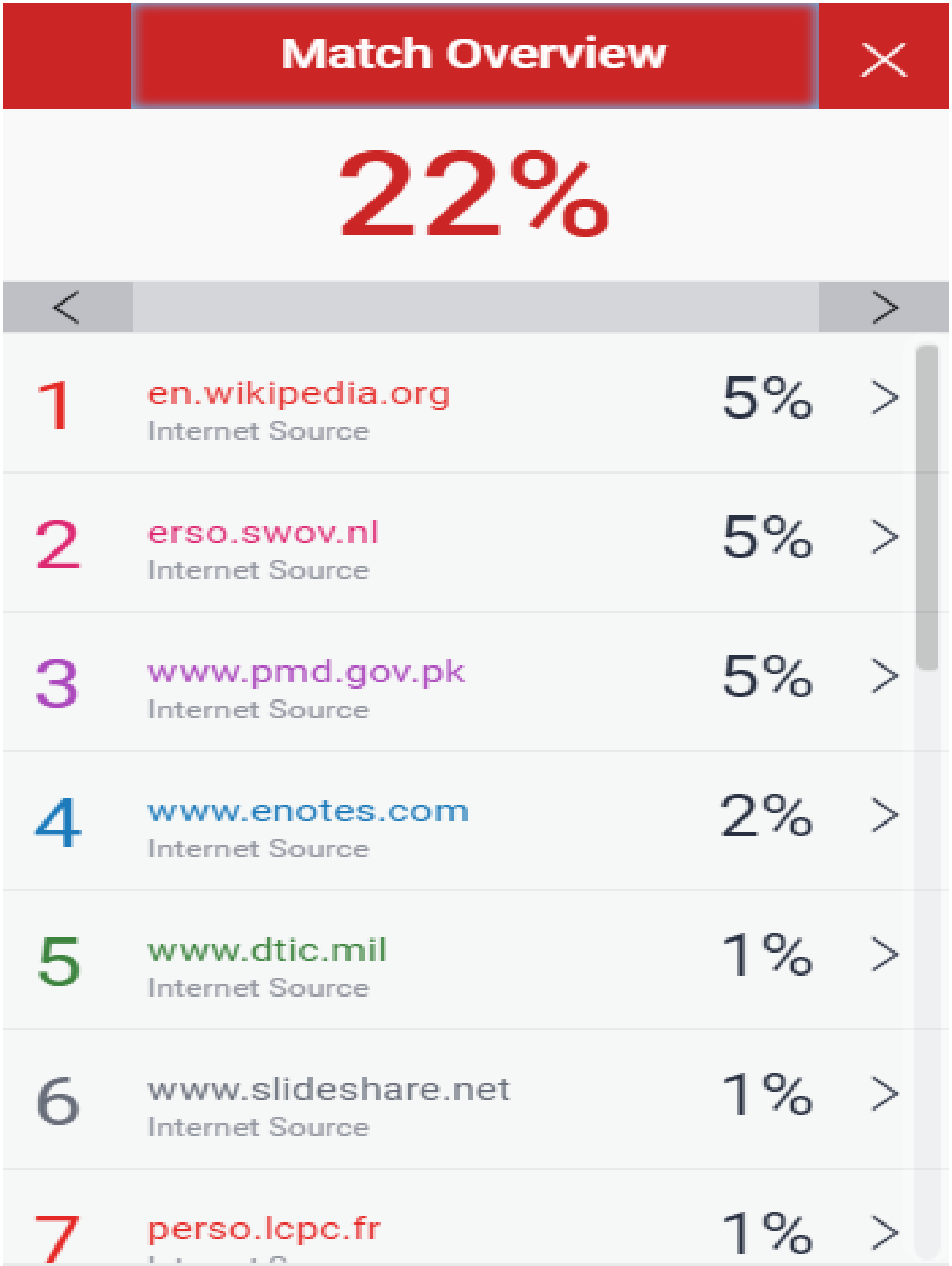
PREFACE

The need of this endeavor was firmly rooted within the ever-increasing number of accidents each year in Pakistan due to fog. In fact, at least 16 deaths were reported in November 2016 due to fog related motor-vehicle accidents in Lahore. This project was given to us by Hella KGaA Hueck & Co to shed light on (so to speak) what a fog lamp needs to be, from an engineering perspective, for it to do its job. This report is about our efforts for the past 8 months directed towards the achievement of this goal. We are thankful to Hella KGaA Hueck & Co in this regard for providing us with the reference lights to be tested, and all their technical support.

ACKNOWLEDGMENTS

To thank individually, we would like to start off with Hella KGaA Hueck & Co for sponsoring our endeavor and helping us out with technical queries. Furthermore, we would like to thank our faculty supervisors Dr. Sami ur Rahman Shah and Col. Naveed Hasan for their sheer dedication and unparalleled support towards the team and the project. We would also like to thank our colleagues Sami Gillani, Ali Haider, Awez Khan, M Ali from our partner team who provided us with constant support, coordination and valuable input towards our common aims. Finally, the team working at the Manufacturing Resource Center (MRC) in SMME Mr. Faisal, Mr. Irfan, Mr. Farhad, Mr. Abbas, Mr. Shoukat deserves an honorary mention for their dedicated assistance in all our problems related to manufacturing.

ORIGINALITY REPORT



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ABBREVIATIONS

NHA National Highway Authority

SSD Stopping Sight Distance

MRC Manufacturing Resource Center

dMT Braking Distance

V Design Speed

dPRT Driver perception-reaction distance

SAE Society of Automotive Engineering

TI Thermal Imagers

IR Infrared

NOMENCLATURE

Stopping Sight Distance:

Stopping sight distance is the distance traveled during the two phases of stopping a vehicle: perception-reaction time (PRT), and maneuver time(MT). [IV]

Perception Reaction Time:

Perception-reaction time is the time it takes for a road user to realize that a reaction is needed due to a road condition, decided what maneuver is appropriate (in this case, stopping the vehicle), and start the maneuver (taking the foot off the accelerator and depressing the brake pedal). [IV]

Maneuver Time:

Maneuver time is the time it takes to complete the maneuver (decelerating and coming to a stop). The distance driven during perception-reaction time and maneuver time is the sight distance needed. [IV]

CHAPTER 1

INTRODUCTION

The existence of heavy fog is a problem for most drivers. Poor visibility on the road can turn out to be a major reason for fatal vehicle accidents. To increase the visibility in these harsh weather conditions, a need arises to evaluate the performance of fog lamps. Fog usually arises due to a temperature difference of 2.5 ℃ between the dew-point temperature and the ambient air temperature. Two effects of fog need to be taken in to account: How much the light attenuates as it propagates in the environment (extinction), and how the light's path of propagation changes as it interacts with the particles (scattering). Using these two parameters, any type of fog can be characterized. This information helped us generate a fog-profile and compare it with the existing profile in Pakistan with information from the Meteorological Department. In this way, the fog conditions existing in Pakistan around the year were recreated in a laboratory setting.

The laboratory setup consists of a skeletal frame of steel pipes covered in water-proof nylon fabric to provide a dark room, or "tunnel". A light fixture of variable height with the capability to install a given sample fog light was made. This fixture was placed at the open end of the tunnel, while the other end was a screen with a grid of 2x2 inches. Using this setup, it was observed how the light attenuates with respect to distance, and whether the pattern generated on the screen is in line with the stringent criteria of fog lamp beams. A fog generation system was used to recreate the effects of fog in this tunnel. The lights were tested in this fog environment as well to analyze (through visual inspection of the pattern on the screen and data from the photo sensor) how effectively the light will perform on road conditions. Different lights were thus compared with one another and the best performing light was selected. Furthermore, a jute net was used to replicate the reflection and attenuation effects of the fog. The intensity of light reflected from the net was also measured using a lux-meter. Road markings were paved and cutouts were introduced in the tunnel to observe how visible they were in the fog atmosphere. Several fog lights with different beam patterns, angles and spread were mounted on the fixture and readings were noted incorporating the attenuation coefficient and back reflectance and the results were compared with the readings taken under real fog conditions and conclusions were drawn about the effectiveness of different fog lights.

CHAPTER 2

LITERATURE REVIEW

To decide how to characterize the performance of a fog-lamp, we first needed to know how light and fog interact. A variety of papers, journals, articles and texts were studied. A major portion of the project time was spent on literature review which helped us to learn how to characterize light and fog and how to replicate fog effects in the laboratory environment.

Introduction to Fog:

Fog is a meteorological phenomenon in which a cloud (stratus) which has its base on or close to ground level and the visibility reduces to < 1000 meters. **[VIII]** There are different types of fog:

1. Radiation fog
2. Advection fog
3. Frontal fog
4. Industrial fog
5. Upslope fog
6. Steam fog
7. Ice fog

Fog formation can occur in two ways. First, the air is cooled to the dew point which leads to the formation of **fog** droplets. When the sun rises, the air and ground warm up. This leads to the air temperature being warmer than the dew point temperature, which **causes** the **fog** droplets to evaporate. [II]

We'll be discussing the two important and prevalent fog types in the study area of our project.

1. Advection fog:

Advection fog forms due to moist air moving over a colder surface, and the resulting cooling of the near-surface air to below its dew-point temperature. Advection fog occurs over both water (e.g., steam fog) and land. [VI]

2. Radiation fog:

Radiation cooling produces this type of fog. Under stable nighttime conditions, longwave radiation is emitted by the ground; this cools the ground, which causes a temperature inversion. In turn, moist air near the ground cools to its dew point. Depending upon ground moisture content, moisture may evaporate into the air, raising the dew point of this stable layer, accelerating radiation fog formation. [VI]

The **radiation fog** is the most dominant type of fog, which occurs when the radiation cooling at night decreases the air temperatures to its dew point temperature.

Favorable Conditions:

The favorable conditions for its development are **light wind, clear sky, high moisture and lack of turbulence**. The soil conditions like soil moisture and vegetation cover influence the soil thermal conductivity which plays a vital role in formation of radiation fog. Fog also forms in the environment, where there are large concentrations of aerosols characterized by a low activation super saturation. The high aerosols loads are an important factor contributing in severity of fog events. The enhanced pollution load result in atmospheric reactions, producing the secondary pollutants that may lead to increased aerosol concentration in the atmosphere. This could cause enhanced water aerosol in the presence of favorable meteorological conditions and high relative humidity. [VIII]

Timeline of Fog in Pakistan:

Fog usually forms during **November to February** in Pakistan. Most of the studies made Punjab as a focal point for fog formation. It should be accounted that dense fog in Pakistan appears in two phases, the first phase during the midst of November to end of December while the second phase being comparatively shorter than the prior one, spanning over the month of February. In the months of October and January there is fog but depends, it can be displacement fog and patchy i.e. it will be moving from places to places, you'll find maximum fog at one location and just a few kilometers apart there'll be clear sky. [VIII]

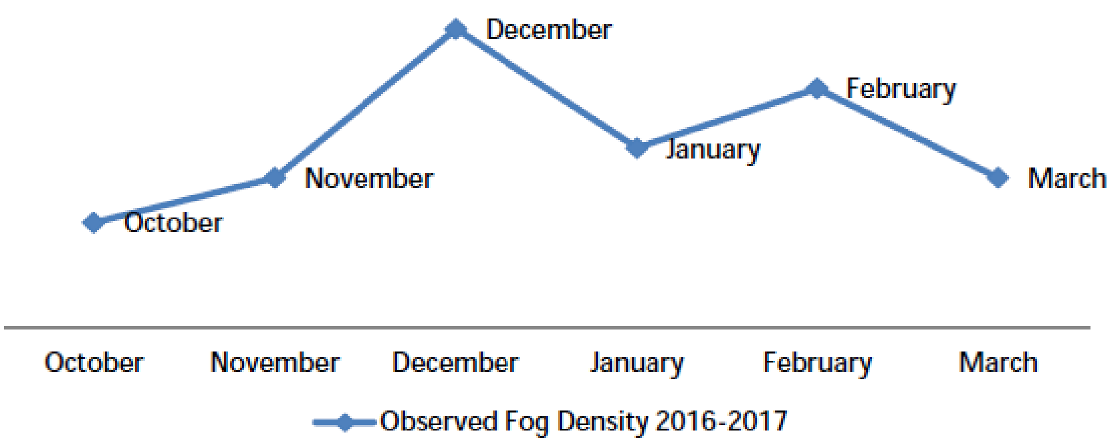


Figure 1 Observed Fog Density 2016-2017

Replicating fog effects in laboratory setting:

For replicating the effects of fog in a laboratory environment, we need to measure different characteristics on which fog depends. Fog is boundary layer phenomena whose formation is usually influenced by surface conditions. Fog is considered as serious hazard in Punjab and Sindh particularly during winter. Winter in Pakistan became short and intense under the changing climate. The increasing trend of fog frequencies in the last decade result in various kind of impacts on human life, irrigation network and economy of the country. [VIII]

The aim of this study is to identify the fog characterization and visibility. The international definition of fog is a visibility of less than 1 kilometer (3,300 ft.); mist is a visibility of between 1 kilometer (0.62 mi) to 2 kilometers (1.2 mi) and haze from 2 kilometers (1.2 mi) to 5 kilometers (3.1 mi). Fog and mist are generally assumed to be composed principally of water droplets, haze and smoke can be of smaller particle size; this has implications for sensors such as Thermal Imagers (TI/FLIR) operating in the far-IR at wavelengths of about 10 μm which are better able to penetrate haze and some smokes because their particle size is smaller than the wavelength; the IR radiation is therefore not significantly deflected or absorbed by the particles. A visibility reduction is probably the most apparent symptom of air pollution. Visibility degradation is caused by the absorption and scattering of light by particles and gases in the atmosphere. Absorption of electromagnetic radiation by gases and particles is sometimes the cause of discolorations in the atmosphere but usually does not contribute very significantly to visibility degradation. Scattering by particulates impairs visibility much more readily. Visibility is reduced by significant scattering from particles between an observer and a distant object. The particles scatter light from the sun and the rest of the sky through the line of sight of the observer, thereby decreasing the contrast between the object and the background sky. Particles that are the most effective at reducing visibility (per unit aerosol mass) have diameters in the range of 0.1-1.0 μm. The effect of air molecules on visibility is minor for short visual ranges but must be considered for ranges above 30 km. [VII]

Visibility criteria:

Furthermore, for the design of tunnel and how the person should be able to stop the car within safe distance speed limits were also studied. A speed limit is based on both safety and mobility considerations and increasingly also on environmental considerations. The general framework for speed limits is the responsibility of the national government. Generally, local and regional road authorities determine the speed limit on a road. The current general speed limits vary across EU Member States. Also, the application of variable speed limits related to traffic and weather conditions vary across EU Member States

A balance between safety, mobility and environmental considerations

Safety is only one element that affects what speed limit is applied. Also the effects on travel time, mobility must be considered. Setting limits aims to meet the optimum total cost by balancing safety and mobility consequences. There may be a different optimum for different roads depending on their accident rate and their function for mobility. What the optimum is, is largely determined by the method and assumptions that are applied to calculate the costs of road accidents and mobility loss, and increasingly also the costs of air pollution and noise. This, in the end, is a political decision. Assessment frameworks have been proposed to support these decisions. Some administrations are now proposing that the "balance" between safety and mobility should be judged from a more ethical standpoint. This requires that an upper limit is put on the injury risk that could occur on the road (e.g. virtually eliminating the chance of a fatality occurring). The speed limit and the design of the road infrastructure would then be matched to ensure that the injury risk was not exceeded. [I]

Parameters to characterize fog and light:

The main parameter that characterizes fog is visibility. The meteorological visibility distance $Vmet$ is a convenient unit and is related to the extinction coefficient k:

$$Vmet\ = \frac{3}{k}\,[\mathrm{V}]$$

Visibility in fog depends upon many factors. One such is the extinction coefficient which describes how visibility decreases in fog conditions. We can calculate the extinction coefficient using Beer-Lambert extinction model,

$$Ls(d)\ =\ Ls(0)e^{\,-kd}\ [\mathrm{V}]$$

Here $Ls(0)$ is the luminance of the object, k is the extinction coefficient, d the observation distance.

For better approximation, we can use two light sources which will give the estimated value of k as:

$$k\ =\ \frac{\ln(\frac{LiLj\ (0)}{Lj\ Li(0)})}{dj-di}\ , Li(0)\ =\ Lj\ (0)\ \Rightarrow\ k\ =\ \frac{ln\ (Li/Lj\ )}{dj-di}\ [\mathrm{V}]$$

The Beer-Lambert extinction model is used in transmissometer which is used for measurement of extinction coefficient and visibility. The transmissometer has two main units i.e., transmission unit and receiver unit. The transmission unit has a light source and the receiver unit has a photodetector. The beam from the light source is made straight using a convex lens and at the receiver unit another convex lens is used for converging the beam to a photodetector. The distance between the two units is known and using the beer-Lambert extinction relation the extinction coefficient can be calculated.

The quantities like visibility and extinction coefficient are to be calculated using the following formulas:

Table 1 Fog parameters and their calculation

Quantity	***Relation Used***
Visibility (Vmet)	$Vmet = 3/k$
Extinction Coefficient (k)	$Ls(d) = Ls(0)e^{-kd}$

Lux meter can measure the back reflectance caused due to fog which will affect the visibility for the driver. So this chapter of literature review shows which topics we had to study and which concepts and research papers were the basis of our design and the methodology of the experiment.

CHAPTER 3

Methodology

The project was divided into two major sections. In the first section, design and manufacturing of light tunnel was done along with the cutouts, obstacles and road markings. For the design and size of light tunnel we carried out following calculations.

Design calculations of light tunnel

Our initial calculation was based on the absolute worst-case scenario needed to stop a vehicle from 50 km/h, which is often the maximum allowable speed limit during heavy fog. [I]

For deceleration rates, an emergency braking value commonly seen on production vehicles was used, which was 1g or 9.81 m/s^2 [III]

The calculation is as follows:

Braking distance is calculated by:

$$dbraking = 0.039 \times V^2 / a$$
$$V = 50 km/h$$
$$a = 9.81 \text{ m/s}^2$$
$$dbraking = 9.93 \text{ m}$$

Where:

$dbraking$ = distance to bring the car to a full stop, m
V = design speed, km/h
a = deceleration rate, m/s^2

Furthermore, research told us that head-lamp aiming tests are conducted at 10 meters, and our discussion with Hella also motivated us to test at 10 m.

This motivated us to build the light tunnel which is **10m** long. After measuring the spread of various fog lights provided to us the width of the tunnel was decided to be **6m** because the spread of the fog lights was in this range. The height of the tunnel is decided to be **2m**.

Parametric Analysis

The parameters for the design of light tunnel are then:

Table 2 Tunnel sizing parameters

Parameter	***Dimension***
Tunnel length	*10m*
Tunnel width	*6m*
Tunnel height	*2m*

Structure and material of tunnel

After finalizing the dimensions of tunnel, the structure and material of the tunnel was to be decided. The structure was chosen based on the Engineering Mechanics study to be having trusses along the length of the tunnel and the vertical support after every 2m to ensure the stability of tunnel. For materials, we had to select the material keeping in mind the strength and cost of the material. After several visits to local market, the material for the frame of the tunnel was chosen to be mild steel of 0.75in square cross-section. PVC was another option but it was discarded because it was not as strong as mild steel and given the weight of covering material and the frame itself, it would have bended and could not support the frame so mild steel was chosen. The frame was joined using electric welding so to give it more strength and to ensure that it remained intact.

For the selection of covering material, the material which would be covering the frame and isolating the tunnel from external light, a lot of thought processing had to be done keeping in mind the money and strength of the material and parachute canvas was chosen after several visits to local market as it was the material that best suited our requirements. It was enclosed by sewing and clipped with the tunnel so no light could penetrate it and no fog which was produced was lost outside to the environment.

Aerodynamic drag calculations:

Due to the tunnel being covered with a large area of nylon fabric, effects of aerodynamic drag were expected. The calculations were also carried out and are as follows:

$$\text{Parachute drag coefficient} = 1.75$$
$$\text{Air density} = 1.229\ \text{kg}/m^3$$
$$\text{Top Area} = Width \times Length = 6 \times 10 = 60\ m^2$$
$$\text{Side Area} = Length \times Height = (10 \times 2) = 20\ m^2$$
$$\text{Weight of rig} = 200\ \text{kg}$$
$$\text{Pavement friction coefficient} = 0.53$$
$$\text{Top drag force} = 0.5 \times air\ density \times drag\ coefficient \times velocity^2 \times area = 64.5225 \times velocity^2\ (N)$$
$$\text{Side drag force} = 0.5 \times air\ density \times drag\ coefficient \times velocity^2 \times area = 21.5075 \times velocity^2\ (N)$$

Limiting wind velocity to lift rig is when drag force equals the weight of the rig. This comes out to be **20 km/h vertically.**

Limiting wind velocity to drag the rig across the pavement occurs when the drag force equals the limiting friction due to the rig’s weight. This comes out to be **47 km/h horizontally.**

This calculation assumes no constraints. However, in the interest of safety, the tunnel was grounded to the pavement by tying it to iron rods hammered into the pavement, which increased its stability considerably.

Description of miscellaneous equipment within the tunnel:

To make the tunnel more like road, obstacles, reflectors and road markings were introduced inside the tunnel so it looked like the actual road and the results were more like actual road conditions.

Obstacles:

The obstacles which were introduced were objects made of polyurethane sheet. Their color was grey and they showed Lambertian reflectance. They were placed at varying distance along and across the tunnel. Their purpose was to test constraint in fog conditions.

Reflectors:

Reflecting tape at various heights was used to decide how high reflectors on the roadsides need to be.

Road markings:

Road lane markings on the ground to observe how obscured vision effects road visibility. They were used such that they made 8.5 feet wide lanes and were spaced 5-inch-wide marks of 5 feet length.

Fog machine:

The second part of the project was the production of fog, replicating the effects of fog and manufacturing the light fixture on which different fog lights were to be mounted and tested. For this purpose, a fog machine of 1500W was procured from vendor in Lahore. Then testing was being carried out to determine what proportions of glycerin and water were most suitable to produce a cloud of sufficient density. After testing the most suitable composition of the mixture was determined and it came to be about glycerin/water solution (20% and 80% by volume). This solution was used to produce fog with the help of fog machine and parameters like visibility, fog attenuation measurements and extinction coefficients were considered and measured using lux-meter.

Jute rope net:

For recreating and replicating effects of fog jute net of 2x2 cm square holes being made from jute ropes was recommended by HELLA which can be used in place of fog to check and test different fog lights. It was made using approximately 1000 meters of rope. It was used to recreate the scattering effects of fog because physical barriers scatter light and does not let it be transmitted.

Light fixture and lux-meter:

Lux meter which was used to measure all the readings was mutually used by our group and group 13 which tested the lights in real fog conditions on NHA near Kala Shah Kaku.

Also, a light was also used which was previously fabricated by our partner group It was modified to space two fog lamps at bumper spacing simultaneously. The height of lights was varied between 0.25 to 0.8 meters off the ground as recommended by Hella. Four pair of lights was used and tested which included 1 pair of LED lights and 3 pairs of incandescent lights.

Method used to conduct experiments:

Experiment 1 (Beam pattern testing):

The purpose of this experiment was to observe the beam patterns of our 4 different sample lights, and draw conclusions about their properties based on the pattern that they exhibited. Furthermore, the aim of the experiment was also to decide at what height the fog lamps should be installed within a vehicle. These experiments were conducted by placing the light-fixture at 7.62 meters from the test screen. This distance is recommended by SAE J583 for correct aiming of foglamps. Each lamp was aimed until the top of the beam was 10 cm below the perpendicular between the centerline of the lamp and the screen. Each aimed lamp was first and turned on individually, while varying the height of the lamp, to see at what height the lamps should be installed such that glare for oncoming drivers is minimized, while maximum visibility is ensured. At this decided height, 8 experiments of beam patterns were conducted (4 for the left-side light and 4 for each pair simultaneously), using data gathered for illuminance at the grid points of the screen. Isolux diagrams were plotted using a surface-fitting method, where illuminance (measured in lux) was plotted as a function of space (x, y) coordinates, measured in inches. Based on these diagrams, conclusions were drawn on the effectiveness of these luminaires in fog conditions, per the geometry of their patterns.

Experiment 2 (Back scatter effect of fog):

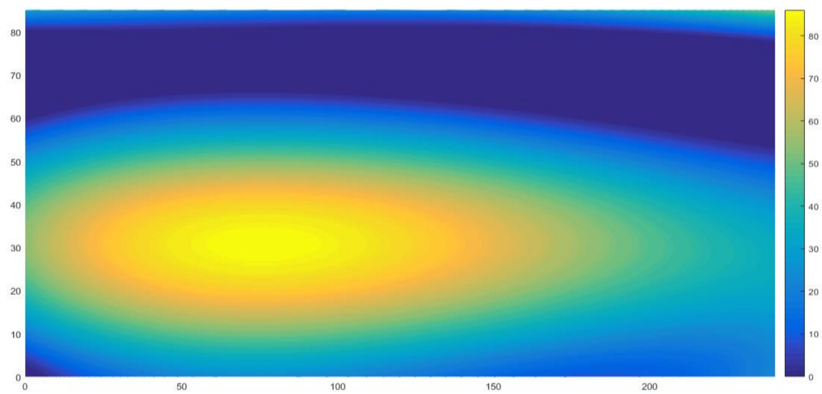
In this experiment a jute rope net fabricated. This consisted of 2x2 cm square holes. When light interacted with the rope material, some of it reflects. The replicates the effects in terms of reflectance and scattering of light. Each light was beamed on to the net from 55 cm and the reflected intensity on top of the luminaire was measured. In this way, could compare the contrast of how much light penetrates through the net as opposed to how much was reflected off it.

CHAPTER 4

RESULTS

Through the data gathered in our experiments, and post processing of the data, we have compiled several results which showcase our findings.

Experiment 1:



Hella LED:

Figure 2 Hella LED Left Lamp

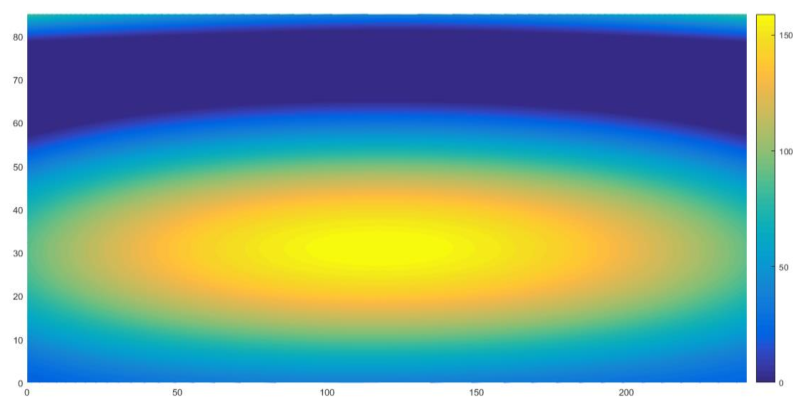


Figure 3 Hella LED Both Lamps

Results:

The iso-lux shows that the fog lamp has a clear cut off both above below which, technically, a fog lamp should have to keep the reflectance of scattered light through fog to a minimum while maintaining maximum visibility.

Hella Lamp 2:

Contours are as follows

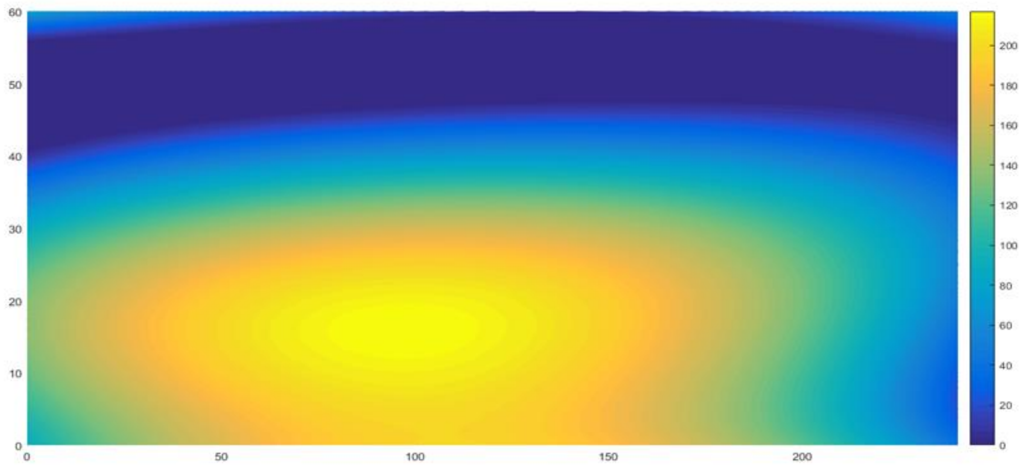


Figure 4 Hella Fluorescent Left Lamp

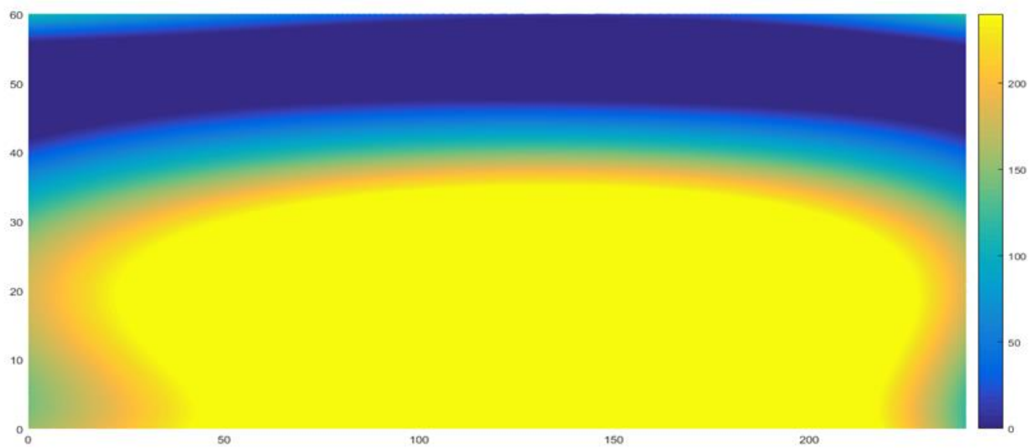


Figure 5 Hella Fluorescent Both Lamps

Results:

This lamp again has a clear cutoff, but a markedly higher intensity than the LED lamp. However, from amongst the people present at the conduct of the experiments, there was consensus that they could see better with the LED lamp than with the fluorescent lamp, in all the experiments. This leads us to the conclusion that instead of the intensity of the light being a factor important in sight it is the contrast ratio. White LED lamps had the better contrast than a yellow light leading to better visibility.

Toyota Fog Lamp:

Iso-lux diagrams:

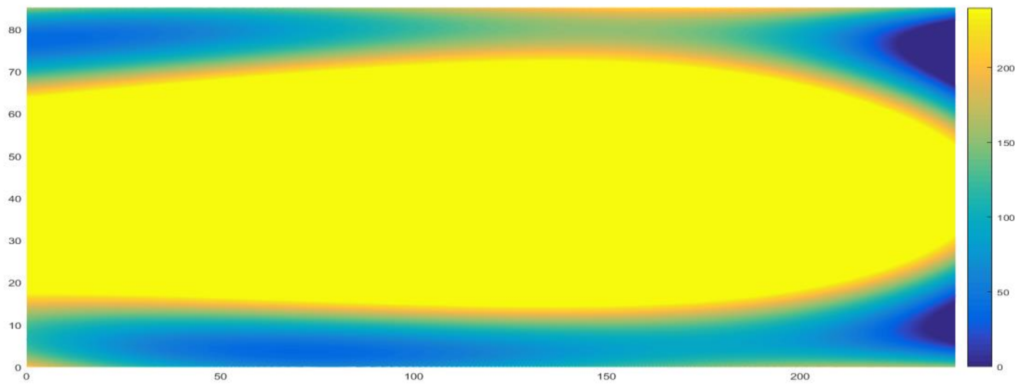


Figure 6 Toyota Incandescent Left Lamp

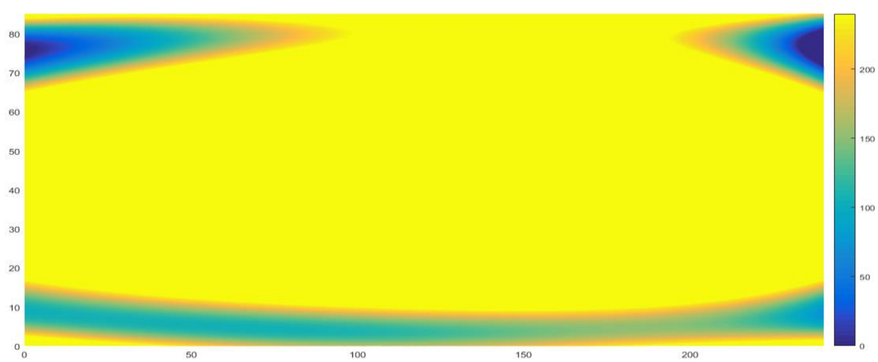


Figure 7 Toyota Incandescent Both Lamps

Results:

The iso-lux show increasing intensity after a decrease near the edges of the screen, which is to be ignored. As a surface fitting algorithm, has been used with the fit being modelled using gathered data and the function being generated which most closely resembled the actual patter observed, the high intensities near the top and bottom edge are a consequence of a fit used that would best capture the patter as whole – for all other parts other than the top and bottom edge of the screen. This fog lamp, though does have a very clear cutoff, covers a much wider area, than it should.

Nissan Fog Lamp:

Iso-lux diagrams

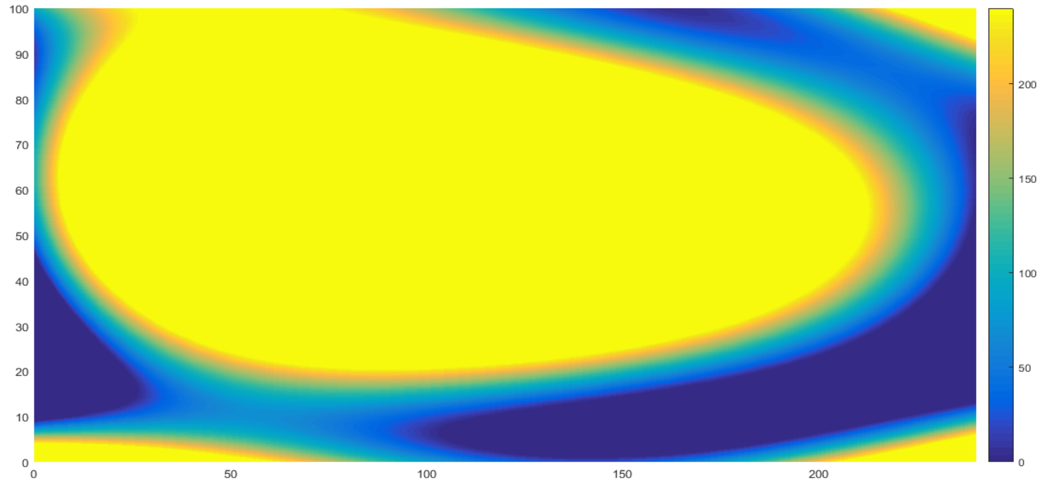


Figure 8 Nissan Fluorescent Left Lamp

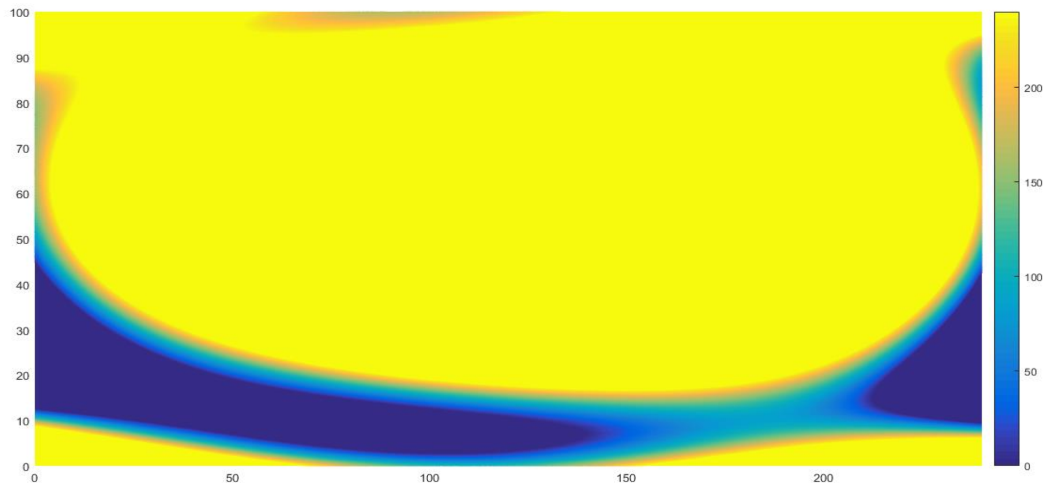


Figure 9 Nissan Fluorescent Both Lamps

Results:

The fit for this lamp too suffers from the limitation that near the bottom edge an increase is seen, because of the function generated, which best fits rest of the data. No actual increase in light intensity near the bottom of the screen was observed. The rest of the details of the iso-lux have been captured accurately.

This fog lamp had a pattern most differing to a desired pattern for a fog lamp. It beams light onto a much wider area which is an undesired characteristic.

Experiments to capture the beam patters at higher height were also set up, however from visual inspection, the pattern was seen to move upwards only with no marked changes in pattern below or above the cutoff which is to be expected from a fog lamp. Hence, these experiments were not further carried out in favor of avoiding repetition. The readings for the lamps in the second experiment, were however, obtained at varying heights of the lamp to find out which height is best to install a fog lamp at.

Experiment 2:

The experiment was conducted using a jute-net which was acting as our scattering medium and replicating fog. The luminaire was placed 55 cm from the rope net and turned on. The lux reading on the net following the centerline of the luminaire and the lux reading on top of the luminaire behind it were recorded. The results are summarized as below.

Table 3 (Jute net experiment results)

Source	Net reading at 55 cm (lux)	Reflected reading (lux)	Reflection Ratio (Net/reflected)
HELLA LED	9800	25	392
HELLA 24V	3400	170.6	19.9
Toyota	3500	500	7
Nissan	9950	206	48.3

CHAPTER 4

CONCLUSION AND RECOMMENDATION

Our findings support the conclusion that there is potential to improve the sight of the driver, in fog conditions, using the fog lamps. Of the 4 sample lights, only the HELLA LED pair had a cutoff enough to be good for road use. Also, due to the use of white LED, the visibility was much better visually as opposed to the other lights even though the hotspot lux readings were up to 3 times lesser. Also, it has the best ratio between light transmitted and back-reflected. **Hence, the HELLA LEDs are recommended by this study.**

Additionally, we also conclude that the dependence of vision upon the intensity of light is non-existent and that visual inspection is the best course of action to determine which lamp yields better results in terms of vision. Hence, any set up, findings or results based solely on the intensity of the light hold little to no significance if they are not backed by visual inspection. Based on our research and experimentation we give the following recommendations.

1. Additional tests should be performed in a dedicated indoor set up whose environment can be controlled and is unaffected in any manner from the outside conditions.
2. During our research we also came across the camera response function which may also be used to evaluate the lights. The camera response function in specific to each camera and related the intensity of a pixel in a picture taken by the camera to the radiance. With a known camera response function a picture taken during the conduct of the experiment can generate better iso-lux plots and using computer vision algorithms the lamps can also be evaluated through objective output instead of subjective results based on the opinion of observers which cannot objectively quantify the results on the same scale.
3. We also recommend the use of fog lamps, but only those which have been properly aimed, installed at a low height and have a narrower pattern with the spread of around 60-100 cm.

REFERENCES

I. Commision, E. (2017). Current speed limit policies. Retrieved from European Commision: https://ec.europa.eu/transport/road_safety/specialist/knowledge/speed/speed_limits/current_speed_limit_policies_en

II. Editor, W. G. (2011). *Why is fog usually seen in the morning?* Retrieved from http://wxguys.ssec.wisc.edu/

III. Michigan, S. o. (2008). *Brake Testing*. Retrieved from michigan.gov: https://www.michigan.gov/documents/msp/BrakeTesting-MSP_VehicleEval08_Web_221473_7.pdf

IV. Officials, A. A. (1994). *A Policy on Geometric Design of Highways and Streets.*

V. Romain Gallen, N. H. (n.d.). *Static Estimation of the Meteorological Visibility Distance.*

VI. Service, N. W. (n.d.). *Fog types.* weather.gov. Retrieved from http://www.weather.gov/media/zhu/ZHU_Training_Page/fog_stuff/fog_guide/fog.pdf

VII. Wikipedia. (n.d.). *Meteorology.* PediaPress. Retrieved from https://en.wikipedia.org/wiki/Visibility

VIII. Yasmeen, G. R. (2012). Impact of Aerosols on Winter Fog of Pakistan. *Pakistan Journal of Meteorology* .