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ASSESSMENT OF TRIALS TO IMPROVE TRAIN CONSPICUOUSNESS APPROACHING PASSIVE LEVEL CROSSINGS

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EXECUTIVE SUMMARY

Visual conspicuousness or visibility of a freight train is an important element in improving safety at level crossings where there are no warning devices or other safety improvement measures. The visual conspicuousness of a freight train depends not only on the actual luminance value of the train, but also on the average luminance of the surrounding background and the viewing options. The luminance of the train itself is influenced by various factors, such as the intensity and colour of light emitted from the train, livery and patterns of the train, cleanliness of the object, viewing settings, etc. The visibility is also dependent on the natural light characteristics and ambient condition.

To improve train visibility, flashing beacons on locomotives and the conversion of locomotive headlights from halogen globes (SEALED) to Light-Emitting Diodes (LED) have been carried forward to a trial implementation. Monash Institute of Railway Technology (IRT) undertook an independent assessment of these trials based on scientific principles. The objective was to develop a methodology to subjectively assess the change in conspicuity with respect to lighting/luminance scheme changes on rollingstock.

This report summarises previous similar studies in the railway sector and other applications, the methodology of the experimentation and the results of the findings. A visibility model, based on luminance contrast only, is adopted in this assessment. The luminance contrast between the front end of the locomotive cab and the background around the front end of the locomotive has been used as a measurable quantity in the visibility model. Other effects such as the contrast sensitivity, glare effect and the transient factor are not considered in the visibility model. Further, light pollution effects to the surrounding and to train crew are not considered. The current study is purely focused on the development of methodology to assessing the effects of rollingstock lighting on its visibility. Only locomotive frontal visibility is considered in this report.

A number of parameters and conditions has been identified to define scenarios for trial measurements. A Design of Experiment methodology based on fractional factorial design was then applied to design the experimental plan and to collect data from the field trials which covered a combination of the relevant variables. A number of scenarios with different background and locomotive configurations were developed and tests were conducted using a luminance camera GL Opticam 3.0 instrument. The scenarios included a combination of LED or SEALED halogen headlights and beacon lights arrangements. The GL Opticam system has been previously used mainly in road marking and road lighting quality assessment and in tunnel entrance luminance measurements. It is the first time this instrument has been used in a railway visibility study, and it is the first time that the instrument has been used in the Southern Hemisphere.

Two sites were identified for trial testing in Western Australia, one in Aurizon facilities at Avon yard and another at a passive level crossing in service near to York. Another test site identified for the trial testing was at Spotswood yard in Victoria. Based on the collected measurements, the effects of the suggested control measures and other identified variables relevant to the conspicuity of locomotives were analysed. The trials were limited to explore the visual conspicuity of freight locomotives mainly in day-light hours as a large percentage of level crossing collisions occur during day time.

The distance from the observer to the locomotive and the angle that the observer is viewing the locomotive significantly affect the visibility of the locomotive lighting. The viewing angle corresponds to the layout design of the level crossing and the orientation of the locomotive approaching the level crossing. It is observed from the study that the efficacy of conversion of headlight from SEALED to LED is highly dependent on the distance between the observer and the locomotive as well as by the viewing circumstances. It is also clear from the current trial assessment that the visibility of the locomotive lighting is affected by the level crossing layout (locomotive orientation), vegetation density and weather. The study concludes that there are no significant differences between LED and SEALED headlights when considering the effects of the conversion of the headlight from SEALED to LED alone.

The LED headlight provides an improved visibility in comparison to SEALED headlight in misty conditions. However, the visibility improvement due to headlight conversion in clear weather condition is insignificant. Although the effect of LED headlight on visibility is marginal, there are other operational advantages that the LED headlight may have compared to SEALED headlights.

The effect of the beacon lighting configuration considered within this trial is significant only if the observer is close to the level crossing and the distance to the oncoming locomotive is short. In terms of the angle that the observer is viewing the locomotive, the effect of the beacon light at its current configuration is significant at small view angles. This is to say that, the beacon lights' effect is significant when the level crossing angle is obtuse and when the road user is in close range to the level crossing.

Although the current trial assessment was limited to assess the frontal visibility of oncoming freight locomotive, for certain level crossing layout designs, such as level crossings at an acute angle, the locomotive's side visibility is as important as the frontal visibility. Future trials should include visibility improvement measures on the side of freight train. Further, the effects of lighting pattern, configuration and colour needs to be looked at in future trials. Another important aspect to assess in future trials is the effects of locomotive livery and livery patterns on its conspicuity in day-light hours.

DISCLOSURE NOTICE

(Please read before reading report)

PURPOSE:

This report presents the findings and assessment results pertaining to trials of train conspicuity improvement at passive level crossing.

AUDIENCE:

The work described in this report was carried out for Office of the National Rail Safety Regulator (ONRSR).

ASSUMPTIONS/QUALIFICATIONS:

The findings, assessments, discussion and recommendations made in this report are based on an analysis/assessment of information obtained from trials, public domain and provided by ONRSR.

FURTHER INFORMATION:

Further information can be obtained from Professor Ravi Ravitharan at Monash Institute of Railway Technology.

EXTERNAL SOURCE MATERIALS:

Monash Institute of Railway Technology (IRT) and/or Monash University do not accept responsibility for the validity or accuracy of any source material, measurements or data used in this study that was not generated by Monash IRT.

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NOMENCLATURES AND DEFINITIONS

In this report, notations of variables used in the factorial design are bold-faced.

Notations

C1, C2 and C3	Luminance contrasts
Cr1	Luminance ratio
$\bar{C}_{ref}$	Threshold contrast
DGF	Disability glare factor
f_s	Aperture number
K_c	Calibration constant
N_d	Digital number of pixel or grayscale value
RCS	Relative contrast sensitivity
S	ISO shutter speed rating
t	Exposure time
TAF	Transient adaptation factor

Acronyms

ACRI	Australasian Centre for Rail Innovation
ARA	Australasian Railway Association
AS	Australian standard
CFR	Code of Federal Regulations
DoE	Design of experiment
EN	European Standard
FEMA	Federal Emergency Management Agency
FORG	Freight On Rail Group
FRA	Federal Railroad Administration
IRT	Monash Institute of Railway Technology
ISO	International Organisation for Standardisation
LC	Level crossing
LED	Light-Emitting Diodes
ONRSR	Office of the National Rail Safety Regulator

PN	Pacific National
PoI	Point of interest for the spot meter readings
RISSB	Railway Industry Safety and Standards Board
RSSB	The Rail Safety and Standards Board
SSR	Southern Shorthaul Railroad
ToR	Top of rail
VI	Visibility index
WA	Western Australia

Glossary

Beacon lights	Lights mounted on the brow of a locomotive displaying flashes of light (white or coloured) to warn road users and other motorists
Ditch lights	Also known as visibility lights, auxiliary lights or crossing lights used to make trains easier to spot, for safety
Headlights	A powerful light mounted at the front of a locomotive or cab that are positioned at the top of the cab to illuminate the railway track ahead
Interaction effect	The amount a response is influenced by the level of two or more factors
Main effect	The amount a response is influenced by the level of a single factor
Passive LC	An unprotected level crossing with no warning system
Viewing angle	The angle the camera (observer) view towards the front of the locomotive cab end
Viewing distance	The distance between the camera (observer) and the locomotive

CONTENTS

1 INTRODUCTION

1.1 BACKGROUND

A Freight Train Visibility Review Report [1] by the Australasian Centre for Rail Innovation (ACRI), working together with the Office of the National Rail Safety Regulator (ONRSR), Freight On Rail Group (FORG), Australasian Railway Association (ARA), Railway Industry Safety and Standards Board (RISSB), and TrackSAFE suggested a range of controls that may improve train visibility, including freight-vehicle mounted systems. As part of the suggested measures, two recommendations from the report were carried forward to a trial implementation and considered as part of this trial, these being:

- Flashing beacons on locomotives; and
- Conversion of locomotive headlights from halogen globes to light-emitting diode (LED).

ONRSR engaged the Monash Institute of Railway Technology (IRT) to advise on and undertake an independent assessment of these trials based on scientific principles. It was agreed to propose a method that can measure and quantify the visibility of a freight locomotive and assess the effect that different variables have on it. To that end, Monash IRT has proposed a scientific and statistical procedure to measure the visibility indicating parameters, to quantify train visibility and to assess the effects of different variables on the visibility of freight locomotives.

1.2 PURPOSE

The objective of this project is to develop a methodology to assess the efficacy of headlight conversion from SEALED halogen to LED and the addition of a flashing beacon light on the conspicuity of a freight locomotive. Based on light measurements considering a number of scenarios, the project aims to quantify and analyse the effects of the suggested control measures and other relevant variables on the conspicuity of locomotives. It aims to base the investigation on previous knowledge and to provide an independent assessment of the implemented trials based on scientific principles. The investigation is limited only to the two control measures implemented and their efficacy on visual conspicuity of a locomotive. Based on the assessment results, recommendations will be provided. Possible additional recommendations of other measures to improve the locomotive conspicuity, not included in the current trial, that may warrant serious consideration, will also be given.

1.3 SCOPE OF WORK

The proposed approach to deliver the project has three stages. These are:

Stage 1 – Review of Report and Standards, and Field Experimental Design

- Review of the Freight Train Visibility Review Report [1] and identification of main variables that may influence the observation results;
- Review of Australian and other international standards to identify acceptable levels of luminous intensity for good lighting and improved conspicuousness;
- A Fractional Factorial design for data collection from the field trials based on a design of experiments (DoE) methodology; and

- A plan for the reference data collection.

Stage 2 – Collection of Data

- Reference data collection in a controlled environment, with known variables; and
- Data collection from the actual field trial, at multiple sites.

Stage 3 – Data Analysis and Risk Assessment

- Analysis of data gathered from the field trial; and
- Risk assessment of visibility of train.

1.4 PROJECT EXECUTION STEPS

A project team was formed comprised of ONRSR, Aurizon, Pacific National (PN), Southern Shorthaul Railroad (SSR) and Monash IRT. A regular weekly/bi-weekly meetings was held continuously with the project partners consisting of FORG members on the activities of the project throughout the project duration. The adopted approach and the scope of work to conduct the trial assessment was proposed to ONRSR and the FORG members and agreed during the project inception period.

First, the variables possibly affecting visibility of locomotive were identified based on reviews of ACRI report and other reports, and visual inspection conducted during the field trials. For the current investigation, the variables considered were limited to only those variables that the railway operators have control of and the variables that may interrelate with the luminance value of the locomotive's frontal view and the background. The important variables and levels of variation has been agreed by the project team.

Detailed test plan and test scenarios for the field trial testing of the lighting systems were prepared for the two test sites, one in Western Australia (WA) and the second in Victoria. Samples sizes, variable composition, testing set up and limitations were discussed and agreed. A design of experimental methodology was followed to prepare the experimental planning. Trial tests were conducted and data were collected using different apparatus. Members of the project team and others from CBH were witnessing during the field measurement and data collection conducted in WA.

1.5 ORGANISATION OF THE REPORT

This report is organized into nine sections. In Section 2, relevant literature and standards which have been reviewed are summarised. Section 3 discusses the definitions of visibility and visual conspicuity in general terms and in the context of this project. A number of visibility models discussed in different literature for applications other than railway and the adopted visibility model in the current assessment are discussed in this section. Also, a number of variables affecting visibility are discussed. The methodology and the approach adopted to collect data and plan the experimental design is discussed in Section 4. The apparatus used and the procedures to collect measurements, the experimental scenarios and the different testing sites for the trial are also discussed. Section 5 details the data collection at the different trial sites. In Section 6, the data analysis and results are discussed. Important findings from the different analysis are summarised in Section 7. Conclusions and important recommendations are discussed in Sections 8 and 9, respectively.

2 REVIEW OF RELEVANT REPORTS AND STANDARDS

This section presents the review of ACRI's report [1], both Australian and relevant international standards in terms of locomotive visibility and other relevant reports and research findings.

2.1 REVIEW OF ACRI REPORT

An extensive literature review of freight train visibility is summarised in the ACRI report [1]. The report covered the enhancement of freight train visibility including literature review, data analysis, potential initiatives, and recommendation. This review of the ACRI's report focuses only on the parameters identified and the potential controls to improve level crossing safety.

Various parameters that could contribute to level crossing safety are stated. The main parameters and some of the examples are extracted and summarized in Table 1.

TABLE 1. PARAMETERS AND SOME EXAMPLES MENTIONED IN THE ACRI'S REPORT

Parameters	Examples
Rail vehicle conspicuity	▪ Colored lighting, e.g. strobes, during daylight hours ▪ Lighting positions and lighting arrangements; ▪ Reflective strip; ▪ Flashing light.
Road and Rail Alignment	▪ Delay road user's ability to detect the presence of the freight locomotive or wagons
Infrastructure Control	▪ Dirt could cover the high contrast paint of vehicle; ▪ Vehicle cleanliness.
Surrounding Environmental Condition	▪ Vegetation; ▪ Surrounding building along the rail corridor.
Weather (and other visibility impairing factors)	▪ Wet, clear, adverse, etc.; ▪ Time of day.
Road user behavior	▪ Inability to identify the oncoming train; ▪ Inability to determine the approaching train's speed; ▪ Lack of awareness of warning signs; ▪ Failure to drive according to conditions; ▪ Inattentional blindness.

In terms of potential controls, the report identified and assessed thirty controls that may improve vehicle conspicuity in different aspects. These included lighting (13 initiatives), cleanliness (6 initiatives), vehicle exterior appearance (3 initiatives), road users' awareness improvement (3 initiatives) and others (5 initiatives) such as low frequency sound, count down timer, automated radio broadcast, etc. Two initiatives under the lighting category, flashing beacons and headlight conversion from SEALED halogen to LED, were carried forward to a trial implementation.

With reference to the incident cases mentioned in the ACRI report, a number of variables and conditions are identified which are related to general site condition, on-track vehicle and road vehicle. Details of the variables are shown in Table 2.

TABLE 2. IDENTIFICATION OF VARIABLES AND CONDITIONS

Variables related to general site condition			
Weather	Dull/ Overcast	Partly Cloudy	Clear
Time of day	Morning	Afternoon	Evening
Train Direction/Road Vehicle	E /SE /S / SW/ W/ NW/ N/ NE		
Track Design	Straight	Curve	
Road Design	Straight	Curve	
Road to Track Design	Acute Angle	Obtuse Angle	Right Angle
Viewing angle (road user's view)	Good visibility	Fair	Low visibility
Vegetation	Dense	Fair	Light
Variables related to On-Track Vehicle and Road Vehicle			
Sunlight Direction to Road Vehicle	Facing	On LH or RH side	Behind
Sight to crossing from road vehicle	Blocked by …	Partially Blocked	Clear
On-track Vehicle Contrast	High (Colour: Red & Yellow)	Medium (Color: Blue)	Low (Colour: Grey)
On-track Vehicle Cleanliness	Clean	Fair	Dirty
On-track Vehicle Lighting Arrangement	Two lights at front	Three lights in triangular	
On-track Vehicle Lighting Colour	White	Coloured	
Speed & Distance	60 km/h Min. 134 m	80 km/h Min. 178 m	100 km/h Min. 222 m

2.2 REVIEW OF AUSTRALIAN AND INTERNATIONAL STANDARDS

Australian standard, AS 7531:2015 [2] and relevant standards discussing vehicle conspicuity/ visibility have been reviewed. AS 7531:2015 references numerous other documents and this review has focused on the following:

- AS/NZS 1906.4 Retroreflective materials and devices for road traffic control purposes; Appendix A [3];
- UK RSSB standard GM/RT 2483 Visibility requirements for trains (which superseded by UK RSSB GM/RT 2131) [4];
- EN 15153-1, Railway applications - External visible and audible warning devices - Part 1: Head, marker and tail lamps for heavy rail [5];
- US Code of Federal Regulations 49 CFR 229.125 Headlights and auxiliary lights [6]; and
- US Code of Federal Regulations 49 CFR 229.133 Interim locomotive conspicuity measures – Auxiliary external lights [7];

2.2.1 AS 7531:2015 AND AS/NZS 1906.4 APPENDIX A

AS 7531 [2] specifies requirements for headlight and visibility lights (ditch lights) to rollingstock operating up to a nominal maximum speed of 160 km/h (~44.4 m/s). The standard specifies requirements for the position of the head light above the rail, the luminous intensity of the headlight at different angles, and the distance the headlight must aim in the centre of the track ahead of the rolling stock. In the context of this project, there is no mention of the headlight requirements for visibility of locomotives for road users. There is no explicit statement that requires the intensity of the headlight required on approach to level crossings considering the visibility of the locomotive itself. Hence, it is recommended that any future review of the AS 7531 standard needs to include headlight type, colour and luminous intensity requirements considering the efficacy these lightings have on rolling stock visibility to road users, such as road vehicle drivers approaching a level crossing.

The standard also specifies requirements for visibility lights (ditch lights). It specifies the requirements for two white visibility lights at any leading end. However, the requirement does not differentiate between incandescent/halogen lights and LEDs. It is important to note that incandescent lights (including halogen) produce a continuous spectrum. LEDs do not produce a continuous spectrum and the appearance of white light is approximated by using several different narrow-band colour LEDs in combination [8]. The standard further states the requirements to the luminous intensity at different angles and the position of the light above the top of the rail. In the context of this project, the standard specifically addresses the following two requirements:

- The visibility lights must aim at a point at least 25 m in front of the vehicle at the top of the track such that they are between 7.5° and 15° from the longitudinal centreline of the vehicle;
- Lights must alternatively flash when a) the horn is sounded and b) vehicle changes direction

- Flashing must continue for at least 15 seconds after horn has sounded
- Flash rate must be between 40 flashes per minute (0.67 Hz) and 180 flashes per minute (3 Hz)

The distance and angle requirements outlined above have been taken into consideration as a basis for the planning of this trial assessment.

Further, the standard specifies the requirement for the lighting maintenance and inspection requirements to preserve their illumination and alignment properties. Appendix A of AS/NZS 1906.4 includes a method for measuring luminance factor, specifically using a calibrated light source and measuring the reflected spectrum. It is intended for measuring colour chromaticity and luminance factor under daylight conditions for specific classes of materials.

In terms of locomotive visibility, AS 7531 [2] should be considered as a minimum set of requirements. However, further development of the standard is needed to specify recommendations for headlight and other external auxiliary lights requirements when investigating locomotive conspicuity.

2.2.2 RSSB GM/RT 2131 AND EN 15153-1:2020

The UK RSSB Standard GM/RT 2131 also addresses visibility in Part 3. This standard itself heavily relies on LOC & PAS TSI Section 4 [9], but does include additional requirements:

- In the UK “full beam” (high intensity) and “dimmed” (low intensity) are intended for day time and night operation respectively (G 3.1.1.2).
- The UK does not have separate visibility lights but instead relies on the headlights (headlamps) and a top marker lamp in combination (G 3.1.1.5).
- BS EN 15153-1 Section 6 is cited for measuring front end lamp luminosities. This standard also specifies the requirements for headlights, marker lights and tail lights. Headlights and marker lights are to be white and tail lights red (both have defined colour spaces in the standard).
- Headlight glare is controlled through Clause 5.3.4 Table 3 of EN15153-1:2013, unlike in the RISSB standard.
- Headlights can be set to flash at 40 cycles per minute (0.67Hz) ± 10% for the purpose of enabling the driver to warn oncoming trains of a hazard. This is distinctly different to the use case in Australia, where the flashing visibility lights (ditch lights) are used to warn of motorists of the approaching train.

BS EN 15153-1:2020 [5], Section 6, provides a method for measuring headlight luminosity. It is a laboratory test for a single type and involves a colorimetric test (colour of the light emitted) and a photometric test (luminous intensity for the angles for which luminous intensities are specified). The photometric test may be suitable for confirming that the headlights and visibility lights meet the intensity requirements as prescribed by AS 7531 [2]. However, due to its setting (lab test with a photometer) and scope, it is not suitable for assessing the visibility of the locomotive in the context of this project.

2.2.3 US CODE OF FEDERAL REGULATIONS 49 CFR 229

US Code of Federal Regulations 49 CFR 229 [6],[7] has also been reviewed. The luminous intensity requirements in AS 7531 appear to mostly originate with the US CFR. Of particular note are the following points:

- 229.125(a) [6] specifically distinguishes between single and dual bulb/lamp headlights (i.e. multiple globes in the one fitting). From this, it is possible to reasonably infer that the number of globes/bulbs/LEDs is not important as long as the sum total generates the required luminous intensity.
- 229.125(d/e/f) [6] refer to auxiliary lights and 229.133 [7] specifically address the use of the auxiliary external lights, additional to the headlight, for improved conspicuity. AS 7531 clearly draws its requirements for visibility lights from these subsections.
- 229.133 [7] includes multiple different configurations such as Strobe lights, Oscillating lights and Crossing lights, from which only the Crossing lights configuration appears to be referenced by AS 7531.

In light of the current project, the US CFR does not appear to add any other aspect beyond AS 7531.

2.3 REVIEW OF REPORTS DISCUSSING VEHICLE CONSPICUITY

There are several reports published by the US Federal Railroad Administration (FRA) dealing with rail vehicle conspicuity testing and conspicuity enhancement studies. The following two reports are reviewed:

- The US Department of Transport (DOT) FRA report ORD-21/15, Compliance Testing for Locomotive LED Headlights and Auxiliary Lights, Phase III [10]; and
- The US DOT Evaluation of Retroreflective Markings to Increase Rail Car Conspicuity DOT-VNTSC-RB97-PM-98-22 [11].

2.3.1 FRA REPORTS FOR COMPLIANCE TESTING FOR LOCOMOTIVE

The US Federal Railroad Administration (FRA) published a series of reports for Compliance Testing for Locomotive LED Headlights and Auxiliary Lights [10]. Although the purpose of the Phase III compliance testing was visibility of targets along the track, it also addressed the visibility of the pattern formed by the locomotive lights by an observer outside on the track wayside. The experiment included perceptual evaluation made by observers located at a distance from the locomotive. The distance at which an observer was able to identify the target (geometric pattern formed by the headlights and auxiliary lights on the front of a locomotive) and the distance at which the observer was able to discern that the locomotive is moving closer were used to quantify visibility. LED and halogen lamps were used both as headlights and auxiliary lights in the testing. The study concludes that there were no significant differences between LED and halogen lights in terms of detecting the lamp pattern. Further, the report concludes that there were no significant differences in the visibility of the track and wayside when illuminated by LED or halogen lamps.

In light of the current project, the FRA report contain interesting results on the comparison of the visibility between LED and halogen headlights and auxiliary lights.

2.3.2 EVALUATION OF RETROREFLECTIVE MARKINGS

To enhance the conspicuity of standard hopper cars at night time, retroreflective marking systems were tested and evaluated [11]. A number of cases considering combinations of colour, shape and distribution patterns were included in the test program. The evaluation concludes that any retroreflective systems lead to an improved train conspicuity when compared to a nonreflective marking. Further, the study found that combination of colour pattern and distribution pattern contributed more to the effectiveness of the marking systems than the individual colour pattern or distribution pattern contributed alone. The retroreflective materials were more effective if placed over a relatively large area of the wagon side rather than being concentrated along the bottom of the wagon. Although the study was for night time conspicuity improvements, contrasting colour and visible lights in a certain pattern on the side of freight trains may improve the day time conspicuity.

2.4 OTHER NON-RAIL STANDARDS AND REPORTS IN OTHER APPLICATIONS

Outside the rail industry, visibility and conspicuity has been an important issue for road vehicles (predominantly trucks) and emergency vehicles. Various studies and standards have been written to address this issue. Below are the ones examined for this project:

- AS 1428.1:2021 Design for access and mobility, Part 1 [12];
- Motor Vehicle Conspicuity (SAE International, 1983) [13];
- Improved Commercial Vehicle Conspicuity and Signalling Systems (NHTSA US, 1985) [14]; and
- FEMA Study FA-323 Emergency Vehicle Visibility and Conspicuity [15].

2.4.1 AS 1428.1:2021 DESIGN FOR ACCESS AND MOBILITY

AS 1428.1 Appendix B includes luminance contrast requirements and a method for calculating luminance contrast. It relies on a tristimulus colorimeter (aka three-filter colorimeter), but the principle can be adapted to a luminance meter as it only relies on the Y (reflected luminance) value. The key difference between these instruments is that the colorimeter separates the luminance values into the standard XYZ tristimulus values. The Konica Minolta CS-100A instrument and the GL Opticam 3.0 luminance camera used in the current trial can measure the absolute Y luminance value and the tricolour measurements. However, only the luminance value was used for calculating luminance contrast in the current trial assessment.

2.4.2 MOTOR VEHICLE CONSPICUITY STUDY

Henderson, et.al. [13] addressed the vehicle conspicuity in relation to probability of accident involvement. The research paper referred conspicuity as “noticeability” and “recognizability” of the vehicle and its behaviour relative to the observer. Parameters related to vehicle, driver and environmental characteristics that may affect vehicle conspicuity were identified. The paper discussed use of vehicle lights to enhance conspicuity in day time in addition to its principal function to illuminate the road at night. In light of the current study, use of vehicle lights to enhance vehicle conspicuity in day time is being tested in other applications.

2.4.3 IMPROVED COMMERCIAL VEHICLE CONSPICUITY AND SIGNALLING SYSTEMS

Smith et.al, [14] reported different conspicuity techniques and evaluation of improved conspicuity systems by a series of conspicuity experiments. The study mainly focused on retro-reflective materials and so are generally not relevant to the current scope of this project. However, there were several points of interest that are worth mentioning with respect to improving locomotive and train conspicuity. The colour of lighting and retroreflective materials influenced the conspicuity of vehicles. In particular, a combination of white & red or white & blue was found to be more effective than white on its own (the recommendation in the US is for white and red retroreflective material, but white and blue was permitted in the study due to the colour scheme of the company involved).

2.4.4 EMERGENCY VEHICLE VISIBILITY AND CONSPICUITY

The Federal Emergency Management Agency (FEMA) emergency vehicles study [15] noted that fluorescent colours, particularly yellow-green and orange, were most visible during daylight. This is consistent with the move in the rail industry to strong shades of yellow on the front of trains to improve conspicuity. The findings of the FEMA study raise some relevant points for this project in terms of effect of locomotive livery in its conspicuity. Further, increased contrast is reported to aid conspicuity. In particular, the definitions of luminance contrast, the degree to which an object is brighter than its background is found to be relevant to the current trial assessment.

3 DEFINITIONS AND VISIBILITY MODELS

3.1 VISUAL CONSPICUITY OR VISIBILITY

In this section, the term ‘visibility’ of an object is defined in a general context and procedures to measure or quantify visibility are discussed. The ‘visibility’ of an object is described as how much an object, or light source, stands out against the background or ambient conditions for a specific viewing condition. Cole and Jenkins [16] proposed an operational definition for visual conspicuity as:

> *A conspicuous object is one that will, for a given background, be seen with certainty within a short observation time, regardless of the location of the object in relation to the line of fixation.*

Whether an object is seen with certainty will depend on the background. It is important to note that the railway operates in a variable background environment and hence the environmental characteristics is considered as an important variable in the current assessment. An object that is conspicuous in one visual environment may not necessarily be conspicuous when it is in another [16].

A study by TNO Human Factors (TNO) [17] defines conspicuity of a target as the region around the centre of visual field where the target is capable to attract visual attention. The concept of conspicuity area as a measure for visual conspicuity of target is illustrated in Figure 1 by the two subjects in a wooded environment. The scene in Figure 1 (taken from [17]) shows two subjects (indicated by the arrows) with different conspicuity areas (indicated by the bright areas). The subject on the left is conspicuous because of a high luminance and colour contrast with the local background. The subject on the right is less conspicuous because of a low luminance and colour contrast with the local background. The brighter areas represent the conspicuity area (conspicuity measure) of the subjects in the centre. The TNO study uses a conspicuity meter to measure conspicuity of subjects. No other reference in use of the conspicuity meter is found other than the reports by TNO and hence this approach has not been examined further in the current assessment. However, the concept has been applied in the choice of the area of the background to the locomotive and in the definition of immediate and larger background near to the target object, see Section 3.3.

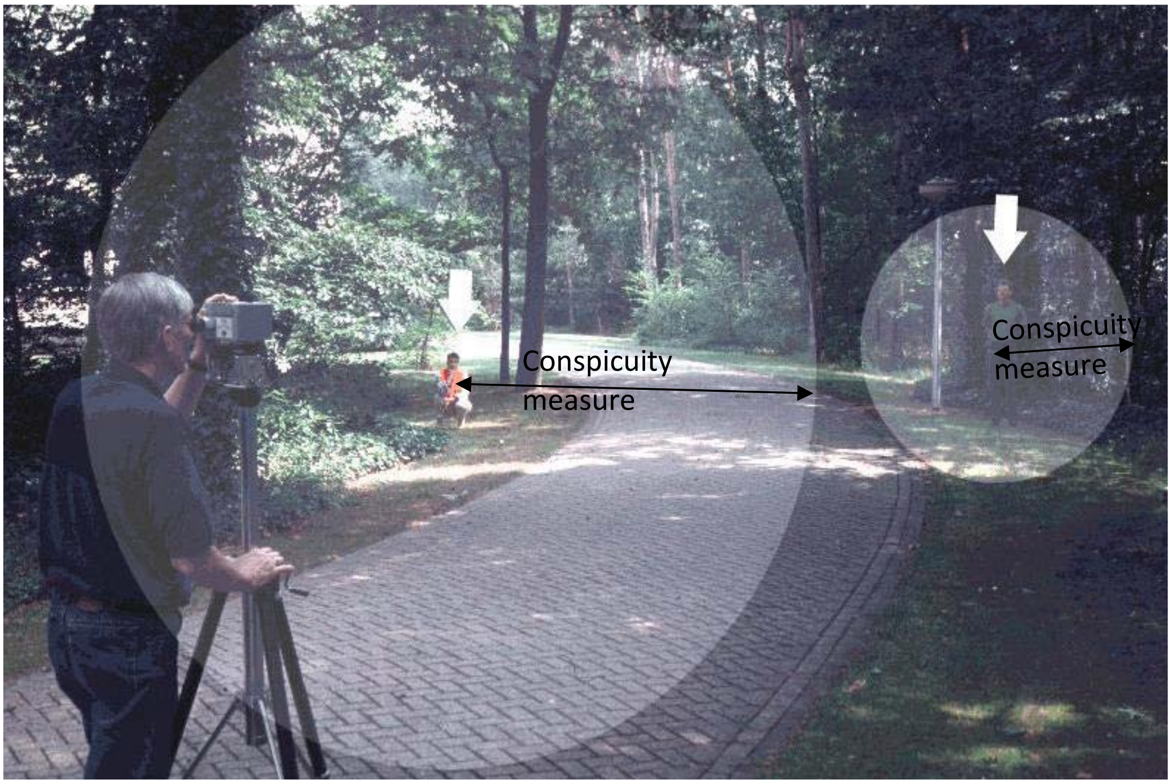


FIGURE 1. ILLUSTRATION OF THE CONCEPT OF CONSPICUITY AREA OF TWO DIFFERENT SUBJECTS WITH DIFFERENT LEVELS OF CONSPICUITY. THE BRIGHTER AREAS REPRESENT THE CONSPICUITY AREA (CONSPICUITY MEASURE) OF THE SUBJECTS IN THE CENTER [17]

Visibility level is being adopted as a standard quality index in road lighting design. According to Bremond et.al. [18], computing visibility level in road lighting design needs three photometric values of a target: its luminance, the luminance of its near background and the adaptation luminance of the ambient light. Luminance is described as the amount of light that passes through or is emitted from a particular area and falls within a given solid angle [19]. It is an approximate measure of how 'bright' a surface appears when it is viewed from a given direction.

Use of luminance measurement in road marking visibility and traffic lights is widely reported. For example, luminance measurements of a target object and the background have been used for things such as traffic lights and automobile tail lights to determine the intensity of a light source and to assess the visibility of road markings [20] - [23]. However, this type of measurement hasn't been done before in the rail industry and hence there are no accepted processes and procedures. The common method in the rail industry is a qualitative approach using the human eye to assess the visibility of the locomotive with light fittings at different distances and viewing angles. Hence, best practices from other similar industries have been researched and adopted in the current project. In this trial, luminance measurements were adopted as a measurable quantity to assess the efficacy of freight locomotive mounted lighting measures on its visual conspicuity.

3.2 VISIBILITY MODELS

A number of visibility models are discussed in this section. Although there is no generally accepted formula, references are made to different application areas relevant to the current assessment.

To predict visibility of an object, the CIE 19-2 analytical model is often utilised as demonstrated in a number of previous reports researching roadway lighting visibility [20], [21] & [23]. It is based on visibility index (VI), which is defined as the product of equivalent contrast, relative contrast sensitivity, disability glare factor and other factors.

The model uses the contrast formulas between the maximum luminance of the target and maximum luminance of the background. The visibility index formula used by CIE 19/2 to define the purely physical measures of visibility is [20]:

$$VI = (C \cdot RCS \cdot DGF \cdot TAF)/0.0923 \tag{1}$$

where,

C = contrast;

RCS = relative contrast sensitivity;

DGF = disability glare factor; and

TAF = transient adaptation factor.

Here, glare is a condition of vision in which there is discomfort or a reduction in the ability to see significant objects, or both, due to an unsuitable distribution or range of luminance or due to extreme contrasts in space or time. Luminance is a measure of brightness of a surface and it is measured in candela per square metre (cd/m^2) [24].

There has been a number of research programs addressing the question of what is the correct visibility model for roadway lighting [18], [20], [23] & [25]. The visibility index for roadway lighting was originally defined as [20]:

$$VI = C \cdot RCS \cdot DGF \tag{2}$$

Shelby & Howell [23] developed a number of possible luminance contrast formula and evaluated through experimental data to determine an accurate representation of the contrast that show good correlation with visual evaluator or human eye. Although, other factors such as relative contrast sensitivity and disability glare factor are used in the visibility index (VI) formulation, the luminance contrast alone can be used as a reasonable visibility indicator in the absence of data for the other factors.

Blackwell [25] defined visibility as the ratio between the luminance contrast C and the reference threshold contrast, $\bar{C}_{ref}$, which is a function of reference luminance L, as:

$$V = \frac{C}{\bar{C}_{ref}} \tag{3}$$

The reference threshold contrast, $\bar{C}_{ref}$ is empirically determined as a function of reference luminance. To apply the visibility formula suggested in [25], measured and evaluated reference contrast is needed to set a contrast threshold between visible and invisible contrast values.

To our knowledge, there is no “correct” model for visibility that can be applied in the current trial assessment. However, all the presented models indicate that there is a direct relationship between luminance contrast and visibility index. Hence, luminance contrast is used directly as a physical measure for visibility in the current trial assessment.

3.3 VISIBILITY INDEX IN THE CURRENT CONTEXT

The visibility index in the current context is used as a physical measure for visibility performance (rather than absolute visibility) of locomotive and its light fittings. It is based on luminance contrast between the target (object) and the background, as described by the target luminance contrast in references [18] & [25].

The larger the difference in contrast, the easier it is for a person to detect an object. In day-light hours, when the ambient light is high and the sun is shining towards the locomotive, the contrast between the locomotive light and the background can become lower as the sun-light visually masks the locomotive light. Similarly, when the sun is shining towards the locomotive, the glare may mask the locomotive light and the contrast can be reduced. Hence, visibility of locomotives can be affected by the level of the ambient light and the direction of the sun-light.

In this assessment, the front of a locomotive with its light fittings was the target while the region near and around the front of a locomotive is considered as the background. Two background boundaries were defined, the immediate background near the target and a wider background with a larger view area. The angle subtended by the immediate background around the target ranges from 1.5° to 3.5°, depending on the viewing distance between the observer (luminance camera) and the target (front of the locomotive). The field of view subtended by the wider background ranges from 7° to 10°, depending on the distance between the observer and the target, as illustrated in Figure 2.

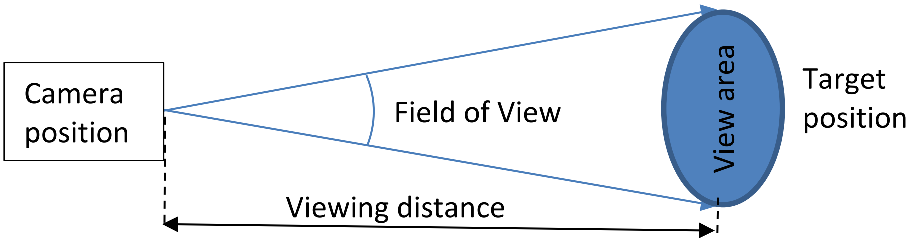


FIGURE 2. ILLUSTRATION OF VIEWING DISTANCE AND FIELD OF VIEW

3.3.1 LUMINANCE CONTRAST

In the visibility index calculation, the average luminance of the target area and the average luminance of the background area were used. Figure 3 shows a description for the boundaries of the object and the background. Here, the locomotive’s front is oriented at 45° from the direction of the viewer (camera).

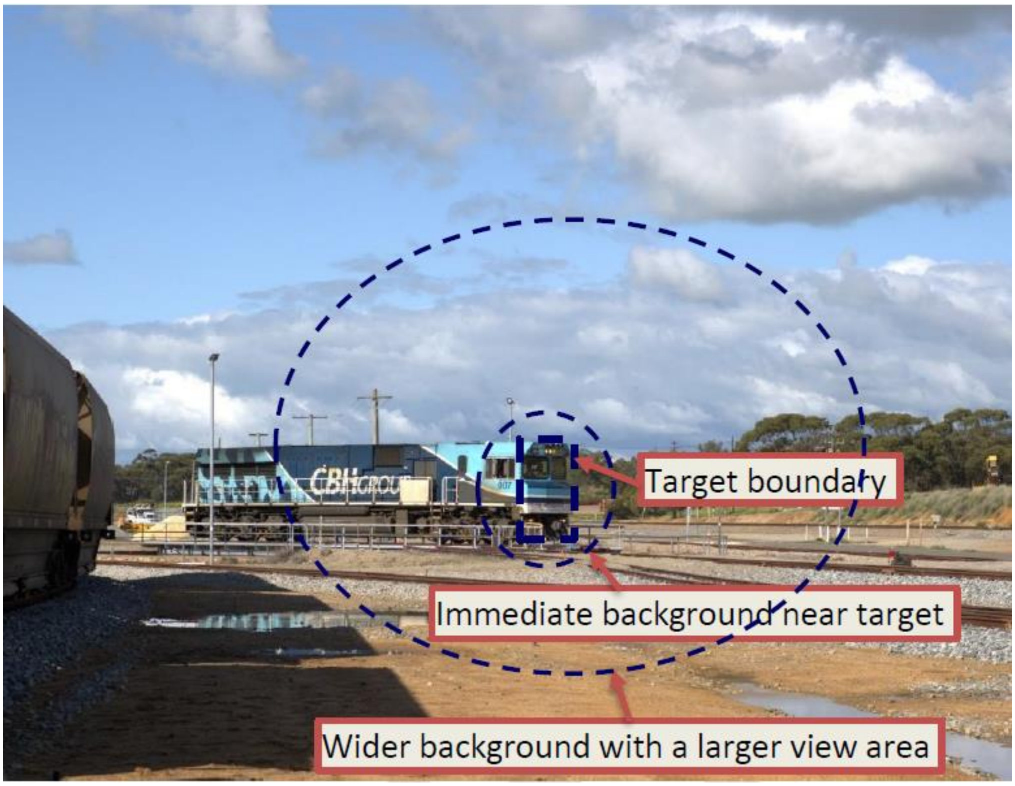


FIGURE 3. REGION OF INTEREST FOR VISIBILITY INDEX CALCULATION WITH THE BOUNDARY OF THE TARGET, IMMEDIATE BACKGROUND AROUND THE TARGET AND THE WIDER BACKGROUND WITH A LARGER VIEW AREA

Similar representations developed by Shelby & Howell [23] were adopted to describe the luminance contrast of the locomotive lighting with the background. Three luminance contrast formulations $C1, C2$ and $C3$ and a luminance ratio Cr_1 have been defined and adopted as visibility indicators for evaluation of the locomotive conspicuity. These are:

$$C1 = \frac{L_O - L_B}{L_B} \tag{4}$$

$$C2 = \frac{L_O - L_B}{\max(L_O, L_B)} \tag{5}$$

$$C3 = \frac{L_O - L_{IB}}{L_{IB}} \tag{6}$$

$$Cr_1 = \frac{L_O}{L_B} \tag{7}$$

Where,

L_O = average luminance (cd/m^2) of the front of the locomotive (target);

L_B = average luminance (cd/m^2) of the wider ($7° - 10°$ subtended field of view) background around the target;

L_{IB} = average luminance (cd/m^2) of the immediate ($1.5° - 3.5°$ subtended field of view) background around the target.

3.3.2 VISIBILITY INDEX VS. LUMINANCE CONTRAST

In the current assessment, there is no reference luminance value or reference luminance contrast that can be used as a threshold value to describe the actual visibility of the object. The higher the luminance contrast, the higher will be the visibility index but the relationship may not be linear. With no reference threshold limit values, the relationship between the luminance contrast as described by *C1, C2* and *C3* and the visibility index *VI* is non-linear as shown in Figure 4. By the same token, the relationship between the luminance ratio Cr_1 and the visibility index *VI* is non-linear. If the luminance contrast is zero, there is no distinction between the luminance values of the target and the background and hence the visibility of the object is zero, which means the background fully masked the object. For this assessment, based on initial base line measurements, for a given test scenario, a relationship is derived between the visibility index and the luminance contrasts as given by C1 and C2. Luminance measurements and visual judgments of the locomotives' visibility have been used to derive this simple relationship. It is developed to relate Luminance Contrast with a visibility index. Visibility index is 0 when it was not visible and Visibility index is 1 when the locomotive was clearly and distinctly visible. A negative visibility index may indicate that the background is brighter and has higher luminance than the object. However, this relationship has to be tested and validated using psychophysical methods. The relationship may not be valid for other cases and conditions other than the conditions discussed for the current testing scenario. The visibility will be maximum when the luminance contrast is 3 or above. That means the visibility of the object is maximum when the luminance value of the object is 300% or higher than the luminance of its background. On the contrary, when the luminance value of the background is higher than the object, it is not true that the object will be conspicuous or the object will stand out against the background.

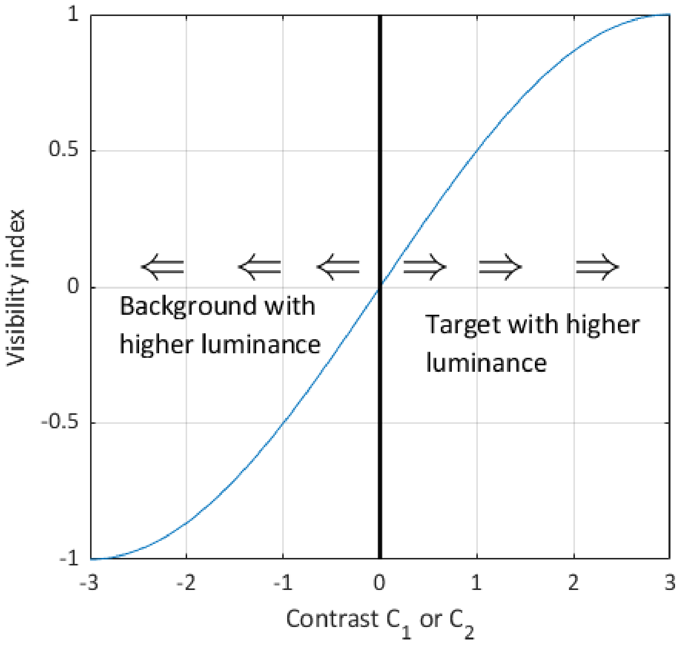


FIGURE 4. LUMINANCE CONTRAST VS. VISIBILITY INDEX

3.3.3 LIMITATIONS IN THE MODEL

The visibility index based on the luminance contrast of the target and the background does not take into account the effect of the natural light variation on the visibility. The model considers only the average luminance of the target and the background area at a given instant of time, and doesn't consider the luminance variation within the target or background area. Further, the luminance values are taken at a given instant of time and no consideration is made for the transient adaptation. The model can be applied to indicate visibility in a stationary situation where there is no transient change in the luminance of the target nor the luminance of the background. Further, the current adopted model is used to indicate relative visibility (visibility improvement) rather than absolute visibility. Therefore, an accurate visibility model that considers not only the luminance contrast between the target and the background, but also the contrast sensitivity, glare effect and the transient factor is critical. Alternatively, a reference luminance contrast or a threshold luminance through psychophysical tests can be employed.

3.4 VARIABLES AFFECTING VISIBILITY

Visual conspicuousness or visibility of an object is described as how much an object or light source stands out against the background or ambient conditions for a specific viewing condition. The visual conspicuousness of the object depends not only on the actual luminance value of the object, but also on the average luminance of the surrounding background and the viewing options. The luminance of the object itself is influenced by various factors, among them:

- colour paint of the object,
- cleanliness of the object,
- the intensity and colour of light emitted from the object,
- viewing angle,
- viewing distance, etc.

The visibility is also dependent on the natural light characteristics and weather condition.

A number of variables that possibly contribute to visual conspicuity of a locomotive have been listed in the ACRI report [1]. They are categorised in three main attributes as Viewing circumstances, Object related, and Environment. These three main aspects are interrelated with each other in terms of conspicuity [26]. However, the effects these variables have on the visual conspicuity of freight locomotives are not yet known. Object related factors include the luminance of the lighting and livery of the locomotive, the colour of lighting and reflective materials, lighting arrangement and paint pattern. The average luminance of the background, the contrast of the locomotive with the background, the orientation and view angle, the natural day light and direction of the sun, as well as the distance between the viewer and the locomotive are some of the environmental and viewing condition related parameters. These parameters or variables are categorised into their three aspects in Table 3.

TABLE 3. POSSIBLE VARIABLES AND CATEGORIES

	Categories		
	Viewing circumstances	Object	Environment
List of variables	• LC type (viewing angle and locomotive orientation) • Viewing distance (between the viewer and the locomotive)	• Headlight type • Degraded headlight operation • Ditch light • Beacon light • Locomotive livery • Headlight color • Locomotive livery cleanliness • Lighting arrangement • Paint pattern • Reflective materials	• Ambient light condition • Vegetation coverage • Sunlight direction • Weather condition

To illustrate these three category variables, images of a locomotive approaching an observer (camera position) from a far distance with differing visibility, cleanliness and ambient light condition are shown in images of Figure 5 - Figure 8. Note that the changes in viewing angle, viewing distance and the surrounding condition such as vegetation and natural light condition vs. the visibility of the locomotive.

3.4.1 VIEWING SETTINGS

At a far distance, the visibility is low as seen in Figure 5 (a) and (b), while the headlight is brighter in Figure 5 (a) compared to Figure 5 (b). The locomotive was at the top of the grade at location (a) as shown in Figure 5 (a) while the locomotive was in the slope section directing down gradient at location (b) as shown in Figure 5 (b). The locomotive lighting visibility was partially blocked by the dense vegetation when the locomotive was at location (c) as shown in Figure 5 (c).

The track layout with a grade at a far distance and an illustration of the vertical layout of the track, including the location and orientation of the locomotive approaching towards the camera are shown in Figure 5 (d) and (e), respectively.

When the locomotive was running down the gradient section, as shown in Figure 5 (b), the locomotive lighting was oriented down the grade and hence reduced visibility of the lighting. That means, the headlight is less bright in Figure 5 (b) in comparison to Figure 5 (a). Also, at a far distance, the flashing beacon light was masked by the glare of the headlight. Vegetation density can also obscure and reduce the visibility of the lights as shown in Figure 5 (b) and (c).

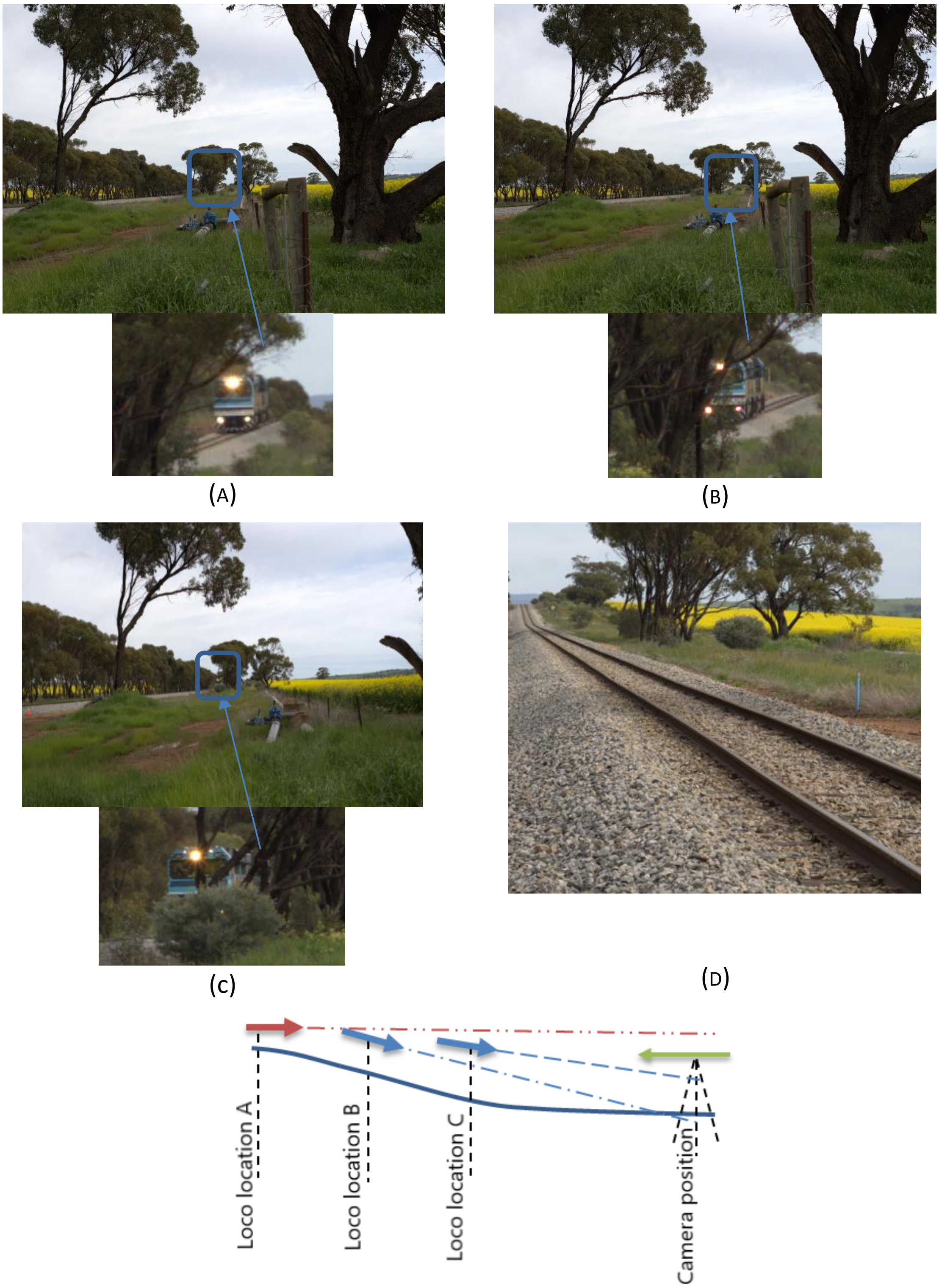


Figure 5. Images of a locomotive approaching an observer (camera position). (a) Long viewing distance; (b) long viewing distance and locomotive going down a gradient; (c) vegetation blocking locomotive visibility; (d) track gradient at a far distance; and (e) Illustration of the vertical layout of the track, the location of the locomotive in images (a) to (c), and the locomotive orientations at these locations

Viewing angle is another factor that affects the visibility of the locomotive. For comparison, images of the locomotive viewed at different distances and viewing angles are shown in Figure 6 (a) - (d). Note that the lighting is visibly brighter in Figure 6 (a) with a small viewing angle compared to the image in Figure 6 (d), with a wide view angle, although the locomotive is closer to the camera in image in Figure 6 (d). One can also notice that the brightness of the headlight and the ditch lights changes with a slight change in viewing angle, see the images of Figure 6 (b) and (c). Note that the beacon light was ON only in Figure 6 (d).

All the photos shown in Figure 6 were taken using a Sony camera, Model: ILCE-7M3, with camera setting ISO100, F/5.6, 0 step exposure bias, aperture priority exposure, spot metering mode, no flash and 50mm focal length. Exposure time were 1/400 sec. in Figure 6 (a), (c), and (e), 1/320 sec. in Figure 6 (b) and 1/500 sec. in Figure 6 (d) and (f). In photography, exposure time refers the time that allows the light to hit the camera's sensor [27]. The longer the exposure time, the more the light to reach the sensor. In the exposure settings in Figure 6, it showed that the shortest exposure time was 1/500, i.e. 0.002 seconds, in Figure 6 (d) and (f), and the longest exposure time was 1/320, i.e. 0.003125 seconds in Figure 6 (b) That means less light was allowed to enter the camera in Figure 6 (d) and (f) under the given settings.

(A)

(B)

(C)

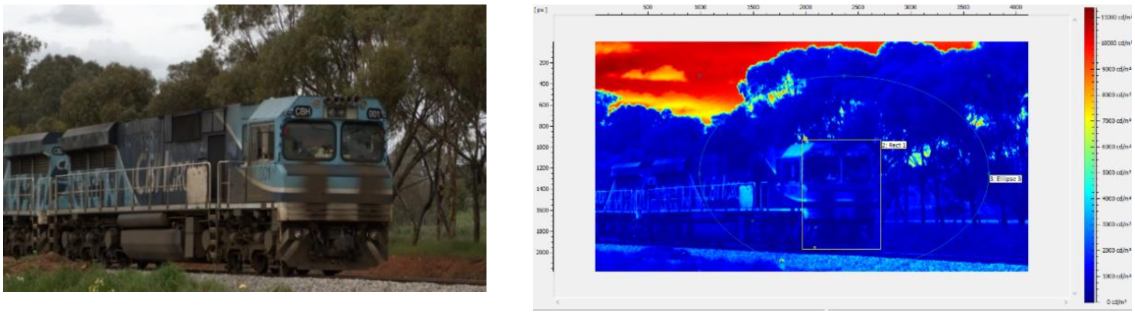
(D)

(e) (f)

Figure 6. Images of a locomotive approaching an observer (camera position). (a) sunny and the locomotive is at a far distance, (b) the locomotive approaching the farthest marker position, and (c) shadowy and the locomotive at about 7.5° view angle, (d) Sunnier and the locomotive at about 22.5 ° view angle, (e) shadowy and the locomotive at about 22.5 ° view angle, and (e) Sunny and the locomotive at about 22.5 ° view angle

3.4.2 Object condition

The effects of cleanliness of the locomotive livery, locomotive external lighting and the contrast with its background on the visibility can be seen in Figure 7, where one locomotive has uncleaned livery and another one a cleaned livery. The viewing condition (view angle and viewing distance) and the locomotives class are the same in both images. The corresponding images of the locomotives taken by luminance camera are shown to the right of the same figure. A qualitative view of the images to the left shows that the cleaned locomotive is more easily identifiable from the background than the uncleaned livery. The contrast of the uncleaned locomotive livery with its near background is less compared to the contrast of the cleaned livery with its near background. The lighting in the lower image in the clean livery makes the locomotive easily identifiable compared to the locomotive without lighting.



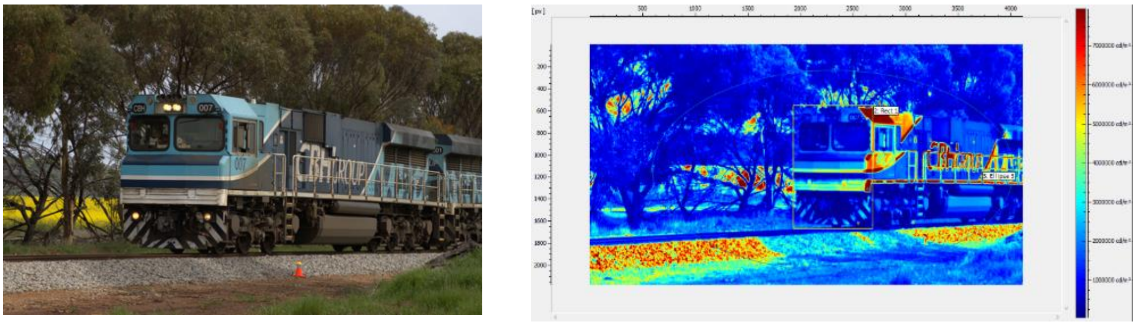


FIGURE 7. IMAGES OF TWO LOCOMOTIVES IN CLEAR VIEW: UNCLEANED LIVERY LOCOMOTIVE CBH001 (TOP), AND A CLEANED LIVERY LOCOMOTIVE CBH007 (BOTTOM)

3.4.3 ENVIRONMENTAL CONDITION

Another important factor is the effect the direction of sunlight and the ambient day-light may have on the locomotive visibility. Images of the locomotive captured at different day-light intensity are shown in Figure 6. The images in Figure 6 (a) and (d) were taken when the ambient day-light was sunnier, while images of Figure 6 (b), (c) and (e) were taken when the ambient day-light was slightly dimmer. For the same position and orientation of the locomotive, the locomotive visibility in the images of Figure 6 (d), (e) and (f) is different due to the change in the ambient day-light brightness. The image in Figure 6 (d) is brighter and more visible than the image of the locomotive in Figure 6 (e), despite the exposure time in Figure 6 (d) was 25% shorter than in Figure 6 (e), i.e. the amount of light captured is less in Figure 6 (d) than Figure 6 (e). Although, all lights of the locomotive are switched to ON setting in Figure 6 (d) and the locomotive's lights may have increased its frontal visibility, the ambient light improved the visibility of the frontal and clearly the side view of the locomotive in comparison to the locomotive's visibility in Figure 6 (e) and Figure 6 (f). That means, excluding the other factors, the effect of ambient day-light brightness and sun direction in the visibility of the locomotive is clearly significant.

The effect of vegetation density on visibility can also be clearly depicted in the two images in Figure 8. The same class of locomotive is positioned in the same location and viewing angle with respect to the camera location. In the first image the view was obstructed by vegetation while the second image was taken when the camera was positioned on the opposite side of the track, with the same distance and view angle, but the view is clear with no vegetation. As can be seen from the two images in Figure 8, the vegetation has obscured the view and masked the visibility of the locomotive compared to the clear view.

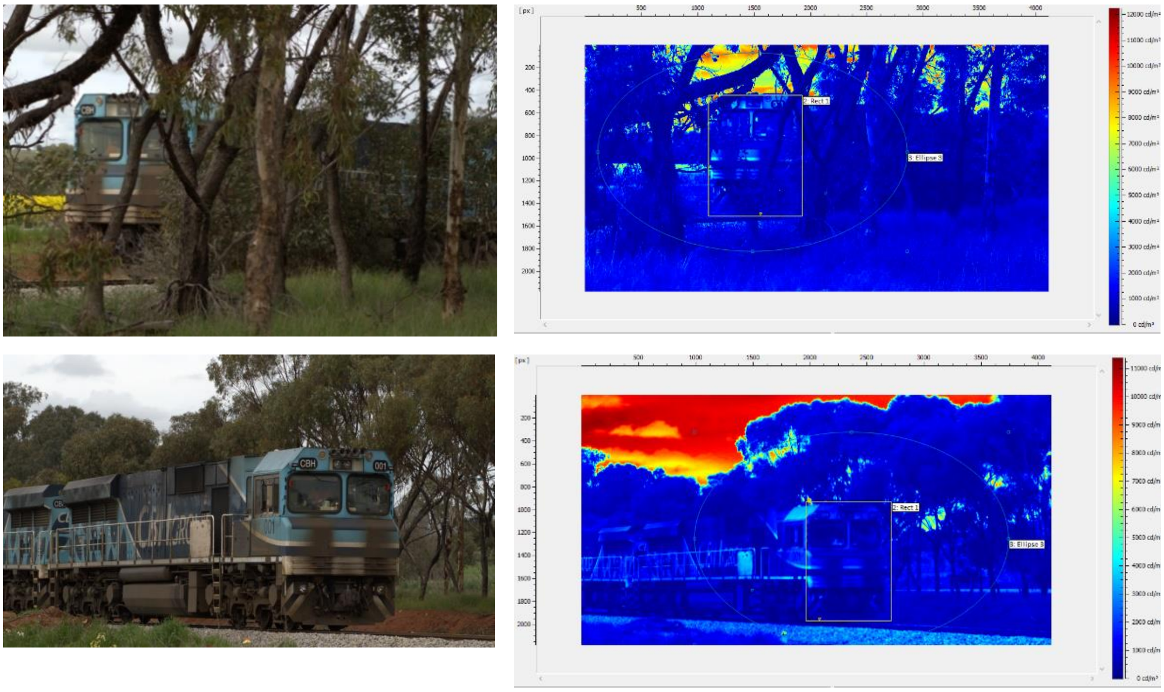


Figure 8. Locomotive CBH001 in obscure viewing due to vegetation (top), the same locomotive CBH001 in unobstructed view (bottom). The target (the rectangle circumscribing the front of the locomotive) and the background boundaries (the oval around the target) are shown on the corresponding luminance camera images

4 METHODOLOGY

In this section, a methodology is proposed to assess the effects of conversion of locomotive headlights from SEALED halogen to LED and the addition of flashing beacons on the conspicuity of freight locomotives. A number of previous assessments and studies examined the efficacy of locomotive livery contrast and retroreflective systems on locomotive conspicuity. However, there is almost no literature found regarding measuring, or a method based on measurements to assess train conspicuity. All the reviewed studies assessed conspicuity or visibility of rail vehicles through perceptual evaluation of participating observers able to identify trains and by that to quantify the effects of locomotive livery, lighting colour and lighting arrangements. This kind of approach is subjective to the individual participants. To be statistically representative, it would require a large number of participants with a wide variation in age, gender, experience, cognitive ability, etc. Hence, in this project a methodology is proposed to quantify visibility indicating values through measurable quantities and to include a wide scatter in the input variables to have a good representation of the actual operational condition. In order to do so, luminance measurement is proposed as a measure of visibility of light sources at the target and at the background to the target.

With the consideration of the interrelation between the three main aspects discussed in Section 3.4, and the effects (or combined effects) of the parameters or variables, quantitative measurement of luminance of the object and the ambient background under various viewing conditions are suggested. The measured luminance values are used to calculate the luminance contrast and luminance ratio as an indicator for the efficacy of the proposed trial implementation.

The visibility index definition described in Section 3.3.2 takes into account the luminance value of the object and the luminance value of the background to calculate the luminance contrast or luminance ratio. The visibility index described by the luminance contrast of the target with its background and luminance ratio between the target and the background described in Section 3.3.2 will be used as the measure of locomotive conspicuity.

This section discusses the apparatus used to collect data, the process of trial measurements, data collection and trial site identification, possible variables (factors) for the trials, and the methodology followed to plan the experimental design at the different trial sites.

4.1 APPARATUS

To understand the interrelation between the three main aspects, i.e. Object, Environment and Viewing settings, different apparatuses are being considered and adopted for the measurement at a number of trial site. Measurement of luminance[1] of the object and the environment (ambient background) under various viewing conditions are considered. Tools and equipment used in this measurement included: -

- luminance measurement and light meter to capture luminance data and light intensity data from the source and the background,

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[1] Luminance: is the measure of light emitting from a source and measure in candela per meter square (cd/m²).

- Konica Minolta CS-100A luminance meter with 1 degree view, see Figure 9
    - Opticam 3.0 Imaging Luminance camera, see Figure 10
    - Lux meter to measure light intensity, see Figure 12
- digital camera;
- survey instruments; and
- range finder.

The luminance measurement equipment was calibrated prior to use. A brief introduction of the measuring apparatuses is as follow.

4.1.1 OBJECT

4.1.1.1 Luminance meter

A portable/ hand-held spot luminance meter (1° view angle), see Figure 9, is a device used to measure luminance value of the object at the time of measurement. It gives the average luminance of the spot area and the measurements is done one at a time. A point to note is that the ambient condition may vary when reading the next spot in the same measurement setup. In addition, the spot area varies with viewing distance, the further the viewing distance the larger will be the spot area, the measurement reading will be the average luminance of the spot area.

Konica Minolta's Chroma Meter, model CS-100A is a Luminance & Colour Meter which can be used to measure the brightness and colour of light sources. This portable spot luminance meter has a 1° acceptance angle and 9° field of view. The range of calibrated luminance measurement is from 0.01 cd/m² to 49,900 cd/m² in slow mode and 299,000 cd/m² in fast mode.

FIGURE 9. LUMINACE METER – MODEL CS-100A

4.1.1.2 Luminance camera

A luminance camera can not only measure the luminance conditions of the object, but also capture the luminance conditions in the entire image of the scene. GL Optic's Opticam 3.0 4K Tech, seen in Figure 10, is an instrument used to measure the luminance distribution of a selected area in an image. [28]. It provides the value of luminance in the entire selected area. The Opticam instrument consists of a sensor, filter and lens. A schematic of this is shown in Figure 11. Measuring range of luminance by the Opticam is from 0.01 cd/m² to 150,000 cd/m² (the upper range can be higher depending on lens aperture and use of ND filter[2] which can reach for higher measurement range, e.g. measuring headlight). The instrument was calibrated also with one type of ND filter.

FIGURE 10. GL OPTIC - OPTICAM 3.0 4K [28]

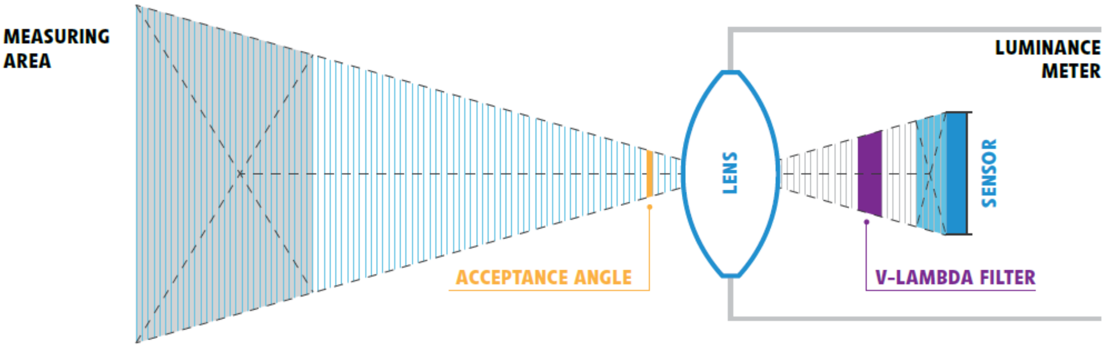

FIGURE 11. SCHEMATIC OF LUMINACE METER - GL OPTICAM [28]

4.1.2 ENVIRONMENT

4.1.2.1 Light intensity meter (Lux Meter)

The light intensity meter has been used to measure the illuminance of the ambient condition/ light falling on a surface. RS Pro RS-3809 Light Meter is an instrument that can measure light levels within the environment. It offers the measurement range from 40 lx to 400,000 lx. The equipment is shown in Figure 12.

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[2] Neutral Density (ND) filter blocks/ reduces the light entering the camera's sensors/ lens. This filter is useful for bright scene.

FIGURE 12. RS PRO RS-3809 LIGHT METER

4.1.2.2 Luminance camera

As mentioned in Section 4.1.1, the luminance camera can capture the luminance conditions of the entire scene in the same image captured by a single shot. The GL Opticam luminance camera gives the luminance value of each pixel in the image and the statistical values with the selected region of interest.

The Opticam system has been used mainly in road marking and road lighting quality assessment according to the EN 13201 Road lighting standard. The system has also been used in Tunnel entrance luminance measurement according to the CIE 88 standard (Guide for the lighting of road tunnels and underpasses). Recently, this system is being used for the lighting specification studies for sporting arenas (such as stadiums flood lights) and in indoor or outdoor events for lighting and visibility specification [28]. The Opticam 3.0 luminance camera system has both a dynamic measurement feature and a static measurement. The dynamic measurements work as sequence of images captured in a single measurement.

For the current assessment, the Opticam 3.0 luminance camera was the main measurement tool. It was the first time it had been used in the Southern Hemisphere and was brought to Australia especially for this trial. For each measurement run, two readings were taken and the average reading was used in the effect analysis.

4.1.3 VIEWING SETTING

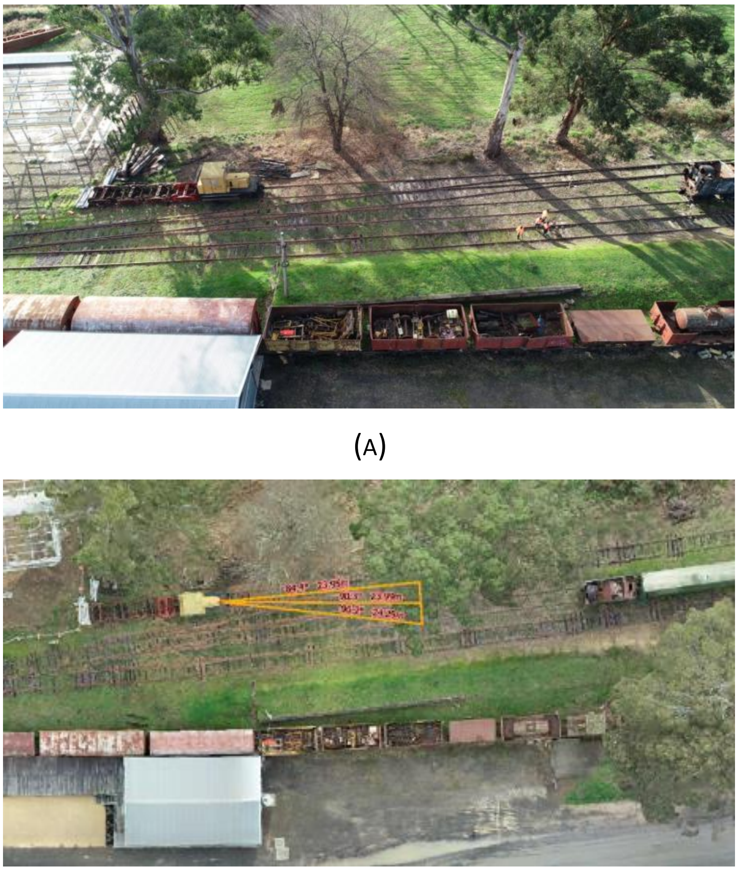
4.1.3.1 Survey instrument

Survey instruments were used to set up different measurement positions and measurement angles. Sokkisha Electronic Total Station, Model SET 4, as seen in Figure 13, is a surveying instrument that measure the horizontal angles and distances. A range finder was also used to locate the experimental settings and to collect the distance reading.

FIGURE 13. TOTAL STATION, SOKKISHA MODEL SET 4

4.1.3.2 Drone (Optional)

Initially, it was planned to make use of the drone's Real Time Kinematic (RTK) processing to have an aerial mapping and records GPS information during flight. Use this RTK technology for triangulation and test location positioning. Figure 14 shows the trial at Healesville and 2D triangulation at the scene at the initial trial of all the instrumentation and the testing procedure.



(A)

(B)

FIGURE 14. (A) TRIAL FLIGHT AT HEALESVILLE STATION AND, (B) TRIANGULATION USING DRONE

4.2 ALTERNATIVE EQUIPMENT – LUMINANCE MEASUREMENT BY DIGITAL CAMERA

A digital camera may be used to compare the luminance of a light source to the luminance of the area around it. The theory is that luminance can be calculated using the average "grayscale" value of an area through the following formula [29]:

$$Luminance = N_d \times \frac{1}{K_c} \times \left(\frac{f_S^2}{t \times S}\right) \tag{7}$$

where,

N_d: Digital number of pixel or grayscale value;

K_c: Calibration constant;

f_s: Aperture number;

t: Exposure time (s); and

S: ISO shutter speed rating.

Monash IRT conducted several trials to find the camera calibration constant, Kc value. Photos were taken in a controlled environment. In this environment there was one constant light source and a known ambient condition.

Photos were taken with varying camera settings, e.g. exposure time, aperture, ISO setting, and analysed to calculate the value of Kc. Table 4 and Figure 15 show the camera settings and the nominal values.

TABLE 4. DIFFERENT CAMERA SETTING

	Range tested	**Acceptable Range**	**Nominal Value**
Exposure Time	$\frac{1}{10} \rightarrow \frac{1}{200}$	$\frac{1}{80} \rightarrow \frac{1}{200}$	$\frac{1}{100}$
F Number	$1.8 \rightarrow 11.0$	$4.0 \rightarrow 5.6$	4.0
ISO Speed	$100 \rightarrow 1600$	$100 \rightarrow 125$	100

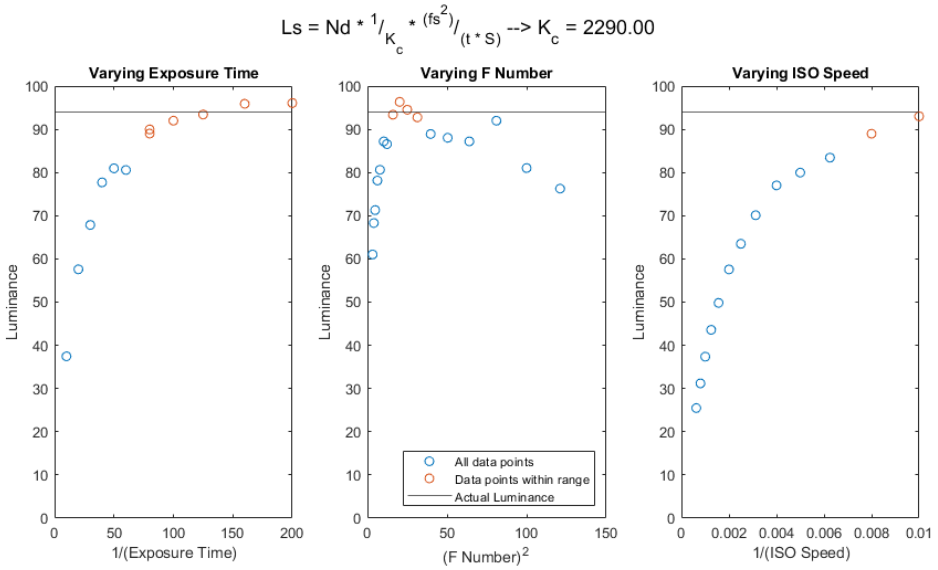


FIGURE 15. VARYING CAMERA SETTING

In grayscale, the maximum possible value of 65,536, 2^{16}, represents pure white or a saturation of the camera. The minimum possible value of 0 represents pure black or a saturation of the camera. The camera can be set up to take in more or less light using exposure settings. Each of these will require a different K_c value and a separate calibration.

Using the calculated K_c value, the appropriate camera settings and adjusting for light saturation, it will be able to measure the luminance of points of interest in a scene.

A photo of the train was taken and the luminance value has been analysed at several points:

- At the light itself
- Areas around the light
- Areas in the background

The conceptual idea is shown in Figure 16.

It is worth noting that there would be a constraint about using the normal digital camera for luminance measurement, while capturing the image in either a very bright scene or very dark scene. The grayscale/ pixel values may be saturated and cannot get the true value under the normal digital camera's sensor setup and hence it would affect the luminance value. To extend the luminance range, usage of a neutral density (ND) filter can be one option.

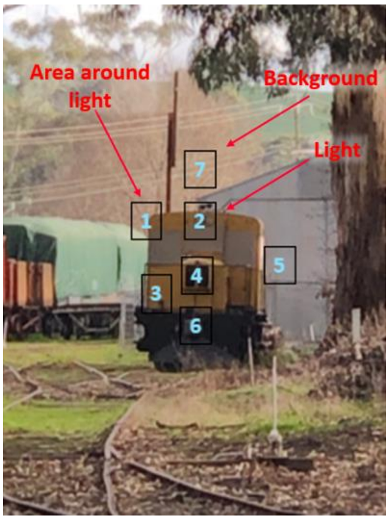


Figure 16. Points of interst on around a stationary locomotive for trial of digital camera setting

4.3 Possible Variables for the Trial

The total number of variables that were listed in Table 3 is 16. These are possible variables that may have an effect on the luminance contrast of the target with its background, and hence the visibility index. To evaluate the effect of all the 16 variables listed in Table 3, only considering two levels of variation for each variable, would require 2^{16} or 65,536 experimental trials. Hence, for this investigation, only those variables listed in Table 5 will be considered for possible evaluation of their effects. The effect of degraded headlight operation on the visibility index will also be assessed separately, considering different levels of degraded performance of LED headlights.

Table 5. List of possible variables (factors) that may be included for the trials

#	Variables	categories
1	Viewing distance (position)	Viewing conditions
2	LC design (angle of view to the train - viewing angle)	
3	Head light type	Object related
4	Beacon light	
5	Ditch light	
6	Locomotive livery	
7	Locomotive livery cleanliness	
8	Ambient light condition	Environment
9	Vegetation coverage	
10	Sun direction	
11	Weather condition	

4.4 PROCEDURE

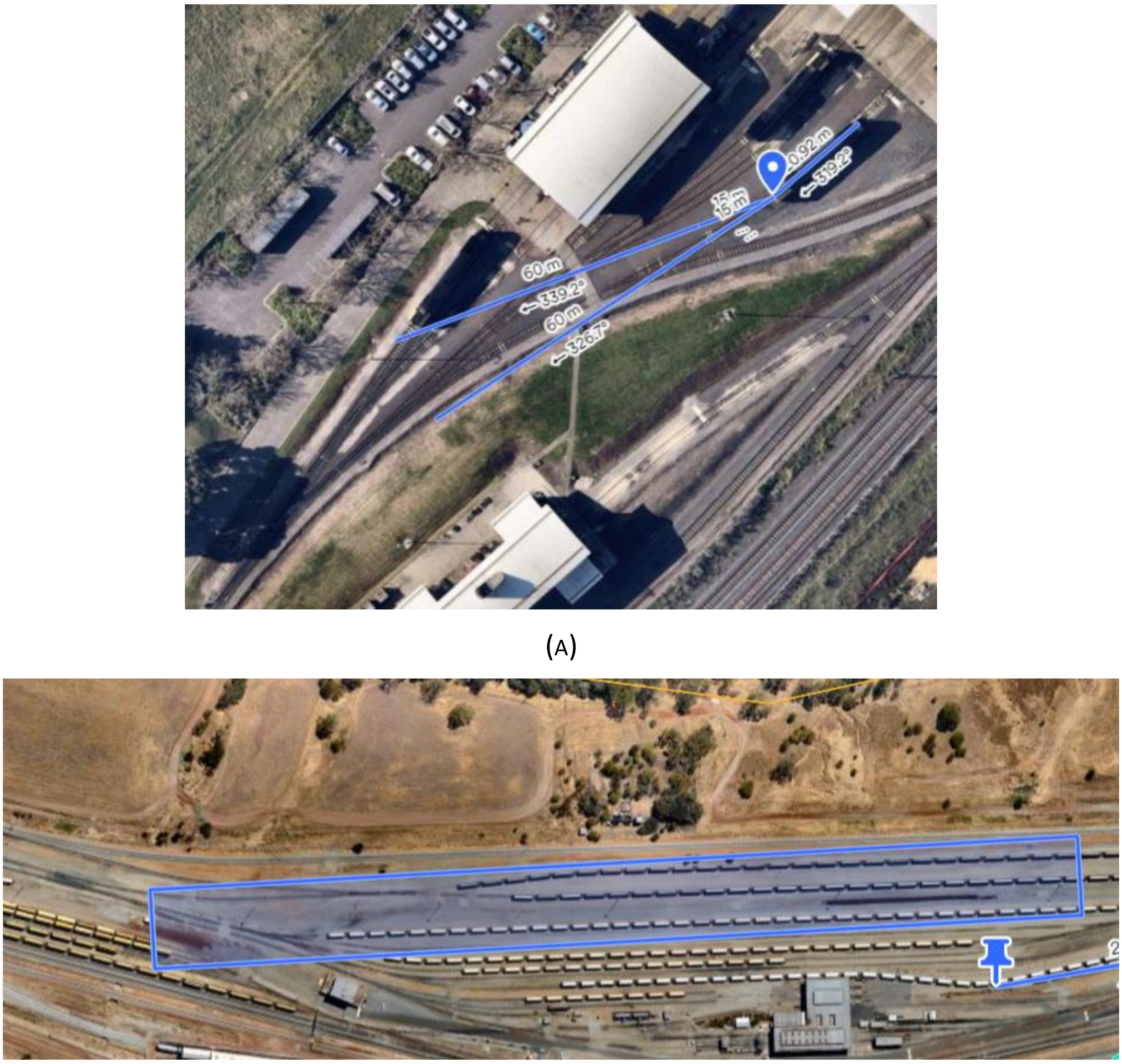
In consideration of different variables under the three main aspects, i.e. Object, Environment and Viewing conditions, different test scenarios have been considered and selected to detect the influence of each variable (factors). The trial involved measurements which have been conducted at different sites, including Spotswood Yard in Melbourne, Avon Yard in Western Australia (W.A.) and one operating level crossing near York in W.A. Details of the initial test plan and testing scenarios for the two test sites are in Appendix A.1 and A.2. The initial test plan included most of the variables that may have an effect on day time operation

Primarily, trials were planned to be conducted at actual level crossings while trains are in their normal operation. However, this was found to be not feasible for several reasons. Firstly, there were only a few locomotives fitted with the added lights required for trial purposes and these trains are not operating in all the networks. Secondly, it wasn't possible to get level crossing locations and actual time tables for the locomotives fitted with the trial lighting as this would require involvement of the infrastructure manager/owner. Thirdly, the luminance measurement apparatus was only tested and calibrated for objects in stationary or in very slow speed (although the system is capable of dynamic measurements for moving objects as in the case of road markings and road lighting measurement from a moving vehicle). Hence, the trial was planned to be conducted at a railway yard or depot, or at a level crossing while the locomotive is stationary.

4.4.1 BEFORE THE MEASUREMENT

Prior to beginning the experiments, a search for appropriate sites with the required area and scenario were conducted. An aerial view map, Nearmap®, was used to have an overall aerial view of the possible measurement locations in the yards and level crossing. The use of aerial view helped to narrow down the possible areas where further site inspection and location confirmation have been conducted for measurement and locomotive positioning. Based on the experimental design variables, e.g. required distance for viewing conditions, possible testing sites were identified. As it was only possible to conduct the trial with locomotives in a stationary condition, the trial sites were limited at two railway yards, one at Aurizon Yard at Avon in W.A. and another at Spotswood Yard in Victoria. Further, locations of several level crossings operating in W.A. were discussed among the project partners, and Aurizon identified two level crossings as possible measurement sites, one with an active warning system and the second a passive level crossing. As the current trial is meant to look only passive level crossings, the active level crossing alternative was not considered further as part of this assessment.

Figure 17 (a) shows the possible measurement locations with 60 m viewing distance and with certain viewing angles in Spotswood Yard in Melbourne. Similarly, possible locations were identified by using Nearmap® for the Avon Yard in W.A. as shown in Figure 17 (b). However, due to the site constraints, the identified locations did not match the requirements for the measurement.



(A)

(B)

FIGURE 17. POSSILBE MEASUREMENT LOCATIONS IN A) SPOTSWOOD YARD, VICTORIA, AND B) AVON YARD, W.A.

During the yard visit in Avon, a turntable was found to be a possible measurement location as shown in Figure 18. The reason for choosing the turntable is that the locomotive can be placed on the turntable and rotated to the desired angles which can simulate different viewing angles. The sites were then inspected and arrangements were made for positioning of the locomotives and the measuring instruments.

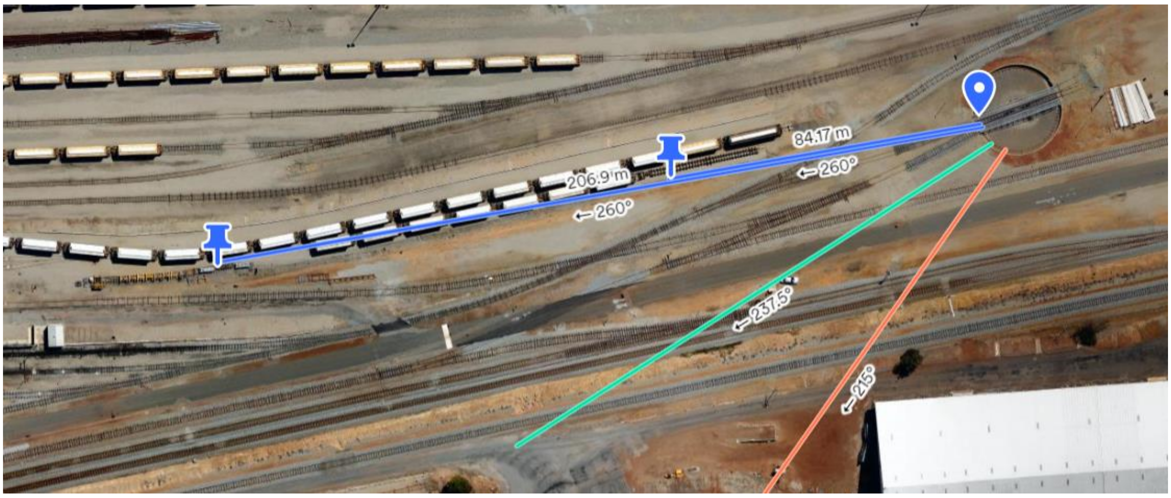


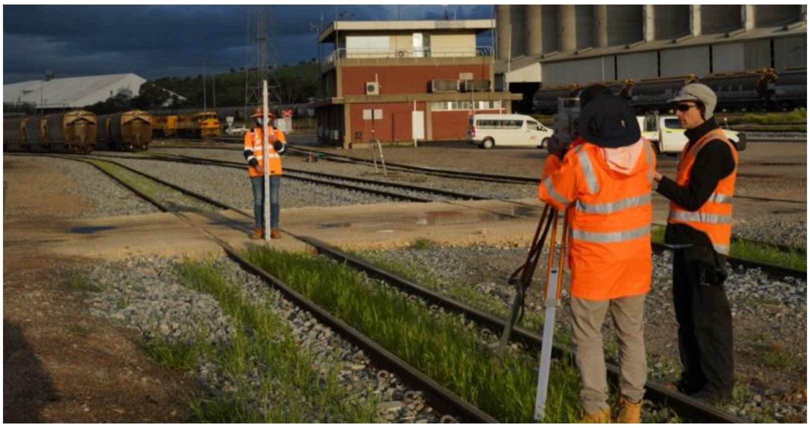
FIGURE 18. MEASURMENT USING THE TURNING TALBE AT AVON YARD, W.A.

As initially planned and to include the operating environment of a level crossing in service (parameters not available at the yard/ depot), a typical operating passive level crossing was identified during the site visit, and selected to conduct trial measurements. An image of the selected passive level crossing, located near York adjoining the Spencers Brook-York road is shown in Figure 19.

FIGURE 19. IMAGE OF THE UNPROTECTED LC NEAR YORK. IMAGE TAKEN FROM THE SPENCERS BROOK – YORK ROAD.

4.4.2 DURING THE MEASUREMENT

After identifying the possible locations and onsite confirmation, range finder and survey instruments were used to locate and mark the measurement points with respect to the locomotive's positions. An example of such measurement of distances and angles with respect to locomotive position, and marking of identified position is shown in Figure 20.



(A)

(B)

FIGURE 20. (A) POSITION AND ANGLE MEASUREMENT USING SURVEY INSTRUMENTS BY THE PROJECT TEAM, AND (B) MARKING OF IDENTIFIED POSITIONS FOR INSTRUMENTATION SET-UP AND LOCOMOTIVE POSITION AT THE SELECTED LEVEL CROSSING TEST SITE.

Once the measuring locations were identified, equipment was set up in the designated positions. Two luminance measuring apparatus were adopted, the luminance camera and the luminance spot meter. The luminance spot meter was used to provide a general comparison between the results of the two instruments in different operating conditions. Figure 21 (a) and (b) shows the setup of traditional hand-held luminance spot meter on a tripod and a luminance camera setup secured on a tripod to keep the apparatus stable. The luminance camera was also elevated to gain the required height as shown in Figure 21 (a) and (b), taken at the operating passive level crossing trial site.

(A)

(B)

FIGURE 21. A) HAND-HELD TRIDITIONAL LUMINANCE METER AND B) LUMINANCE CAMERA IN OPERATION AT A TRIAL SITE IN W.A.

After setting up the equipment, luminance (in cd/m^2) readings of the locomotive and the background were taken by both the hand-held luminance spot meter and luminance camera. To mimic and include different environmental and operating conditions, such as vegetation obscurity and light rain, the leaves of branched plant was held in front of the camera and mist was sprayed. Images of Figure 22 (a) and (b) show examples of trial scenarios mimicking light vegetation and light rain or foggy weather.

(A)

(B)

FIGURE 22. A) BRANCHES OF A TREE WITH LEAVES HELD IN FRONT OF THE CAMERA TO MIMIC VEGETATION COVERAGE AND B) MIST SPRAYED IN FRONT OF THE CAMERA TO MIMIC LIGHT RAIN OR FOGGY WEATHER

By using the luminance spot meter, data was recorded at five regions of interest including above the locomotive, front of locomotive (upper and lower part) and sides of locomotive (adjacent environment condition/ locomotive itself). The five points of interest (PoI) are shown in Figure 23. By using the luminance camera, luminance of the entire environment condition and locomotive was captured in one measurement. Measurements of the luminance of the locomotive for different lighting conditions, with lights ON/OFF, and for a number of pre-defined scenarios were taken. In addition, the ambient light value for all the defined scenarios was recorded using the light intensity meter (lux meter). In addition to the luminance and ambient light value, the following background information was recorded during the measurement.

- Type of headlight (LED / Incandescent)
- Cleanliness of locomotive
- Distance and viewing angle from locomotive
- ON/ OFF of headlight, ditch lights and beacon lights
- High/ low beam of headlight

FIGURE 23. FIVE POINTS OF INTEREST FOR THE SPOT METER MESASUREMENT

4.5 DESIGN OF EXPERIMENT METHODOLOGY

The most obvious way to conduct experiments is by changing one-factor-at-a-time at each trial, with the remaining factors or variables held constant. This method would have been more acceptable if the trial was assessing the effect of one factor at selected and fixed conditions of the other factors. As it is known in a railway operation, the variables and factors discussed earlier are not always fixed and the effects of headlight conversion from SEALED to LED or the effects of additional flashing beacon lights cannot be assessed independently from the other factors. In order to determine which factors do have significant effect on the response(s) and which factors affect the response(s) more if varied together, a scientific approach is sought. A factorial experiment, with full or fractional factorial designs, is found to be the most economic and statistical based methodology to conduct trial experiments with several identified variables considered.

Hence, a Design of Experiment (DoE) [30] methodology was applied to systematically collect data from the field trials for a combination of the possible variables identified for these trials, as listed in Table 5. The influence of two or more independent input variables (factors) on a single or multiple output (response) can be studied efficiently by use of a DoE methodology. One variable alone may have a significant effect on the response(s), or the effect may be significant if one variable is combined with another. The response values used in the effect analysis for this assessment are the luminance contrast and the luminance ratio at each experimental run. Further, with factorial design, the variables or factors analysed can be quantitative, as in case of viewing distance and viewing angle, or qualitative, as in the case of headlight type, LED or SEALED halogen.

In DoE, each factor is assigned a number of levels. For example, the influence of headlight type may be studied by performing trials with two levels, LED headlights and SEALED headlights. The influence of locomotive's lightings arrangement may also be studied at three levels; top, triangular and rectangular arrangement or other lighting arrangements. The influence of the change of state of ditch lights and the beacon light may be studied in two levels. Although the beacon light is a flashing light, and the ditch lights may also flash for a nominated period at level crossings, ON or OFF states of these lights may be considered in the two-level experimental design. As a result of flashing light, the measured luminance may fluctuate depending on the frequency of the flashing light. The effect of the frequency of the variation of the fluctuating luminance is not considered in the current assessment. In the current methodology, the effect of the flashing beacon lights and ditch lights were considered in the two-levels factorial design through the change of state of the lights from the 'ON state' to the 'OFF state'. The first level can be when the average measured luminance was the highest during few flashing cycles 'ON state'. When the state of the light is OFF, that can be considered as the second level 'OFF state'.

The response(s) are the resulting quantities whose values are assumed to be affected by variation in the factor levels. The amount a response is influenced by the level of a single factor is called *main effect*. The joint effect of two or more factors is called an *interaction effect*. In an experimental trial involving several factors, a two-level factorial design is an efficient method to investigate the joint effect of all possible combinations of the factor levels. With this methodology, it is possible to evaluate the effects of the factors or interaction effects with fewer number of trials compared to the method of varying one-factor-at-a-time. Based on the possible variables listed in Sections 4.3, and the conditions discussed in Sections 3.4, experimental design was planned with two levels of variation for each variable. The detail of the variables and their levels are tabulated in Table 6.

TABLE 6: VARIABLES OF INTEREST FOR THE ASSESSMENT WITH TWO LEVELS OF VARIATION

Term	Variables to consider	Level (+1)	Level (-1)
X1 (a)	Level Crossing Design (view angle)	22.5 deg	45 deg
X2 (b)	Distance (position)	70 - 85 m	170 - 220 m
X3 (c)	Head light type	LED	Incandescent (Halogen)
X4 (d)	Beacon light	ON	OFF
X5 (e)	Ditch light	ON	OFF
X6 (f)	On-track vehicle contrast / livery	Pacific National (PN) livery NR class	CBH class

X7 (h)	Vehicle livery cleanliness	Clean	Unclean
X8 (i)	Ambient light condition	Morning/evening	Afternoon
X9 (j)	Vegetation coverage	Light or none	Dense
X10 (k)	Sun direction to road vehicle	Facing	Behind
X11 (l)	Weather condition	Clear	Rainy/Overcast

To evaluate the effects of a single factor or interaction effects of two or more factors for the 11 variables listed in Table 6 with a full factorial design, with only two levels of variation for each variable, requires 2^{11} or 2,048 experimental runs. In order to keep the number of measurements to a reasonable amount, a fractional factorial design was used to plan the experiments.

4.6 FRACTIONAL FACTORIAL DESIGN

To reduce the number of experimental runs, a fractional factorial design was applied by selecting only a fraction of the full design. A two-level fractional factorial design with k factors containing 2^{k-p} runs requires p independent generating relations for the design, where the experimental design is introduced by defining relation based on the p generators and their interactions [30]. Hence, only $\left(\frac{1}{2}\right)^{p}$ fraction of the full 2^{k} factorial design would be needed with a 2^{k-p} runs.

A number of test scenarios were defined to detect the influence of the different variables. In order to reduce the number of experimental runs to a reasonable number at the different test sites, variables that may affect visibility in day time were selected. The testing in W.A. was limited to explore the visual conspicuity of freight locomotives in day-light hours considering the influence of light emitted from the locomotive as well as the natural light characteristics. As reported in the 2009 update to the Train Illumination Report [31], between 75% and 94% of all level crossing collisions occur in daylight hours. This can be considered largely attributable to the higher traffic levels experienced during daytime operation.

The initial test plan for the two test sites was revised as it was found that there are a number of variables unable to be considered in the actual experimentation. As a result, only those variables that can be controlled and variables that are able to be varied into two different levels were considered. Variables such as locomotive livery, ambient light condition and sun direction to the observer were excluded from the design variables.

The main objective of the testing was to assess the efficacy / improvement of the visual conspicuity of freight locomotives by converting the halogen (SEALED) headlight to LED, as well as to assess any improvement in visual conspicuity due to the addition of a flashing beacon lights. Using a scientific experimental design, fractional factorial design, the trials were planned keeping the statistical representation of the variations and neglecting higher interaction effects. In the experimental design using the DoE with two levels of variations for the variables, the two levels of variation are coded as (+) for higher level (variation 1) and (-) for the lower level (variation 2).

4.6.1 FACTORIAL DESIGN FOR THE TRIAL AT AVON YARD IN W.A.

The experimental design for the trial at Avon Yard in W.A. was carefully planned to consider a good representation of the possible variables that may have effect on the measurement result. It was possible to consider variations of only six of the variables at the Avon Yard test site, as listed in Table 7.

TABLE 7. VARIABLES (FACTORS) AND LEVEL OF VARIATION INCLUDED IN THE DESIGN OF EXPERIMENT AT AVON YARD TRIAL

Notations	Variables	Units	Low (-1)	High (+1)
(A)	Viewing distance (position)	[m]	80 (Short)	200 (Far)
(B)	LC type (angle of view to the train - viewing angle)	[degrees]	22.5 (Small)	45 (Large)
(C)	Head light type	-	LED	SEALED
(D)	Beacon light	-	ON	OFF
(E)	Ditch light	-	ON	OFF
(F)	Locomotive livery cleanliness	-	Clean livery	Unclean livery

A fractional factorial design, considering 3 or more factor interaction is confounded, is used to identify the main effects from the less important effects, i.e., the effects of a 3- or more factors interaction cannot be distinguished from other 3- or more factors interactions, and hence such higher-order interactions can be ignored. A fractional factorial design for the 6 variables, excluding the higher factor interactions, required only $2^{6-2} = 16$ runs, which is equivalent to 4 variables with full factorial. This fractional factorial requires 2 independent generators for confounding. Based on this, the experimental plan was prepared. The experimental plan for the 16 runs considering possible combination of the six independent variables is given in Table 8. The details of the test scenarios and the experimental design employing fractional factorial design in coded units can be found in Appendix B.1.

TABLE 8. EXPERIMENTAL PLAN FOR THE AVON YARD TEST SITE

Variables	A	B	C	D	E	F
Test runs	Sighting distance	Viewing angle	Headlight type	Beacon light	Ditch light	Cleanliness
	(m)	(degrees)	-	-	-	-
1	80	22.5	LED	ON	ON	Clean
2	80	22.5	LED	OFF	OFF	Unclean
3	80	22.5	SEALED	ON	OFF	Unclean
4	80	22.5	SEALED	OFF	ON	Clean

5	80	45	LED	ON	OFF	Clean
6	80	45	LED	OFF	ON	Unclean
7	80	45	SEALED	ON	ON	Unclean
8	80	45	SEALED	OFF	OFF	Clean
9	200	22.5	LED	ON	ON	Unclean
10	200	22.5	LED	OFF	OFF	Clean
11	200	22.5	SEALED	ON	OFF	Clean
12	200	22.5	SEALED	OFF	ON	Unclean
13	200	45	LED	ON	OFF	Unclean
14	200	45	LED	OFF	ON	Clean
15	200	45	SEALED	ON	ON	Clean
16	200	45	SEALED	OFF	OFF	Unclean

4.6.2 FACTORIAL DESIGN FOR THE TRIAL AT A PASSIVE LEVEL CROSSING NEAR YORK IN W.A.

The experiment at the passive level crossing test site near York was planned to include vegetation coverage and weather condition as variables, in addition to the variables considered at Avon Yard. The fractional factorial design can make use of both qualitative and quantitative variables. Here, the viewing setting was taken as one variable, which is a combination of viewing angle and viewing distance. The high level (+1) for the viewing setting is large view angle and short view distance while low level (-1) is for small view angle and far view distance. In effect, the experimental design was planned to include the effects of two additional variables and their interaction effects with all the variables in addition to what is being planned at Avon experimental design.

The total number of independent variables considered for this experimental plan was 7. The variables, notations and levels of variation considered at the passive level crossing trial site are listed in Table 9.

TABLE 9. VARIABLES (FACTORS) AND LEVELS OF VARIATION INCLUDED IN THE DESIGN OF EXPERIMENT AT THE PASSIVE LC TRIAL

Notations	Variables	Units	Low (-1)	High (+1)
(AB)	Viewing setting (angle of view to the train - viewing angle)	[degrees]	Small angle – far distance	Large angle – short viewing distance
(C)	Head light type	-	LED	SEALED Incandescent
(D)	Beacon light	-	ON	OFF
(E)	Ditch light	-	ON	OFF
(F)	Locomotive livery cleanliness	-	Clean livery	Unclean livery

(G)	Vegetation coverage	-	None (clear view)	Dense
(H)	Weather condition	-	Clear	Mist

The experimental design was carefully planned to consider a good representation of the seven variables that may have effect on the measurement result. Again, a fractional factorial design was used to identify the main effects from the less important effects. A fractional factorial design with $2^{7-2} = 32$ runs of equivalent to 5 variables with full factorial – requires 2 independent generators for confounding. Based on this, the experimental plan was prepared. Example of combinations of variables for some of the runs is given in Table 10. Some 32 experimental variations were conducted and measured. The full experimental design in coded form with 32 runs for the trial at the level crossing is included in Appendix B.2.

TABLE 10. EXAMPLES OF THE EXPERIMENTAL DESIGN IN WESTERN AUSTRALIA AT THE PASSIVE LEVEL CROSSING

Variables	View setting (View angle)	Headlight type	Beacon light	Ditch light	Cleanliness	Vegetation coverage	Weather condition
Levels	Small /Large	LED/ SEALED	ON/ OFF	ON/ OFF	clean/ unclean	None/ dense	clear/mist
	Coded Units of Factors						
Coded Units	{-/+}	{-/+}	{-/+}	{-/+}	{-/+}	{-/+}	{-/+}
Codes/ Runs	**AB**	**C**	**D**	**E**	**F**	**G**	**H**
1	Small	LED	ON	ON	Clean	Dense	Mist
2	Small	LED	ON	ON	Unclean	None	Clear
3	Small	LED	ON	OFF	Clean	None	Clear
4	Small	LED	ON	OFF	Unclean	Dense	Mist
5	Small	LED	OFF	ON	Clean	None	Clear
6	Small	LED	OFF	ON	Unclean	Dense	Mist
7	Small	LED	OFF	OFF	Clean	Dense	Mist
8	Small	LED	OFF	OFF	Unclean	None	Clear
9	Small	SEALED	ON	ON	Clean	None	Mist
10	Small	SEALED	ON	ON	Unclean	Dense	Clear
11	Small	SEALED	ON	OFF	Clean	Dense	Clear
12	Small	SEALED	ON	OFF	Unclean	None	Mist

4.6.3 EXPERIMENTAL DESIGN FOR THE TRIAL AT SPOTSWOOD YARD IN VICTORIA

Recognising that over a period of time (years) in service LED lights will degrade and progressively become dimmer, measurements to simulate reduced percentage of LED headlight working is proposed. The measurements are planned to be conducted at Spotswood Yard. This trial is focused to assess the risk of reduced visual conspicuity of freight locomotives due to degraded LED headlight performance. Again, this trial is limited for day-light hours as a large percentage of level crossing collisions occur in daylight hours [31]. For the night time, the performance of degraded LED headlight will be controlled from the operational requirement of the headlight and the visibility of track during night hours.

The experimental design is planned to simulate degraded performance of LED headlight to 0%, 25%, 50% and 75%. A 100 % performance of the LED headlight is included as reference measurement to calculate the visibility reduction at different levels of degraded performances. The experiment is planned for headlight intensity in low and high beam and at two different distances, short and far. Table 11 shows the list of test runs and experimental plan for evaluation of degraded performance of LED headlight. To evaluate the visibility of the locomotive with the different degraded settings, conspicuity index is calculated for each setting and compared with the conspicuity index calculated when a 100% headlight performance setting is used.

TABLE 11. LED HEADLIGHT PERFORMANCE SETUP

Test runs	**Sighting distance**	**Viewing angle**	**LED Headlight setting**	**Headlight Intensity**	**Headlight performance**	**Ditch light**
unit	(m)	(degrees)	-	-	(%)	-
1	Far viewing distance	0	Off	-	-	Off
2			On	Low Beam	100	Off
3			On	High Beam	100	Off
4			On	High Beam	100	On
5			On	Low Beam	100	On
6			On	Low Beam	50	Off
7			On	High Beam	50	Off
8			On	Low Beam	75	Off
9			On	High Beam	75	Off
10			On	Low Beam	25	Off
11			On	High Beam	25	Off
12	Short viewing distance	0	Off	-	-	Off
13			On	High Beam	25	Off
14			On	Low Beam	25	Off
15			On	Low Beam	50	Off

16			On	High Beam	50	Off
17			On	Low Beam	75	Off
18			On	High Beam	75	Off
19			On	High Beam	100	Off
20			On	High Beam	100	On
21			On	Low Beam	100	On
22			On	Low Beam	100	Off

5 DATA COLLECTION

To conduct measurements for a number of variables, Aurizon facilities at Avon Yard in W.A., Figure 24, and UGL facilities at the Spotswood Yard in Victoria, Figure 25, were selected.

FIGURE 24. AVON YARD IN W.A.

FIGURE 25. SPOTSWOOD YARD IN VICTORIA

Measurements of luminance of the front of the locomotive and the ambient background were taken with various viewing conditions, environment condition and light fittings at the different trial testing sites. Variables that may affect the luminance of the locomotive and /or the ambient background such as the ambient light condition, the direction of the sun with respect to the viewing condition and time of day were excluded from the experimental plan as design factors. All measurements were taken towards the locomotive's cab end facing towards the measuring devices. The viewing distance was measured from the locomotive's cab- towards the measurement device while the viewing angle was also measured from the locomotive cab towards the measuring devices. The distance and angle measurements were made using the survey instruments and range finder, and markings are made prior to the luminance measurements. All the trial tests conducted at the different testing sites were documented in sufficient detail and with video footage for traceability. During the trial campaign in W.A., members of the project team and representatives and officials from ONRSR, CBH, and Aurizon witnessed the field trials, refer Figure 26.

FIGURE 26. SAFETY BRIEFING TO THE PARTICIPANTS AND WITNESSES TO THE TRIAL TESTING CONDUCTED AT A LEVEL CROSSING NEAR YORK IN W.A.

5.1 LOCOMOTIVE CONFIGURATION

The locomotives used for the trial were CBH class locomotives provided by Aurizon and NR class locomotives provided by Pacific National (PN). The front of both types of locomotives were equipped with dual-lamp headlights above the cabin and two separate ditch lights were installed near the bottom of locomotive next to the coupler[3]. The CBH locomotives were also fitted with beacon lights on the brow. Figure 27 shows an image of a CBH class locomotive fitted with beacon lights and a schematic figure showing the mounting location on the brow. The current trial has limitations and focused only on the improvement of the frontal visibility of the locomotive due to the lighting setup. Different lighting arrangement and other configuration of the beacon lights including on the side of the locomotive need to be looked at as a continuation to the current study.

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[3] Train Coupler is a device which allows rolling stock to be connected to each other and form in a train.

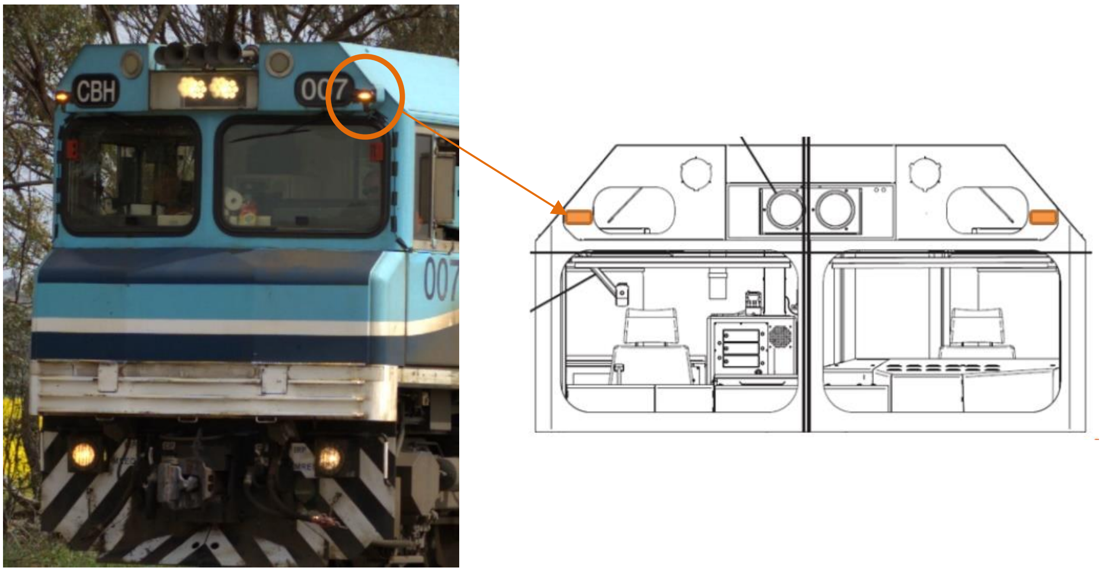


Figure 27. CBH class Locomotive with Beacon Light Installed and its Schematic Figure, [32]

The CBH locomotives were used for the trials in W.A while NR class locomotives provided by PN were used for the trials in Victoria. Figure 28 (a) shows the CBH 007 locomotive with its LED headlight on, Figure 28 (b) shows CBH 001 locomotive with unclean livery where the SEALED headlights, beacon lights and ditch lights are all on, and Figure 28 (c) shows a PN Locomotive with the LED headlight on.

(A)

(B)

(C)

FIGURE 28. (A) CBH LOCOMOTIVE WITH CLEAN LIVERY AND LED HEADLIGHT ON, (B) CBH LOCOMOTIVE WITH UNCLEAN LIVERY AND ALL LIGHTS ON, AND (C) PACIFIC NATIONAL LOCOMOTIVE WITH LED HEADLIGHT ON

5.2 MEASUREMENT CONFIGURATION

An example of a possible testing arrangement at level crossing is shown in Figure 29 which includes a given viewing setting, viewing distances $(d/sin(\theta_1), d/sin(\theta_2), \cdots)$, and viewing angles $(\theta_1, \theta_2, \cdots)$ facing the locomotive.

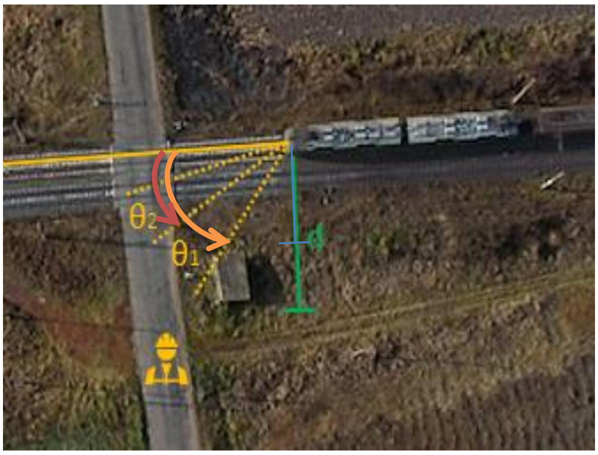


FIGURE 29. AN EXAMPLE OF A POSSIBLE TESTING ARANGEMENT AT A LEVEL CROSSING

5.3 MEASUREMENTS AT AVON YARD IN W.A.

The track at the turntable was aligned to two different angles and measurements were conducted from two locations at about 200 m (far viewing distance) and at about 80 m (near viewing distance) from the locomotive cab end, see Figure 30. A turntable was used with orientation marked for the locomotive to be at 22.5° and 45° from the straight alignment towards the measurement locations. Testing was conducted using the turntable, with a possibility to change the locomotive orientation with respect to the camera while the camera was positioned in the same place and oriented at the same view angle.

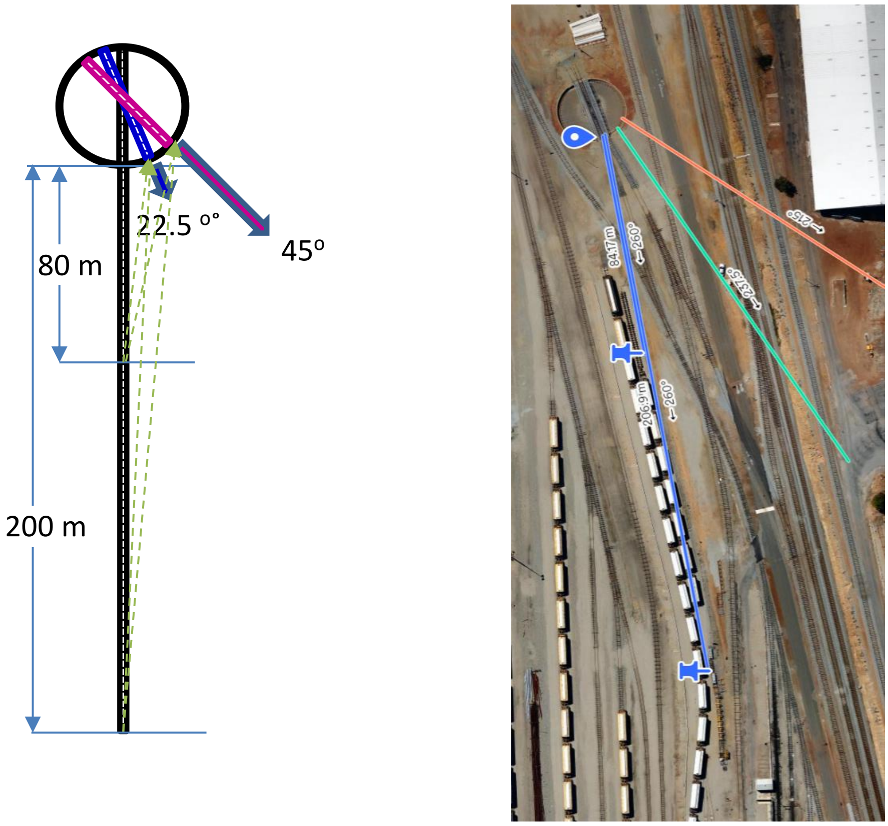


FIGURE 30. LOCOMOTIVE CONFIGURATION IN A TURNTABLE (LEFT), AND A NEARMAP® IMAGE OF THE MEASUREMENT SITE AND MARKINGS OF MEASUREMENT INSTRUMENT POSITION (RIGHT).

Locomotive CBH007 fitted with LED headlight, and locomotives CBH001 and CBH025 with halogen SEALED headlights were used in the trial. Both CBH007 and CBH025 were also fitted with flashing beacon lights mounted on the brow. Measurements were conducted during the day, where the ambient daylight and the sun direction were varying. Clean and unclean locomotives were included in the trials. To simulate the effects of mist and vegetation obstruction, measurements simulating these conditions have been conducted for some of the measurement configurations. Figure 31 shows some examples of the measurement configurations. An example of a set of luminance measurements and the measurement configuration is shown in Table 12.

At 200 m distance, 22.5° view angle, uncleaned livery

At 200 m distance, and 45 ° view angle, cleaned livery

At 80 m distance, and 22.5° view angle, cleaned livery

At 80 m distance, and 45° view angle, cleaned livery

FIGURE 31. SOME EXAMPLES OF THE MEASUREMENT CONFIGURATIONS

TABLE 12. EXAMPLE OF A SET OF LUMINANCE MEASUREMENTS AND MEASUREMENT CONFIGURATION FOR A FEW NUMBERS OF TEST RUNS

Test run	View distance	View angle	Camera height above ToR[4]	Headlight type	Cleanliness	Beacon light	Ditch light	Luminance camera image #	Luminance camera image #	PoI[5]	Spot reading 1	Spot reading 2
	(m)	(deg)	(m)								cd/m^2	cd/m^2
1	200	45	1.59	LED	Unclean	Off	Off	D200_A45_CBH007_B-off_D-off_read_1	D200_A45_CBH007_B-off_D-off_read_2	0	4850	5060
										1	829	803
										2	802	849
										3	752	868
										4	1150	1150
2	200	45	1.59	LED	Unclean	On	Off	D200_A45_CBH007_B-on_D-off_read_1	D200_A45_CBH007_B-on_D-off_read_2	0	4300	5220
										1	905	1080
										2	855	1020
										3	838	987
										4	991	1300
3	200	45	1.59	LED	Unclean	On	On	D200_A45_CBH007_B-on_D-on_read_1	D200_A45_CBH007_B-on_D-on_read_2	0	5000	5970
										1	954	1050
										2	1040	1170
										3	972	1050
										4	1170	1430
										4	1240	1140

---

[4] ToR: Top of rail

[5] PoI: Point of interest for the spot meter readings

5.4 MEASUREMENTS AT THE PASSIVE LEVEL CROSSING (LC) NEAR YORK IN W.A.

A set of measurements were conducted at a level crossing (LC) near York adjoining Spencers Brook – York road. The level crossing is an unprotected (passive) LC with no warning system, to the side of a main road, which is typical of other LCs in the region. An image of the LC site where measurements were taken is shown in Figure 19. The distance from the centre of the railway track to the edge of the main road is less than 30 m.

This level crossing has a number of features important to the trial measurement. First, it was possible to place the measurement system on either side of the LC, which enables the consideration of differing background. On one side the background was a yellowish field containing canola plants, as seen in Figure 32 (a), while on the other side the background was a dense green vegetation, as seen in Figure 32 (b). The vertical alignment of the track approaching the LC in both directions appeared flat. Hence, the locomotive and lighting vertical orientation from both positions was similar. As the place where the camera was located was very low in height in comparison to the locomotive, the luminance camera was raised up to a required height so that the luminance camera is in horizontal level with the ground and the captured image covers sufficient background around the locomotive front.

(A)

(B)

FIGURE 32. IMAGES OF LOCOMOTIVES WITH DIFFERING HEADLIGHT TYPE, LIVERY CLEANLINESS AND NEAR BACKGROUND (A) LED HEAD LIGHT, CLEAN LIVERY AND YELLOWISH YARD BACKGROUND. THE BEACON LIGHT IS OFF; (B) SEALED HEADLIGHT, UNCLEAN LIVERY AND GREEN VEGETATION BACKGROUND. THE BEACON LIGHT IS FLASHING

The measurement site layout and the locations of the camera and positions of the locomotive facing towards the LC is shown in Figure 33. Measurements were conducted from the two locations, each located about 22.5 m from the centreline of the track (location 1 and Location 2 in Figure 33). Figure 34 shows a schematic Nearmap® of the measurement site with the test configurations.

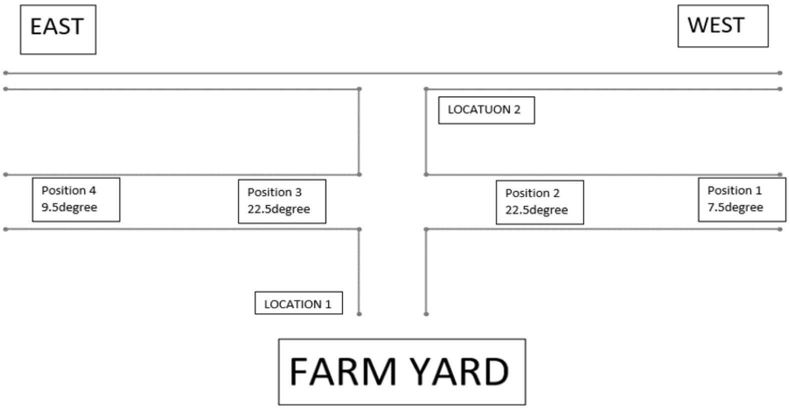
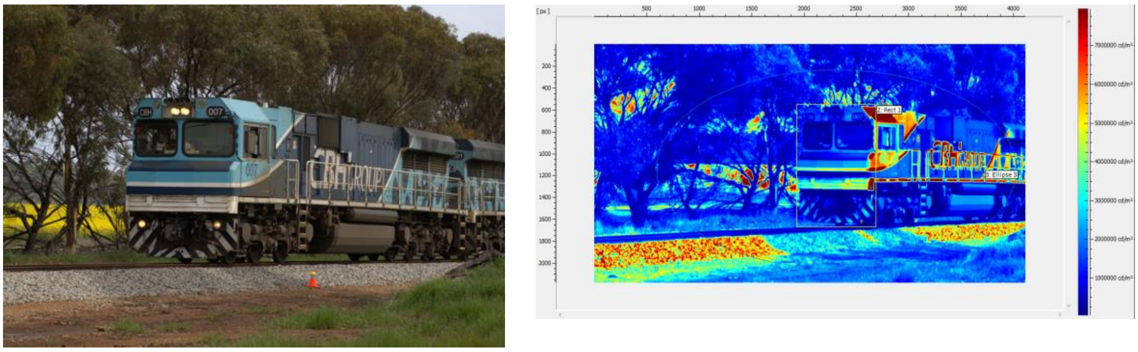


FIGURE 33. LAYOUT OF THE MEASUREMNT SITE AT THE LC NEAR YORK IN WA

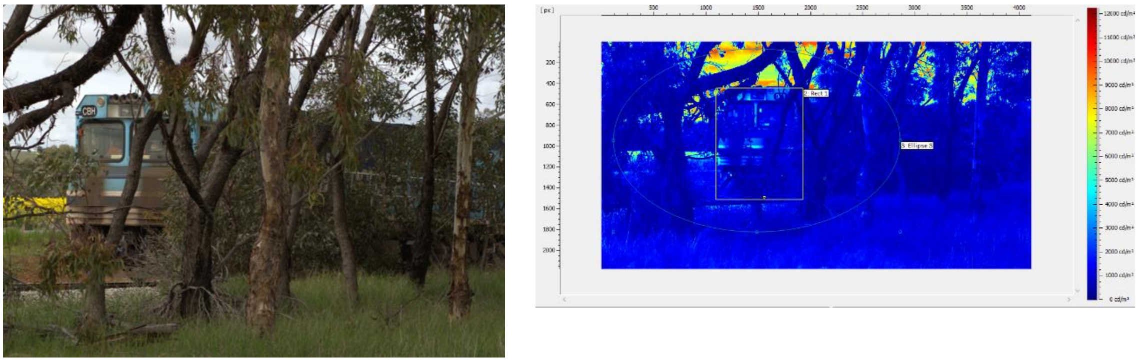
FIGURE 34. SCHEMATIC NEARMAP® ILLUSTRATING THE MEASUREMENT ARRANGEMENT AT LC NEAR YORK. MEASUREMENT LOCATION ON EACH SIDE OF THE LC AND THE POSITION OF THE LOCO ARE MARKED

Locomotives CBH007 and CBH025 facing towards the LC were positioned at two locations where the viewing angles were about 7.5^o (position 1) and 9.5^o (position 4) for small view angle, and 22.5^o (position 2 and 3) for the large view angle. Clear and obscure viewing with dense vegetation or misty condition, clean and unclean locomotives, were included as variables in these measurements. The vegetation was dense when viewed from camera location 1 while the vegetation obstruction to the front view of the locomotive was none when viewed from camera location 2. Two measurement location and two positions for each locomotive were used. Thus, a total of 8 variations in the background and two viewing settings were considered for the analysis.

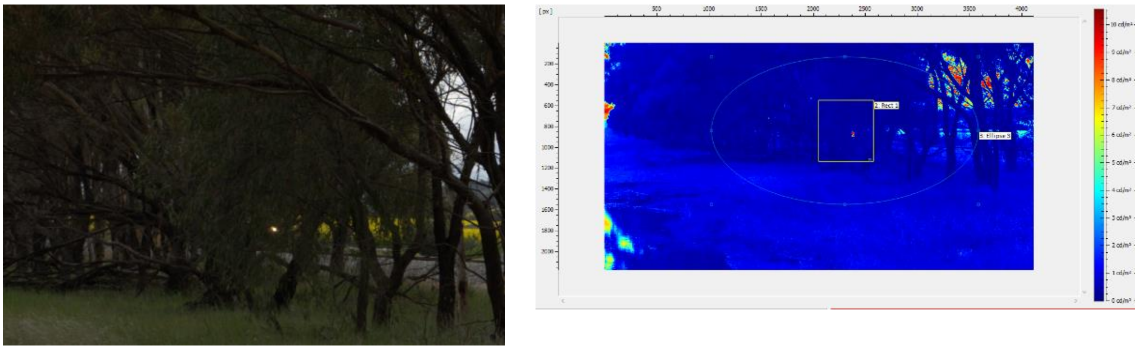
Specifically, this trial was conducted when the locomotive was positioned at two locations on the same side of the track, which gives to an angle of 7.5^o (9.5^o) and 22.5^o, as viewed from the luminance camera locations 1 and 2, refer Figure 33. In addition to the viewing setting, the vegetation density varies as the luminance camera location moved to the other side of the level crossing (from location 1 to location 2). Images of CBH locomotives viewed from different camera position is shown in Figure 35. For the same view angle (view setting), the locomotive was in clear view as in Figure 35 (a), and obscured by trees as shown in Figure 35 (b). In Figure 35 (c), a locomotive ditch light is slightly visible as the whole locomotive was fully masked by the dense vegetation.



(a) 22.5° view angle - Clear View - LED headlight - Cleaned livery



(b) 22.5° view angle – vegetation obstruction View – SEALED headlight – Uncleaned livery



(c) 7.5° view angle – dense vegetation obstruction

Figure 35. Some sample measurements and onsite photos

This trial test focused on evaluating the effects of locomotive lighting combined with mist and vegetation obscurity, while the viewing distance and viewing angle were combined into one variable, viewing setting. The number of variables considered at this test site was then only 7 variables. Data was collected for a number of scenarios. For example, for a fixed viewing setting and background condition, measurements were taken when the lighting arrangements were changed, as shown in Figure 36.

(A) All lights off

(B) Only headlights ON

(C) Headlights and ditch lights ON

FIGURE 36. EXAMPLE OF MEASUREMENT SCENARIO WITH DIFFERENT LIGHTING ARRANGEMENTS (A) ALL LIGHTS OFF, (B) ONLY LED HEADLIGHTS ON, AND (C) LED HEADLIGHTS AND DITCH LIGHTS ON

A further example with uncleaned livery with different lighting settings and a different background is shown in Figure 37. The setting scenarios include all lights OFF, only headlights ON, headlights and ditch lights ON and the last scenario with headlights, ditch lights and beacon lights are turned to ON setting.

(A) All lights OFF

(B) Headlights ON

(C) Headlights and ditch lights ON

(D) All lights including flashing beacon lights ON

FIGURE 37. EXAMPLES OF LIGHTING SCENARIOS FOR UNCLEANED LIVERY WITH DIFFERENT LIGHTING SITUATION (A) ALL LIGHTS OFF, (B) ONLY SEALED HEADLIGHTS ON, (C) ONLY SEALED HEADLIGHTS AND DITCH LIGHTS ON, AND (D) ALL LIGHTS INCLUDING FLASHING BEACON LIGHTS ON

5.5 LED HEADLIGHT PERFORMANCE MEASUREMENT AT SPOTSWOOD YARD

As discussed in the earlier sections, the LED lights will degrade and progressively become dimmer over a period of time in service. Scenarios were defined to simulate and to take measurements of reduced percentage of LED headlights in service at the Spotswood Yard in Victoria. A PN NR class locomotive fitted with LED headlights was used. The scenarios were simulated by covering part of the headlight using a plate, as seen in Figure 38.

FIGURE 38. HEADLIGHT COVERED BY A PLATE TO SIMULATE DEGRADED HEADLIGHT. IN THIS IMAGE HALF OF THE HEADLIGHT IS COVERED TO SIMULATE 50 % DEGRADED PERFORMANCE

The trial was conducted to simulate degraded performance of the LED headlight with 0%, 25%, 50%, 75% and 100% performance. The luminance camera was placed at 80 m (short distance) and 150 m (far distance) in front of the locomotive and measurements were conducted. All measurements were conducted at 0^{o} view angle to the front of the locomotive, at which the luminance camera was placed in line of sight to the locomotive’s front cab. Some examples of the testing arrangement to simulate degraded headlight performance are shown in Figure 39.

No headlight

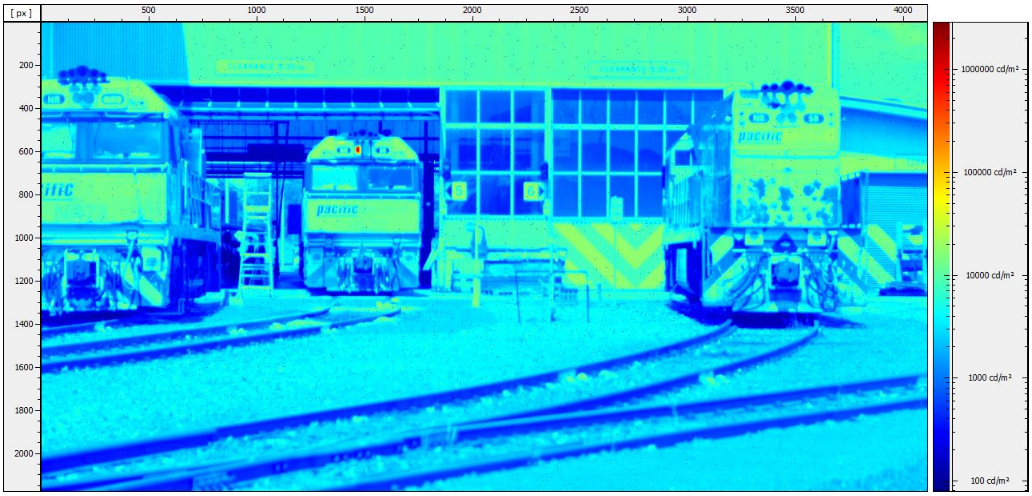
Headlight degraded to 75% in full beam

Headlight 100% in full beam with ditch light on

Headlight 100% in low beam with ditch light on

FIGURE 39. SOME EXAMPLES OF TESTING ARRANGEMNTS TO SIMULATE DEGRADED HEADLIGHT PERFORMANCE

Luminance reading of the different simulated scenarios were conducted using the luminance camera. The experiment was conducted with the headlight intensity in both high and low beam. Examples of images taken by the luminance camera for the different testing arrangements are shown in Figure 40.



75% COVERED HEADLIGHT SIMULATING 75% DEGRADED PERFORMANCE

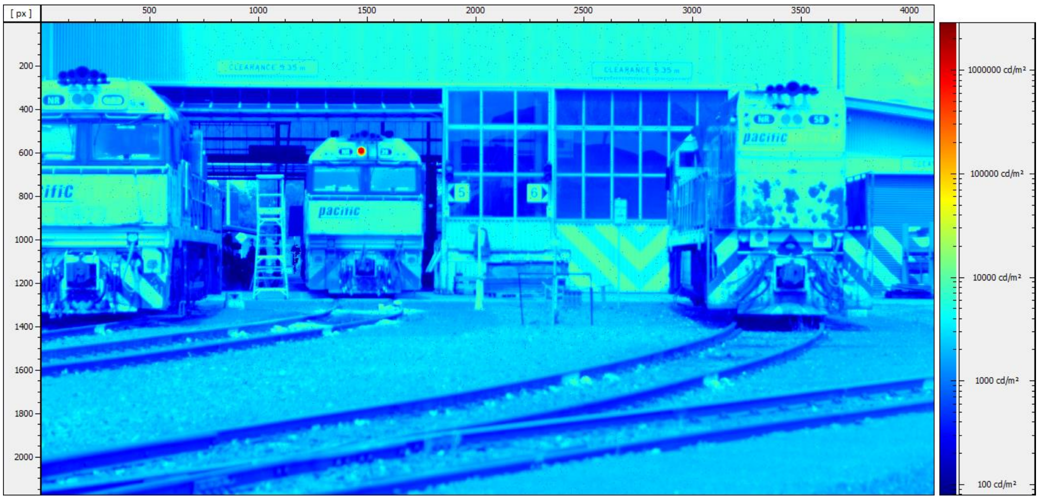
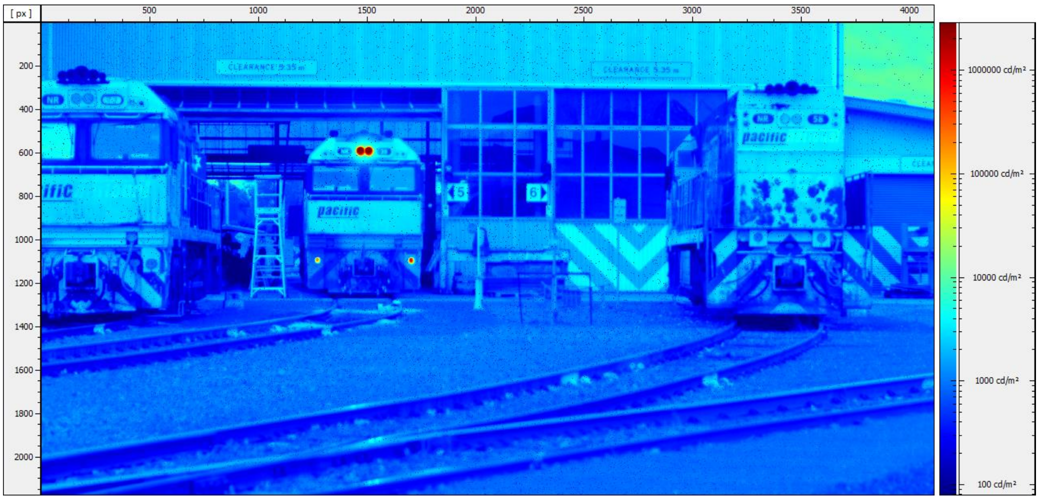


IMAGE OF HALF COVERED HEADLIGHT SIMULATING 50% DEGRADED PERFORMANCE



SIMULATING FULL PERFORMANCE OF HEAD LIGHT AND DITCH LIGHT

FIGURE 40. SOME SAMPLE MEASUREMENT EXAMPLES OF SIMULATED DEGRADED PERFORMANCE

6 RESULTS AND FINDINGS

6.1 VALIDATION

For the current trial assessment, the GL Optic luminance camera has been used as the main source of data collection. It enables collection of luminance data for the entire event including the primary object and the background, within the same captured image. By comparison, the spot meter takes readings of small regions, one at a time, during which the ambient light condition may change. Further, the region of interest for the spot meter must be predefined. This is specially the case when the measurement is conducted from close range.

Since the GL Optic luminance camera was being employed for such a study for the first time, the first step is to validate the instrument reading. Further, the procedure followed in this study to determine visibility index is based on the average luminance of the defined area. Through a direct comparison of the spot meter reading with a corresponding reading by the luminance camera, the camera reading and the procedure followed can be validated.

The measurement made by the GL Optic luminance camera was compared with those taken by a spot meter luminance camera for the same event. The comparison is to validate the GL Opticam luminance camera as well as the procedure of taking the average luminance of the defined area. For the contrast calculation, the average luminance of the target area and the average luminance of the background area are considered.

6.1.1 VALIDATION OF GL OPTICAM LUMINANCE CAMERA

Five points of interest were identified, as coded from 0 to 4 for the validation exercise, refer Figure 23. Point 1 and 2 are inside the target area while points 0, 3 and 4 are located in the background area.

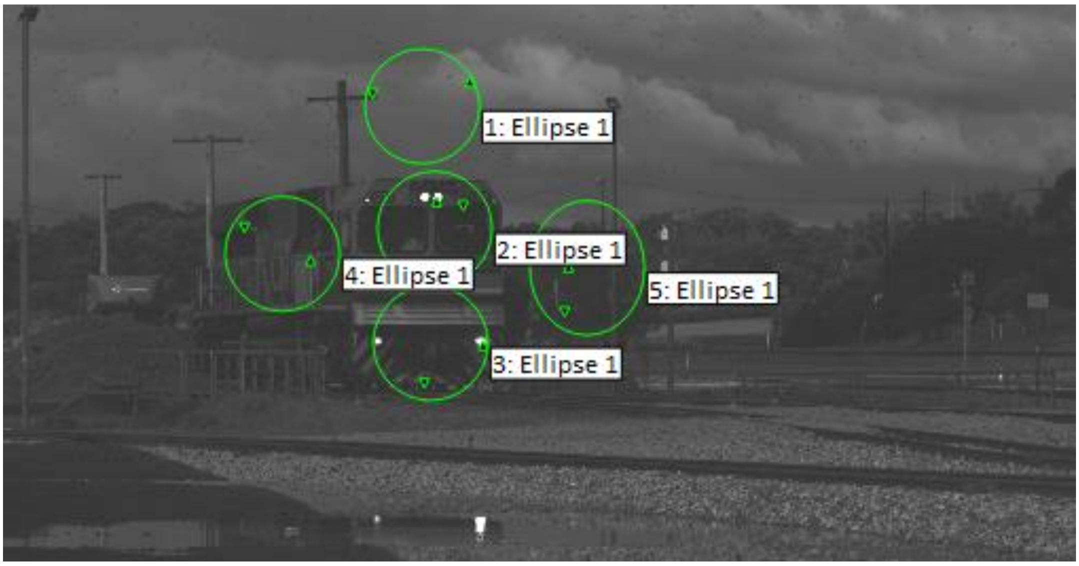


FIGURE 41. FIVE POINTS OF INTEREST CORRESPONDING TO THE SPOT METER READINGS, REFER FIGURE 23

The spot meter took these five target spots as point of interest, while the luminance camera read all the scene in one captured image. The luminance of each pixel in the captured image can be obtained. The average luminance, the maximum and minimum luminance value within a defined area can also be obtained.

To make a direct comparison, five ellipses corresponding to the five points of interest (PoI) were defined, as shown in Figure 41. The area of the ellipse was determined based on a 1° field of view and the distance between the camera and the object.

Measurements were conducted for two separate events to use for the validation exercise. The first event was the CBH025 locomotive, fitted with SEALED head light, positioned at 200 m away from the camera. The view angle towards the front cab of the locomotive was 22.5°. The readings by the spot meter and the corresponding value from the luminance camera are given in Table 13. The difference in the readings for each point of interest (PoI) is also given in Table 13.

TABLE 13. CBH 025 LOCATED AT 200M, 22.5° FROM THE CAMERA, SEALED HEADLIGHT

Point of Interest (PoI)	Mean luminance – GL Optic	Luminance value – Spot meter	Difference
	(cd/m²)	(cd/m²)	%
0	5132	5040	1.8
1	1501	1575	4.7
2	1497	1525	1.9
3	968	1065.5	9.2
4	1056	968.5	8.2

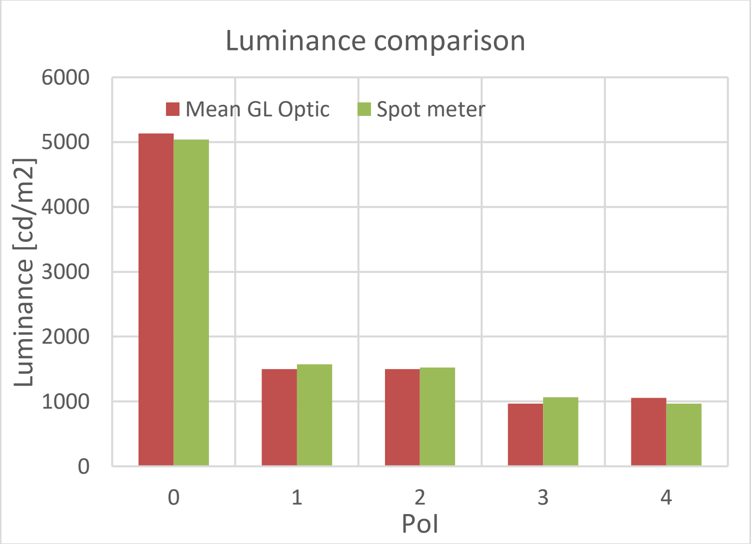


FIGURE 42. LUMINANCE VALUE COMPARISON BETWEEN GL OPTIC AND SPOT METER

The comparison between the readings of the two instruments is shown in Figure 42. The difference between the two instrument readings is very small for each PoI. The maximum difference is about 9% for Point 3. The discrepancy can be described by a number of factors, one being the change in the ambient light.

The second event selected for the validation was the CBH007 locomotive, fitted with LED headlight, positioned at 80 m distance from the camera. This time, both the headlight type and the range have been different from the first event. The view angle towards the front cab of the locomotive was still 22.5°. The readings by the spot meter and the corresponding value from the luminance camera are given in Table 14. The difference in the readings for each point of interest (PoI) is also given.

TABLE 14. CBH 025 LOCATED AT 200M, 22.5° FROM THE CAMERA, SEALED HEADLIGHT

Point of Interest (PoI)	Mean luminance – GL Optic	Luminance value – Spot meter	Difference
	(cd/m^2)	(cd/m^2)	%
0	6715	6220	7.3
1	2584	2225	13.9
2	2582	2100	18.6
3	2891	1895	34.4
4	1693	1335	21.1

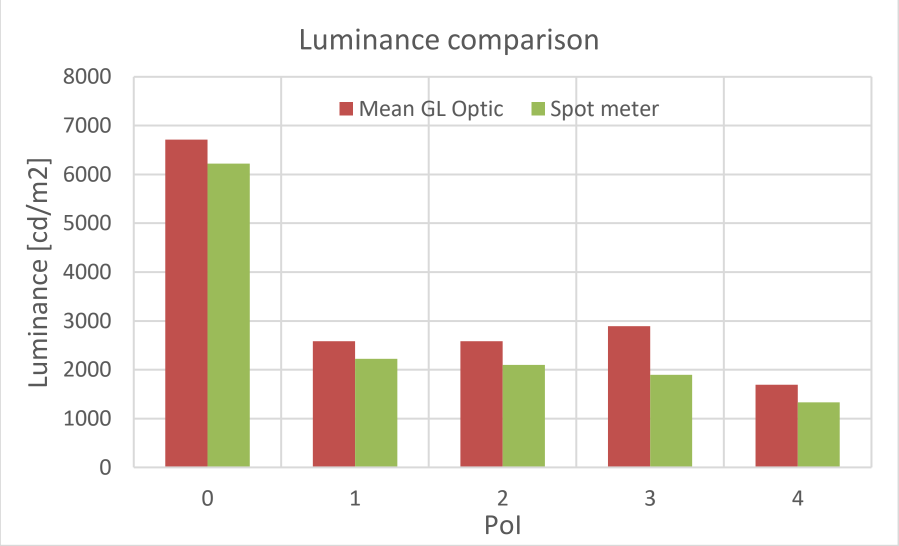


FIGURE 43. LUMINANCE VALUE COMPARISON BETWEEN GL OPTIC AND SPOT METER

In general, the readings by the GL Optic Luminance Camera at all PoI are higher than the corresponding reading by the spot meter. The comparison between the readings of the two instruments for the second event are shown in Figure 43. The highest difference between the two instrument readings is again at Point 3. The discrepancy can be described by a change in the ambient light, the region (area) of the PoI. For a closer range measurement, the PoI for the comparison must be at similar spot as a slight variation may give a different reading.

6.1.2 VALIDATION OF THE PROCEDURE

As a further validation of the procedure, contrast calculations using the mean luminance within the defined region were determined for the two instruments

The visibility index calculation described in the earlier section takes into account the luminance value of the object and the luminance value of the background. In this trial, the luminance contrast formulations and a luminance ratio formulation have been defined and adopted as visibility indicators.

The luminance contrast and the luminance ratio equations are as follows:

$$C = \frac{L_O - L_B}{L_B} \tag{8}$$

$$Cr = \frac{L_O}{L_B} \tag{9}$$

where,

C is the contrast;

Cr is the luminance ratio;

L_O is the luminance of locomotive's front view (in cd/m²);

L_B is the luminance of background to the locomotive's front (in cd/m²)

The visibility index is calculated by using both the luminance contrast of the average luminance of the front of the locomotive and the background and the contrast ratio. Table 15 shows the luminance contrast C and luminance ratio Cr, using the GL Opticam meter and the spot meter luminance measurements. For the first event, the luminance contrast C by the GL Optic differs by about 8% from the corresponding calculated value using the measurements by the spot meter. The luminance ratio for the same event has only a 4% difference between the measurement readings of the two instruments.

TABLE 15. COMPARISON OF LUMINANCE CONTRAST AND CONTRAST RATIO BETWEEN READINGS OF GL OPTIC AND SPOT METER READINGS

	Point of Interest (PoI)	Mean luminance – GL Optic	Luminance value – Spot meter	Luminance Contrast C – GL Optic	Luminance Contrast C – Spot meter	Luminance ratio Cr – GL Optic	Luminance ratio Cr – Spot meter
		(cd/m²)	(cd/m²)				
Event 1	Target	1499	1550	-0.37	-0.34	0.63	0.66
	Background	2385	2358				
Event 2	Target	2583	2162	-0.31	-0.31	0.68	0.69
	Background	3766	3150				

The negative luminance contrast I reading indicates that the average luminance of the background was higher than the average luminance of the locomotive, i.e. the background was brighter than the locomotive. This usually indicates that the background contained a large area of clear sky. As can be seen from the luminance readings in Table 13 and Table

14 at the different PoI, (refer Figure 23 and Figure 41 for the PoI), the luminance reading at PoI 0 was about 3 times higher than the luminance readings at PoI 1. The PoI 0 refers to the top background which basically contained a large area of clear sky, whereas PoI 1 refers to the top part of the locomotive which contained the headlight and beacon light.

The luminance contrast C and luminance ratio Cr, using the GL Optic camera and the spot meter luminance measurements of event 2 were also compared as a means of validating the procedure. Although the mean luminance readings at the target and background for event 2 between the two instruments have shown large differences, about 19%, the difference in luminance contrast C and the contrast ratio Cr between the readings of the two instruments were less than 0.5% and 1.5%, respectively. Hence, use of the mean luminance of the target area and mean luminance of the background can be utilised for the luminance contrast and contrast ratio calculations.

6.2 AVON TRIAL

For each measurement run, visibility indices were calculated based on visibility contrast and contrast ratio. This considered the larger background and the immediate background around the locomotive. The difference between the maximum and the minimum visibility index of all the measurements at Avon Yard was about 300%. The difference in the visibility index is in the same range by use of all the different definitions of visibility index, as shown in Figure 44. This indicates that there are one or many factors or their combinations that affect the visibility.

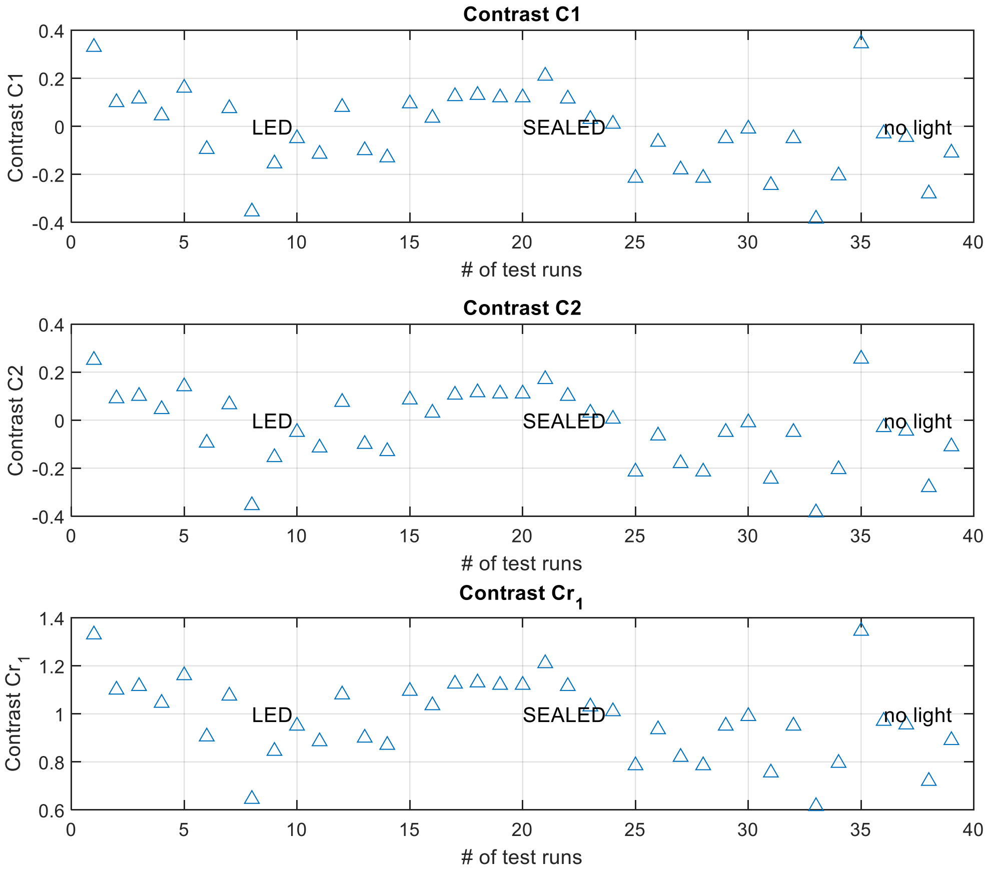


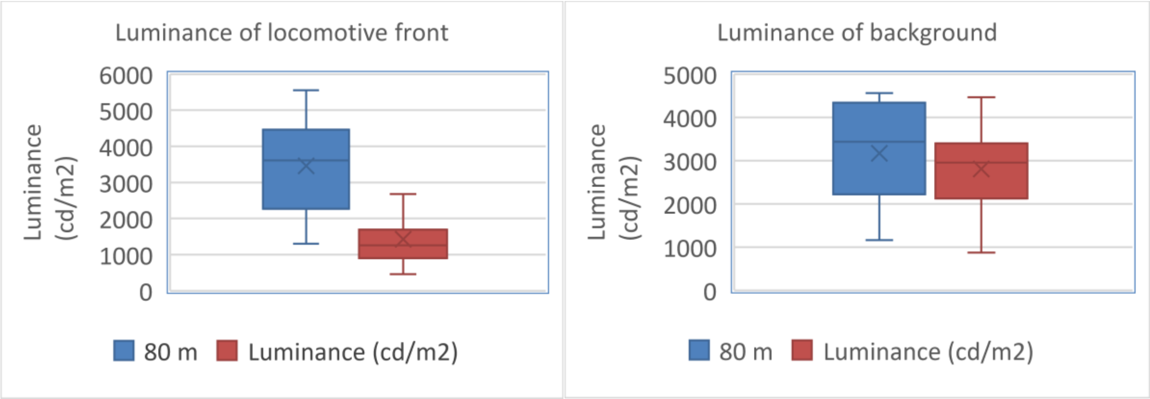
FIGURE 44. VISIBILITY INDEX VALUES OF ALL THE OBSERVATIONS AS DEFINED BY LUMINANCE CONTRAST C1 (TOP), LUMINANCE CONTRAST C2 (MIDDLE) AND LUMINANCE RATIO CR1 (BOTTOM)

6.2.1 EFFECTS OF INDIVIDUAL VARIABLES

Initially the measured luminance value of the target, the front of the locomotive, is used to assess the effects of individual variables, assuming that the background and other variables are fixed. The effects of the individual variables on the visibility index, defined by the luminance contrast, knowing that the background and other variables can vary, have been assessed. This is demonstrated by evaluating the effects of viewing distance and viewing angle on the luminance and visibility index of the locomotive. It is well recognised that visibility is highly affected by the distance to the locomotive and the angle of level crossing design (viewing angle). Hence, this can be used as a validation of the procedure and methodology followed.

6.2.1.1 Effect of viewing distance

Two viewing distance between the camera and the locomotive were selected to provide the appropriate variation, the lower range being 80 m distance and the higher range being 200 m. Figure 45 shows the luminance of the target and the background from the two ranges. It is clear that the luminance measurements of the target, Figure 45 (a), from close range were higher than the measurements from the farther range. For the background, the difference in luminance measurements from close range and far distance was relatively small as shown in Figure 45 (b). The average luminance of the locomotive front boundary measured at 80 m and 200 m from the locomotive front cab were about 3460 cd/m^2 and 1427 cd/m^2, respectively. However, the average measured luminance of the background measured at 80 m and 200 m from the locomotive front cab were about 3170 cd/m^2 and 2800 cd/m^2, respectively

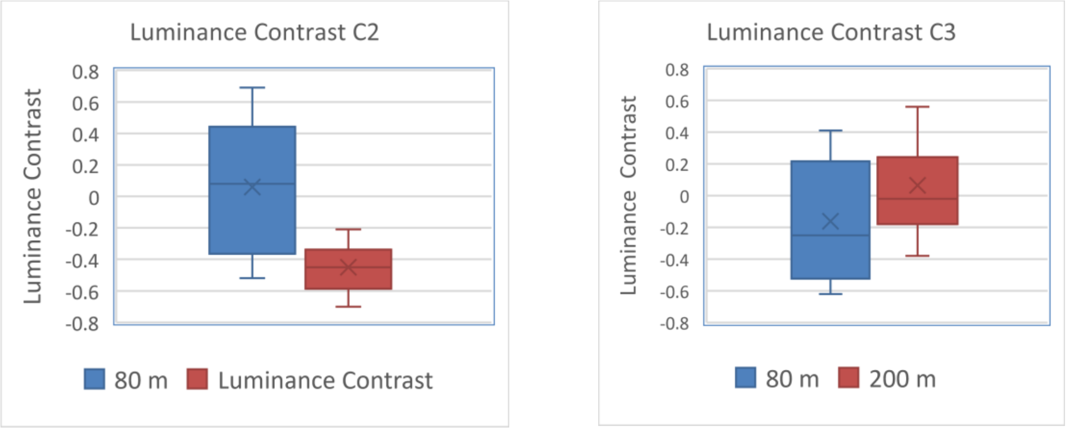


(A) (B)

FIGURE 45. RANGE OF LUMINANCE READINGS FOR 80 M AND 200 M VIEWING DISTANCE. (A) LUMINANCE OF THE FRONT OF LOCOMOTIVE AND (B) LUMINANCE OF THE BACKGROUND

To assess that the effect of distance is as clearly evident using the contrast calculations, the luminance contrast C2, considering wider background, and luminance contrast C3, considering the immediate background, were used. Figure 46 (a) shows the calculated luminance contrast C2 for a number of measurements. The range of luminance contrast C2 for the measurements from 80 m distance was higher, and the result is clearly proportional to the luminance values. Also, the average luminance contrast C2 for the measurement at 80 m was higher than at 200 m distance, but in absolute value the luminance contrast at 200 m was higher. Here the short viewing distance resulted in improved visibility.

The calculated luminance contrast C3 is shown in Figure 46 (b). The average luminance contrast C3 for the measurement at 200 m was higher than at 80 m distance, while in absolute value the measurement at 80 m was higher than at 200m. Here, the short viewing distance resulted in reduced visibility. The luminance contrast with respect to the wider or smaller field of view for the background was not consistent. Further, there are a number of other factors, such as viewing angle or environmental condition, that may need to be considered as these factors were not fixed.

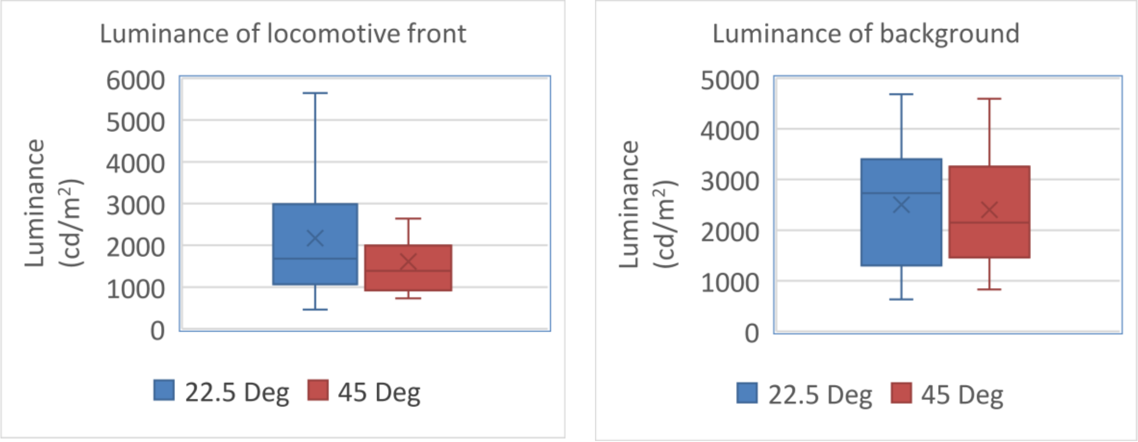


(A) (B)

FIGURE 46. RANGE OF LUMINANCE CONTRAST FOR A NUMBER OF MEASURMENTS CONDUCTED AT 80 M AND 200 M VIEWING DISTANCES. (A) LUMINANCE CONTRAST C2 AND (B) LUMINANCE CONTRAST C3

6.2.1.2 Effect of viewing angle

The viewing angle, i.e. the angle the observer view towards the front of the locomotive cab end, is again varied into two levels, namely 22.5° and 45°. Figure 47 shows the range of luminance values of the target (locomotive's front view) and the background when viewed at the two viewing angles. The average luminance values of all the measurements of the target were about 2170 cd/m^2 and 1610 cd/m^2 for 22.5° and 45° view angles, respectively, as shown in Figure 47 (a). On the other hand, the average luminance values of all the measurements of the background were about 2500 cd/m^2 and 2400 cd/m^2 for 22.5° and 45° view angles, respectively, as shown in Figure 47 (b). It is clear that the average luminance value of the locomotive's frontal view was higher for the small view angle than the large view angle, while the average luminance values of the background were about the same for both the small and large view angles.

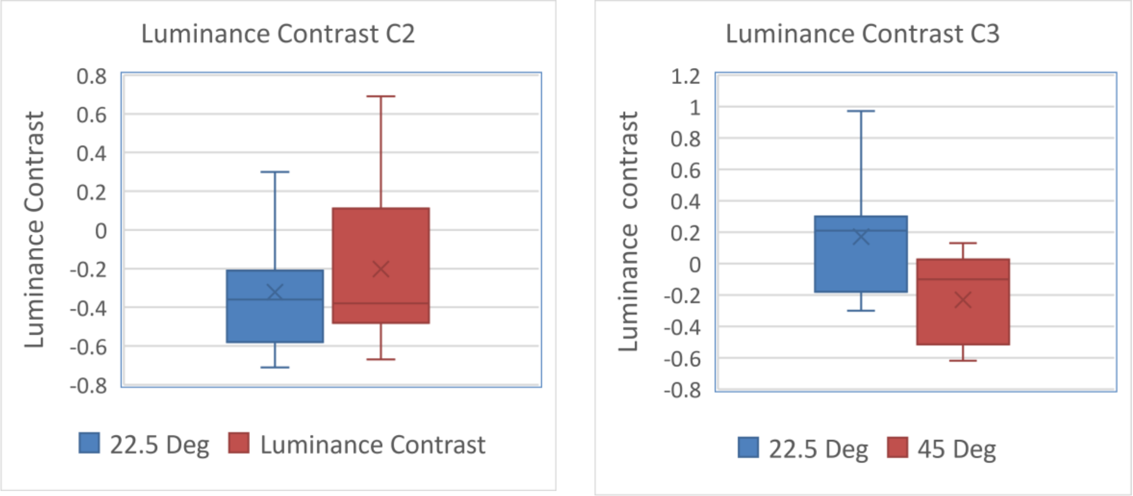


(A) (B)

FIGURE 47. RANGE OF LUMINANCE READINGS FOR 22 DEG AND 45 DEG VIEWING ANGLES. (A) LUMINANCE OF THE FRONT OF LOCOMOTIVE AND (B) LUMINANCE OF THE BACKGROUND

The luminance contrast or contrast ratio has been used in the trials to evaluate visibility improvements when altering the variables. To assess the effect of viewing angle, the luminance contrasts C2 and C3 were used as visibility indicators. Figure 48 (a) shows the calculated luminance contrast C2 and Figure 48 (b) shows the calculated luminance contrast C3 for a number of measurements. Contrary to viewing distance, it is clear that smaller view angles give a lower luminance contrast compared to large view angles. The average luminance contrast C2 (in absolute value) for 22.5^{o} view angle was about 45% higher than for 45^{o} view angle.

Considering the immediate background and the luminance contrast C3, the average contrast for the measurement at 22.5^{o} was higher than at 45^{o} view angle. From this, one may deduce that the smaller viewing angle resulted in an improved visibility. Again, the luminance contrast with respect to the wider or smaller field of view for the background was not giving consistent results. As there may be other factors interacting, and not all the factors were fixed, effect analysis may reveal whether the change in angle or change in distance has any significant effect on the visibility. Further, the effect analysis will reveal any interaction factors with a significant effect on the visibility.



(A) (B)

FIGURE 48. RANGE OF LUMINANCE CONTRAST AND LUMINANCE RATIO FOR A A NUMBER OF MEASURMENTS CONDUCTED AT 22 DEG AND 45 DEG VIEWING ANGLES. (A) LUMINANCE CONTRAST C2 AND (B) LUMINANCE CONTRAST C3

6.2.2 EFFECT OF HEADLIGHT TYPE AND VIEWING CONDITIONS

It is clear that visibility is highly affected by the distance to the locomotive and the angle of level crossing design (viewing angle). This is consistent with the findings of the factors effect analysis of all the measurements. Analysis indicates that the interaction effects of viewing setting and type of headlight is significant. That is, the effect of the type of headlight is dependent on the viewing condition (distance and viewing angle). The LED headlights improve visibility only under certain angles and distances but at other conditions there is no difference between SEALED and LED. Figure 49 shows the normal plots of the estimated effects on the Luminance Contrast C1 and C2 as observation results. C1 and C2 are defined as the luminance contrast between the target and the wider background, while C3 is the luminance contrast between the target and the immediate background.

As can be seen from the normal probability plots of estimated effects on Luminance Contrast C1 and C2 in Figure 49, the main effect ($\boldsymbol{A}$) (the distance to the locomotive) is significant. That means, the visibility is significantly affected by the distance from the observer to the locomotive. This is an expected observation and this indirectly demonstrates that the methodology followed in the assessment for visibility index is acceptable. Further, 2-factor interaction effect ($\boldsymbol{A} \times \boldsymbol{C}$) - the interaction of distance and type of head light and 3-factor interaction effect ($\boldsymbol{A} \times \boldsymbol{B} \times \boldsymbol{C}$) – the interaction of viewing condition (the distance and angle of level crossing design) and type of head light are significant. The main effect ($\boldsymbol{C}$) for headlight type is insignificant as seen from the normal probability plots of the estimated effects. The estimated effect analysis indicates that while changing from SEALED to LED headlights only provided insignificant improvement in luminance contrast under most viewing conditions, a significant improvement in visibility index is observed when the headlight type was changed with viewing conditions simultaneously. That means, the effect of the change in headlight type is significant when the distance or both distance and angle change simultaneously.

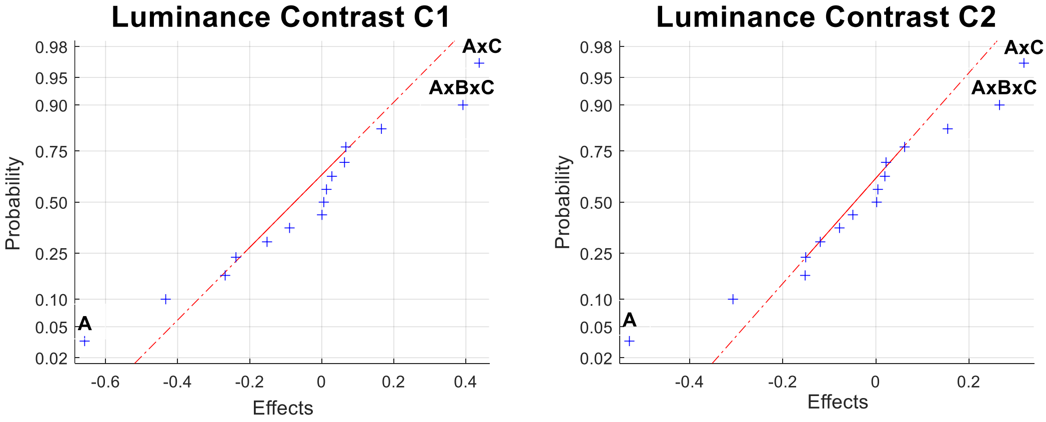


FIGURE 49. EFFECT ANALYSIS OF THE 16 TEST RUNS BY USE OF CONTRAST C1 (LEFT) AND CONTRAST C2 (RIGHT)

6.2.3 EFFECT OF DITCH AND BEACON LIGHTS

Changes in visibility due to individual factors and combinations of factors were also analysed. The observations indicate that the change in visibility due to a change in viewing angle by half is similar to a 50% reduction in headlight operating performance, see Figure 50. The visibility variation through changing the viewing angle from 45° to 22.5° is the same as the visibility change due to the headlight operating from degraded 50% to 100% performance while keeping the ditch light and beacon light on. When changing both the ditch and beacon lights from ON to OFF, a slight change (about 5%) in the contrast value is observed. It is therefore concluded that the effects of ditch lights and beacon lights in the visibility index is insignificant in comparison to the headlight for the considered testing conditions.

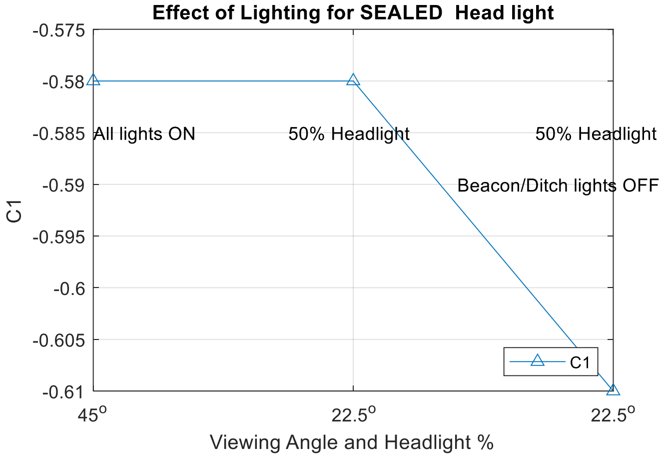


FIGURE 50. EFFECT OF LIGHTS AND VEIW ANAGLE WITH DEGRADED HEADLIGHT

The normal probability plot of effect considering luminance contrast C3 as the observation result is shown in Figure 51. The Luminance Contrast C3 considers the immediate background, which is related more to the foveal vision while the C1 and C2 definition is more related to the peripheral vision with a large field of view. As shown in Figure 51, the main effects $(\boldsymbol{A})$ and $(\boldsymbol{B})$ are very significant, while the main effect $(\boldsymbol{D})$ and the interaction effect $(\boldsymbol{B} \times \boldsymbol{D})$ are also significant in the visibility index as defined by C3. The variable $(\boldsymbol{D})$ is for the beacon light, with other variables being as previously indicated.

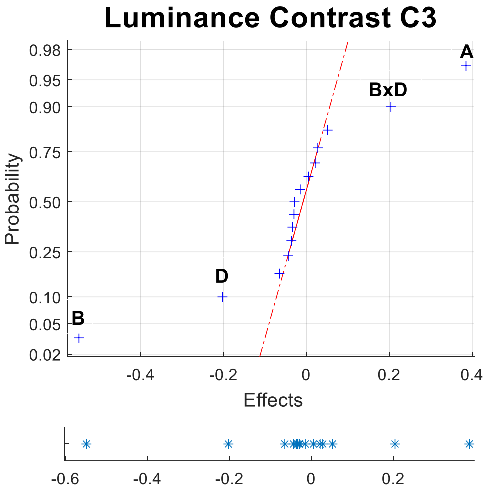


FIGURE 51. EFFECT ANALYSIS OF THE 16 TEST RUNS BY USE OF CONTRAST CONTRAST C3 AS OBSERVATION RESULTS

The effect of the variable $(\boldsymbol{D})$ - beacon light is insignificant when a wider background is considered as a luminance contrast result C1/2 or Cr1. The effect is not significant as can be seen in Figure 49. However, when an immediate background area is considered in the contrast analysis C3, the effect of beacon lights on visibility becomes significant, as seen in Figure 51. Further, the effect of beacon lights is significant when the beacon light is simultaneously changed with view angle $(\boldsymbol{B}\text{x}\boldsymbol{D})$ as can be seen in Figure 51.

6.2.4 EFFECT OF HEADLIGHT AND ENVIRONMENTAL CONDITION

Further analysis of the individual factors and combinations of factors reveals that there is a strong interaction between environmental condition in terms of vegetation and mist obscurity and the type of headlight. This infers that the effect of headlight type (LED or SEALED) is dependent on environmental condition.

The relationship between headlight type and environmental condition, in terms of vegetation and mist has also been analysed. The LED headlight seems to give an improved visibility in misty condition in comparison to a clear view. Visibility of LED compared to SEALED headlight improved by 31% in clear daytime weather while the improvement is 360% in misty conditions, see Table 16. As a control reference, the change in visibility in dense vegetation condition when changing the headlight from SEALED to LED is only 3%.

TABLE 16. EFFECT OF HEAD LIGHT TYPE AND ENVIRONMENTAL CONDITION

	SEALED to LED for Clear view	SEALED to LED with Mist	SEALED to LED with Vegetation
Change in Contrast C1	31%	360%	3%

6.2.5 EFFECT OF DITCH LIGHTS AND ENVIRONMENTAL CONDITION

The effects of locomotive cleanliness, ditch light and beacon light were also analysed. Images of the CBH locomotive with different light condition are seen in Figure 52. The image (a) in Figure 52 shows a clean livery with only headlights ON, while image (b) is the same locomotive with flashing beacon and ditch lights ON in addition to the headlights.

The luminance contrast C1, considering the wide background and the luminance contrast C3, considering the immediate background, for cleaned livery is compared with uncleaned livery of the same locomotive class. Keeping all the conditions fixed, 200 m viewing distance 22.5^o viewing angle, SEALED headlight, clear view, and changing only the ditch light while changing the livery of the locomotive to clean livery, the visibility index had a significant increase. Figure 53 shows the effects of locomotive cleanliness and ditch light condition. The analysis result indicated that the effect of locomotive cleanliness in daytime is more significant than the effect of ditch lights (visibility lights), as shown in Figure 53, in both the visibility index definitions.

(A) (B)

FIGURE 52. IMAGES OF CBH LOCOMOTIVE AT THE TEST TURNTABLE. (A) HEAD LIGHT ON, AND (B) HEADLIGHT, FLASHING BEACON AND DITCH LIGHTS ARE ALL ON

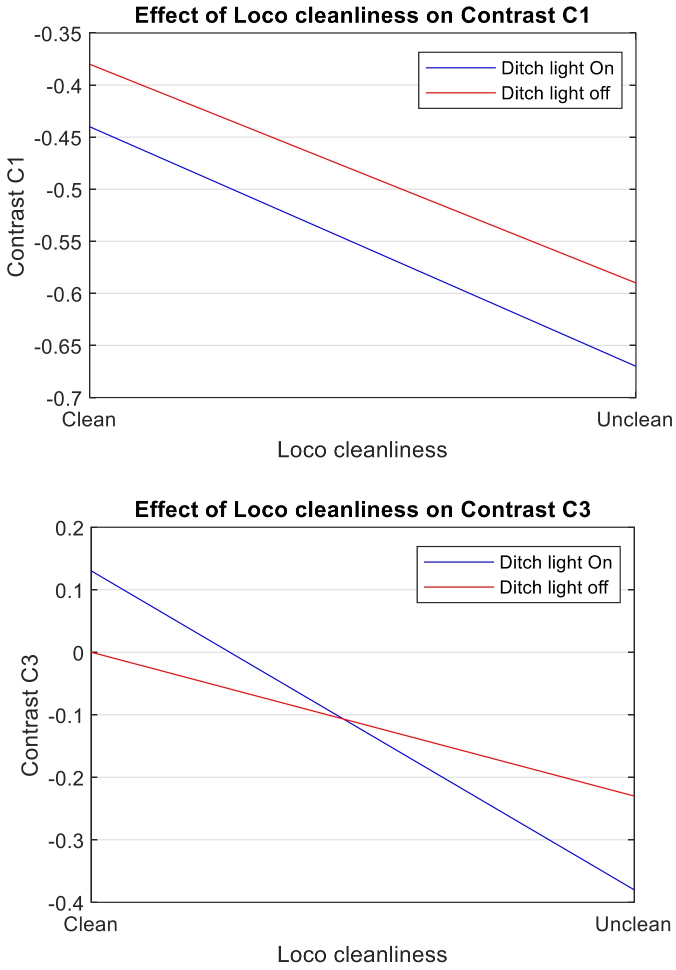


FIGURE 53. EFFECT OF CLEANLINESS OF LOCOMOTIVE LIVERY AND DITCH LIGHTS. (TOP) LUMINANCE CONTRAST C1 AND (BOTTOM) LUMINANCE CONTRAST C3

Changing the ditch light to OFF state, while keeping all the other variables fixed, leads to a reduction in the luminance contrast to zero. For the clean livery case, the luminance contrast reduced by about 13 % to almost 0 contrast, when the ditch lights were changed from ON state to OFF state.

6.3 LEVEL CROSSING ADJOINING SPENCERS BROOK – YORK ROAD

Factors considered in the experimental run near York were viewing condition, headlight type, beacon light, ditch light and obscurity. The analysis of all the observations indicated that the difference between the maximum and the minimum visibility indices is about 200%.

The effects of the factors and their combination effects are analysed using the DoE effect analysis. The analysis indicates that the effects of viewing condition and headlight type, and viewing condition with obscurity are significant. Effect analysis of the 32 test runs by use of contrast ratio is shown in Figure 54. Cr1 is defined as the contrast ratio of the luminance value of the target to the luminance value of the wider background. As can be seen from the normal probability plot in Figure 54, there are two 2-factor interaction effects that are significant. Here, $(\boldsymbol{AB} \times \boldsymbol{C})$ is the interaction of viewing condition and type of head light and $(\boldsymbol{AB} \times \boldsymbol{G})$ is the interaction of viewing condition and obstruction. The factors included in the experiment and their notation is given in Table 17. This is consistent in both the definitions of visibility based on Contrast and Contrast ratio.

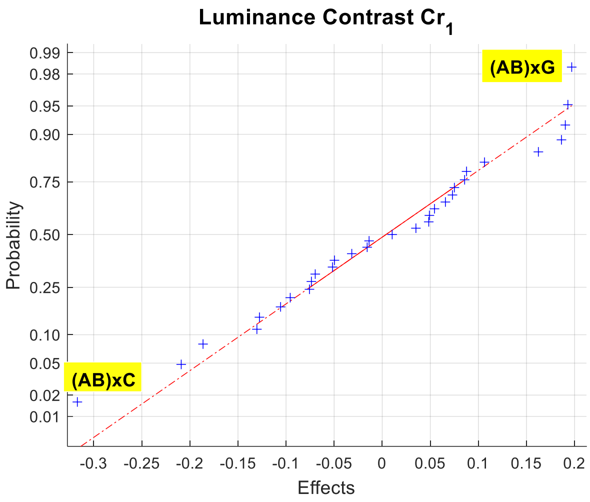


FIGURE 54. EFFECT ANALYSIS OF 32 RUNS FROM LC TRIAL EXPERIMENTATION

TABLE 17. FACTORS INCLUDED IN THE DESIGN OF EXPERIMENT AT THE PASSIVE LC TRIAL AND THEIR NOTATIONS

Variables	Viewing setting	Headlight type	Beacon light	Ditch light	Livery cleanliness	Vegetation coverage	Weather condition
Notations	**(AB)**	**(C)**	**(D)**	**(E)**	**(F)**	**(G)**	**(H)**

6.3.1 EFFECT OF HEADLIGHT, DITCH LIGHT AND BEACON LIGHT

The effects of headlights, ditch lights and beacon lights were analyzed whilst the other conditions were kept constant. The visibility index of the locomotive is calculated for three lighting conditions: no lights, only headlights ON, all lights ON. All lights ON corresponds to the headlight, beacon lights and ditch lights turned ON. Figure 55 shows the effects of locomotive lights as defined by luminance contrast C1 and Luminance ratio Cr_1.

Table 18 lists the visibility index values for LED and SEALED headlights combined with beacon and ditch lights. For LED headlights the visibility index increased by 300 % as defined by the Luminance Contrast C1, when only the headlights are ON. When all lights are ON (headlight, beacon lights and ditch lights), the corresponding visibility index increased by 760 % compared to the situation where all lights are OFF. This corresponds to an increment of the visibility index by about 230% when ditch lights and beacon lights are ON.

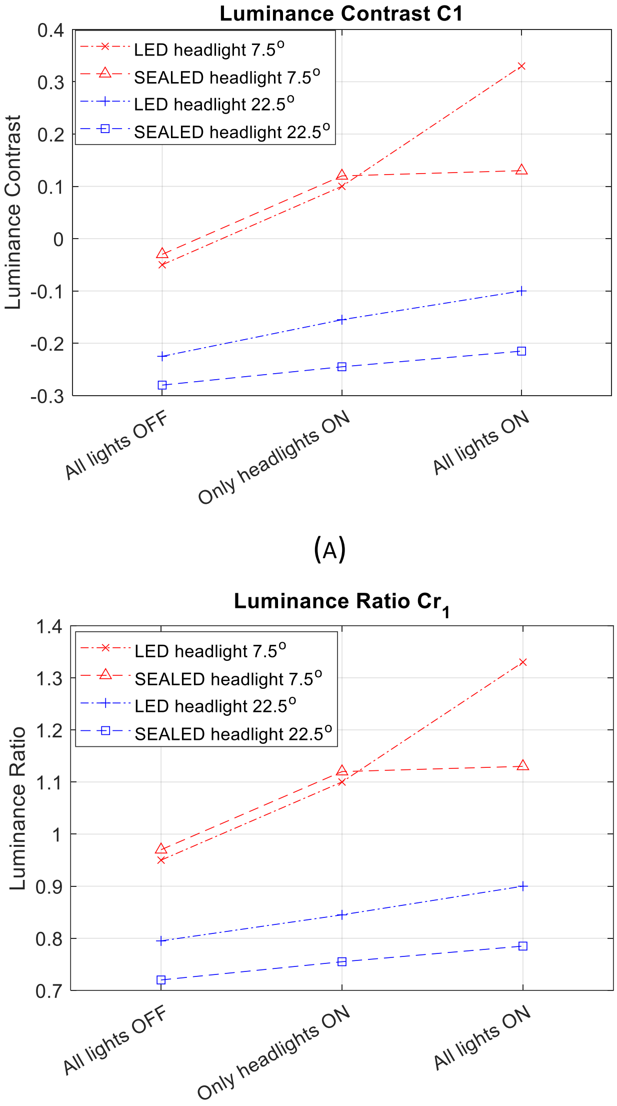
Table 18. Effects of locomotive lights on luminance contrast and Luminance ratio when the view angle is at 7.5°

	LED headlight			SEALED headlight		
	Contrast C1	Contrast C2	Contrast Cr_1	Contrast C1	Contrast C2	Contrast Cr_1
NO lights	-0.05	-0.05	0.95	-0.03	-0.03	0.97
Only Headlights	0.1	0.09	1.1	0.12	0.11	1.12
All lights ON	0.33	0.25	1.33	0.13	0.115	1.13

The visibility index as defined by the luminance ratio Cr_1, increased by 16 % when only the headlight is ON while the value increased by 40% when all the lights were ON compared to all lights OFF. This corresponds to that the effect of LED headlight and the effects of ditch lights and beacon lights together are about the same. These observations are for a viewing angle of 7.5°.

For SEALED halogen headlights the visibility index increased by about 500% as defined by the Luminance Contrast C1, when only the headlights are ON. When all lights are ON (headlight, beacon lights and ditch lights), the corresponding visibility index increased further by a small margin, to about 533% compared to the situation where all lights are OFF. The visibility index as defined by the luminance ratio Cr_1, increased by 16% when only the headlight is ON while the value increased by an additional 1% when all the lights were ON. This indicates that the effect of ditch lights and beacon lights in the locomotive visibility is insignificant if the headlight is SEALED halogen. These observations are for a viewing angle of 7.5°.

The effects of headlight, beacon lights and ditch lights for a viewing angle of 7.5° and 22.5° are shown in Figure 55. Both the calculated luminance contrast C1, Figure 55 (a) and the calculated luminance ratio Cr1, Figure 55 (b) show similar results for all the different light conditions.



(A)

(B)

FIGURE 55. EFFECT OF LOCOMOTIVE LIGHTS (A) LUMINANCE CONTRAST C1, (B) LUMINANCE RATIO CR1

The luminance contrast and luminance ratio values are tabulated in Table 19 for LED and SEALED headlight when the viewing angle is 22.5°. The change in the visibility index, defined by luminance contrast C1, is only 31% when LED headlights are ON compared to all lights OFF. The corresponding change is 300% when the viewing angle was 7.5°. The visibility index, Luminance Contrast C1, changed by an additional 36% when all lights were turned ON. The corresponding increment for 7.5° viewing angle was 230%. These observations clearly indicate that the effect of LED headlights on visibility improvement is highly impacted by the viewing settings. In addition, it become clear that the effect of the headlight is comparable to the combined effects of ditch and beacon lights.

TABLE 19. EFFECTS OF LOCOMOTIVE LIGHTS ON LUMINANCE CONTRAST AND LUMINANCE RATIO WHEN THE VIEW ANGLE IS AT 22.5°

	LED HEADLIGHT			SEALED HEADLIGHT		
	CONTRAST C1	CONTRAST C2	CONTRAST CR_1	CONTRAST C1	CONTRAST C2	CONTRAST CR_1
NO LIGHTS	-0.225	-0.225	0.795	-0.28	-0.28	0.72
ONLY HEADLIGHTS	-0.155	-0.155	0.845	-0.245	-0.245	0.755
ALL LIGHTS ON	-0.10	-0.10	0.90	-0.215	-0.215	0.785

For SEALED halogen headlights, the change in the visibility index, luminance contrast C1, is about 13% and 23% when only the headlights are ON and all lights are ON, respectively. The corresponding change in Cr1 values are 5% and 9%, respectively. These observations are for a viewing angle of 22.5°.

A normal probability plot of the effect analysis by use of contrast ratio Cr1 as response value is shown in Figure 54. Also, a normal probability plot of the effect analysis by use of Luminance Contrast C2 as response value is shown in Figure 56. From both effect analysis plots, it is clear that the effects of beacon lights ($\boldsymbol{D}$) and ditch lights ($\boldsymbol{E}$) are negligible.

6.3.2 EFFECT OF OBSCURATION BY VEGETATION

As can be seen in in Figure 54, the two parameters with significant effect on the response are $(\boldsymbol{AB} \times \boldsymbol{C})$, which is the interaction of viewing condition and type of head light, and$(\boldsymbol{AB} \times \boldsymbol{G})$ which is the interaction of viewing condition and vegetation obstruction. It is clear from the effect analysis that there is an interaction effect of the two factors, viewing condition and vegetation, in the visibility of the locomotive. This is consistent with what is observed by the test personnel. The locomotive visibility changes from a clear view to an obscured view when the viewing setting changes from one level to another.

The effect of obscuration can be seen when the Luminance Contrast C2 is used as a response, as shown in Figure 56. One can see clearly that the main effects of vegetation coverage ($\boldsymbol{G}$) and the viewing settings ($\boldsymbol{AB}$) are very significant. The interaction effect of viewing setting and headlight type ($\boldsymbol{AB} \times \boldsymbol{C}$) is also significant, as can be seen in the normal probability plots of all effects.

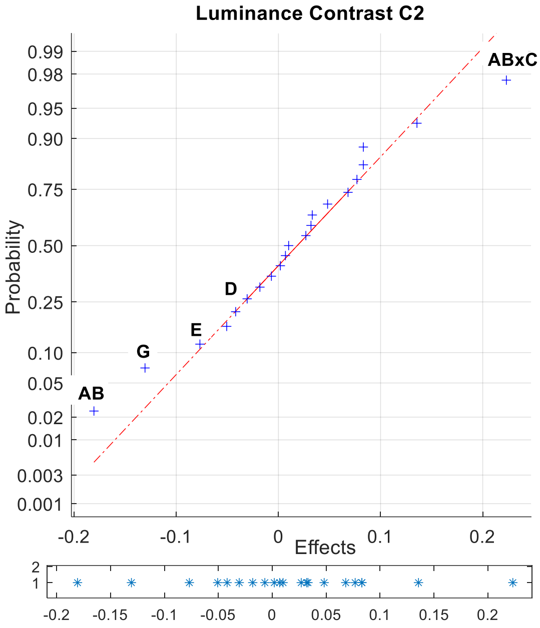


FIGURE 56. EFFECT ANALYSIS OF 32 RUNS FROM LC TRIAL EXPERIMENTATION WITH C2 AS RESPONSE

6.4 LED HEADLIGHT PERFORMANCE AT SPOTSWOOD (VICTORIA)

The effect of degraded LED headlight performance in visibility has been evaluated with differing levels of degradation and with low and high beam scenario. Measurements were made at 80m and 160m distances. Figure 57 shows the luminance contrast for the different scenarios. Results of the luminance contrast C1 with low beam headlight and with high beam head lights are listed in Table 20, respectively.

With 100% performance in full beam, the luminance contrast C1 decreased to about 1/3 when the ditch lights were turned ON for measurements at 160 m. For measurements at 80 m, the luminance contrast C1 increased by about 1/3 when ditch lights were turned ON. The assessment found that visibility reduced by about 40% when the LED headlight performance degraded from 100% to only 75%.

When headlight performance degraded by 50%, visibility index reduced further to about 30-40% of the full performance head light. Note that the visibility index is related with the visibility or visual conspicuity of the locomotive. A further reduction of the LED headlight performance to only 25% degraded performance reduced the visibility by almost 9 % when compared with 100% performance operated in full beam.

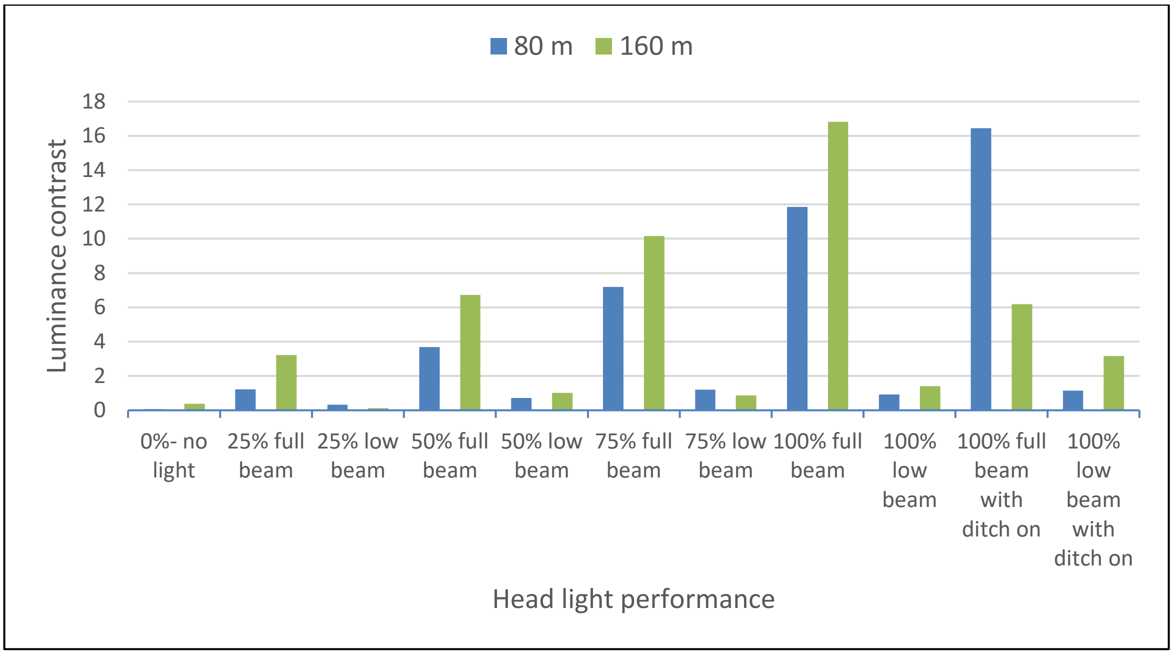


FIGURE 57. LUMINANCE CONTRAST WITH DEGRADED LED PERFORMANCE IN HIGH AND LOW BEAM

TABLE 20. LUMINANCE CONTRAST C1 FOR DEGRADED PERFORMANCE OF LED HEADLIGHT

LUMINANCE CONTRAST C1		
	80 M	160 M
0%- NO LIGHT	0.07	0.39
25% FULL BEAM	1.23	3.21
25% LOW BEAM	0.32	0.12
50% FULL BEAM	3.68	6.73
50% LOW BEAM	0.72	1.01
75% FULL BEAM	7.2	10.15
75% LOW BEAM	1.2	0.87
100% FULL BEAM	11.86	16.81
100% LOW BEAM	0.93	1.41
100% FULL BEAM WITH DITCH ON	16.44	6.19
100% LOW BEAM WITH DITCH ON	1.15	3.16

7 SUMMARY

Improving the visual conspicuousness or visibility of a freight train is an important element in improving safety at passive level crossings where there are no warning devices. The visual conspicuousness of a freight train depends not only on the actual luminance value of the train, but also on the average luminance of the surrounding background and the viewing options. The luminance of the train itself is influenced by a variety of factors, such as the intensity and colour of light emitted from the train, livery and patterns of the train, cleanliness of the object, viewing settings, etc. The visibility is also dependent on the natural light characteristics and weather condition.

To improve train visibility, flashing beacons on locomotives and the conversion of locomotive headlights from halogen globes (SEALED) to Light-emitting diodes (LED) have been broadly carried forward to a trial implementation with additional work being undertaken to LED intensity. This section summarises the results and important findings from the independent assessment of trials conducted at a number of test sites.

- Trials of locomotives with LED headlight, SEALED beam headlights and beacon lights have been tested using luminance measurements.
- A number of scenarios with different background and locomotive configurations were developed and tests were conducted using a luminance camera GL Opticam 3.0 instrument.
- The measurements were used to determine the relative luminance (contrast) between the locomotive and the background.
- To conduct the investigation, visibility of a locomotive is defined in measurable quantities. A term “visibility index (conspicuity index)” is developed to describe improvement or reduction in visual conspicuity of a locomotive. This is a relative value and it is not an absolute value of how good or worse the conspicuity of the locomotive is. It rather gives an indication whether the conspicuity has improved or worsened.
- The larger the difference in contrast, the easier it is for a person to detect an object. In day-light hours, when the ambient light is high, the contrast between the locomotive light and the background can become lower as the sun-light may visually mask the locomotive light. Hence, visibility of locomotives can be affected by the level of the ambient light and the direction of the sun-light.
- An observer would have a better visibility of oncoming trains if the view angle is small and the distance to the train is short. Conversely, if the viewing angle to the train is large or the distance is far, the visibility becomes worse. Hence, the design of the level crossing is another important factor which needs to be considered.
- The effect of headlight type in different viewing settings was not known. Hence, a methodology to consider the effects of the individual factors and the effects of the combination of factors was proposed, and the effects of the main factors and interaction of two or more factors was evaluated.
- Different approaches for visibility index have been defined based on the measured luminance, and luminance contrast results were consistent with a subjective assessment of locomotive visibility carried out by test personnel.
- The visibility model adopted in this assessment is based on luminance contrast only. An accurate visibility model that considers not only the luminance contrast

between the target and the background, but also the contrast sensitivity, glare effect and the transient factor is critical. Alternatively, a reference threshold contrast or reference luminance accepted by psychophysical tests can be employed.

- A GL Opticam luminance camera was the primary device used in the current study. As this device has not been used before in a similar exercise, calibration was initially carried out using a spot luminance meter.
- Further, the effect analysis is used as a validation to the methodology followed in this assessment. It is a known fact that viewing distance and viewing angle have effect on visibility of objects. The farther the distance the lower gets the visibility. This is demonstrated by evaluating the effects of viewing distance and viewing angle by use of the luminance measurements and the visibility index adopted. Hence, this can be used as an intuitive validation of the procedure and methodology followed.
- It is observed from the effect analysis that the visibility is significantly affected by the distance from the observer to the locomotive, by the interaction of distance and type of head light as well as by the interaction of viewing condition (the distance and angle of level crossing design) and type of headlight.
- A significant improvement in visibility index is observed when the headlight type and the viewing conditions change simultaneously. That means, the effect of the change in headlight type is significant only when the distance or both distance and angle change.
- Observations indicate that the change in visibility due to change in viewing angle (from 22.5^{O} to 45^{O} or from 7.5^{O} to 22.5 ^{O}) and due to degraded headlight is comparable. The visibility has reduced equally when doubling the view angle from 22.5^{O} to 45^{O} or when the headlight was degraded to a 50% performance.
- Environmental condition in terms of vegetation and mist obscurity has significant effect on locomotive visibility. Further, the effect of headlight type (LED or SEALED) is dependent on environmental conditions. The LED headlight seems to give an improved visibility in misty condition in comparison to a clear view. Locomotive visibility improved by 360% when LED headlight was used compared to SEALED headlight in misty condition.
- Cleaned livery provides an improved visibility in comparison to uncleaned livery. The effect of livery cleanliness was more significant compared to the effect of ditch lights on visibility. Note that ditch lights are also called visibility lights.
- The interaction of viewing condition and type of headlights and the interaction of viewing condition and obstruction have shown to have a significant effect on the luminance contrast.
- The effect of the beacon light in its current configuration on locomotive visibility was insignificant when a wider background was considered as a luminance contrast result C1/2 or Cr1. However, when an immediate background area was considered in the contrast analysis C3, the effect of the beacon light was significant. Further, the effect of the beacon light was significant when the beacon light was simultaneously changed with view angle. The current trial is inconclusive in terms of the efficacy of the beacon light mounted in its current configuration on locomotive visibility as the effect is significant only when the view setting has a

small viewing angle (7.5°). The assessment should continue to explore a variety of beacon light configurations in terms of their efficacy considering a range of viewing settings and different day time ambient conditions.

- The interaction effect of change in headlight type with change in ditch light and beacon lights operation is significant. Visibility of locomotives increased by about 300% when the LED headlight is turned ON. The corresponding increase in visibility when the SEALED headlight is turned on is about 500%. The locomotive visibility further improved by the same amount for the LED headlights when both ditch lights and beacon lights are turned ON. In comparison, the ditch lights and beacon lights do not contribute to locomotive visibility improvement for SEALED headlights. This is the case only when the view setting has a small angle (7.5°). The result is different when the view setting is changed to a wide view angle (22.5°).
- When the LED headlight performance degraded by 50% or more, the visibility of the locomotive reduces by over 60%. If the performance of the headlight further degrades, there is a risk that the locomotive visibility in day-light hour falls to the level that the headlight effect will be negligible. Hence, it is important for operators to monitor the LED headlights and maintain the performance of the headlights, to at least 50% to 75%.
- The testing of degraded headlight performance confirmed the findings from the other trial test on the significance of headlight on locomotive visibility.
- The current approach for the experimentation uses two-levels of variation for the parameters, i.e. changing the parameters or variables from one level to another level. This assumes that the effect in the result due to the change in the variable is linear. The current testing method needs to be extended and carefully planned to account for more levels of variation. For example, to assess the effect of LED vs Incandescent lights at different viewing conditions may need more than two levels of variation. Several background condition and viewing settings need to be simulated to reach a conclusive recommendation on the efficacy of the headlight conversion to LED and on the efficacy of beacon lights on locomotive conspicuity.
- Further, additional variables not included in the trial may have significant effect on locomotive conspicuity in day-light hours. Future trials should include parameters not looked at in the current study such as variable weather conditions, different background situations including effects of sunlight glare, different locomotive livery and varying lighting colour and pattern.
- The current trial focused on visibility of the front end of a locomotive, without taking into consideration the wide variation in the level crossing layout design. Future assessment should include visibility of the side of the locomotive which may be treated with reflectorised system or additional lighting on the side of the locomotive.

8 CONCLUSIONS

To improve freight train visibility in passive level crossings, two control measures were recommended and implemented for trial. These are flashing beacons on locomotives and conversion of locomotive headlights from SEALED to LED.

The effects of the implemented control measures on the visual conspicuity of a locomotive are assessed based on scientific principles and statistical procedure. A method is proposed to measure and quantify the visibility of a freight locomotive and assess the effect that different variables have on it. For this, a visibility index was defined based on luminance contrast.

The visibility model adopted in this assessment is based on luminance contrast only. Two background regions are defined for the luminance contrast, the immediate background with a narrow field of view and the background with a wider field of view. The luminance contrast between the target and the immediate background and the luminance contrast between the target and the wider background have been used alternately. An accurate visibility model that considers not only the luminance of the target and the background, but also other effects such as the contrast sensitivity, glare effect and the transient factor is critical. Developing and testing such a model is beyond the scope of this project.

The current AS 7531 standard specifies requirements for headlight and visibility lights (ditch lights) to rollingstock operating up to a nominal maximum speed of 160km/h. It also specifies the requirement for the position of the headlight and ditch lights, the luminous intensity and the distance these lights must aim to illuminate the track for locomotive drivers. The standard states the inspection requirements and method for measuring luminance factor. In the context of locomotive visibility, AS 7531 should be considered as a minimum set of requirements.

Based on these limitations it is recommended that future review of AS 7531 should include headlight type, colour and luminous intensity requirements considering the efficacy these lightings have on rolling stock visibility to road users, such as road vehicle drivers approaching a level crossing. Further, AS 7531 should include a method for measuring headlight luminosity and other measurable quantities in relation to locomotive conspicuity. To have a consistent definition and analysis model, the definitions of luminance contrast and other relevant visibility analysis models need to be addressed in the standard.

Literature and reports dealing with locomotive visibility have been reviewed and a number of parameters and conditions have been identified. The variables included in the assessment are viewing circumstances, locomotive lighting and obscurity due to vegetation or mist. A Design of Experiment methodology based on fractional factorial design was then applied to design the experimental plan and to collect data from the field trials for a combination of the variables identified. A number of scenarios with different background and locomotive configurations were developed and tests were conducted using a luminance camera GL Opticam 3.0 instrument. The scenarios include a combination of LED and SEALED headlights and beacon lights arrangements.

The Opticam system has been used mainly in road marking and road lighting quality assessment according to the EN 13201 Road lighting standard. The system has also been used in Tunnel entrance luminance measurement according to CIE 88 standard (Guide for the lighting of road tunnels and underpasses). However, it is the first time this has been used in railway visibility study, and the instrument is used for the first time in the Southern Hemisphere. It was brought to Australia especially for this trial.

A number of measurements were conducted and data was collected from two test sites, one from Aurizon facilities at Avon Yard and another from a passive level crossing in service near York. Another test site used for the trial is Spotswood Yard in Victoria. Based on the collected measurements, the effects of the suggested control measures and other identified variables relevant to the conspicuity of locomotives were quantified into luminance contrasts and contrast ratios and analysed. The current study is purely focused only on locomotive frontal visibility.

The effect analysis indicate that locomotive visibility is significantly affected by the distance to the locomotive. The efficacy of conversion of headlights to LED on locomotive visibility is highly dependent on the distance between the observer and the locomotive as well as by the viewing circumstances. It is clear from the current trial assessment that the visibility of the locomotive lighting is affected by the level crossing layout (locomotive orientation) and vegetation density. Large viewing angle and dense vegetation are the worst combination. Hence, measures to improve visibility of the side of the train by use of auxiliary flashing lights or similar measures are important to improve freight train visibility. However, due to use of auxiliary flashing lights, light pollution effects to the surrounding and to train crew and the potential to “dazzle” road users are plausible. These two elements are not considered as part of this study.

The effect of beacon lighting, mounted in its current configuration, on locomotive visibility is insignificant when a wider background is considered. However, when an immediate background area is considered in the contrast analysis, the effect of beacon light on visibility is significant. Further, the effect of beacon light is significant when the beacon light is simultaneously changed with view angle. One can conclude that the beacon light is effective in improving locomotive visibility only if the observer is in close range and the view angle is smaller. Other configurations of the beacon light need to be explored further to assess its effect in a range of view settings and in different day time ambient conditions.

Further, beacon light and ditch light together with LED headlight is effective in improving locomotive visibility when viewed at a small angle. However, the effect of beacon light is found to be insignificant when the headlight is a SEALED halogen light. The result is inconclusive, as the effect is only significant when the view angle is 7.5°. For other view angles, the result is insignificant.

Efficacy of conversion of locomotive headlights from SEALED halogen globes to LED on visual conspicuity of a locomotive significantly dependent on environmental condition. The LED headlight provide an improved visibility in misty condition in comparison to a clear weather condition. The locomotive became 360% more conspicuous when LED headlights are used compared to SEALED headlight in misty condition. The corresponding difference in conspicuity level in clear view condition is only 30%.

The current assessment found that a degraded headlight has effect on locomotive conspicuity reduction. Visibility of locomotive reduced by about 40% when the LED headlight performance degraded by 25%. A 50% degraded LED headlight reduces the locomotive visibility by over 60% in day-light hours. The effect of LED on locomotive visibility will be insignificant if the LED is degraded to only 25% performance. Hence, it is important for operators to monitor the LED headlights and maintain the performance of the headlights to an acceptable level, considering both day-light hour visibility and night time illumination of track.

The study concludes that there were no significant differences between LED and SEALED (halogen or incandescent) headlights in terms of locomotive conspicuity. However, the current study is limited in scope and variations considered.

Although the effect of LED headlight on visibility is marginal, there are other operational advantages that the LED headlight may have compared to SEALED headlights. LEDs consume a fraction of the energy of incandescent and halogen lightbulbs. According to Divvali [33], LED bulbs convert 95% of their energy input to light, while incandescent bulbs convert only 5% of their energy input to light. SEALED lightbulbs produce UV radiation while LED lightbulbs do not contain hazardous chemicals or gases. In addition, LED light bulbs are economical which will give 85% cost saving for material cost and energy cost. One main advantage of LED headlights is that LEDs do not suddenly fail, rather the luminance of LEDs reduces gradually [34]. The ability of LED headlights for smart monitoring is another advantage, which will enable to monitor the percentage of LEDs in degraded performance.

9 RECOMMENDATIONS

The followings are recommendations based on the assessment as part of this project:

- The current approach for the experimentation uses two-levels of variation for the parameters, i.e. changing the parameters or variables from one level to another level. This assumes that the effect in the result due to the change in the variable is linear. However, the testing method needs to be carefully planned to account for more levels of variation to assess the effect of LED vs Incandescent lights at different viewing conditions. Several background conditions and viewing settings need to be simulated to reach a conclusive recommendation on the efficacy of the headlight conversion to LED and addition of beacon lights on locomotive conspicuity.
- The effect of additional variables not included in the trial may have a significant effect on the efficacy of LED headlights on locomotive conspicuity in day-light hours. Future trials should include additional parameters to accommodate variable weather, different background situations and sunlight glare, locomotive livery and lighting colour and patterns.
- The current assessment was limited to assess the visibility of oncoming freight locomotive's frontal view. For certain level crossing designs, such as level crossings with an acute angle, the side view of the locomotive is also important to be considered as a target view. Visibility improvement of the side of freight train has been researched and several solutions have been suggested by various stakeholders. These include livery of the side of the train, lighting fitted on the side of a train flashing when passing level crossings at certain angles, additional strobe lights on the side, and reflectorised systems on the side. The efficacy of these and other suggested solution on visibility improvement needs to be assessed, including the potential health effects of strobe light solutions.
- Only one lighting configuration and lighting colour are included in the current assessment. Studies in the United States show that lighting colour and lighting configuration may influence the locomotive's conspicuity. Further assessment of different lighting options, in terms of lighting configurations and lighting colours, is recommended while the locomotive is moving towards the observer or the locomotive is positioned to have different view settings.
- The visibility model adopted in this assessment is based on luminance contrast. Research is needed to develop a visibility model that considers not only the luminance contrast, but also other effects such as the contrast sensitivity, glare effect and the transient factor.
- The current version of AS 7531 specifies requirements for headlight and visibility lights (ditch lights) from the perspective of illuminating the track for locomotive drivers. However, there is no mention of the headlight requirements for day-light visibility of locomotives from road users' perspective. Hence, further development of the standard is recommended to specify locomotive lighting requirements from the perspective of locomotive conspicuity in day time in addition to its principal function to illuminate the track at night time.
- Further, AS 7531 specifies the requirements for the lighting maintenance to preserve their illumination and alignment properties. However, it doesn't specify

the requirements of the lighting maintenance from the perspective of locomotive conspicuity in day-light hours. Hence, further development of the standard is recommended to specify the requirement for lighting and livery maintenance to include the effects of degraded lighting on locomotive conspicuity.

- The current assessment involved only photometric testing. It would be recommended to include colorimetric testing (colour of the light emitted) in any future trials.
- The efficacy of the lighting pattern and configuration may be studied through a number of lighting arrangements. The influence of the colour of lighting and retroreflective materials on the conspicuity of locomotive in day-light and night time needs to be looked at in future trials. Another important aspect to assess is the effect of locomotive livery in its conspicuity.
- Visibility indicators, similar to the visibility index adopted in the current investigation, valid for locomotive visibility, can be developed, as an alternative to a general visibility model. However, a reference luminance contrast or a threshold luminance value is required as to know whether the measured luminance contrast is related to the visibility of the measured object. Such a threshold value can be developed through psychophysical tests employing variable train operative environments and weather conditions. Hence, it is recommended to include in AS 7531 an acceptable threshold limit for the luminance contrast taking locomotive visibility into consideration.

10 REFERENCES

[1] ACRI, Freight Train Visibility Review - Final Report, SN0243974 v1.0, 31 January 2022, pp.134.

[2] AS-7531:2015, Rolling Stock Standard, “Lighting and Visibility”, RISSB.

[3] AS/NZS 1906.4 Retroreflective materials and devices for road traffic control purposes; Appendix A.

[4] UK RSSB, Railway Group Standard GM/RT2131, “Audibility and Visibility of Trains”, December 2015.

[5] NS EN 15153-1, “Railway applications - External visible and audible warning devices - Part 1: Head, marker and tail lamps for heavy rail”, January 2020.

[6] Code of Federal Regulations (CFR), Title 49, Subtitle B, Chapter II, Part 229, “Railroad Locomotive Safety Standards”, Subpart C, “Safety Requirements”, 229.125 Headlights and auxiliary lights, US.

[7] Code of Federal Regulations (CFR), Title 49, Subtitle B, Chapter II, Part 229, “Railroad Locomotive Safety Standards”, Subpart C, “Safety Requirements”, 229.133 Interim locomotive conspicuity measures - auxiliary external lights, US.

[8] David, A. and Whitehead, L., “LED-based white light”, Comptes Rendus Physique, 19-3, 2018, p 169-181, doi.org/10.1016/j.crhy.2018.02.004.

[9] European Railway Agency, ERA/GUI/07-2011/INT, Guide for the application of TSI LOC&PAS, January 2015.

[10] DOT/FRA/ORD-21/15, “Compliance Testing for Locomotive LED Headlights and Auxiliary Lights, Phase III”, US Federal Railroad Administration (FRA), April 2021.

[11] Volpe, J.A., “Evaluation of Retroreflective Markings to Increase Rail Car Conspicuity”, Safety of Highway-Railroad Grade Crossings, DOT-VNTSC-RRB97-PM-98-22, October 1998.

[12] AS 1428.1:2021, “Design for access and mobility”, Part 1: General requirements for access - New building work, 2021.

[13] Henderson, R., Ziedman, K., Burger, W., and Cavey, K., "Motor Vehicle Conspicuity," SAE Technical Paper 830566, 1983, https://doi.org/10.4271/830566.

[14] Smith, R., Burger, W., Ziedman, K., and Mulholland, M., "Improved Commercial Vehicle Conspicuity and Signalling Systems," SAE Technical Paper 856096, 1985.

[15] FEMA Study FA-323, “Emergency Vehicle Visibility and Conspicuity”, August 2009.

[16] Cole, B.L. and Jenkins, S.E., “The Nature and Measurement of Conspicuity”, Volume 10, Part 4, 1980.

[17] Toet, A., Hogervorst, M. and Bijl, P., “Conspicuity and Identifiability: efficient calibration tools for synthetic imagery”, Targets and Backgrounds X: Characterization and Representation, edited by Wendell R. Watkins, Dieter Clement, William R. Reynolds, Proceedings of SPIE Vol. 5431 (SPIE, Bellingham, WA, 2004) · 0277-786X/04/$15 · doi: 10.1117/12.539118.

[18] Bre´mond, R., Dumont, E., Ledoux, V. & Mayeur, A., Photometric measurements for visibility level computations, Lighting Res. Technol. 2011; 43, pp. 119–128.

[19] Choudhury, A. K. R., Characteristics of light sources, Editor(s): A. K. R. Choudhury, Principles of Colour and Appearance Measurement, Woodhead Publishing, 2014, pp. 1-52, https://doi.org/10.1533/9780857099242.1.

[20] Shelby, B. L., Does Roadway Luminance Correlate with Visibility Metric of CIE 19/2? Transportation Research Record 904, January 1, 1983, pp. 75-80.

[21] Keck ,M. E., Loch, C. H. & Shelby, B. L., Evaluation of Roadway Lighting using the Visual Model of CIE 19–2, Journal of the Illuminating Engineering Society, 12:4, 1983, pp. 251-259, DOI: 10.1080/00994480.1983.10748839.

[22] Hu, J., Guan, Y., Wang, R., Cao, Q., Guo, Y. & Hu, Q., Investigating the Daytime Visibility Requirements of Pavement Marking Considering the Influence of CCT and Illuminance of Natural Light. Int. J. Environ. Res. Public Health 2022, 19, 3051. https://doi.org/10.3390/ijerph19053051.

[23] Shelby, B.L & Howell, B.G, "Further Evaluation of Roadway Lighting using the Visual Model of CIE 19–2", Journal of the Illuminating Engineering Society, 14:1, 1984, pp. 421-447, DOI: 10.1080/00994480.1984.10748910.

[24] Bayliss, C.R. and Hardy, B.J., Chapter 7 - Substation Building Services, Editor(s): Bayliss, C.R. & Hardy, B.J., Transmission and Distribution Electrical Engineering (Fourth Edition), Newnes, 2012, pp. 189-228. https://doi.org/10.1016/B978-0-08-096912-1.00007-1.

[25] Blackwell, H.R., A Comprehensive Quantitative Method for Prediction of Visual Performance Potential as a Function of Reference Luminance. Journal of the Illuminating Engineering Society, Oct. 1982.

[26] SAFER-LC Project, Deliverable D1.3: Needs and requirements for improving level crossing safety, January 2018, pp.67.

[27] Mansurov, N., Introduction to Shutter Speed in Photography. Photography Life, September 16 2022. https://photographylife.com/what-is-shutter-speed-in-photography.

[28] GL Optic, GL Opticam Systems, Catalogue, Luminance Under Control, 2022, 20 pages.

[29] Hiscocks, P.D., Measuring Luminance with a Digital Camera, Syscomp Electronic Design Limited, 16 September 2011.

[30] George. B., et. al, Statistics for Experimenters, Design, Discovery, and Innovation, 2nd edition, John Wiley & Sons Inc, 2005, ISBN: 9780471718130, pp. 672.

[31] House of Representatives Standing Committee on Infrastructure, Transport, Regional Development & Local Government, "Level Crossing Safety, An Update to the 2004 Train Illumination Report", June 2009 Canberra, p.65.

[32] Aurizon, CBH Visibility and Lighting Update, May 2022.

[33] LED Products, Divvali LED Lighting. https://www.divvalilighting.com/led-product-info.php?id=109.

[34] Polllefliet, J., Applications of Power Electronics, Editor(s): Polllefliet, J., Power Electronics, Academic Press, 2018, pp. 15.1-15.44. https://doi.org/10.1016/B978-0-12-814643-9.50015-5.

[35] Wertheim, A. H., Visual conspicuity: A new simple standard, its reliability, validity and applicability. Ergonomics, 53(3), 2010, 421-442.

APPENDIX A.1

Test plan and testing scenarios at Aurizon facility in West Australia

Measurement 1 to 8 incorporates CBH class Locos or similar painted locos with cool white (natural light) head light

	Position (m)	**Angle (deg)**	**Headlight type**	**Beacon light**	**Ditch light**	**Locomotive livery**	**Lighting Colour**	**Cleanliness**	**Ambient light**	**Vegetation**	**Sun direction**	**Weather**
Test no/ parameter	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**X11**	**X12**
1	200	45	HAL	OFF	OFF	CBH or similar colour	Cool white	Unclean	Noon	Dense	Behind	Bright
2	200	45	HAL	ON	ON	CBH or similar colour	Cool white	Unclean	Noon	Light or none	Facing	Rain/Dull
3	200	45	LED	OFF	ON	CBH or similar colour	Cool white	Clean	Morn/evening	Dense	Behind	Rain/Dull
4	200	45	LED	ON	OFF	CBH or similar colour	Cool white	Clean	Morn/evening	Light or none	Facing	Bright
5	75	22.5	HAL	OFF	OFF	CBH or similar colour	Cool white	Clean	Morn/evening	Light or none	Facing	Bright
6	75	22.5	HAL	ON	ON	CBH or similar colour	Cool white	Clean	Morn/evening	Dense	Behind	Rain/Dull
7	75	22.5	LED	OFF	ON	CBH or similar colour	Cool white	Unclean	Noon	Light or none	Facing	Rain/Dull
8	75	22.5	LED	ON	OFF	CBH or similar colour	Cool white	Unclean	Noon	Dense	Behind	Bright

Measurement 9 to 16 incorporates CBH class Locos or similar painted locos with warm white head light

9	75	45	HAL	OFF	ON	CBH or similar colour	Warm white	Unclean	Morn/evening	Dense	Facing	Bright
10	75	45	HAL	ON	OFF	CBH or similar colour	Warm white	Unclean	Morn/evening	Light or none	Behind	Rain/Dull
11	75	45	LED	OFF	OFF	CBH or similar colour	Warm white	Clean	Noon	Dense	Facing	Rain/Dull
12	75	45	LED	ON	ON	CBH or similar colour	Warm white	Clean	Noon	Light or none	Behind	Bright
13	200	22.5	HAL	OFF	ON	CBH or similar colour	Warm white	Clean	Noon	Light or none	Behind	Bright
14	200	22.5	HAL	ON	OFF	CBH or similar colour	Warm white	Clean	Noon	Dense	Facing	Rain/Dull
15	200	22.5	LED	OFF	OFF	CBH or similar colour	Warm white	Unclean	Morn/evening	Light or none	Behind	Rain/Dull
16	200	22.5	LED	ON	ON	CBH or similar colour	Warm white	Unclean	Morn/evening	Dense	Facing	Bright

APPENDIX A.2

Test plan and testing scenarios at Pacific National facility in Victoria

Table A2.1 - Arrangement for Test plan I at Spotswood

	Position (m)	Angle (deg)	Head light	Beacon light	Ditch light	Vehicle livery	Lighting Colour	Cleanliness	Ambient light	Vegetation	Sun direction	Weather
Test no/parameter	**X1**	**X1**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**X11**	**X12**
Measurement 1	200	45	HAL	OFF	OFF	Ghan/Other than PN	Cool white	Unclean	Noon	Dense	Behind	Bright
Measurement 2	200	45	HAL	OFF	ON	PN	Warm white	Clean	Morn/evening	Light or none	Facing	Rain/Dull
Measurement 3	200	45	HAL	ON	OFF	PN	Warm white	Clean	Morn/evening	Dense	Behind	Bright
Measurement 4	200	45	HAL	ON	ON	Ghan/Other than PN	Cool white	Unclean	Noon	Light or none	Facing	Rain/Dull
Measurement 5	200	45	LED	OFF	OFF	PN	Warm white	Unclean	Noon	Light or none	Facing	Bright
Measurement 6	200	45	LED	OFF	ON	Ghan/Other than PN	Cool white	Clean	Morn/evening	Dense	Behind	Rain/Dull
Measurement 7	200	45	LED	ON	OFF	Ghan/Other than PN	Cool white	Clean	Morn/evening	Light or none	Facing	Bright
Measurement 8	200	45	LED	ON	ON	PN	Warm white	Unclean	Noon	Dense	Behind	Rain/Dull
Measurement 9	75	45	HAL	OFF	OFF	PN	Cool white	Clean	Noon	Light or none	Behind	Rain/Dull
Measurement 10	75	45	HAL	OFF	ON	Ghan/Other than PN	Warm white	Unclean	Morn/evening	Dense	Facing	Bright
Measurement 11	75	45	HAL	ON	OFF	Ghan/Other than PN	Warm white	Unclean	Morn/evening	Light or none	Behind	Rain/Dull

Measurement 12	75	45	HAL	ON	ON	PN	Cool white	Clean	Noon	Dense	Facing	Bright
Measurement 13	75	45	LED	OFF	OFF	Ghan/Other than PN	Warm white	Clean	Noon	Dense	Facing	Rain/Dull
Measurement 14	75	45	LED	OFF	ON	PN	Cool white	Unclean	Morn/evening	Light or none	Behind	Bright
Measurement 15	75	45	LED	ON	OFF	PN	Cool white	Unclean	Morn/evening	Dense	Facing	Rain/Dull
Measurement 16	75	45	LED	ON	ON	Ghan/Other than PN	Warm white	Clean	Noon	Light or none	Behind	Bright
Measurement 17	200	22.5	HAL	OFF	OFF	PN	Cool white	Unclean	Morn/evening	Dense	Facing	Rain/Dull
Measurement 18	200	22.5	HAL	OFF	ON	Ghan/Other than PN	Warm white	Clean	Noon	Light or none	Behind	Bright
Measurement 19	200	22.5	HAL	ON	OFF	Ghan/Other than PN	Warm white	Clean	Noon	Dense	Facing	Rain/Dull
Measurement 20	200	22.5	HAL	ON	ON	PN	Cool white	Unclean	Morn/evening	Light or none	Behind	Bright
Measurement 21	200	22.5	LED	OFF	OFF	Ghan/Other than PN	Warm white	Unclean	Morn/evening	Light or none	Behind	Rain/Dull
Measurement 22	200	22.5	LED	OFF	ON	PN	Cool white	Clean	Noon	Dense	Facing	Bright
Measurement 23	200	22.5	LED	ON	OFF	PN	Cool white	Clean	Noon	Light or none	Behind	Rain/Dull
Measurement 24	200	22.5	LED	ON	ON	Ghan/Other than PN	Warm white	Unclean	Morn/evening	Dense	Facing	Bright
Measurement 25	75	22.5	HAL	OFF	OFF	Ghan/Other than PN	Cool white	Clean	Morn/evening	Light or none	Facing	Bright
Measurement 26	75	22.5	HAL	OFF	ON	PN	Warm white	Unclean	Noon	Dense	Behind	Rain/Dull
Measurement 27	75	22.5	HAL	ON	OFF	PN	Warm white	Unclean	Noon	Light or none	Facing	Bright
Measurement 28	75	22.5	HAL	ON	ON	Ghan/Other than PN	Cool white	Clean	Morn/evening	Dense	Behind	Rain/Dull

Measurement 29	75	22.5	LED	OFF	OFF	PN	Warm white	Clean	Morn/evening	Dense	Behind	Bright
Measurement 30	75	22.5	LED	OFF	ON	Ghan/Other than PN	Cool white	Unclean	Noon	Light or none	Facing	Rain/Dull
Measurement 31	75	22.5	LED	ON	OFF	Ghan/Other than PN	Cool white	Unclean	Noon	Dense	Behind	Bright
Measurement 32	75	22.5	LED	ON	ON	PN	Warm white	Clean	Morn/evening	Light or none	Facing	Rain/Dull

Table A2.2 - Test Plan II – LED Head Light Performance Measurement

Test no.	Angle (deg)	Position (m)	Head light LEDs percentage	Beacon lights, Ditch lights and interior lights
1	7.5	15, 75	100%	*OFF*
2	7.5	15, 75	75%	OFF
3	7.5	15, 75	50%	OFF
4	7.5	15, 75	25%	OFF
5	20	15, 75	100%	OFF
6	20	15, 75	75%	OFF
7	20	15, 75	50%	OFF
8	20	15, 75	25%	OFF

APPENDIX B.1

Experimental plan for the Avon test site

Variables	Distance	Angle	Headlight	Beacon light	Ditch Light	Cleanliness	Reading 1	Reading 1	Reading 1	Reading 1
Levels	80/200	22.5/45	LED/SEALED	ON/OFF	ON/OFF	clean/unclean	*C1 = (Lo-Lb)/Lb*	*C2 = (Lo-Lb)/max(Lo,Lb)*	*C3 = (Lo-Lbla)/Lbla*	*Cr1=Lo/Lb*
Units	m	deg								
	Coded Units of Factors									
Coded Units	{-/+}	{-/+}	{-/+}	{-/+}	{-/+}	{-/+}				
Codes/ Runs	**A**	**B**	**C**	**D**	**E**	**F**	**Contrast C1**	**Contrast C2**	**Contrast C3**	**Ratio Cr1**
1	-1	-1	-1	-1	-1	-1				
2	-1	-1	-1	1	1	1				
3	-1	-1	1	-1	1	1				
4	-1	-1	1	1	-1	-1				
5	-1	1	-1	-1	1	-1				
6	-1	1	-1	1	-1	1				
7	-1	1	1	-1	-1	1				
8	-1	1	1	1	1	-1				
9	1	-1	-1	-1	-1	1				
10	1	-1	-1	1	1	-1				
11	1	-1	1	-1	1	-1				
12	1	-1	1	1	-1	1				
13	1	1	-1	-1	1	1				
14	1	1	-1	1	-1	-1				
15	1	1	1	-1	-1	-1				
16	1	1	1	1	1	1				

APPENDIX B.2

Experimental plan for the test site at LC near York

Variables	**View setting**	**Headlight type**	**Beacon light**	**Ditch light**	**Cleanliness**	**Vegetation coverage**	**Weather condition**	**Reading 1**	**Reading 1**	**Reading 1**	**Reading 1**
Levels	Small/ Large	LED/ SEALED	ON/ OFF	ON/ OFF	clean/ unclean	None/ dense	clear/ mist	*C1 = (Lo-Lb)/Lb*	*C2 = (Lo-Lb)/max(Lo,Lb)*	*C3 = (Lo-Lbla)/Lbla*	*Cr=Lo/Lb*
	Coded Units of Factors										
Coded Units	{-/+}	{-/+}	{-/+}	{-/+}	{-/+}	{-/+}					
Codes/ Runs	**AB**	**C**	**D**	**E**	**F**	**G**	**H**	**Contrast C1**	**Contrast C2**	**Contrast C3**	**Ratio Cr1**
1	-1	-1	-1	-1	-1	1	1				
2	-1	-1	-1	-1	1	-1	-1				
3	-1	-1	-1	1	-1	-1	-1				
4	-1	-1	-1	1	1	1	1				
5	-1	-1	1	-1	-1	-1	-1				
6	-1	-1	1	-1	1	1	1				
7	-1	-1	1	1	-1	1	1				
8	-1	-1	1	1	1	-1	-1				
9	-1	1	-1	-1	-1	-1	1				
10	-1	1	-1	-1	1	1	-1				
11	-1	1	-1	1	-1	1	-1				
12	-1	1	-1	1	1	-1	1				
13	-1	1	1	-1	-1	1	-1				
14	-1	1	1	-1	1	-1	1				
15	-1	1	1	1	-1	-1	1				

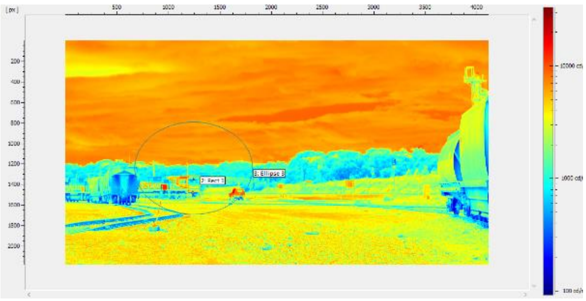
16	-1	1	1	1	1	1	-1				
17	1	-1	-1	-1	-1	1	-1				
18	1	-1	-1	-1	1	-1	1				
19	1	-1	-1	1	-1	-1	1				
20	1	-1	-1	1	1	1	-1				
21	1	-1	1	-1	-1	-1	1				
22	1	-1	1	-1	1	1	-1				
23	1	-1	1	1	-1	1	-1				
24	1	-1	1	1	1	-1	1				
25	1	1	-1	-1	-1	-1	-1				
26	1	1	-1	-1	1	1	1				
27	1	1	-1	1	-1	1	1				
28	1	1	-1	1	1	-1	-1				
29	1	1	1	-1	-1	1	1				
30	1	1	1	-1	1	-1	-1				
31	1	1	1	1	-1	-1	-1				
32	1	1	1	1	1	1	1				

APPENDIX C

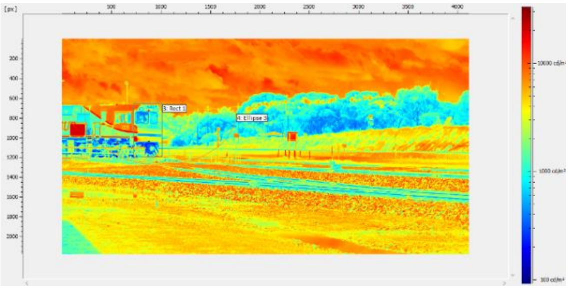
Sample Measurement at Avon Yard, West Australia

On Site Photo and Sample Measurement Result using Luminance Camera – Avon Yard, West Australia

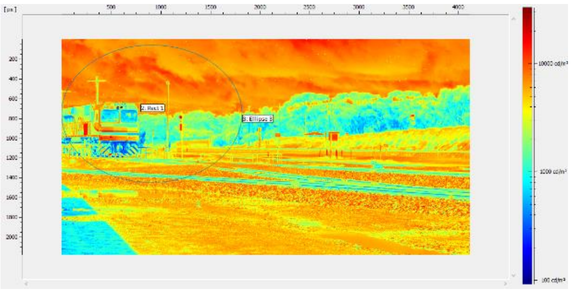
Viewing Angle: 45° - Locomotive livery unclean



Viewing Angle: 45° - Clean locomotive livery



Viewing Angle: 22.5°- Locomotive livery unclean

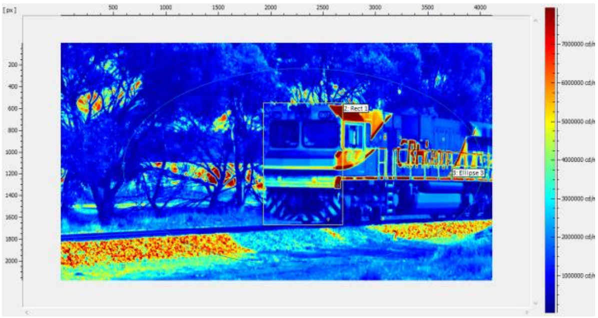


APPENDIX D

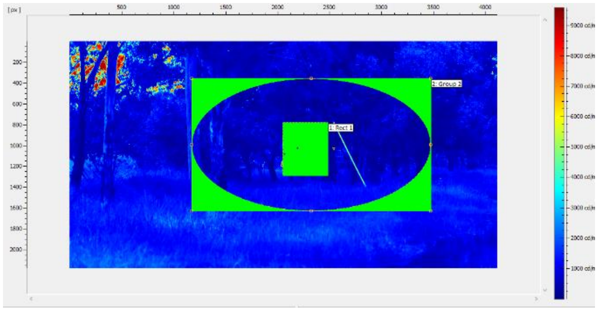
Sample Measurement at Level Crossing, West Australia

On Site Photo and Sample Measurement Result using Luminance Camera – Level Crossing, West Australia

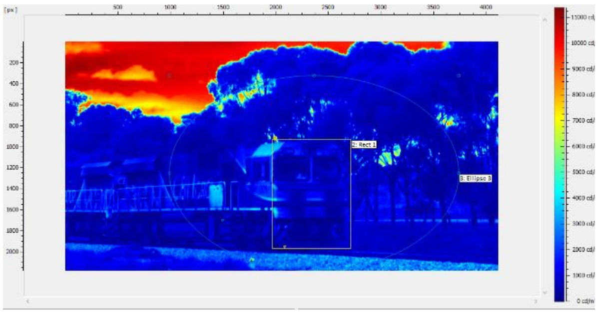
Viewing Angle: 22.5° - Clear View clean livery



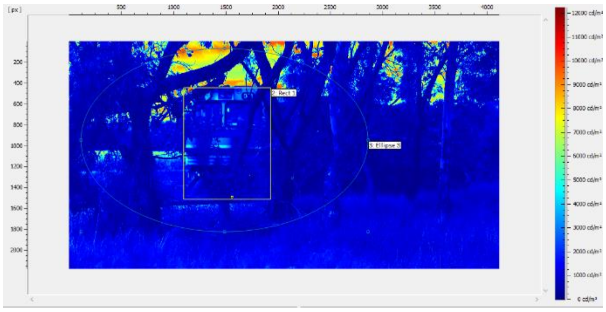
Viewing Angle: 22.5°- with obstruction clean livery



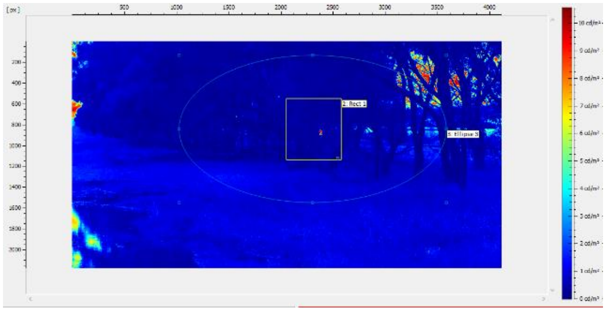
Viewing Angle: 22.5°- Uncleaned Locomotive livery



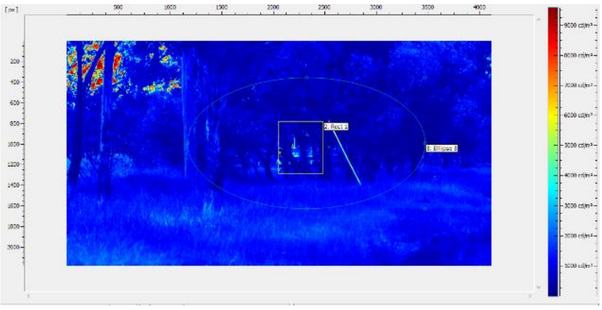
Viewing Angle: 22.5°- Uncleaned livery & with obstruction



Viewing Angle: 7.5°- with obstruction



Viewing Angle: 9.5°- with obstruction



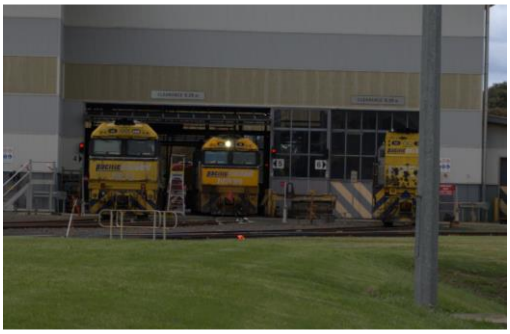
APPENDIX E

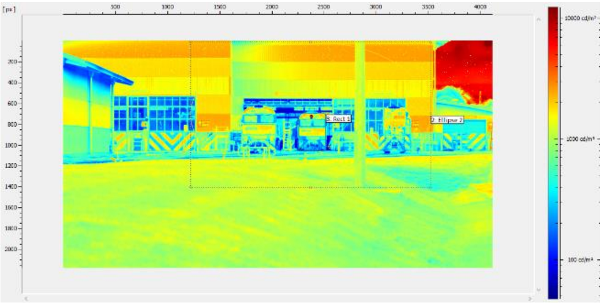
Sample Measurement at Spotswood, Victoria

On Site Photo and Sample Measurement Result using Luminance Camera for Light Performance Simulation – Spotswood, Melbourne

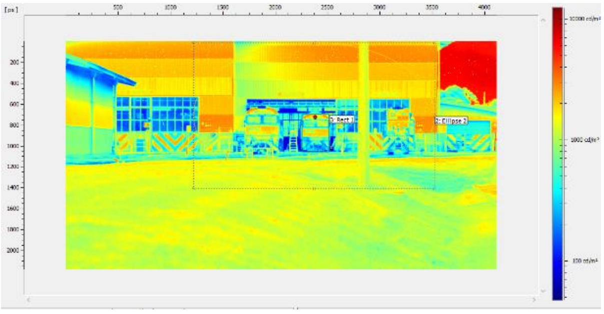
Viewing Angle: 0°, 150 m distance, Headlight 100% Performance

Viewing Angle: 0°, 150 m distance, Headlight 75% degraded performance





Viewing Angle: 0°, 150 m distance, Headlight 50% degraded performance



Viewing Angle: 0°, 150 m distance, Headlight 25% degraded performance