PAPER • OPEN ACCESS

The Relationship between Safety of Night Voyage and Light Pollution at Sea

To cite this article: Rongjun Zhang 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **252** 042057

The Relationship between Safety of Night Voyage and Light Pollution at Sea

Rongjun Zhang

Jiangu Maritime Institute, Nanjing 211170, China

52582699@qq.com

Abstract: In order to study the relationship between the safety of night voyage and the light pollution at sea, based on the theory of system engineering, the safety of night voyage of ships affected by light pollution at sea is analysed from two aspects: the recognisability of ship lights and navigation aids and the visual effect of human body. The following conclusions are drawn: Marine light pollution does exist in China, and its pollution sources include at least glare of urban landscape lighting, evanescent light of fishing lighting at sea, direct light of harbour wharf operation area, and intensive mooring lights of ships in harbour and colour highlight lights of bridges. Based on the analysis of optical principle, the brightness contrast and colour contrast of ship lights and navigation aids are reduced by light pollution at sea, which has an impact on the safety of night voyage. Analysing by using visual ergonomics principle, light pollution at sea weakens the contrast sensitivity, colour vision function and stereo vision function of the driver's visual effect, and affects the safety of ship's night voyage.

Keywords: light pollution at sea; night voyage; safety; statistical analysis.

1. Introduction

Compared with the mature physical pollution such as water pollution, soil pollution and air pollution, the research on light pollution lags behind a lot. The problem of light pollution was first put forward in the 1930s. Because the strong background lights in the night sky have a negative impact on astronomers' observation of the stars, light pollution is gradually paid attention to [1]. On land, light pollution refers to the phenomenon that excessive light radiation has adverse effects on human life and production environment. With the acceleration of the construction process of landscape lighting in port cities and the wide application of light fishing technology, the problem of light pollution has extended to the sea, resulting in light pollution at sea [2]. The effect of excessive light radiation in port cities on the safety of night voyage of ships is becoming more and more obvious. There has been a definition of light pollution on the sea by domestic scholars. The causes of light pollution are further analysed, and the principles of optics and systems engineering are applied to analyse its impact on the safety of night voyage of ships.

2. Methodology

2.1. Definition of light pollution
Light pollution at sea refers to the phenomenon that the evanescent light, reflected light and glare produced by night lighting and fishing lighting in modern cities interfere with or negatively affect human beings and marine organisms [3]. However, it is believed that the marine light pollution should also include other light pollution sources, such as direct lighting in the harbour terminal operation area, intensive mooring lights in the harbour, brightened colour highlight lights of bridges and so on, which have an impact on the safety of night voyage of ships.

2.2. Sources of light pollution at sea
Light pollution at sea mainly occurs at sea or in the waters connected with it and can be used for navigation by ships. The main sources of pollution are night scene lights of coastal cities, fishing boats' lure lights, mooring lights of ships, lighting of wharf operations, bridge lighting and lighting of offshore engineering operations, etc. The objects affected include night voyage safety and marine organism.

3. Results and discussion

3.1. Recognition of ship lights and navigation aids affected by light pollution at sea
In a certain light environment, in order to recognize an object, there must be enough difference or contrast between the colour or brightness of the object and its environment.

The recognition of ship lights is affected by brightness contrast. In order to quantify the difference between the brightness of the target and the brightness of the background, the brightness contrast in optics is defined as [4]:

$$\mathrm{C} = \frac{(L_\mathrm{o} - L_\mathrm{b})}{L_\mathrm{b}}$$

In the above formula, L_o refers to the identified object brightness (cd.m-2); L_b suggests the background brightness (cd.m-2).

When the human eye is just able to recognize the object, the difference in brightness between the object and the background is called the critical brightness difference, which is expressed as ΔL_t, and then the critical contrast C_t is:

$$\mathrm{C}_\mathrm{t} = \frac{\Delta L_\mathrm{t}}{L_\mathrm{b}}$$

The ratio of the brightness contrast C to the critical contrast C_t of the identified object to the background is called the visibility level.

$$\mathrm{VL} = \frac{C}{C_\mathrm{t}} = \frac{\Delta L}{\Delta L_\mathrm{t}}$$

In the above formula, ΔL is the actual brightness difference between the object and the background. The greater the value of VL at the visibility level is, the clearer the markers are [5]. The simplified formula is as follows:

$$\mathrm{VL} = \frac{C}{C_\mathrm{t}} = \frac{\Delta L}{\Delta L_\mathrm{t}} = \frac{(L_\mathrm{o} - L_\mathrm{b})}{\Delta L_\mathrm{t}}$$

Under certain weather conditions, the brightness L_o of other ship's signal lights and navigation aids is fixed in the night voyage. When the background brightness L_b of night navigation environment is close to the brightness L_o of signal lights and navigation aids, then the brightness contrast C between signal lights and navigation aids and background decreases, which leads to the visibility VL of other ship's signal lights and navigation aids decreases. As a result, it is difficult for the driver to recognize other ship's signal lights and navigation aids.

The recognition of ship lights is affected by the colour contrast. According to Grassmann's law [6] of colour mixing in chromaticity, the comparison of various colours in an optical system will produce mixed colours, that is to say, any colour C can be regarded as consisting of three primary colours of red, yellow and blue. The specific components of the three primary colours (red (X), yellow (Y), and blue (Z), i.e. the three stimulus values of the colour light, can also be measured in the colour matching test. At this time, any colour C can be expressed as:

$$C = X(X) + Y(Y) + Z(Z)$$

Formulas for calculating three stimulus values X, Y and Z matching any colour are shown below:

$$\begin{cases} X = \mathrm{k}\int_{380}^{780} \phi(\lambda) \cdot \bar{\mathrm{x}}(\lambda)\, \mathrm{d}\lambda \\ Y = \mathrm{k}\int_{380}^{780} \phi(\lambda) \cdot \bar{\mathrm{y}}(\lambda)\, \mathrm{d}\lambda \\ Z = \mathrm{k}\int_{380}^{780} \phi(\lambda) \cdot \bar{\mathrm{z}}(\lambda)\, \mathrm{d}\lambda \end{cases}$$

In the formula, if $\phi(\lambda)$ is the colour stimulus function, when calculating the colour of the light source, there is $\phi(\lambda) = \mathrm{S}(\lambda)$; $\mathrm{S}(\lambda)$ is the relative spectral power distribution of the light source, and k is the adjustment factor, which is obtained when the Y value is adjusted to 100 [7].

$$\mathrm{k} = \frac{100}{\mathrm{k}\int_{380}^{780} \phi(\lambda) \cdot \bar{\mathrm{y}}(\lambda)\, \mathrm{d}\lambda}$$

In the formula, $\bar{\mathrm{x}}$, $\bar{\mathrm{y}}$ and $\bar{\mathrm{z}}$ are the spectral three stimuli values of the standard chrome observer, which can be found through wavelength interval $\Delta\lambda$ (nm) [8].

There are two kinds of colour light S1 and S2. Their three stimulus values are R1, G2, B1 and R2, G2 and B2 respectively. According to Glassman's law of colour mixing, the three stimulus values of mixed light S are as follows:

$$\begin{cases} R = R_1 + R_2 \\ G = G_1 + G_2 \\ B = B_1 + B_2 \end{cases}$$

As shown in Figure 1 (R, G, and B are ratios, no units), colour matching can also be visually expressed in geometric way. In Figure 1, S1 is the vector of the first colour light, and S is the mixed light vector obtained by mixing S1 and S2. It can be seen from the figure that as long as different kinds (The proportion of three stimulus values are different) of colour lights S1 and S2 are mixed, the colour of the mixed light S is different from that of the original colour light. Moreover, the bigger the difference of colour attributes between colour lights S1 and S2 is, the bigger the angle between mixed light vector S and original colour light vector S1 is, and the bigger the difference between mixed light vector S and original colour light vector S1 in visual observation is.

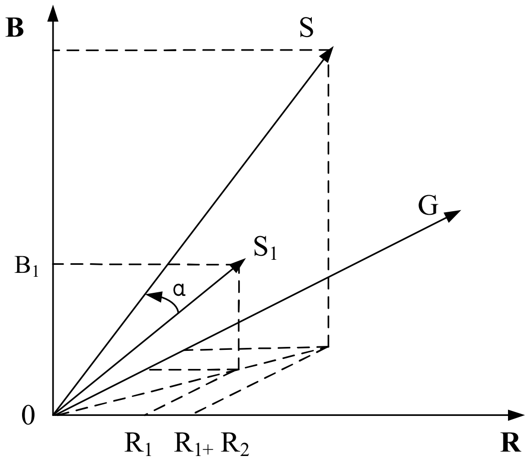

Figure. 1 Colour matching schematic

According to the above analysis, the colour attributes of mast (white) and taillight (white) are similar to those of background light when ships sail at night in high brightness background. When mast and taillight are mixed with background light, the colour of mast and taillight is almost unchanged, and the factors affecting their recognition mainly depend on the brightness contrast. Because of the great difference between the colour attributes of the side lights and the background lights, the red and green ring lights will produce new colour light when they are mixed, which changes the colour attributes of the original lights visually, thus making it difficult for the navigator to judge the encounter situation between ships according to the observed colour of the signal lights. The visual colour attributes of navigation aids will also change, which may lead to accidents caused by the driver's wrong judgment of channel information.

3.2. Human visual efficacy affected by light pollution at sea

According to the investigation and analysis at home and abroad, glare is the main factor causing visual fatigue and reducing visual efficacy in the field of navigation and aviation. The Commission Internationale de l'Eclairage (CIE) classifies operations and activities into five categories according to the degree of brightness control required, as shown in Table 1.

Table 1. Quality level of flare limitation

Quality level	Types of operations or activities
A (very high quality)	Very accurate visual operations
B (high quality)	Operations with high visual requirements and moderate visual requirements require a high degree of concentration.
C (moderate quality)	Operations with moderate visual requirements, moderate concentration requirements, and workers sometimes have to move around.
D (poor quality)	Municipal Bureau requirements and attention level requirements are relatively low, and workers often move around the prescribed areas.
E (rather poor quality)	Workers are not confined to an indoor workstation but to walk anywhere. The operations have low visual requirements or it is not continuously used by the same group of people.

There are different evaluation systems for glare. At present, the United Glare Rating (UGR) is the most unified evaluation system in the world. The model for calculating glare value under given conditions is as follows:

$$\mathrm{UGR}=8\lg\frac{0.25}{L_b}\sum\frac{L^2\Omega}{P^2}$$

In the formula: L_b represents the background brightness, cd/m2; L is the brightness of the luminous part of each luminaire in the direction of the observer's eye, cd/m2; Ω is the stereo angle of the luminous part of each luminaire to the observer's eye, sr; P is the position index of each luminaire, which is related to the position of the luminaire relative to the direction of the observer's eye.

According to this model, the glare value can be calculated accurately. The bigger the UGR value is, the stronger the glare will be, and vice versa, the weaker the glare will be. The system with UGR value of 10 has no glare, and the system with UGR value of more than 19 will have a greater negative impact on human visual efficacy.

First, contrast sensitivity is affected by marine light pollution. Visual contrast sensitivity is a form inspection method, which reflects the recognition ability of the visual system to different spatial frequencies of sinusoidal gratings under bright contrast changes, represents the functional status of the retina, and reflects the visual quality of the human eye to a certain extent. When the human eye is stimulated by high brightness glare, the pupil shrinks, the conformity state becomes worse, and the eye obviously feels uncomfortable. If the brightness reaches or exceeds the maximum brightness that the human eye can bear (about 106 cd/m2), it may damage the retina and make people lose the ability to see.

If the vision is in the glare environment which cannot be perceived in time for a long time, people will often feel slight dizziness, vision decline, and will have serious eye soreness, tears, rapid decline of vision and so on. According to the domestic experimental research, glare has a significant effect on the visual efficacy of naval pilots' twilight vision. The distance of correct target recognition is reduced by 30%, the correct rate is reduced by 20%, and the reaction time is prolonged by 7%.

Generally speaking, the glare stimulation on night voyage driver's is not strong, but the driver's eyes are stimulated by this kind of glare for a long time during navigation and mooring, which will reduce the driver's visual contrast sensitivity. The main manifestations are as follows: When identifying the target distance, the distance judged will be shorter than the actual distance; when observing and judging the signal, ship dynamics, encounter situation and collision danger of the target ship, the correct rate will decrease; when taking action against other ship, the action that is the most helpful action to avoid collision, the sudden encounter situation and changes in navigation environment taken by other ship under emergency danger will make the response time prolonged.

Second, the colour perception function is affected by light pollution at sea. Human three primary colours sensation is determined by the photosensitive pigments of the cone cells. When the cone cells are stimulated by the same amount of tricolour light, they can produce full-frequency white, which makes the cone cells lose their colour-matching function and form a visual environment of "strong light and weak colour". This environment has strong reflection of full-frequency light, but no colour. The eyes are strongly stimulated and the colour vision function is enhanced, thus causing visual fatigue in the eyes.

When a ship navigates through the waters seriously polluted by light, such as shipyards, ship repair factories and water engineering construction sites, the driver's eyes may be directly illuminated by the intense light such as electric welding. The background brightness of the visual environment is strong, which seriously affects the driver's colour perception function. It is mainly embodied as: When a ship encounters a situation, the limitation of the driver's colour perception function caused by the strong light may lead to the misjudgement of his ship's signal lights, which may result in the misjudgement of encounter situation and collision danger. When the navigation aids are used to determine the course and direction, the misjudgement of the navigation aids may occur, which may lead to the operation error. When encountering a small boat, the light level of the small boat is low, and the light of the small boat is easy to be neglected, which leads to the misjudgement of the encounter situation.

4. Conclusion

Light pollution at sea does exist in China. Its pollution sources include at least urban landscape lighting glare, marine fishing lighting escape light, direct lighting in harbour wharf operation area, intensive mooring light of ships in harbour and colour highlight light of bridges. Based on the analysis of optical principle, the brightness contrast and colour contrast of ship lights and navigation aids are reduced by light pollution at sea, which has an impact on the safety of night navigation. In accordance with the principle of visual ergonomics, light pollution at sea weakens the contrast sensitivity, colour vision and stereo vision of the driver's visual efficacy, and has an impact on the safety of night voyage of ships.

Acknowledgements

The authors acknowledge the National Natural Science Foundation of China (Grant: 111578109), the National Natural Science Foundation of China (Grant: 11111121005).

References

[1] Erbe C, Verma A, Mccauley R, et al. The marine soundscape of the Perth Canyon[J]. Progress in Oceanography, 2015, 137: 38-51.
[2] Zhu Y J, College N S. Risks' Analysis on Safety and Pollution Prevention of Sea Trials Ship[J]. Journal of Qingdao Ocean Shipping Mariners College, 2014, 8(2): 31-33.
[3] Liu L, Zhang Y J, Liu J, et al. Application of Infrared Binocular Vision for Monitoring Moving Target in Port[J]. Applied Mechanics & Materials, 2014, 678: 155-161.
[4] Erbe C, Verma A, Mccauley R, et al. The marine soundscape of the Perth Canyon[J]. Progress in Oceanography, 2015, 137: 38-51.
[5] Ružica Popović, Mirsad Kulović, Tatjana Stanivuk. Meteorological safety of ships sailing into the eastern Adriatic ports[J]. Transactions on Maritime Science, 2014, 3(1): 53-60.
[6] Goerlandt F, Montewka J, Kuzmin V, et al. A risk-informed ship collision alert system: Framework and application[J]. Safety Science, 2015, 77(1): 182-204.
[7] Yan-Yun Y U, Lin Y. Optimization of ship inner shell to improve the safety of seagoing transport ship[J]. International Journal of Naval Architecture & Ocean Engineering, 2013, 5(3): 454-467.
[8] Lakhtakia R. Ships passing in the night: opportunities for cancer education[J]. Journal of Cancer Education the Official Journal of the American Association for Cancer Education, 2014, 29(4): 702-3.