C65-11.2.2.7

GUIDELINE

G1073

CONSPICUITY OF AtoN LIGHTS AT NIGHT

Edition 2.0

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DOCUMENT HISTORY

Revisions to this IALA document are to be noted in the table prior to the issue of a revised document.

Date	Details	Approval
June 2011	1st issue	Council 51
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1. INTRODUCTION

In the past, Marine Aid to Navigation (AtoN) lights were designed largely as landfall lights for mariners and intended to be viewed at a distance against a dark background and so were observed at the threshold of vision. Consequently, older IALA documentation tended to concentrate on the luminous range at the threshold of vision, and on the geographical range. Nowadays, most AtoN lights are used as visual confirmation of position at ranges much less than the published nominal range. Furthermore, the background against which an AtoN light is viewed is more likely to be illuminated with artificial lighting.

With the proliferation of built up shorelines and consequent increase in light pollution, the mariner often has difficulty in detecting and identifying AtoN lights against a background scene of general lighting and individual bright light sources. Features such as town or street lighting, harbour area floodlighting, architectural lighting and lit signage may look enchanting but can cause serious problems for a mariner trying to identify an important AtoN light.

This guideline provides an overview of the factors affecting the usefulness of a marine AtoN light and ways to improve its effectiveness by increasing conspicuity.

Conspicuity is a complex subject. Considering the many different types of AtoN signals, and the even higher number of possible backgrounds against which the AtoN signal may be viewed, the number of signal and background possibilities is huge. There are a limited number of conspicuity studies that have examined the impact of changing one signal characteristic while the signal is viewed against a simple background. However, considering the huge number of possible AtoN signal/background combinations, these studies barely scratch the surface. Some of the information in this Guideline is qualitative and/or anecdotal. It documents the current and incomplete understanding of conspicuity factors. Quantitative information is desired but for the most part, does not exist. Conspicuity research that can be used to develop quantitative models is encouraged. The long-term goal is the development of a comprehensive model that can be used to quantify the conspicuity of any AtoN signal against any background.

2. PURPOSE

This guideline describes factors affecting conspicuity and suggested methods of increasing the conspicuity of a marine AtoN light, or lights, when viewed against a background of general lighting or rival lights. At this time, it is not possible to give models, or design parameters, for designing an AtoN to have a sufficient conspicuity under defined conditions. This is because the state of scientific knowledge concerning conspicuity and the human eye is not complete today and the number of variables precludes quick development of models based on experiment. Indeed, there is no recognised scientific measure or scale for conspicuity.

Consequently, this guideline is an overview of the current state of knowledge, with guidance and rules-of-thumb where possible, based on empirical evidence.

3. SCOPE

The scope of this guideline is AtoN lights viewed at night against a background scene of background interfering lighting. It addresses the conspicuity of a marine signal light when viewed against a background of general lighting or rival lights.

The guideline does not consider AtoN lights viewed at threshold of perception; this is covered in IALA Recommendation R0202(E-200-2) [6]. It does not address daytime lights or daymarks. For guidance on daytime lights refer to IALA Recommendation R0202(E-200-2) [6] and for guidance on daymarks refer to IALA Guideline G1094 [26].

The subjects of geographical range and obstructions that may prevent the mariner from seeing an AtoN light, for example high waves, are not dealt with in this guideline and neither are lights moving as a consequence of being placed on a floating platform. The IALA NAVGUIDE [22] and the IALA Guideline No. 1065 on Vertical Divergence [25] give further guidance on such topics.

4. DEFINITION OF THE VISUAL TASK

There are three concepts to consider when judging conspicuity; these are detection, recognition and identification. Typically, an AtoN light may be detected very quickly, after a further period it will be recognised as an AtoN, but not until its rhythmic character has been fully understood will the AtoN be identified.

The visual task of the mariner is to reliably identify an AtoN light. The time taken to undertake this task should be as short as possible. By increasing the conspicuity of an AtoN, the time taken to complete the visual task will be reduced.

The following examples illustrate examples of these concepts:

1. A green lateral mark or buoy light – the green light may be quickly detected against a background of yellow street lighting, the fact that it is flashing green enables it to be recognised as an AtoN, but not until the rhythmic character of the mark has been viewed more than once will the exact AtoN be identified.
2. A bright strobe light exhibited by an AtoN light at the beginning of its rhythmic character – this will make the light conspicuous for detection. In other words, it will draw the observer's eye to where the AtoN character may be viewed and, in time, recognised and identified.
3. A unique lighthouse tower, prominent on the shoreline, floodlit with a magenta light, this colour also being unique in the area – once detected, the observer will very quickly recognise the object in view and identify it as a particular lighthouse.

5. DISCUSSION OF CONSPICUITY FACTORS

5.1. INTRODUCTION TO CONSPICUITY FACTORS

When considering the conspicuity of AtoN lights within the scope of this document, there are a number of factors which need to be taken into consideration. Many of these factors cannot be considered in isolation because changes in one factor may affect the conditions of another factor.

Each of these 'Conspicuity Factors' are shown in Figure 1 and are grouped into types (Observer, Atmosphere, AtoN Light and Background).

The following sections will describe each of these factors, or combination of factors, where they affect one another.

			
The Observer	**The Atmosphere**	**The AtoN Light**	**The Background**
• Adaptation (Eye State) • Knowledge/Experience • Colour • Colour Contrast • Differences between observers • Illuminance (Int/Dist^2) • Illuminance Ratio • Angular Subtense	• Visibility (Atmospheric Scatter) • Distance	• Spectral Properties • Intensity • Rhythmic Character and Flash Profile • Size of Light Source • Shape of Light Source	• General Background (Luminance) • Rival Lights (Intensity) • Spectral Properties

Figure 1 Conspicuity factors

5.2. THE OBSERVER

5.2.1. ADAPTATION (EYE STATE)

It is known that the performance of the eye varies with the ambient light level to which it is exposed. In full daylight the normal observer has full colour vision in direct view (photopic vision) and is not very sensitive to movement (or apparent movement) in peripheral view. After twenty minutes or so in full darkness, the eye adapts to the dark and becomes very sensitive. In this very sensitive state at low light levels, the colour sensing elements of direct vision are not active and objects appear grey. The most sensitive region of the eye in this (scotopic) state is the periphery, about 10 degrees away from direct vision. In scotopic vision, the peak spectral response of the eye shifts towards shorter wavelengths. This 'blue-shift' causes blue-white lights to be more pronounced at night when compared to yellow-white lights. Therefore, changing an AtoN light to a higher colour temperature (lower wavelength) will increase its conspicuity under scotopic or mesopic conditions, even though its luminous intensity remains the same [12].

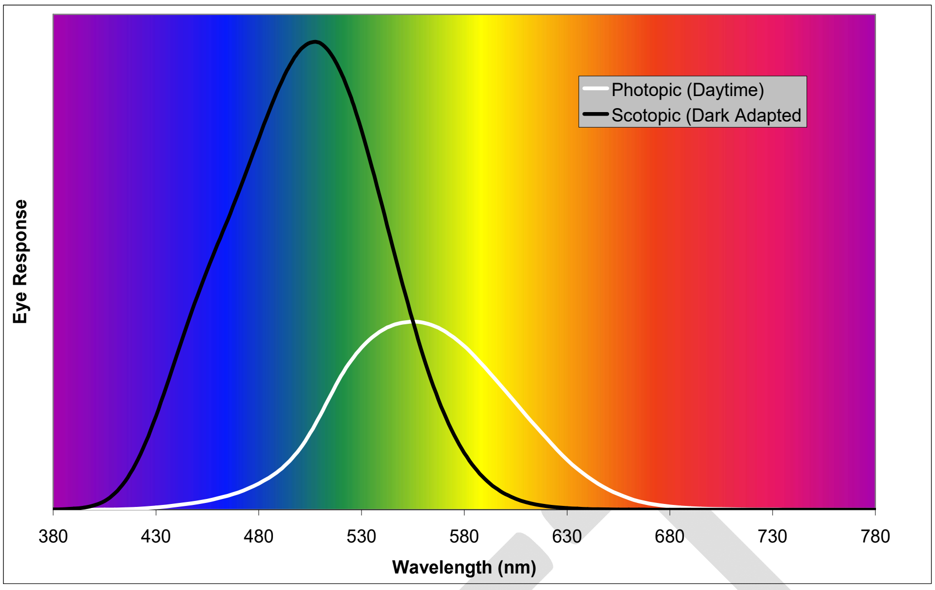

Figure 2 Daytime (Photopic) and Dark Adapted (Scotopic) Eye Response

At low levels of light (e.g. twilight), the eye reaches a state midway between photopic and scotopic that exhibits elements of both states (mesopic). The mariner at night on the low-lit bridge of a ship is most likely in mesopic vision, where there is limited direct colour vision and enhanced sensitivity in peripheral vision. At low levels of incident light, when the observer strains to see an AtoN, the observer's visual response is much slower than at higher levels of light. There is also much more chance of colour confusion, especially for flashing lights, and especially between green, blue and white. A longer flash duration will reduce colour confusion at these low levels of light [12].

5.2.2. KNOWLEDGE/EXPERIENCE

When a mariner has prior knowledge or experience of a particular port entry or navigational channel, he or she will be able to discern the relevant AtoN lights more easily. AtoN that appear conspicuous and obvious to an experienced mariner can often appear indistinct or may be missed altogether by an inexperienced one. This is due to the expected field of view. An experienced mariner will have a narrower field of view where he expects to see the AtoN which therefore takes less effort and time to detect, recognise and identify an AtoN. Whereas an inexperienced mariner will have a much larger initial field of view within which an AtoN will be more difficult to detect, recognise and identify.

5.2.3. COLOUR

Colour perception is a function of the human visual system and not a property of the light. The spectrum emitted by a light source, as seen by the eye, is translated into colour by the tristimulus function of the eye and brain. The standard human colour observer is usually represented by a two-dimensional colour chart such as that developed by CIE in 1931 as shown in Figure 3.

Despite the science of colour measurement and representation, the human colour observer can be easily fooled. Lights that are dim, small in size, flashing or seen against another background colour can be easily mistaken for a light of a different colour. This is less true of red than any other colour. Generally, the purer (less saturated) the light colour, the less chance there is of confusion.

5.2.4. COLOUR CONTRAST

The ability of the human observer to detect slight differences in colour is well known. For surface colour, a slight difference in hue or chroma can be easily detected by the average person. However, when it comes to discerning differences in emitted light, knowledge is less well documented.

At very low levels of illuminance, when an observer can barely detect a light, the colour of the light and the duration of a flash of light are difficult to discern. As illuminance levels at the eye of the observer increase, colour recognition and the duration of a flash become clearer. But the appearance of a point source of light is more difficult to predict than that of an area of light.

When an AtoN light is seen against a background luminance, it is more easily discernible when the colours of background light and AtoN light are different. The greater the difference, as shown on the chromaticity diagram, the easier it is to detect one against the other.

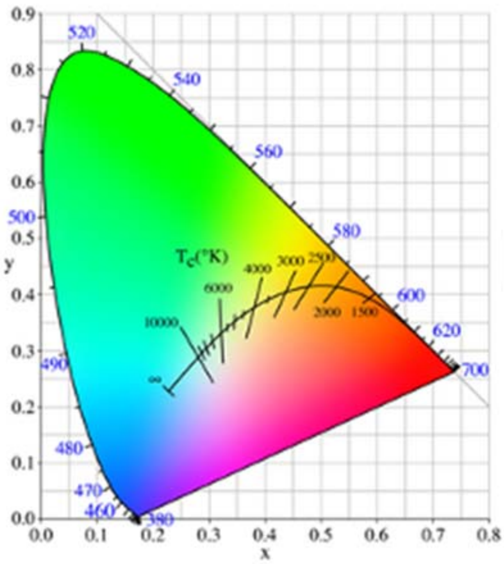

Figure 3 *CIE 1931 Chromaticity Diagram*

5.2.5. DIFFERENCES BETWEEN OBSERVERS

When a signal light colour is chosen to stand out against the background, the increase in conspicuity experienced by normal observers, may not be experienced by colour deficient observers. As an example, for approximately 5% of male observers a red light will appear no different from a yellow light. So choosing a red AtoN light for use against a background of yellow lights will not achieve the desired conspicuity results for this portion of the population. It is important to note that people in command of commercial vessels at sea undergo regular health checks including colour vision tests. However, amateur sailors may go to sea without undergoing any such screening.

For information on colour deficient observers, including lines of colour confusion, see IALA Recommendation R0200-1. Blue-yellow confusion is very rare (1:63000), reinforcing the advantage of blue-white lights against a yellow sodium background.

Age affects the performance of an observer's vision. Older observers have a reduced sensitivity to blue because of degradation of the cornea. Typically, a 50-year-old observer has between 10% and 20% of sensitivity to blue compared with a 20-year-old observer. This clearly has implications on the conspicuity of blue lights. In observers of all age groups, tiredness adversely affects the performance of the visual system.

5.2.6. ILLUMINANCE

The IALA dictionary provides the following definition [17]:

Illuminance (at a point of a surface)

> *The quotient of the luminous flux (dF) incident on an infinitesimal element of the surface containing the point under consideration, by the area (dA) of that element.*

The amount of illuminance an AtoN light casts upon the eye of the observer depends upon its intensity, the distance of AtoN from the observer and the state of the atmosphere. The minimum discernible illuminance at the eye of a photopic observer is often quoted as 0.05 microlux (for a dark-adapted observer in scotopic vision however, it can be as low as 0.0015microlux). At these levels, i.e. at the threshold of visual perception, the chances of seeing a light are little better than 50%. The minimum recommended illuminance level for an AtoN light in darkness is 0.2 microlux, based on international agreement in 1933 [16]. This is the value from which the nominal range figure is calculated. At this level, the colour and rhythmic character of an AtoN can be recognised with confidence.

It should however be noted that with high levels of background lighting, a higher value of illuminance is required in order to see the AtoN light. At these higher levels, the human visual system behaves quite differently than at low illuminance levels. Phenomena such as short flashes (strobes), fast repeating flashes and flicker become more conspicuous as illuminance levels increase.

5.2.7. ILLUMINANCE RATIO

When an AtoN light is brighter than a neighbouring light, it is more conspicuous. The ratio required for an observer to notice a difference in eye illuminance between two light sources is roughly 4:1 [13]. However, when dealing with a point source of light to be just discernible against a background luminance, the relationship is approximately to the power of two [13]. For example, a three-fold increase in background luminance should be matched with a nine-fold increase in AtoN light intensity.

5.2.8. ANGULAR SUBTENSE

The subtense angle of the target is not considered a human factor but a property of the geometry of size and distance. However, the visual acuity of the eye determines the degree of detection and recognition of an object that has a particular subtense angle.

Viewed from far away, most AtoN lights are point sources and therefore have no discernible size. As the observer gets closer to the AtoN light, the size increases so that the size and shape of the light source become noticeable. If the angle subtending the eye, in other words the angle at the eye from one side of the viewed object to the other side, is less than one minute of arc, it can be said to be a point source.

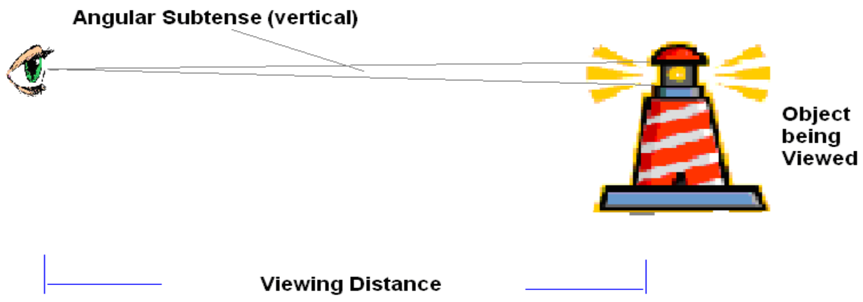

Figure 4 Diagram explaining Angular Subtense

As a rule of thumb, the angular subtense required to recognise a simple shape is three minutes of arc. In order to recognise complex shapes, such as letters, ten minutes of arc is the minimum angular subtense required. These minimum subtense angles may vary with luminance contrast and colour contrast between the AtoN light and the background. Illuminated signs and objects may also cause glare when the illuminance at the eye of the observer is high. This may cause the shape of the lit area to become indistinct [24].

5.3. THE ATMOSPHERE

5.3.1. VISIBILITY

Visibility is generally considered as meteorological visibility, which is defined as:

the greatest distance at which a black object of suitable dimensions can be seen and recognised by day against the horizon sky [17].

For night-time viewing:

The greatest distance at which a black object of suitable dimensions could be seen and recognised if the general illumination were raised to daylight level [17].

The state of the atmosphere will determine the greatest distance at which a light of given intensity can be seen at night. This distance is known as the 'luminous range' of the light. The method by which luminous range is determined is Allard's law, which takes into account the intensity of the light, the distance of the observer from that light and the visibility.

Another way of defining the state of the atmosphere is by its 'transmissivity', which can be thought of as the throughput of light for one nautical mile of atmosphere. Transmissivity is usually given as a factor, e.g. 0.74, which means that light exiting one nautical mile of atmosphere will be 74% of the light input after the inverse square law has been applied [6]. Both meteorological visibility and transmissivity assume that the atmosphere is spectrally neutral. In other words, all wavelengths of visible light are affected equally. Unfortunately, the impact of the atmosphere is somewhat more complicated than this and will often affect wavelengths within the visible spectrum unequally.

The two phenomena traditionally used to describe the way the atmosphere scatters light are Rayleigh scatter and Mie scatter. These are traditionally used to describe how sunlight is affected. A model that more completely describes how light at sea level is affected is that of Ångström. This model includes the effects of Rayleigh and Mie scattering as well as the effect of aerosol particulates such as salt.

Generally, Rayleigh scattering occurs when visibility is moderate to good where light is scattered preferentially by wavelength to the fourth power of the wavelength. Therefore, a blue light will be scattered more, and will have less luminous range, than a red light of the same intensity. Mie scattering occurs during conditions of poor visibility when water droplets within the atmosphere are larger. Mie scattering is spectrally neutral. The Ångström model combines both Mie and Rayleigh and includes other factors for aerosols present in the atmosphere close to the sea.

The chart below shows how required intensity for a given luminous range can vary with wavelength. It is valid for a photopic (daytime) observer. This chart can be considered during the design stage of implementing an AtoN light, however, luminous range calculations should be carried out using IALA Recommendation R0202(E-200-2) [6].

Input Min Contrast, Visibility, Observer Distance and Photopic/Scotopic Dominant Wavelength DSPW											
Min Contrast	0.0000002	lux	Transmisivity (T)	0.74		Distance (D)	10	M	DSPW (P)	555	nm
Sea Mile Candela	0.69	lux/M^2	Visibility (V)	10	M	Intensity (I)	1372	cd			

Luminous Range (M)	Wavelength (nm), corresponding Transmissivity and Illuminance at Observer (lux)													
	460	470	500	510	520	530	540	550	590	620	630	640	650	660
	0.62	0.63	0.67	0.69	0.70	0.71	0.73	0.74	0.79	0.84	0.85	0.86	0.88	0.89
	2.0E-07	2.0E-07	2.0E-07	2.0E-07	2.0E-07	2.0E-07	2.0E-07	2.0E-07	2.0E-07	2.0E-07	2.0E-07	2.0E-07	2.0E-07	2.0E-07
	Required Intensity (cd)													
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	6	6	5	5	5	5	5	5	5	5	5	5	4	4
3	19	19	17	17	16	16	16	15	14	13	13	13	13	13
4	51	**49**	43	42	40	39	38	**37**	33	31	30	30	29	29
5	116	110	95	91	88	84	81	78	68	63	61	60	58	57
6	245	230	193	184	175	167	159	152	130	117	113	110	107	104
7	489	454	371	349	329	312	295	281	233	207	199	192	185	179
8	935	860	683	637	596	559	526	496	402	350	335	322	309	297
9	1735	1578	1219	1127	1045	973	908	850	670	574	547	522	499	478
10	3140	2826	**2120**	1943	1788	1651	1529	**1421**	1091	918	870	827	787	750
11	5570	4960	3616	3285	2997	2745	2524	2329	1741	1440	1358	1283	1215	1152
12	9716	8561	6064	5462	4942	4491	4098	3753	2733	2221	2083	1958	1845	1742
13	16714	14573	10030	8955	8035	7244	6559	5964	4229	3379	3152	2948	2764	2597
14	28412	24513	16393	14509	12911	11547	10377	9366	6469	5079	4713	4385	4091	3825
15	47808	40815	26522	23270	20535	18220	16248	14559	9793	7557	6975	6457	5993	5578

Figure 5 Required Intensity Wavelength Dependent, according to Ångström, for Photopic Vision

For an observer in scotopic vision, which has a different spectral response to photopic, these required intensity values will change, as seen below in Figure 6.

Input Min Contrast, Visibility, Observer Distance and Photopic/Scotopic Dominant Wavelength DSPW								
Min Contrast	0.0000002 lux	Transmisivity (T)	0.74	Distance (D)	10 M	DSPW (P)	505 nm
Sea Mile Candela	0.69 lux/M^2	Visibility (V)	10 M	Intensity (I)	1372 cd		

Luminous Range (M)	Wavelength (nm), corresponding Transmissivity and Illuminance at Observer (lux)													
	460	470	500	510	520	530	540	550	590	620	630	640	650	660
	0.62	0.63	0.67	0.69	0.70	0.71	0.73	0.74	0.79	0.84	0.85	0.86	0.88	0.89
	1.6E-07	1.6E-07	1.7E-07	1.7E-07	1.7E-07	1.7E-07	1.7E-07	1.7E-07	1.7E-07	1.7E-07	1.8E-07	1.8E-07	1.8E-07	1.8E-07
	Required Intensity (cd)													
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	5	5	5	5	5	5	5	5	4	4	4	4	4	4
3	17	17	15	15	15	14	14	14	13	12	12	12	12	12
4	42	**41**	37	36	35	34	33	**32**	29	27	27	26	26	26
5	93	89	78	75	73	70	68	66	58	54	53	52	50	49
6	188	178	153	146	139	134	128	123	107	98	95	93	90	88
7	359	336	281	266	253	241	230	220	186	168	162	157	152	148
8	657	610	498	468	441	417	395	375	311	275	265	256	247	238
9	1166	1072	853	796	745	699	658	620	503	438	420	403	387	373
10	2019	1839	**1427**	1321	1227	1143	1069	**1002**	793	680	649	620	593	569
11	3426	3092	2338	2148	1981	1833	1702	1585	1225	1036	983	935	891	850
12	5719	5113	3769	3436	3145	2890	2665	2466	1862	1550	1465	1387	1316	1250
13	9413	8338	5992	5420	4925	4493	4116	3783	2792	2289	2152	2029	1916	1813
14	15310	13436	9413	8449	7621	6904	6281	5737	4135	3339	3125	2932	2757	2598
15	24648	21431	14637	13038	11673	10501	9489	8611	6063	4821	4492	4195	3928	3686

Figure 6 Required Intensity Wavelength Dependent, according to Ångström, for Scotopic Vision

As blue light passes though the atmosphere it tends to be selectively scattered and, as a result, blue signal lights consisting of a filament lamp and filter may appear purple or red when viewed at a distance. So choosing a blue light, because blue is more conspicuous against a given background, may not be satisfactory if the blue light is intended to be viewed at a distance.

5.3.2. DISTANCE

The single most important factor that affects a mariner's ability to detect an AtoN light signal against a background of general lighting and individual light sources is the observer's distance from the AtoN light signal. However, when analysing conspicuity it is not distance, per se, that is analysed but rather the impact of distance on other factors that in turn influence conspicuity. Because distance ultimately affects conspicuity via so many other conspicuity factors, one must first look at the impact of distance on those other conspicuity factors and then consider the impact of these factors on the observer's ability to detect an AtoN signal. Consider the following examples:

1 Increasing the distance from an AtoN light signal decreases the signal's illuminance upon the eye of the observer. The illuminance is used to analyse conspicuity.

2 Increasing the distance from an AtoN signal increases the length of atmosphere that the light passes through before being viewed by the observer. Because different wavelengths experience different atmospheric absorption and scattering, the distance affects the spectral distribution of the signal received by the observer. The spectral distribution of the received signal is used to analyse conspicuity.

3 Increasing the distance from an AtoN signal decreases the signal's angular subtense. This, in turn, affects the observer's ability to distinguish the shape of an extended light source or a floodlit object. The target's angular subtense and shape are used to analyse conspicuity.

4 Decreasing the distance from an AtoN signal increases the illuminance contrast between the AtoN signal and the background lighting. The illuminance contrast is used to analyse conspicuity.

In each of these examples, the identified factor – rather than distance – is used to analyse conspicuity. Observation distance influences far too many factors to allow a direct link from distance to conspicuity.

5.4. THE AtoN LIGHT

5.4.1. SPECTRAL PROPERTIES

The spectral properties of a light source are translated by the human visual system to colour; however, it is normal to associate a light source with a given colour and, for simplicity, this shall be the convention in this section.

AtoN lights are often restricted by their navigational requirements. For example, a starboard hand buoy in Region B must exhibit a green light and this may limit the ability to enhance conspicuity by changing spectral distribution or colour. However, improving the purity of the colour, for example, by using a light source with a narrow spectral distribution, will often improve conspicuity.

For white lights, changing the colour temperature of an AtoN light will often improve the conspicuity against a background of different colour temperature white lights. An example is when a high colour temperature (blue-white) AtoN light, such as an LED buoy light, is viewed against a background of low colour temperature (yellow-white) sodium street lighting (see 6.2.4 Colour Contrast).

To make a light conspicuous at short range, rapidly changing colours have proved to be effective. An example of this application is the emergency wreck-marking buoy (EWMB), which has an alternating blue and yellow light.

5.4.2. INTENSITY

The intensity of an AtoN light determines its nominal range and its luminous range for a given visibility, as described in IALA Recommendation R0202(E-200-2) [6]. However, to make a light more conspicuous by increasing the intensity, that increase usually needs to be substantial, typically tenfold. This is because the intensity required of a light to be perceived against a background luminance is proportional to the square of the background luminance (from Langmuir & Westendorp 1931 [13]). Guidance is given in IALA Recommendation R0202(E-200-2) [6] for required intensities at different levels of background lighting.

When considering a flashing light, effective intensity is the relevant parameter to use at threshold illuminance levels. However, when considering short flashes at higher levels of illuminance, and this is usually the case when viewed against background luminance, the value of effective intensity is not proportionate to conspicuity. It has been found that the eye responds quicker to flashes with a higher level of illuminance of the eye, and more details can be found in IALA Recommendation R0204(E-200-4).

Excess intensity may make a signal light conspicuous but it can lead to glare at short ranges. Glare can restrict the ability of the mariner to see other salient features or signals. The whole zone of utilisation of the AtoN should be considered when deciding the intensity of a given signal light.

5.4.3. RHYTHMIC CHARACTER AND FLASH PROFILE

The rhythmic character of an AtoN light is what distinguishes it from its surroundings and identifies it from other AtoN lights. Generally, the rhythmic character of signal lights, such as Cardinal Marks, cannot be altered for operational reasons. At high levels of illuminance, quickly repeated short flashes are generally more conspicuous than longer flashes with longer eclipse times between them. Care should be taken to ensure that the character is still suitable in conditions of poor visibility, when illuminance levels at the eye of the observer may be low and the visual response slows down as a result (see section 5.2.1 Adaptation).

The shape of the flash, or flash profile, is also important to conspicuity. A rectangular flash shape, i.e. one with a fast rise and fall time, is more conspicuous at high illuminance levels than, say, a Gaussian flash shape (such as observed from a rotating lens system) [12].

5.4.4. SHAPE OF LIGHT SOURCE

The shape of a light source is irrelevant when it is viewed as a point source. However, if it is intended to be viewed as a lit area or extended light source, a given shape can be instantly recognisable to an observer. A lit shape can provide a very conspicuous marker, used either as a pointer to an AtoN or as an AtoN in its own right.

Such things as extended light sources or floodlit areas are generally designed to given shape information [10] [20] [21]. Therefore, the extremities of such lights need to correspond to an angular subtense of 3 minutes of arc or greater to be useful as AtoN (see section 5.2.8). The physical size of such a light source would therefore determine its useful range.

5.4.5. Size of Light Source

The size of an AtoN light will determine its horizontal/vertical subtense for an observer at a given distance. For an extended light source, it is important to make the size large enough so that it may be recognised at the maximum operational distance. Furthermore, if the light source is to be viewed obliquely within its arc of utilisation, the width of the light source should be wide enough to account for the oblique view (see Figure 8). The cosine of the angle of view may be used to calculate the required increase in depth/height.

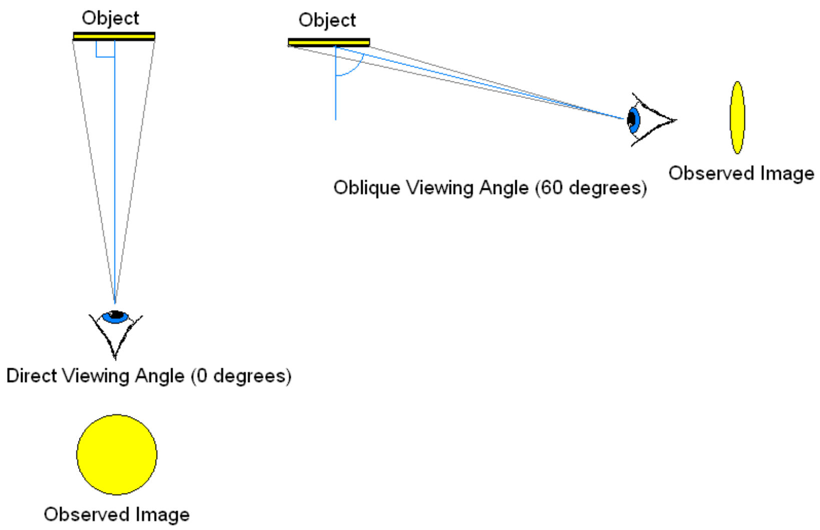

Figure 7 Viewing an object from different angles

Because it is not viewed as a point source, the luminance of the extended light source, rather than its intensity, is relevant to the observer. Therefore, as a rule of thumb, the luminance of the extended source should be at least four times greater than the background luminance for the eye to detect a difference.

In a paper presented to the 12th IALA Conference in Holland in 1990, Marc Mandler of the U.S. Coast Guard gave details of experiments carried out on extended light sources [21]. However, one important feature of the USCG experiment was the introduction of a conspicuity index based on the reciprocal of the time taken for observers to recognise a light signal. Such a metric is considered a valid way of modelling conspicuity and could form the basis of a conspicuity model.

Among the conclusions of the experiment was that:

- Conspicuity increased with size of extended sources;
- Conspicuity decreased with higher luminance of background lighting;
- Higher luminance backgrounds caused less reduction in conspicuity of large signals than small signals;
- Flashing enhanced conspicuity of small targets more than large targets.

In the paper, methods are provided for aiding design engineers in the sizing and selection of extended sources.

The size of a light source has an effect on its performance at distance when scintillation[1] occurs. When observing the difference between a large light source and a small light source of similar intensity at a distance, the difference in scintillation is quite marked. On a clear night, when distant lights scintillate (twinkle or flicker), a large light source, for instance a large lens panel, scintillates much less than a small one. Trying to find a flashing light among twinkling lights can be difficult. A large light source, even when it is flashing, scintillates less and therefore stands out from its surroundings as a result.

1 Scintillation is caused by a temperature difference between the air and the sea. Its effect is experienced as a random flickering of a distant light.

5.5. THE BACKGROUND

5.5.1. GENERAL BACKGROUND (LUMINANCE)

A general area or large patch of light of roughly uniform brightness, directly behind an AtoN light, can impair the mariner's view of an AtoN light of interest. The luminance of the background lighting can be measured in candelas per square metre.

When a large mass of shore lighting forms a backdrop to an AtoN light and the individual light sources within the background are indistinguishable, it may be taken as a homogenous background luminance.


Figure 8 Background luminance due to town lighting

To the observer, shore lights tend to merge at a distance, for instance, when the mariner is some way offshore. Therefore, the AtoN lights most affected by background luminance are usually long-range lights.

When closer to shore, background lighting may usually be considered as a patch of individual point sources with a given density. This is a much more complex picture than a patch of uniform luminance and the density of the point sources will vary with the number background lights in view, their proximity to each other and the observer's distance from them.

5.5.2. RIVAL LIGHTS (INTENSITY)

Rival lights can be considered as individual point sources of unwanted light that mask or obscure an AtoN light and prevent easy detection or recognition of the AtoN. Sometimes a slight change in position of the mariner within a channel, or the height of observation can make the difference between seeing an AtoN or not.


Figure 9 Rival lights caused by individual point sources

Background scenes are often comprised of a mixture of general background lighting and rival lights. Calculations of background and rival lights are detailed in the guideline produced from Recommendation R0202(E-200-2).

Another example of rival lights is when there are too many AtoN lights in an area, thereby causing confusion. An example is when a large number of fish farms, each with its own flashing light, surround a buoy with its own flashing light. The buoy is therefore difficult to detect or recognise amongst many more flashing lights, even though the rhythmic characters in view are different.

5.5.2.1. Avoidance of background illumination and rival lights

Where possible, lighting around existing AtoN should be controlled such that any new lighting does not significantly affect the operation of the AtoN light. This may be carried out by legislation or by existing planning arrangements.

It may also be possible to relocate, shade, or redirect rival lights [15]. This usually needs the consent of the owner or user of the rival lights in question but, quite often, a small adjustment in the position, direction or luminaire of a rival light can result in a major difference in conspicuity of the AtoN being interfered with.

If no other course of action is available, it may be possible to move the AtoN away from rival lights, or for a new installation to locate the AtoN away from a rival light or lights (discussed in IALA Guideline No. 1051 [11]), so that they are not in the same direction of view. A small vertical shift can often separate the AtoN light from the background or rival light from the observer's viewpoint. However, any relocation should not affect the primary navigational significance of the AtoN. Conflict between rival lights and AtoN can often occur in specific locations within the AtoN's zone of utilisation. The performance of the whole zone of an AtoN light should be considered over a range of observation heights.

5.5.3. SPECTRAL PROPERTIES OF BACKGROUND LIGHTING

Since most background luminance is white or near-white, the AtoN most susceptible to masking or interference are white AtoN lights. However, low-pressure sodium lights are yellow and could easily mask a yellow 'special mark' AtoN light.

The colour of general background lighting is a mixture of all the lights in view but usually takes on the colour of the dominant light source. For instance, if the background scene is comprised mainly of high pressure sodium, the overall colour seen from a distance will be yellow-white with a hint of orange. If the background is a busy floodlit container port however, the background lighting could be predominantly metal-halide lamps giving a blue-white hue.

A rival light, on the other hand, could consist of an individual light source of any colour. It may be a single street lamp, road traffic signal or navigation lights on-board other vessels.

6. A SUMMARY OF METHODS FOR IMPROVING THE CONSPICUITY OF AtoN LIGHTS

6.1. INTRODUCTION

The conspicuity of an AtoN light is usually only improved after complaints from the mariner and it is done on a case by case basis. The usual scenario is that a mariner complains that he or she has difficulty in detecting or identifying a particular light. The AtoN provider then needs to investigate the complaint and this is done by communicating with the person lodging the complaint and asking where the problem occurred, whether it frequently occurs, if so at what position. The AtoN provider should also ascertain what the exact nature of the problem is and whether local conditions (e.g. weather, height of observer or background) affect the conspicuity.

If the complaint is deemed justified, the provider would usually prompt an inspection or review of the AtoN light concerned to ensure that it was performing satisfactorily or whether there was a fault with the AtoN light apparatus. During the inspection, causes other than the performance of the AtoN can be investigated but it is often difficult to pinpoint a problem when positioned at the AtoN itself. Following an inspection of the AtoN, if the problem is still unresolved, the provider should carry out a viewing trial of the AtoN light in question from the area where the difficulty occurred. If possible, it is a good idea to invite the person that prompted the complaint along to the viewing trial.

Once the exact nature of the conspicuity problem has been identified, the AtoN provider may look at the list of options given in this and other relevant IALA documents in order to improve conspicuity. This should be done whilst taking the navigational and operational requirements into account.

Many conspicuity problems arise, not from new AtoN installations, but from shoreline development. A new housing estate, retail park or industrial complex usually brings with it a plethora of lighting that can interfere with an existing AtoN. Quite often, liaison with the planners, builders, owners or occupiers of such sites can be fruitful before, during and after development. A slight change in the direction, position or luminaire design of a few lights can make a significant difference in the performance of an AtoN light from the viewpoint of the mariner.

Further information on improving AtoN light conspicuity can also be found in IALA Guideline No. 1051 on the Provision of Aids to Navigation in Built-up Areas, which, for example, was used to solve problems of conspicuity at Kinnaird Head in Scotland [18]. The heart of the problem lay with a new shopping development and associated car park lights, which were placed on high poles in line with the existing AtoN light. After discussions with the local authority, the poles were reduced in height and the conspicuity of the AtoN light restored.

6.2. DESIGNING AN AtoN LIGHT USING STANDARD METHODS

When designing AtoN lights, the starting point is usually the navigational requirement, which can be viewed as the requirements of the user. This will specify such parameters as colour, nominal range, rhythmic character etc., and these are usually relatively inflexible.

There may well be additional concerns at some locations about factors such as prevailing visibility or background lighting. These are addressed in guidelines which support IALA Recommendation R0200-2 [6] using standard models such as Allard's Law and a three-step background light model: no background light; minor background light; and substantial background light. IALA Recommendation R0200-2 [6] may be used therefore to define the operational or system requirements.

6.3. METHODS FOR IMPROVING THE CONSPICUITY OF AtoN LIGHTS

If it is not possible to avoid rival lights or background illumination, the following methods to improve conspicuity may be utilised.

6.3.1. INCREASING THE INTENSITY TO IMPROVE CONSPICUITY

The traditional method of dealing with poor conspicuity of an AtoN light is to increase its intensity. Information on such methods, including the need to consider the effective intensity of a flash of light, can be found in IALA E-200 Series of Recommendations [3]. However, IALA Recommendation R0204(E-200-4) [8] also recognises the inappropriateness of the effective intensity concept when dealing with flashes above threshold of perception (e.g. when viewed against background lighting).

The nominal range of the light may be increased significantly by such actions but the useful range improvement may be much less. The relationship between intensity and range can be found in IALA Recommendation E-200-2 [6].

6.3.1.1. For general background luminance

Typically, intensity needs to be increased by orders of magnitude to achieve any improvement in conspicuity against background lighting. IALA Recommendation R0200-2 recommends tenfold increase in AtoN light intensity for minor background lighting and a hundredfold increase if the background lighting is significant.

6.3.1.2. For rival lights

Allard's Law may be used to calculate the illuminance at the eye of the observer for any given light over a given distance and for a given atmospheric transmissivity. When comparing AtoN lights to rival lights of the same colour, the minimum illuminance ratio required for an observer to see the AtoN light against a rival light is approximately 4:1.

6.3.2. CHANGING COLOURS TO IMPROVE COLOUR CONTRAST

If possible, the colour of the AtoN light should be made different to the colour of the background lighting. For example, changing an incandescent filament lamp to a high colour temperature discharge lamp would improve the contrast between the AtoN and a background of sodium street lighting.

Colour change is often limited with AtoN lights because navigational requirements dictate the colour of the AtoN light but most background and rival lights are white. The usual problem is therefore trying to see a white light against a white background. Since many street lights are sodium, they tend to be yellowy-white. The change of AtoN light source from incandescent filament lamp to a light source of high colour-temperature (e.g. metal halide or white LED) often provides a significant colour contrast to the background whilst still maintaining the correct AtoN colour.

There are two exceptions to this:

- when the background is for example a marshalling yard or football stadium where high colour temperature floodlights are used;
- when the AtoN light is yellow (for example, a special mark) and the background is low-pressure sodium light.

6.3.3. RAPIDLY ALTERNATING COLOURS

To make a light conspicuous at short range, rapidly alternating colours have proved to be effective. An example of this application is the emergency wreck-marking buoy (EWMB), which has an alternating blue and yellow light.

6.3.4. LIGHT SOURCE SHAPE

For short-range navigation, illuminated areas, illuminated contours and extended light sources can be used to provide an identifiable shape. The shape may be used as a standalone AtoN, or used to point towards an AtoN [10].

Light source shapes are recognised more quickly and effectively than a flashing point source. Japan Coast Guard has done some work on illuminated numbers on buoys. This has the advantage, not only of fast recognition but also enables the mariner to gauge his/her distance from the buoy more effectively. This has reportedly reduced the number of collisions with buoys.

Arrangements of point light sources can be used in a similar way. The use of sequenced lights within an arrangement or shape is particularly effective as it can provide apparent movement and/or give direction.

Figure 10 Pictures of the arc-pointer device installed in the Port of Barcelona

6.3.5. FLASH PROFILE AND RHYTHMIC CHARACTER

At high levels of observer illuminance, quickly repeated short flashes are generally more conspicuous than longer flashes with longer eclipse times between them.

A rectangular flash shape, i.e. one with a fast rise and fall time, is generally more conspicuous than a flash shape with a slow rise and fall time (e.g. Gaussian) [12].

At relatively short ranges, where background lighting and rival light interference are high, flickering the AtoN light within the flash profile at a frequency of around 10 Hz is effective [1]. This flickering technique yields better results for red and white AtoN lights than for green.

It is possible to improve conspicuity by utilising a low-level fixed light during the eclipse period of a character. This is especially true for a flashing light where no loom or 'lantern spill' light can be seen during the eclipse. This is referred to as a Fixed Flashing Light and further details are provided in IALA Recommendation E-1116 on 'Selection of rhythmic characters and synchronisation of lights for Aids to Navigation' [28]

6.3.5.1. Choosing a suitable flash profile

The following points may be of assistance in improving the conspicuity of a flashing light.

- Simple flash characteristics (e.g. a group flash four, Fl(4), light on an AtoN is more conspicuous against a background of fixed rival lights than an AtoN with a fixed light characteristic).
- A flash profile with a sharp rise time (and fall-time) is generally more conspicuous than one with a slow rise-time.
- It is possible to improve conspicuity by utilising a low-level fixed light during the eclipse period of a character. This technique enables the user to confirm the position of the AtoN by providing a visible fixed point of reference. See IALA Recommendation E-110 [27]and IALA Guideline 1116 for more information.

Some work has been done on how the repetition rate of a flashing light affects its conspicuity but this is almost certainly dependent on the illuminance at the eye of the observer.

6.3.5.2. Flickering

The use of a flickering light may increase conspicuity for an AtoN against a high level of background lighting but only at high levels of observer illuminance (typically close range). At low levels of observer illuminance, the advantage of the flicker effect is lost and some observers fail to notice any flicker at all.

Flicker at certain frequencies and duty cycles provides a conspicuity gain for white and red signal lights but the gain for green is less noticeable at lower duty cycles. There is uncertainty on improvement of conspicuity by implementing flickering light on yellow and blue lights.

Flickering the AtoN light within the flash profile at a frequency of around 10 Hz, is a technique that has had some success in Japan [1]. Japan Coast Guard experiments [19] with flickering light showed that red, green and white flickering light enhanced conspicuity and the lower the duty ratio within the flicker frequency, the higher the conspicuity becomes. However, as already noted, the degree of the conspicuity varies with colour. The following figure shows the comparison of red, green and white flickering light when flicker frequency is fixed at 10Hz. The graph compares the duty cycle of the coloured lights flickering at 10Hz with a relative conspicuity value.

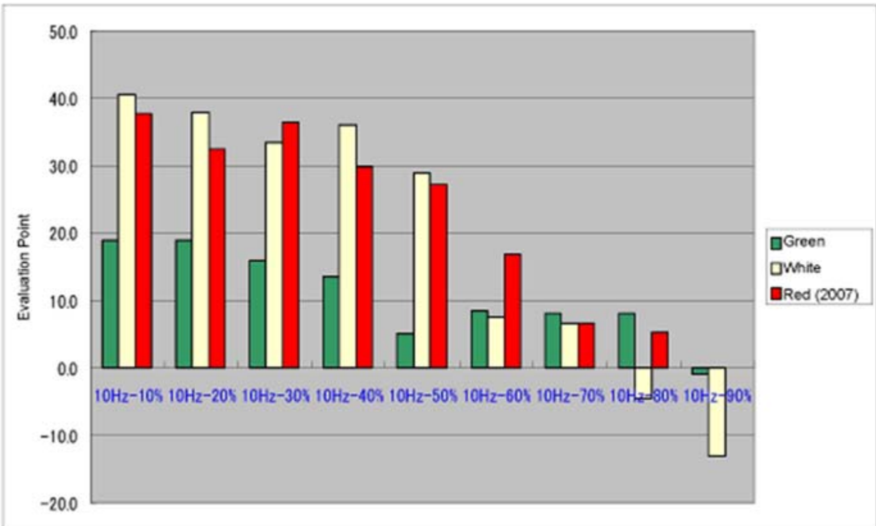

Figure 11 Comparison of Red, Green and White Flickering Lights at Japan Coast Guard

A conclusion from these experiments was that at the duty ratio of 50% or less, the conspicuity of green flickering light is obviously lower than red and white flickering light. Therefore, given other factors such as the Ångstrøm effect, the design of flickering light as aids to navigation requires careful consideration.

An expert meeting of Japan Coast Guard in November 2008 [1] concluded:

'That a flickering LED light is conspicuous and therefore has the possibility of becoming a new lighting method for marine aids to navigation however the flicker range is shorter than the nominal luminous range of the flickering light under certain conditions and thus the designing the flickering light should be done carefully. Further study and research are needed for its practical application.'

6.3.6. SYNCHRONISATION

Synchronising several AtoN lights can increase conspicuity considerably, particularly when viewed from a distance. Synchronisation is particularly suited to leading lights.

This technique is very effective for several buoys marking a channel, for port and starboard port entry lights or for leading light. When viewed at a distance, the effect of several lights all coming on together over a wide area is highly conspicuous. However, if all AtoN lights in the synchronised group have the same rhythmic character, there can be problems in identifying individual AtoN within the group. This is particularly relevant in poor visibility, when perhaps only one of the AtoN can be seen at any one time.

It is possible to retain individual characters within a group of AtoN and synchronise them at the start of rhythmic character with the longest period. For this to be practicable, the AtoN characters need to have a common period or exact divisions of the longest period (or exact multiples of the shortest period). Further information can be obtained from the IALA Guideline 1116 on Selection of Rhythmic Characters and Synchronisation of Lights for Aids-to-Navigation [14].

6.3.7. SEQUENCING

Apart from sequencing lights in an arrangement or shape that are viewed together, sequencing several AtoN lights over a wider area can also increase conspicuity as it provides apparent movement and indicates direction as well as relative distance. However, for sequencing to work satisfactorily several lights need to be in the view of the observer and this may mean increasing the number of lights in a given area. Further information can be obtained from the IALA Guideline 1116 on Selection of Rhythmic Character and Synchronisation of Lights for Aids-to-Navigation [14].

6.3.8. FLOODLIGHTING

Floodlighting can be considered as an extended light source. At close range, an illuminated structure can provide a conspicuous mark for an AtoN light. If the structure is uniquely recognisable, it can provide instant and reliable recognition to the mariner. However, floodlighting usually requires high-powered lamps and may not be practicable for AtoN with low-energy systems.

At distances of a few miles, the effects of floodlighting usually start to fade as the angular subtense of the area illuminated becomes smaller and the recognition of the object becomes more difficult. Therefore, floodlighting is recommended for improving conspicuity at relatively short distances, although this will depend on the illuminated area and the degree of illumination.

Since an illuminated structure is a luminous area being viewed rather than a point source, as with 'light-pipes' or contour lights, the advantages are instant recognition and ability to gauge distance.

However, the effectiveness of floodlighting depends upon the surface being lit and its ability to reflect the light illuminating it. Different surfaces reflect light (and different colours of light) differently. The angle of illumination is also important, as is the area of structure illuminated, which in turn depends upon the beam angle of the floodlight and its distance from the structure. Consideration should be given not to confuse the user with different colour lights, particular due to colour mixing of the AtoN light. All efforts should be made to ensure that floodlighting does not impair the conspicuity of the AtoN light.

Further factors are the change of surface reflectance due to deposits of water (e.g. rain), dirt or growth and the way the floodlit structure is viewed against the background. If possible, a compromise between acceptable floodlight colour, the structure's reflectance of that colour and contrast with the background illuminance should be sought.

Further information can be obtained from the IALA Guideline No. 1061 on Lighting Applications on the Illumination of Structures [10].

Figure 12 Lighthouse Tower Floodlit in different Colours

6.3.9. CONTOUR LIGHTING

Highlighting the outline shape of a structure with additional low luminance strips of light can be useful for two reasons: it provides a recognisable shape and it gives an impression of size and distance. Further information can be obtained from the IALA Guideline No. 1061 on Lighting Applications on the Illumination of Structures [10].

7. WAY FORWARD

As previously noted, conspicuity of AtoN signals is a complex subject. This guideline is merely a review of current state of knowledge and clearly there is a need for further work on this subject.

A future way of dealing with conspicuity for both the initial planning and design of AtoN lights, as well as subsequent reviews, is to take a more holistic approach. The intention is to develop a conspicuity model that can be used to quantify conspicuity by inputting relevant information in order to define the operational requirement [23]. A probabilistic approach for such a model should be considered.

However, there are many factors that affect conspicuity and their impact and interrelation is barely understood at present. Therefore, much in-depth scientific work is needed for such a development. The results could provide not only a model but perhaps simulators based on that model. This would enable preliminary trials to take place in simulation thereby reducing costs of AtoN provision and increasing the chances of providing a useful AtoN.

8. ACRONYMS AND DEFINITIONS

8.1. ACRONYMS

CIE	Commission Internationale de l'Eclairage (International Commission on Illumination)
eILV	Electronic International Light Vocabulary

8.2. DEFINITIONS

Detection of an AtoN light	The observer is aware of a light	[17]
Recognition of an AtoN light	The observer is aware that the light is an AtoN light	[17]
Identification of an AtoN light	The observer is aware of the exact AtoN to which the light belongs	[17]

Conspicuity	Quality of an object or a light source to appear prominent in the surroundings – eILV 845-11-30	[2]
Background Luminance	A general area or large patch of light of roughly uniform brightness, directly behind an AtoN light, that impairs the mariner's view of the AtoN light of interest	[17]
Rival light	Rival lights can be considered as individual point sources of light that mask or obscure an AtoN light and prevent easy detection or recognition of the AtoN	[17]
Background Lighting	Encompasses ambient lighting either directly behind or adjacent to the AtoN having regard to the range of perspectives or directions of intended viewing	[11]
Luminous Intensity	IALA Dictionary 2-1-035	[17]
Illuminance	IALA Dictionary 2-1-055	[17]
Luminance	IALA Dictionary 2-1-045	[17]
Glare	IALA Dictionary 2-1-420 to 2-1-430	[17]
Visibility	IALA Dictionary 2-1-275	[17]

9. REFERENCES

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[4] IALA Recommendation R0200-0 Overview

[5] IALA Recommendation R0200-1 Colours

[6] IALA Recommendation R0200-2 Calculation, definition and notation of luminous range

[7] IALA Recommendation R0200-3 Measurement

[8] IALA Recommendation R0200-4 Determination and Calculation of Effective Intensity

[9] IALA Recommendation R0200-5 Estimation of the Performance of Optical Apparatus

[10] IALA Guideline No. 1061 'Lighting Applications on the Illumination of Structures'

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[28] IALA Recommendation E-1116 on 'Selection of rhythmic characters and synchronisation of lights for Aids to Navigation'