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| --- |
| A number of queries and suggestions arose when this Guideline was being reformatted to the new IALA image, as shown in the comments throughout the document.  The ENG Committee is requested to respond to these queries and suggestions and submit to the Secretariat to enable completion of the reformatting. |

1023

The Design Of Leading Lines

Edition 1.1

December 2005

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

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| Date | Page / Section Revised | Requirement for Revision |
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# INTRODUCTION

## Purpose

The purpose of this publication is to enable a person with little or no knowledge of the fundamentals of leading line design to make use of a computer design program for leading lines is available from <http://www.iala-aism.org/products/publications/0807091215/leading-line-design-programme-v202-e-112-2>.

## Features

The computer program has the following features:

1. Runs as a workbook in Microsoft Excel®. This format allows various leading line parameters to be entered and modified in any order.
2. The output is immediately displayed a change to any of the design parameters results in an immediate update of the program output.
3. Provides recommended intensities in addition to the minimum and maximum intensities, in an effort to provide improved service to the mariner.
4. Allows for evaluation of the performance of both existing and proposed optics.
5. Lateral Sensitivity is expressed as Cross-Track Factor and lends a more physical feel to the performance of the leading line.
6. In addition to evaluating the suitability of proposed night-time leading lights, the program also provides for the evaluation of the performance of daytime leading lights or leading marks. Note, off-axis distances and cross-track factors provided by the program are based on the performance of light signals only. When leading marks are used, these performance values are based on the night-time light signals only. The performance of the design using daytime leading lights, however, is evaluated separately from the performance based on night-time lights. When both light signals and dayboards are to be used, this program presumes the light signals are mounted atop the dayboards. It is possible to consider lower positions of the front signal light relative to the dayboard by taking the additional step of entering the front dayboard as an obstruction to be accounted for in the design of the leading line.
7. Configurations & Constraints. Section 5 provides advice on standard configurations and practical constraints on the design of leading lines. Addressing these issues will enable the novice designer to produce leading line designs that perform as expected and can be safely maintained by servicing units. The Leading Line Category Selection Aid, found in section 5.9, may assist in determining how best to mark the leading line.

## Program Basis

The equations and evaluation factors used in the design program are taken from the IALA Recommendation E-112 for Leading Lights and are explained in detail in section 6. Further references to this document will be made as ‘the IALA Recommendation.’ There is actually a lot from USCG guidelines and practice as well?

# BASICS OF LEADING LINE DESIGN

## Definition of a Leading Line

A leading line is defined in the IALA International Dictionary of Aids to Navigation as: ‘a straight line used for navigation produced by the alignment of marks (leading marks) or lights (leading lights) or by the use of radio transmitters.’ This document is limited to the discussion and design of leading lines based on leading marks (daymarks) and leading lights. Ususally vertical alignment of lights or marks defines the centerline of a channel. *If the alignment is used for marking edge of a channel or other water area, the line is called a transit.*

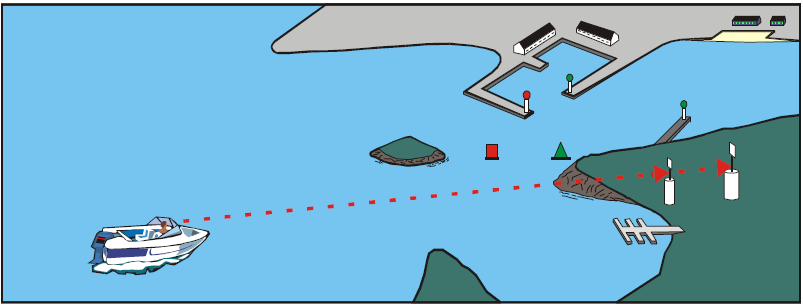
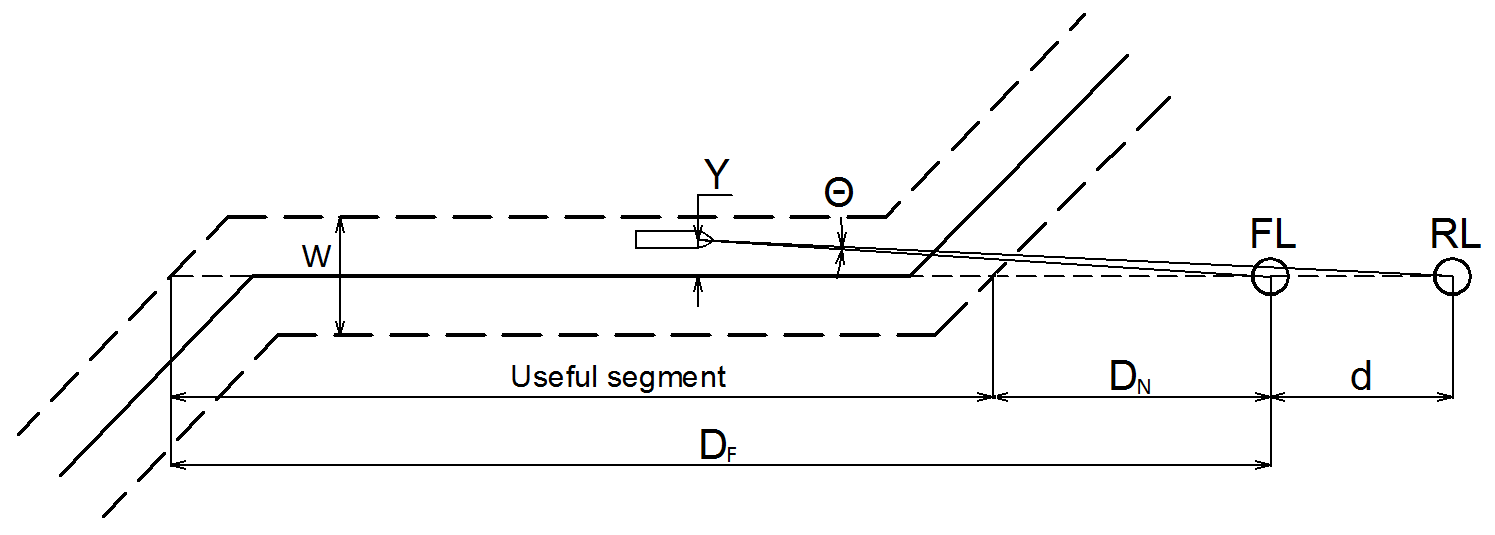


Figure 1 Basic Principle of a Leading Line

## Views of a Leading Line

### Plan View.

Figure 1 shows a plan view of a leading line and defines some variables.



FL, RL – Front light, rear light

DN – Distance from front mark to near end of useful segment of the leading line (m)

DF – Distance from front mark to far end of useful segment (m)

When measuring DN and DF the distances to the near and far edge of the next and previous fairway section respectively must be included to the useful segment. <-- Changes proposed: minimum distance is DN (=M) and DF (=M+C),

d – Distance between front and rear mark (m)

W – Width of channel (m)

Θ – Horizontal angle between the lights as seen by the mariner (m)

Y – Off-axis distance. Distance from the centreline (corresponding to Θ) at which the observer will detect with certainty that the leading lights are no longer vertically aligned, off-axis distance (m)

Off-axis distance is measure of sensitivity of a leading line – the smaller the off-axis distance at the same distance from the front leading light the more sensitive the leading line is.

1. Plan view of a leading line

### Side View

Figure 2 is a side view of leading line structures with some additional variables of interest defined. Note, structure (tower) heights are referenced above mean high water (MHW).

*Include height of ground and height of dayboard too?*

*Improve the side view?*



1. Side view of leading line structures (towers)

### Front view

Figure 3 is a front view of the leading line structures as seen from a vessel located to the right of the channel centerline. It also shows the horizontal () and vertical () angles created by the lights as viewed by the observer.



1. Front view of leading line structures

## Channel Length -> USEFUL SEGMENT

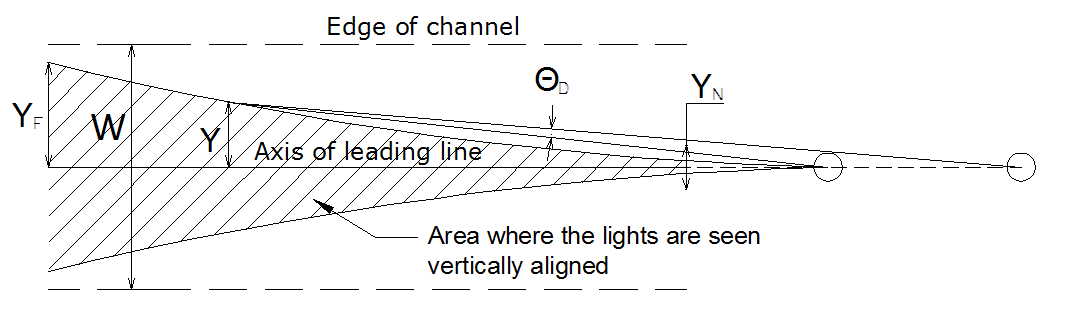
The preliminary decision in designing a leading line is to specify the segment of waterway to be marked by the leading line. This is derived from navigational charts *or survey sheets*.

Generally, it is costly to build a leading line to serve a long channel, as the rear leading mark and light must be of sufficient height to be clearly visible above the front structure. Leading marks must also be large enough to be visible from the far end of the channel. Both of these conditions result in increases to the required height of the rear structure marking a long channel. If near end of a channel gets very close to front mark and height of observer is low, necessary height of rear mark increases rapidly for the mark to be visible above the front mark. The structures must also be sturdy enough to support the leading mark under wind loads. The use of other aids (fixed beacons or buoys) may reduce the overall cost of marking the waterway by reducing portion of the channel marked by the leading line.

## Off-Axis Distance

Sailing along a leading line takes place in the area/zone where the seafarer/master/sailor sees himself/herself being at the axis of the leading line. Only at the edges of that area/zone, where the horizontal gap (bearing difference (Θ)) between the rear and the front light/daymark becomes big enough, it is detected that the leading lights/daymarks are no longer vertically aligned (Figure 4). Perpendicular distance from the centreline at which the observer will detect *with certainty* that the leading lights are no longer vertically aligned is called off-axis distance (Y).

The calculated off-axis distance returned by the program, using Equation 15 from IALA Recommendation E-112, is based on the bearing difference calculated by Equation 3 (D) from IALA Recommendation E-112.

******

**YN** – off-axis distance at the near end of the useful segment

**YF** – off-axis distance at the far end of the useful segment

**ΘD** – *(is D best index for that? First association could be “distance”, as above, not detection.)* Horizontal angle between the lights at which the observer will detect with certainty that the leading lights are no longer vertically aligned (m)

1. Off-axis distance and … of a leading line

The design of a leading line should provide sufficient room for the various ‘nautical margins’ needed to navigate the channel with safety, dependent on the types of ships and navigation conditions that will be encountered, between the off-axis distance and the channel edge. This is discussed more thoroughly in Section 2.5, below.

## Lateral Sensitivity—Cross-Track Factor

### Cross-Track Factor

The computer program for leading line design generates a cross-track factor based on the off-axis distance related in the IALA Recommendation for Leading Lights to the bearing difference, D. The cross-track factor is defined to be a ratio of the lateral distance at which a mariner can detect with certainty that a vessel is not on the channel centerline, divided by half the channel width, and expressed as a percentage. A cross-track factor of 25% indicates that a mariner may be as far as 25% of the way towards the edge of the channel when he can detect, with certainty, that he is off centerline. When using cross-track factor as an expression of lateral sensitivity, a higher cross-track factor implies a lower sensitivity, and vice versa.

### Evaluation of Acceptable Cross-Track Factors

Table 1 provides guidelines on the description and acceptability of various cross-track factors.

Instead of setting upper (%) limits on the cross-track factor, the designer should weigh the nautical margins available against the risk that passing vessels will be overly confined (a small (%) cross-track factor may result in increased risk of collision between passing vessels).

* if the cross-track factor at the far end is adequate, chances are good that the cross-track factor at the near end is much smaller;

If there are marks at the turning point at the near end, they will allow the mariner to judge the edge of the channel, and the small cross-track factor may be of no concern.

* when a small cross track factor is a problem, the range design can be modified to have an identical cross-track factor at the far end, but increased cross track factor at the near end.

Figure 5 illustrates the situation where the cross-track factor at the far end is identical, but the cross-track factor at the near end varies with the two designs. By moving the range structures back from the near end of the channel and increasing DN and d, the cross-track factor at the near end is increased while keeping the cross-track factor at the far end the same.

### Range Design Selection

Usually the range shown on the bottom of Figure ? will give better service because the cross-track factor does not vary as much between the near and far ends, and the illuminance produced by each light on the eye of the user will be more nearly equal along the entire length of the channel. On the other hand, as distance from the observer is longer, this design might require larger dayboards, taller towers, or lights of increased intensity. It is up to the range designer to select the design that is most appropriate for the given situation.

1. Cross-Track Factor\*

|  |  |  |
| --- | --- | --- |
| Values of Cross-Track Factor | Description | Interpretation |
| Over 75% | Not Acceptable | Range must be improved or it will be unworkable |
| 50% - 75% | Poor | Decrease the cross-track factor if physically possible. |
| 30% - 50% | Fair | Decrease the cross-track factor only if moderate cost involved. |
| 20% - 30% | Good | Decrease the cross-track factor only if little cost involved. |
| 15% - 20% | Very Good | Do not expend more funds to decrease the cross- track factor. |
| 10% - 15% | Excellent | The cross-track factor should not be less than 10% at the far end of the channel. |

\* Use this table using the cross-track factor ***at the far end*** of the channel.

*Isn’t the main point, how much room is left to the side of the channel, not what portion this is of the total width of the channel? A leading line should allow using the whole width of the channel. i.e shouldn’t acceptable off-axis distance depend on width of the channel and width of the design vessel?*

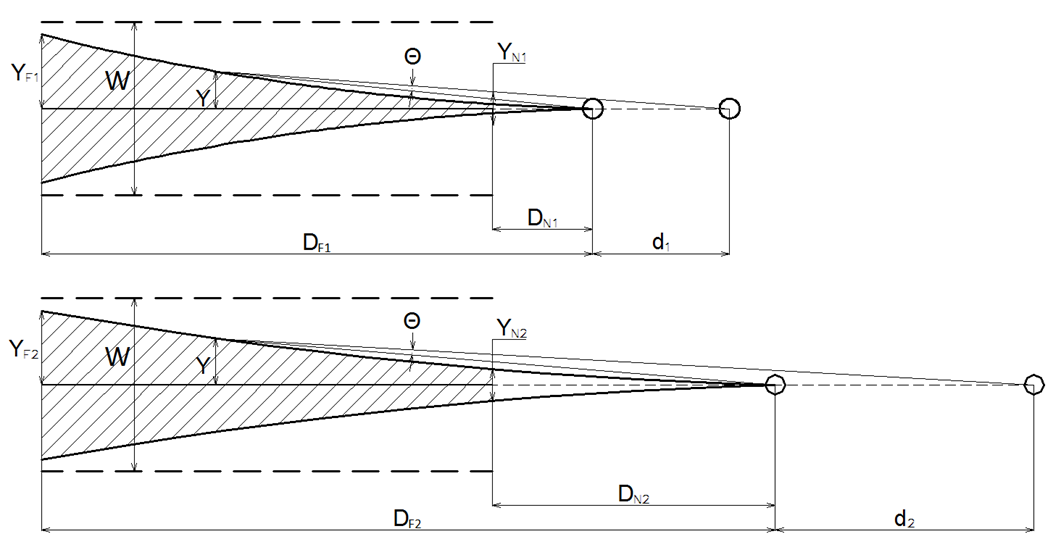
*Russian guideline gives formula for acceptable off-axis distance for*

* *“channel widths > 200 m: YACC = W – B ( where B is width of the ship)*
* *channel widths > 200 m: YACC = K B, where K is a coefficient 0.2…0.6, the wider the channel, the smaller the coefficient*

*The given coefficients are not rigid, they guarantee necessary reserve of “free water” behind the limits of the zone of leading line according to extent of possible deviation practically for all types of vessels. If necessary, these they can be changed, up or down. For example, for leading lines for fairways with width of 2000 to 3000 m coefficient K can be increased, with the cost of some decrease of sensitivity, up to the level where YACC is in the limits of 400 to 800 m.*

*\* Acceptable off-axis distances for a leading line serving navigation between dangers to navigation that are positioned symmetrically in relation to the axis of the leading line is calculated with the formulae … or … . 2B is meant to be the width of the safe passage between the dangers.*

*\* Acceptable off-axis distances for a leading line serving navigation between dangers to navigation that are not positioned symmetrically in relation to the axis of the leading line is calculated with the formulae … or …. for each of the dangers nearest to the axis of the leading line.”*



1. Two range designs having the same cross-track factor at the far end but different cross-track factors at the near end.

## Beam Width of Leading Lights

### Spread Lens

There is often confusion regarding the effect of a narrow spread lens on the sensitivity of a leading line. The beam width of the optic has nothing to do with the lateral sensitivity of a leading line. The beam width is of some concern when a narrow spread lens is used, as care must be taken to ensure that the minimum intensities identified as necessary by the program are provided over the full width of the channel. The angle subtended at the far end of the useful segment,  (see Figure 6) is given by:

1. The angle subtended at the far end of the useful segment

Where:

X is the distance from the light to the far end of the channel, in metres

W is the width of the channel, in metres

W

X2

R

M

C

X1

1

2

1. Beam Width of Leading Lights

## Daymarks or Daytime Lights

Traditionally leading lights, particularly those powered by batteries, were secured during daylight, with the daytime signal provided by leading marks. Recent efficiency improvements in optics combined with solar power have allowed expanded use of daytime leading lights, even when commercial power is not readily available. The following are some points to consider when deciding on the daytime signal:

* daymarks are simple;

Having no moving parts, they require little maintenance and so are more reliable than lights. Smaller marks are also easy to maintain, with no special training required for servicing personnel.

* daytime leading lights provide a superior signal. In marginal conditions they can be seen further than day marks. Furthermore, substituting lights for large marks may result in less costly tower structures and foundations.

Daytime lights, however, require more complex lighting and power systems, which will increase hardware costs and the technical demands on the servicing personnel. The higher initial equipment costs will likely be more than offset by reduced structural costs.

## Considerations Regarding Intensities

1. Night-time lights should be of sufficient intensity to mark the entire channel length for 90% of the nights. The ‘Minimum Intensity’ values provided by the program will provide adequate signals; however, higher intensities will generally provide better signals. Experience has shown intensity values ten times greater than the minimum values will provide a better signal. Therefore, the program provides a ‘Recommended Intensity’ that is approximately ten times the Minimum Intensity, with good illuminance balance. It is often easy to provide the Recommended Intensities and provide not just an adequate, but a good signal.
2. Daytime lights should be of sufficient intensity to maximize the percentage of time that the channel is adequately marked. If you can meet the ‘Minimum Intensity’ you do not need to go beyond that intensity. If you cannot meet the ‘Minimum Intensity’ put in the brightest light possible. The program uses a value of 1000 microlux (1X10-3 lux) as the required illuminance for daytime.

## Standard Leading Line Characteristics 🡪 light characters (of leading lights)

Fixed (F) characteristics should be used sparingly, if at all. Lights displaying a fixed characteristic, especially white light signals, can be difficult to identify against even minimal background lighting. Furthermore, lights displaying a characteristic with e.g. a three second flash duration provide approximately 92% of the intensity of a fixed light signal, yield longer lamp service intervals, have lower power consumption, and provide greater conspicuity than the fixed light signal.

*Russian guideline Инструксия по навигационному оборудованию (ИНО-2000) suggests:*

* Front and rear lights should be synchronised, if possible.
* If the leading lights are not synchronised length of **flashes** and periods **of** the **front light should be shorter** than these of the rear light.
* Length of a flash should not be less than 0.5 s.
* Length of the flashes of the rear light should be selected so that maximum possible overlap of the leading lights in both frequency and length is achieved. The narrower the fairway or channel the more the front and rear lights´ flashes must overlap.
* Front and rear lights must generally be of the same colour.

*Arguments for or against these? Any other good practices?*

*Further reference to the IALA guideline on selection of light characters.*

## Visibility Values

The computer program requires entry of three visibility values; Minimum Visibility, Design Visibility, and Maximum Visibility. All three values are computed in nautical miles (NM) (a nautical mile is 1852 meters).

### Minimum Visibility

The minimum visibility is the historic value of meteorological visibility at the site that is met or exceeded 90% of the time. This value is used by the program to establish the minimum luminous intensities required to ensure that the leading lights are usable as leading line signals at least 90% of the time.

### Design Visibility

The design visibility was originally conceived as the median value of meteorological visibility for the site; that is, the value met or exceeded 50% of the time. Design visibility is used by the program to establish the recommended ratio of luminous intensity of the leading lights. As a practical consideration, use of a fixed value of 10 nm is recommended.

### Maximum Visibility

The maximum visibility value is used by the program to evaluate the potential for glare produced by the leading lights. As a practical consideration, use of a fixed value of 20 NM is recommended.

# PROGRAM OPERATION

## System Requirements

The program will run on any computer that has Microsoft Excel® 97 (Windows), Excel® 98 (Mac OS), or later versions.

## Data Input-Preliminary

You can enter and modify any of the leading line parameters in any order, but when first starting out it is recommended that the input data be entered in the order outlined below. The input cells are shaded and outlined with a box. An Initial Channel Layout Worksheet is included in the workbook to recommend a ‘very good’ leading line design (see Table 1) in the event that the locations of the front and rear structures are not initially known. To use this preliminary design tool, click on the ‘Initial Input’ worksheet tab and enter the data indicated below. All input cells require data unless otherwise indicated.

### Leading Line Name

Enter the name of the leading line. OPTIONAL

### Length of Channel (C)

Enter the length of the channel, in meters. REQUIRED

### Width of Channel (W)

Enter the width of the channel, in meters. REQUIRED

Recommended Distance Between Front Light (FL) & Rear Light (RL) Towers (R), and recommended Distance from FL to Near End of the Channel (M) are computed and displayed on the Initial Channel Layout. These values are also shown on the ‘Leading Line’ worksheet adjacent to the data entry cells for these values. The user then elects to use these values, or other values as circumstances may require.

## Data Input-Leading Line Analysis

Click on worksheet tab ‘Leading Line.’ It is possible to enter and modify any of the leading line parameters in any order, but when first starting out it is recommended that the input data be entered in the order outlined below. All input cells require data unless otherwise indicated. If required input cells are left empty the Cross-Track Factor, Off-Axis Distance and will not be computed correctly. Data is already entered from the previous worksheet for you in the following fields:

* Leading Line Name;
* Length of Channel (C); - change to DF and DN that allow finding length of useful segment too, if wanted
* Width of Channel (W);
* Night or Day Lights (N).

### Mean Range of Tide (MRT)

Enter the mean range of the tide (difference between mean high water and mean low water), in meters. REQUIRED

### Background Lighting

Enter the amount of background lighting that is present, either ‘None,’ ‘Minor,’ or ‘Considerable.’ Minor background lighting refers to widely spaced lights and/or dim lights such as residential lighting. Considerable background lighting refers to numerous lights and/or very bright lights such as parking lots, highways, factories, and industrial lighting that compete with the intensity of the range lights. PROGRAM ASSUMES ‘CONSIDERABLE’ IF CELL IS LEFT BLANK.

### Height of Eye (HoE)

Enter the height of eye of one to three observers above the water, in metres. (The program can evaluate how well the leading line design works for up to three different vessel types simultaneously.) The input cells for HoE are located in the centre of the spreadsheet. AT LEAST ONE ENTRY IS REQUIRED

### Minimum Visibility

Enter the minimum visibility for which the leading line is designed, in NM. Generally, it is the visibility that occurs 90% of the time for the location of the leading line. REQUIRED

### Design Visibility

Enter the design visibility, in NM. A value of 10 NM is recommended. REQUIRED

### Maximum Visibility

Enter the maximum visibility for which the leading line is designed, in NM. For practical considerations, a value of 20nm is recommended. REQUIRED

### Distance Between Front Light & Rear Light (R)

Enter the distance between the structures, in metres. REQUIRED

### Distance Front Light to Near End Channel (M)

Enter the distance from the near end of the channel to the front structure, in metres. REQUIRED

### Safe Height Above Water (SAFHW)

Enter the required safe height above water, in meters. It is the minimum height required to keep the front light/mark from being damaged by wave action, spring tides, or vandals. PROGRAM ASSUMES 0.0 METRES IF CELL IS LEFT BLANK.

### Daymarks To Be Used

Enter a ‘Y’ to use leading marks or an ‘N’ for no leading marks. PROGRAM ASSUMES ‘NO’ IF CELL IS LEFT BLANK.

### Daytime Lights To Be Used

Enter a ‘Y’ to use daytime lights or an ‘N’ for no daytime lights. PROGRAM ASSUMES ‘NO’ IF CELL IS LEFT BLANK.

### Obstructions

Enter the distance from the near end of the channel to the obstruction(s), in metres, and the height of the obstruction(s), in metres. OPTIONAL

### FL Selected Daymark Length

Enter the length of the front leading mark, in metres. Ignore this block if not using leading marks, or enter ‘None’.

### RL Selected Dayboard Length

Enter the length of the rear leading mark, in metres. Ignore this block if not using dayboards or enter ‘None’.

### FL Selected Intensity

Enter the intensity of the selected signal for the front leading light. REQUIRED

### RL Selected Intensity

Enter the intensity of the selected signal for the rear leading light. REQUIRED

### Selected Height FL

Enter the height of the focal plane of the front optic, in meters, above MHW. Note that this value may be different for daytime and night-time leading lights (see Chapter 5 for more details). REQUIRED

### Selected Height RL

Enter the height of the focal plane of the rear optic, in metres, above MHW. Note that this value may be different for daytime and night-time leading lights (see section 5 for more details). REQUIRED

## Data Input-Optional Daytime Leading Lights

Click on worksheet tab ‘Leading Line-Day.’ Data is already entered from the previous worksheet for you in the following fields:

* Leading Line Name;
* Night or Day Lights (D);
* Length of Channel (C);- change to (C+a =)DF and DN
* Width of Channel (W);
* Mean Range of Tide (MRT);
* Background Lighting (None);
* Height of Eye (HoE);
* Minimum Visibility;
* Design Visibility.
* Maximum Visibility
* Distance Between FL & RL (R);
* Distance FL to Near End Channel (M);
* Safe Height Above Water (SAFHW);
* Daymarks To Be Used;
* Obstructions;
* FL Selected Daymark Length;
* RL Selected Dayboard Length;
* Selected Height FL (Night Light Height plus 1 metre);
* Selected Height RL (Night Light Height minus 1 metre);

You can enter and modify either of the daytime intensities in any order, but when first starting out it is recommended that the input data be entered in the order outlined below. Both cells require data. If required input cells are left empty, the Cross-Track Factor, Off-Axis Distance, and will not be computed correctly.

## Program Output

Samples of the output data are included as section 5.11, section 5.12 and section 5.13. Section 5.11 and section 5.12 show the detailed analyses of the leading line performance for all the entered variables and display problems codes if warranted. Section 5.13 shows a more streamlined summary of the design with generic graphic diagrams. The output data is immediately computed upon entering any variable.

Explanations of the outputs:

### Recommended Daymark Length

The recommended length of the daymark, in metres, based on the minimum visibility.

*Frank: The calculation described below should not be supported in future. Instead a simple rule (3 arc-minute rule) is preferred.*

Change This:

*The calculation of the daymark size is based on the distance from the tower to the far end of the channel (FL) or (RL) and the minimum visibility .*

*The visibility may have an integer value between 1 and 10 nautical miles (M), so there are 10 equations to calculate the size.*

*Pärtel:*

*IALA: min height 3’?*

*Russian: min width for a leading line with marks with recognisable shape 2’*

*🡪 both IALA and Russian conditions are met if the length/width ratio is 1/1,5.*

*(Russian guideline allows also marks, which are seen as points at the end of useful segment (hor angle 1’))*

*Height of front mark – 3’ at the end of the useful segment?*

*Height of rear mark – 3’ above the front mark at the end of the useful segment? How much of it visible at near end?*

*Finnish: At far end: 0.2 mrad between lower edge of the rear dayboard and upper edge of the front mark. At near end: at least 2/3 of the rear dayboard visible above the front one. 🡪 Adjusting height of rear daymark.*

*IALA: at least half of the rear mark must be visible at the near end?*

*Vertical angle between (tops of) daymarks affects horizontal angle of detection:*

*Russian: for point leading lines* Θ *D = 1,5…3,0’ @ 2…60’, for line with marks with recognizable shape* Θ *D = 1,0…2,6’ @ 2…60’.*

*See comparison of results of different daymark calculation methods in Comparison\_of\_calculation\_methods\_for\_daymark\_sizes.xls.*

### Minimum Intensity

The minimum intensity (in candela) required to ensure the leading light is useable at the far end of the channel for the given minimum visibility. (For daytime leading lights the program only provides values of minimum required intensities.)

### Recommended Intensity

The recommended intensity (in candela) to assist the mariner in detecting, recognizing, and using the leading lights. This value is approximately ten times the minimum intensity, taking into consideration the recommended illuminance ratio.

### Maximum Intensity

The maximum intensity (in candela) of the leading lights that can be used without causing glare during conditions of maximum visibility.

### Recommended IR/IF

The recommended intensity ratio for the rear and front optics where:

### IR/IF for Selected Intensities

The intensity ratio for the selected light signals.

### Dimensions of retroreflecting film, if used?

### Recommended Min Height

The recommended focal plane height of the optic.

### Distance from Near End

The distance of the observer from the near end of the channel at ten evenly spaced intervals along the entire length of the channel.

### Cross-Track Factor

The cross-track factor at the indicated distance from the near end of the channel.

### Off Axis Distance

The distance perpendicular to the range axis (in metres) needed to indicate to the observer that they are off the leading line axis, at the indicated distance from the near end of the channel.

### mrad) (MLW)

The apparent vertical angle subtended by the leading lights (vertical angle separation), in mrad, at the indicated distance from the near end of the channel.

### Illuminance Ratios & Values

Provides information on the apparent brightness of the two range optics for the selected design visibility, at the indicated distance from the near end of the channel (values are in microlux).

### Problem Codes

Chapter 4 discusses Problem Codes and Daymark Problem Codes which may appear on the output sheet. The sample Night-time/Daymark Design worksheet provided as section 5.11 shows all the potential problem codes for informational purposes.

## Single-Point-in-Time Performance Run

To see how the leading line will perform on a given day with a given visibility enter the same visibility for Minimum, Design, and Maximum Visibility. The output is a snapshot of how the leading line will perform for that given visibility.

## Leading Light Selection

Use the Leading Line Design Program to determine the recommended intensities for the front and rear leading lights. Select the combinations of lanterns, lenses (colour/spread), lamps, and rhythms which best meet the desired intensities, and which have adequate beam widths to cover the required region (see section 2, Section F). When possible, use of omnidirectional lanterns is highly desirable, as the signal can be acquired even when vessels are well off the channel centerline. The use of omnidirectional lanterns also precludes the requirement for passing lights on towers located in navigable waters.

## Sample Leading Line Designs

Four sample printouts are provided in sections 5.10 to 5.13. The first is an Initial Channel Layout based on two simple inputs. The second is a leading light design analysis which shows a Night-time Leading Light with Daymarks for daytime signals. The third sample shows the analysis of the same leading line with daytime light signals added. The fourth sample shows a more streamlined summary of the design with generic graphic diagrams.

# TROUBLE SHOOTING

C

M

R

W

Centreline

FL

RL

1. Leading Line Diagram

## Problem Codes

Below is a list of the possible problem codes that may be displayed while running the leading line design program.

1. Lights will blur.
2. Cross-Track Factor too big.
3. FL not bright enough in min visibility.
4. RL not bright enough in min visibility.
5. FL exceeds glare limit in max visibility.
6. RL exceeds glare limit in max visibility.
7. FL Dayboard too small in min visibility.
8. RL Dayboard too small in min visibility.
9. RL appears lower than RFL.
10. FL below Safe Height Above Water.
11. FL below the horizon.
12. Obstruction #1 obstructs FL.
13. Obstruction #1 obstructs RL.
14. Obstruction #2 obstructs FL.
15. Obstruction #2 obstructs RL.

## Daymark Problem Codes

Below is a list of the possible daymark problem codes that may be displayed while running the leading line design program.

1. Portion of FL mark below horizon.
2. FL mark below Safe Height Above Water.
3. FL obscures part of RL mark.
4. FL obstructs more than 1/2 RL mark.
5. Obstruction #1 obstructs FL daymark.
6. Obstruction #1 obstructs RL daymark.
7. Obstruction #2 obstructs FL daymark.
8. Obstruction #2 obstructs RL daymark.

C

M

R

W

Centreline

FL

RL

1. Leading Line Diagram

## Problems and Fixes

Below are some suggestions on resolving problems with leading line designs, with possible constraints and costs. Common problem codes are grouped together.

1. Problem codes

| Problem | Possible Fix | Constraint/Cost |
| --- | --- | --- |
| 1. Lights will blur. | Raise RL. Reduce intensities. Lower FL. Decrease C. | Extra cost; decreased sensitivities Lights harder to acquire & use Closer to water May not meet users requirements. |
| 2. Cross Track Factor too big. | Increase R.  Increase FL height or decrease RL height. | May need real estate; extra cost; may need to increase RL height. Lights may blur |
| 3. FL (RL) not bright | Increase intensity. | May cause glare/blur; extra cost |
| 4. Enough in min visibility. |  |  |
| 5. FL (RL) exceeds glare | Reduce intensity  Increase M. | Light harder to acquire & use.  May need real estate; extra cost. |
| 6. Limit in max visibility |
| 7. FL (RL) daymark too | Increase daymark size.  Use daytime lights | Extra cost.  Extra initial equipment cost. |
| 8. Small in min visibility |
| 9. RL appears lower than FL. | Lower FL.  Raise RL  Decrease R. | Lights/daymark closer to water. Extra cost; decreased sensitivities  Decreased sensitivities. |

C

M

R

W

Centreline

FL

RL

1. Leading Line Diagram
2. Problem codes (continued)

|  |  |  |
| --- | --- | --- |
| Problem | Possible Fix | Constraint/Cost |
| 10. FL below Safe Height Above Water. | Raise FL. Use smaller daymark. | May cause blur; raise RL. May not be adequate. |
| 11. FL Below Horizon. | Raise FL. Decrease M. | May cause blur; raise RL May cause glare; harder to balance illumination ratios. |
| 12. Obstruction #1, #2 | Raise FL. | May cause blur; need to raise RL |
| 13. Obstructs FL. | Remove obstruction. Decrease M. | May not be legal/possible. May cause glare; harder to balance illumination ratios. |
| 14. Obstruction #1, #2 | Raise RL. | Decreased sensitivities; extra cost. |
| 15. Obstructs RL. | Remove obstruction Decrease R. | May not be legal/possible Decreased sensitivities. |

C

M

R

W

Centreline

FL

RL

1. Leading Line Diagram
2. Daymark problem codes

|  |  |  |
| --- | --- | --- |
| Problem | Possible Fix | Constraint/Cost |
| 1. Portion of FL mark below horizon. | Raise FL daymark. Decrease M. Use daytime lights. | Extra cost due to larger tower; may need to raise rear tower. May cause glare; harder to balance illumination ratios. Extra initial equipment cost. |
| 2. FL mark below Safe Height Above Water. | Raise FL daymark. Use daytime lights. | Extra cost due to larger tower; may need to raise rear tower Extra initial equipment cost. |
| 3. FL obscures part of RL mark. | Lower FL daymark Raise RL daymark. Use daytime lights. | Closer to water, decreased sensitivities. Extra cost, decreased sensitivities. Extra initial equipment cost. |
| 4. FL obstructs more than 1/2 RL mark. | Lower FL daymark. Raise RL dayboard. Use daytime lights. | Closer to water, decreased sensitivities. Extra cost, decreased sensitivities. Extra initial equipment cost. |
| 5, Obstruction #1, #2 | Raise FL. | May cause blur; Extra cost; need to raise RL tower. |
| 7. Obstructs FL daymark. | Remove obstruction. Decrease M. | May not be legal/possible. May cause glare; harder to balance illumination ratios. |
| 6, Obstruction #1, #2 | Raise RL. | Decreased sensitivities; extra cost due to larger tower. |
| 8. Obstructs RL daymark. | Remove obstruction. Decrease R. | May not be legal/possible. Decreased sensitivities. |

## Maximum Intensity less than Minimum Intensity

This situation arises when one or both leading lights (usually the FL) are too close to the channel, creating a glare problem. The best solution is to move the leading lights back from the near end of the channel, increasing M, until the situation is resolved. If that is not possible, then choose a light signal that provides the Minimum Intensity, to alleviate the glare situation as much as possible. Another way to reduce glare is to set the focal heights of the lights so as to be significantly different from the primary HoE for vessels using the channel. This may result in the user being out of the primary portion of the beam, resulting in a reduction in intensity as the vessel approaches the near end of the channel.

## Maximum Intensity less than Recommended Intensity

This problem is similar to that described above, except that the Minimum Intensity does not result in glare. It is still generally best to move the leading lights back from the near end of the channel, thereby allowing selection of the Recommended Intensity. If that is not possible, then select an intensity between the Minimum and Maximum Intensities for the constrained leading light. The intensity for the remaining light should be selected to try and match the recommended ratio of intensities, so as to provide a good balance of illuminances. Note, in some instances this may result in the selected intensity for the RL being less than the Minimum Intensity. The leading line designer must compromise between the intensity requirements and the recommended ratio of illuminance to optimize marking of the channel.

## Compromises During Leading Line Design

There is no single correct design for a given leading line. There are multiple successful combinations of optics, lamps, structure locations, optic heights, flash characteristics, colours, etc. With all the different designs possible for a given leading line, there comes a point where the designer must select which design to use. Selecting the design that optimizes the cost/benefit ratio for marking a channel is a trial and error process that requires practice. The selection criteria may include cost of construction, maintenance, cross-track factor, off-axis distance, tower heights, power requirements, HOE of primary user, and user input. This is just a partial list, but indicates that design of a leading line is more of an art than a science.

# LEADING LINE CONFIGURATIONS & DESIGN CONSTRAINTS

## Introduction

This section discusses a few of the constraints and recommended configurations when designing a leading line. These items should be considered during the design phase, so that performance of the aid will be as predicted and that personnel can safely service the lights and marks.

## Tower Placement

Placement of the leading line structures determines the axis of the leading line. Tower placement along the centerline should be within ±3 metres of the desired position, while the lateral error in placement of the towers to either side of the true centerline should be limited to approximately ±0.3 metres. See Figure 11.



1. Tower placement

## Beacon Placement

Proper beacon placement is necessary to ensure that blur will not occur during night-time and that each light or group of lights will be viewed as a single source. The heights listed in the design program are the heights from MHW to the centerline of the optics. When using day & night leading lights, the lower optic on the front tower and the upper optic on the rear tower should be the night-time lights. The only exception is if the front tower uses an omnidirectional night-time light, which should then be mounted above the daytime light(s). Multiple optics for daytime lights should be installed on a horizontal plane, and should typically not exceed three across. Horizontal separation should be kept to a minimum to be sure the lights are viewed as a point source. Figure 5-2 details some common configurations of day/night optics.

## Additional Lights

If the design does NOT use omnidirectional optics at night, and the structure is located in navigable waters, it may be necessary to add omnidirectional lights to the structure. These additional lights should be mounted where they will not be blocked by the structure.

1. Additional lights should be mounted at a low enough height to ensure that the lights will be visible to vessels with a low height of eye (HoE). As an example, if a leading line has a front tower height of 8 m and a rear tower height of 25 m, the additional light for the front tower can be mounted directly above the front leading light. The additional light should display the same characteristic as the leading light, and should be synchronized with the leading light.
2. On towers greater than about 12 m, the additional lights may be designated as passing lights and installed at a lower level than the leading light. Installation of a passing light requires two optics, as the structure will partially occlude the output from each lantern. The passing lights should be mounted on opposite corners of the structure, and should be synchronized.

## Servicing Considerations

Towers should be designed to ensure that they can be serviced safely. Since many optics are serviced from the front, there should be 0.75 m of deck space available all around the optic, to allow for easy and safe access. Additionally, lanterns should be elevated a minimum of 0.5 m off the deck. When lanterns are installed more than approximately 1.25 m above the deck, a work platform should be built into the structure to allow personnel to comfortably access the lantern. Optic support structures should take into consideration any doors or servicing hatches on the installed lanterns. Railings should be installed, where appropriate, with either careful placement to prevent obstruction of the light or removable safety chains in front of optics. Operation and maintenance guides, if prepared, should be passed to the assigned servicing unit.

## Construction Details

Boat landings should be oriented to allow easy boarding under prevailing current and wind conditions. Boarding ladders should have rail extensions to allow easy transition from the deck to the ladder. For towers in excess of 20 m height, the designer should consider installation of a stairway instead of a ladder. All-weather, hand operated winches, with covers, should be installed on the main deck containing power system equipment and on the lantern deck to facilitate easy handling of hardware. Solar panels should be installed so that access to both sides of the array are possible and shall not be shadowed by railings, antennas, towers, shelters, etc., within an arc of ± 90 degrees of panel orientation.

## Safety

Installations using large batteries should have safety covers on intercell connectors to protect from accidental shorting. Battery rooms should have servicing equipment (hydrometer, tarp for covering solar panel, etc.) and safety equipment (eye wash station, gloves, goggles, etc.) available to servicing personnel in the event they do not bring the equipment with them.

## Daymarks

Daymark mountings on structures should be strong enough to secure the daymark up to the tower’s designed wind load, while allowing servicing personnel easy replacement. Daymark mountings should not exceed the tower strength (daymark mountings should fail before the structure does). Access to the daymark by ladder or platform is necessary to remove/replace fasteners. Use of day/night lights is encouraged on ranges requiring marks in excess of 3 m in length, as these marks are the most hazardous to replace.

Using semi-transparent material on daymarks could enhance conspicuity/contrast of daymarks observed against the sun.

## Leading Line Category Selection Aid

Commercial Powered

C - N Commercial Night (only) Light

C – 24 Commercial 24-Hour Light

C – D/N Commercial Day & Night Lights

C – RLC Commercial Day & Night Lights

(Synch. RL & FL transfer)

Solar Powered

S - N Solar Night (only) Light

S – 24 Solar 24-Hour Light

S – D/N Solar Day & Night Lights

S – RLC Solar Day & Night Lights

(Synch. RL & FL transfer)

Begin

Leading Line needed at night?

DAYMARK?

**Category: C-24**

Single intensity light

24-hours

Power commercial

Is Daytime light needed or cost preferable?

(See note 1)

Is Commercial Power Cost Preferable?

Is Day Light too bright to use at night?

Is a Single intensity light preferable?

(See note 2)

**Category: S-24**

Single intensity light

24-hours

Power Solar

Is Commercial Power Cost Preferable?

Is Day Light more than 50 times as bright as Night Light?

Is Day light more than 50 times as bright as night light?

**Category: S-N**

Daymark

Night only light

Power Solar

**Category: S-D/N**

Bright Day Light, dimmer Night Light

Power Solar

**Category: C-D/N**

Bright Day Light, dimmer Night Light

Power Solar

**Category: C-N**

Daymark

Night only light

Power Commercial

**Category: S-D/N**

Bright day, dim night

Synch transfer of RL & FL

Power Solar

(See note 3)

**Category: C-RLC**

Bright day, dim night

Synch transfer of RL & FL

Power Commercial

(See note 3)

Yes

No

No

No

No

Yes

Yes

Yes

Yes

Yes

No

1. Leading Line Category Selection

### Leading Line Category Selection Notes

1. There are several factors to consider when deciding whether or not to use daytime lights. The leading line designer should compare the performance characteristics and associated costs of a design using daymarks and one using daytime lights before making a final judgment.
2. Like most aspects of leading line design, choosing between a single intensity, 24-hour signal or a dual intensity, day/night signal for solar applications involves trade-offs:
3. Factors that favour a single-intensity light include:
   1. Fewer optics (to buy and service).
      1. No need for day/night control switching.
      2. Higher intensity night-time light usually provides a superior signal.
      3. Simpler system.
   2. Factors that favour a separate optics for daytime and night-time lights
      1. Allows for brighter daytime light and less intense night-time light:
      2. Requires fewer solar panels than a single (high intensity) 24-hour light.
      3. Requires less battery capacity than single (high intensity) 24-hour light.
      4. Less intense night-time light will tend to lower required height of RL.
4. Use of a device to synchronize switching of the front and rear leading lights is recommended when daytime and night-time light signal intensities differ by a factor of 50 or more. If the leading lights do not switch at the same time, the leading line may not be useable during the period when the front and rear lights are not in the same mode.

## Initial Channel Layout Worksheet



1. Initial Channel Layout Worksheet

## Night Time Leading Line with Daymark



1. Night Time Leading Line with Daymarks

## Day Time Leading Lights



1. Day Time Leading Lights

## Final Leading Line Configuration Summary



1. Final Leading Line Configuration Summary

# DESIGN PROGRAM METHODOLOGY

## Introduction

The IALA Leading Lines Design Program is based on the IALA Recommendation for Leading Lights (E-112), hereafter referred to as the Recommendation. The Recommendation provides specific guidelines for the design of towers and lights. The computer program is in the format of a Microsoft Excel Workbook containing four worksheets. The purpose of this enclosure is to show the linkage between the theory of the Recommendation and the detailed leading line design produced by the spreadsheet program. The locations in the spreadsheets of the described calculations are also provided in order to help users and reviewers to understand in detail the spreadsheet calculation methods (e.g.: **see cell B15**).

## Initial Channel Layout Worksheet

The Initial Channel Layout Worksheet (click on worksheet tab ‘Initial Input’) permits the user to establish a beginning position for the leading line towers when they are not otherwise constrained. For these preliminary calculations it is necessary to assume values for vertical separation of the lights, cross-track sensitivity and a distance from the near end of the channel to the front tower.

## Bearing Difference.

Refer to IALA Recommendation E-112 Equation 3b:

1. Bearing sensitivity

for the bearing difference necessary to detect with certainty that the lights are not aligned; on page 1 it is recommended ‘that if before adopting the final luminous intensities a preliminary investigation of appropriate sites is undertaken, it should be based on a value of radians.’

Assuming radians and substituting in Equation 2:

## Off-Axis Distance

Refer to IALA Recommendation E-112 Equation 16 for the off-axis distance at which a mariner can detect with certainty that a vessel is not on the channel centerline:

1. Off-axis distance for detection that a vessel is not on the channel centerline

Where:

*R* is the Distance between the front and rear lights.

*x* is the Distance from front light to far end of channel (C+M), where

*C* is the Channel length - replace C+M with DF

*M* is the Distance between near end and front light - replace C+M with DN

*W* is the Channel Width

The distance M is assumed to be 0.2C. This value is based on design experience, but may be deemed too low if background lighting or low visibility requires bright lights, which could cause glare at the near end of the channel.

## Separation of Front and Rear Towers

By substituting known values in Equation 3 and solving for the unknown value R, a relationship to compute the value for R can be arrived at.

By identity, we can divide both sides of the equation by (1/2W):

In this Guideline’s terms, is defined as the ‘cross track factor.’ The cross track factor is defined to be the lateral distance at which a mariner can detect with certainty that a vessel is not on the channel centerline, divided by half the channel width. For these preliminary calculations, a cross-track factor of 20% is assumed, inferring a ‘very good’ leading line (see Table 1).

Assuming and substituting in above equation:

But ; and

and R, the Distance between the front and rear lights

1. Distance between front and rear lights (1)

Where:

*R* is the Distance between the front and rear lights.

*x* is the Distance from front light to far end of channel (C+M), where

*C* is the Channel length

*M* is the Distance between near end and front light

*W* is the Channel Width

This can also be expressed as:

1. Distance between front and rear lights (2)

**See cell B15.**

This formula will always yield a cross track factor of 20% for = 1.5 mrad.

## Leading Line Design Worksheet

The detailed design for a leading line is accomplished on the Leading Line Design Worksheet (click on worksheet tab ‘Leading Line’).

## Minimum Intensity

IALA Recommendation E-112 suggests that the lights shall provide an illuminance at the eye of the navigator at least equal to 1 x 10-6 lux, and that the lights shall be sized such that the illuminance be as equal as possible while viewing them within the channel segment.

Refer to IALA Recommendation E-112 Equation 5 (Allard’s Law):

1. The illuminance at the eye of the light (Allard’s Law)

Where:

*E* is the threshold -> required? of illuminance in lux

*I* is the intensity in candelas

*D* is the distance from the light to the far end of the channel in metres

*V* is the visibility in metres

The minimum night-time intensity can be calculated by solving Equation.16 for Intensity (I):

1. Minimum night-time intensity (1)

(if I have Equation 6 right, should this not be ?)

**See cells D30 & D35**

Where:

*I* is the intensity in candelas

*E* is the threshold of illuminance in lux

*D* is the distance from the light to the far end of the channel in metres

*D*' is the distance from the light to the far end of the channel in NM

*V'* is the Visibility in NM

The threshold of illuminance (E) increases during night-time conditions when background lighting is present. The illuminance is multiplied by factors of 1, 10 and 100 for none, minor and considerable background lighting, respectively. For daytime conditions the threshold of illuminance (E) multiplier is set to 1000. **See cell C68**.

A selected intensity value lower than the suggested minimum intensity will result in printing of only a portion of the leading line evaluation. It is assumed that the lights will not be usable in the unprinted portions.

## Maximum Intensity

Maximum intensity is determined by the glare limit (see Prevention of Glare, p. 4 in IALA Recommendation E-112) using the same equation, as above. Glare occurs when the illuminance at the eye of the navigator (E) exceeds 0.01 lux when viewed at night with no background lighting and 0.1 lux with background lighting in maximum visibility. See cell C69.

## Equality of Illuminances

The illuminances at the eye of the navigator within the useful channel segment provided by the two lights should be as equal as possible. This requires a suggested intensity ratio between the front and rear lights. Allard’s law is used to determine the ideal ratio.

Since, from Equation 7 ,

and since transmissivity (T) and visibility are related by the expression , then by substitution intensity can also be expressed as:

1. Minimum night-time intensity (2)

Also, since the illuminances of both the front and rear lights are to be designed to be equal (i.e.: ER = EF = E), the following equation applies:

1. Intensity ratio

Where:

is the Intensity ratio

is the distance from the rear light to the halfway point of the channel in NM

is the distance from the front light to the halfway point of the channel in NM

*T* is the transmissivity

*E* is the illuminance (factors out)

The equation determines the ideal intensity ratio to achieve equal illuminance at the halfway point in the channel. An additional calculation is performed at the far end to ensure that the ratio does not exceed 2:1. **See cells C88 to C90**.

**Calculation of area of retroreflecting film on leading marks (Finnish guidelines)**

“Reflectors are mostly used as alternatives to lights on small craft routes and other less important roures. However, they have importance on lighted fairways as well in case of failure of a light.

At first, the light source is selected for observing the reflectors. On small crafts 10 000 cd and on ships ca 100 000 cd search lights can be expected.

Then the minimum size of the reflector can be calculated by the formula:

A = D4E/ IR0,052D/18520 (2.4.1)

Modified for the treshold of illuminance:

E = AIR0,052D/18520/ D4 (2.4.2)

A – area of the reflector [m2];

E – treshold of illuminance [lx];

D – observing distance [m];

I – intensity of the light source [cd];

R – reflecting coefficient of the reflector [lx/m2/cd]. *(At 3M web page it is cd/lux/m2)*

In principle the calculations can be made as for lights but, as the main purpose is to get strong enough reflection, maximum values need not to be calculated. Retroreflecting film is placed on the middle stripe of the leading mark so that it covers ¾ of that stripe, and a quarter of the area of the whole daymark. Film of the front mark begins from the lower edge of the daymark and the film of the rear mark begins from the upper edge of the daymark (so that that the reflectors will not blur making using the leading line difficult). The reflection is decreasing very fast with the distance and the maximum distance does not exceed 4000 m even with powerful searchlights. In practice the distances are 0 ... 2500 m are used. The colour of the reflector is always white.

When the areas to be covered with the reflectors are determined the value of E is determined for both marks with the formula (2.4.2).”

## Separation of Lights

The rear tower shall be of sufficient height so that the lights do not blur together. The calculation is performed at both the near and far ends using the calculated luminances at these points. The following equation determines the vertical separation in milliradians required to prevent the lights from blurring together.

Refer to IALA Recommendation E-112 Equation 11 (master blur equation). **See cells AA7 to AA17, AA23 to AA33 and AA39 to AA49**.

1. Vertical separation in milliradians

Where:

is the illuminance ratio

the maximum illuminance of either the front or rear lights

= vertical separation in milliradians

Refer to IALA Recommendation E-112 Equation 13.

The vertical separation of two lights given the front and rear tower height is expressed as

1. Vertical separation of front & rear lights

Where;

rear tower height at mean low water (MLW) in metres

is the front tower height at MLW in metres

*b* is the height of eye in metres (the program assumes *b* is at MLW)

*c* is the mean range of tides in metres

*x* is the distance from front tower to observer in metres

*R* is the distance between towers in metres

Solving for H2 at mean high water (**cells C108 & C109**):

This calculation is performed at both the near and far ends of the useful segment.

The front tower and dayboard (if equipped) must be tall enough to be seen at the far end of the channel at the lowest height of eye.

Refer to IALA Recommendation E-112 Equation 18, (geographical range).

1. Geographic range (metres)

Where;

*H* is the front tower height in metres

*c* is the mean range of tides in metres

*b* is the height of eye at mean high water in metres

The program uses the equivalent equation in English units:

1. Geographic range (feet & NM))

Where:

*D* is the distance to the horizon in NM

*H* is the height of the tower/observer in feet

The geographic range is the sum of the distance to the horizon from observer (*b*) and front tower (). Therefore:

1. Distance from front tower to observer in nautical miles

Where:

*b* is the height of eye in feet

is the front tower height at mean high water in feet

*x* is the distance from front tower to observer in NM

Solving for in metres:

**See cell C98.**

Since the bottom of the dayboard must be seen at the geographic range, the front dayboard length (if used) is added to .

The entire rear dayboard (if used) must be visible above the front dayboard at the far end of the useful segment and at least one-half of it visible above the front dayboard at the near end of the segment.

Refer to IALA Recommendation E-112 Equation 13 with set to zero.

Where;

rear tower height at MLW in metres

is the front tower height at MLW in metres

*b* is the height of eye in metres

*c* is the mean range of tides in metres

*x* is the distance from front tower to observer in metres

*R* is the distance between towers in metres

for the far end:

1. Height of rear tower from the far end of the useful channel segment

for the near end:

1. Height of rear tower from the near end of the useful channel segment

Where

*RL* is the dayboard length in metres.

**See cells D110 and D111**.

The front tower must be tall enough to be unobstructed by objects placed in front of it. In addition, the rear tower must be tall enough to be unobstructed by objects placed between the towers. Refer to IALA Recommendation E-112 Equation (14):

Where

*H”* is the height of front/rear tower in metres from MHW

*H’* is the height of obstruction in metres from MHW

*b* is the height of eye in metres

*c* is the mean range of tides in metres

u is the distance between observer and obstruction in metres

*S* is the distance between tower and obstruction in metres

Solving for *H”*

See cells C99 to C102 and C112 to C115.

This calculation is performed at both the near and far ends of the useful segment. Since the entire front dayboard (if used) must be visible at either end of the segment, the dayboard length is added to H’ (**See cells D99 to D102**). Likewise, the entire rear dayboard (if used) must be visible above the front dayboard when viewed at the far end of the segment and only one-half of it when viewed at the near end (**See cells C112 to C115 and D112 to D115**).

The program evaluates the tower heights calculated by the safe height above water, necessity to avoid obstructions, ability to see the dayboards, geographic range, and separation of lights (blur) for selected intensities, at either high or low tide (whichever is appropriate), and recommends a front and rear tower height. If the selected tower height values are lower than the recommendations, an error message is posted.

## Sensitivity (Cross Track Factor)

Refer to IALA Recommendation E-112 Equation 16:

1. Off-axis distance

Recalling that , the Off-axis Distance, is defined as the lateral distance at which a navigator can detect with certainty that a vessel is not on the channel centerline. The Cross Track Factor (CTF) is defined as the ratio of the lateral distance at which a navigator can detect with certainty that a vessel is not on the channel centerline, divided by the half-width of the channel, expressed as a percentage. The Cross Track Factor (CTF) provides an intuitive method to relate the sensitivity performance of the leading line signals to the specific channel in which is being used. The following calculation applies:

1. Percentage Cross Track Factor

**See cells AE7 to AE17, AE23 to AE33 and AE39 to AE49**.

Where:

*CTF* is the cross track factor in percent

is the Off axis distance in metres

*W* is the Channel width in metres

The off axis distance, can also be expressed as:

1. Off-axis distance (2)

**See cells AD7 to AD17, AD23 to AD33 and AD39 to AD49**

Where;

is the Position in channel segment being evaluated in metres

*R* is the Distance between lights in meters

*M* is the Distance between useful segment and front tower in metres

Horizontal separation of the lights in radians

## Dayboards

‘The study of visibility by day has not in general been the subject of so much attention. Daymarks are often not so important a necessity to the seaman as are lighthouses, in view of natural landmarks which are available to him. Moreover, it must be admitted that the problem of the visibility of daymarks is vastly more complicated than that of lights by night and this has had its effect in discouraging investigators.’[[1]](#footnote-1)

Early range design calculations were done manually and multiple tables were available to assist the designer in dayboard sizing. Those early tables, derived from work by Dr H. R Blackwell and S. Q. Duntley, provided a method of determining the range of specific dayboard sizes and films against various backgrounds. They were later further simplified to provide the range for a given size, regardless of film type and background. These simpler tables formed the basis of international practice for many years.

The tables used in this leading lines program are derived from the simplified table[[2]](#footnote-2) used by the U.S. Coast Guard from the early 1980’s to the present, and which has provided many years of successful dayboard performance in keeping with design expectations. The following table lists the rated visual range in kilometres of selected dayboard lengths in meters. The shaded portion represents the portion of the table that was extrapolated using the appropriate fill command in Microsoft Excel.

1. Operational Range in km for Specific Dayboard Lengths

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Visibility  NM | *Dayboard Length* | | | | | | |
| *1.6m* | *2.1m* | *3.1m* | *4.2m* | *6.3m* | *8.6m* | *12.2m* |
| 1 | 0.9 | 1.3 | 1.7 | 1.9 | 2.0 | 2.4 | 2.7 |
| 2 | 1.1 | 1.7 | 2.2 | 2.6 | 2.8 | 3.4 | 3.8 |
| 3 | 1.1 | 2.0 | 2.8 | 3.5 | 3.9 | 4.8 | 5.5 |
| 4 | 1.3 | 2.4 | 3.3 | 4.3 | 5.0 | 6.0 | 7.0 |
| 5 | 1.5 | 2.8 | 3.9 | 5.0 | 6.1 | 7.3 | 8.5 |
| 6 | 1.5 | 3.0 | 4.3 | 5.4 | 6.7 | 8.0 | 9.3 |
| 7 | 1.7 | 3.2 | 4.4 | 6.1 | 7.4 | 8.9 | 10.3 |
| 8 | 1.7 | 3.2 | 4.8 | 6.5 | 7.8 | 9.5 | 11.0 |
| 9 | 1.7 | 3.5 | 5.3 | 7.0 | 8.3 | 10.2 | 11.9 |
| 10 | 1.9 | 3.7 | 5.6 | 7.4 | 9.3 | 11.1 | 13.0 |

This table expresses dayboard size in terms of height in meters and range in kilometres based on the presumption that the dayboard height will be 1.5 times the width, a common international practice. For reviewers seeking to reconcile the above dimensions with current U.S. dayboard tables, note that the conversion was based on equivalent areas. U.S. dayboards are constructed with a 2:1 ratio of height to width (largely due to the North American standard plywood size of 4 feet by 8 feet), with height expressed in feet and range in miles.

For example, a U.S. dayboard 24 feet in length and 12 feet in width has a total area of 288 square feet, or 26.8 square meters. The length of an equivalent dayboard using the international ratio is:

Dayboard Length (m)

The contents of Table 5 are plotted to show the pattern of dayboard lengths for specific visibilities. The best curve fit was chosen and appropriate equation displayed to calculate the dayboard length in a given visibility at a specific range. In this case, the natural logarithmic function was chosen. It is noted that due to the slope of the curves, calculated values outside the limits of dayboard length reveal unsatisfactory results. Therefore, error messages were placed in the program warning the user to select values within the limits.

*Something on shape, colours, stripe widths? Reference to guideline on daymarks?*

1. Pattern of dayboard lengths for specific visibilities

The following equations were generated by Microsoft Excel to approximate the curves for the 10 visibilities:

y = 0.8064Ln(x) + 0.6518

y = 1.2356Ln(x) + 0.6893

y = 2.0415Ln(x) + 0.3778

y = 2.6895Ln(x) + 0.2425

y = 3.3375Ln(x) + 0.1072

y = 3.7147Ln(x) - 0.0199

y = 4.199Ln(x) - 0.156

y = 4.5228Ln(x) - 0.2975

y = 4.8962Ln(x) - 0.3264

y = 5.3861Ln(x) - 0.4892

These equations are used in the leading lines program to provide a suggested dayboard size for a specific level of minimum visibility (**See cells N92 to R115**). The range of the selected dayboard size is then calculated and compared to the suggested size, and if smaller, displays an error code at points in the channel beyond which the dayboard may not be visible at the minimum visibility (**See cells N75 to R76**).

**Finnish guideline** has simple formulas for sizes of daymarks:

*“Dimensions of dayboards are calculated by the following formula:*

*k = d × 0,00052 + v1*

*l = d × 0,0004 + v2*

*where*

*k = height of dayboard (m)*

*l = width of dayboard (m)*

*d = observing distance (m)*

*v1, v2 = constants*

*Observing distances:*

*Front mark: d = far end of useful segment*

*Rear mark: d = far end of useful segment + distance between marks*

*Constants:*

*Merchant fairways at sea: v1 = 1,9 ja v2 = 1,4*

*Inland and small vessel routes: v1 = 1,3 ja v2 = 0,9*

*On merchant fairways at sea minimum dimensions of the dayboards are k×l = 4,5×3,0 m2 and inland and small vessel routes 1,5×1,0 m2. Rear dayboard can, in special cases, be remarkably higher. Dayboard’s maximum size is 100 m2.“*

**Russian guidelines** calculate the width of the daymarks according to the distance to the far end with the formulas 2b1 = 0.58D (front dayboard) and 2b2 = 0.58(D+d) (rear dayboard) (resulting in 2’ width) and „in most cases“ multiply it with 3...5 to get the height of the marks.

Finnish guidelines result in biggest daymarks among the guidelines mentioned here.

Would reference to IALA Guideline on Daymarks for AtoN be relevant in the Guildeine on Leading Lines?

## Daytime Leading Line Design Worksheet

The detailed design for a leading line is accomplished on the Daytime Leading Line Design Worksheet (click on worksheet tab ‘Leading Line-Day’). All computations are the same as described on the night-time leading line worksheet, with the threshold of illuminance (E) set to1000. **See cell C68**.

## Final Leading Line Configuration Design Worksheet

No additional calculations are made on this final spreadsheet (click on worksheet tab ‘Final Design Layout’). This sheet provides a conveniently summarized presentation of all the leading line’s prominent configuration and design attributes on a single worksheet suitable for printing and filing in project records.

# DEFINITIONS

The definition of terms used in this Guideline can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary) at <http://www.iala-aism.org/wiki/dictionary>.

# ACRONYMS

CTF Cross Track Factor

FL Front light

HoE Height of Eye

IALA International Association of Marine Aids to Navigation and Lighthouse Authorities - AISM

Mac Macintosh (Apple)

MHW Mean High Water

MLW Mean Low Water

mrad milliradians

MRT Mean range of tide

NM nautical miles

OS Operating System

RL Rear light

SAFHW Safe height above water

US United States (of America)

USCG United States Coast Guard

YMF Off-axis distance at far end of channel

YMN Off-axis distance at near end of channel

# REFERENCES

1. IALA Recommendation E-112 For leading lights.

1. M. Blaise, IALA Bulletin No. 47 (April, 1971) article Titled ‘Daymarks as Aids to Navigation.’ [↑](#footnote-ref-1)
2. USCG, Instruction M16500.4, Range Design (1980), p. E2-2 [↑](#footnote-ref-2)