Paper 56 - Contribution of channel lighting to the safety of navigation as seen from the pilots perspective

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ABSTRACT: Inland channels in the Netherlands with combined inland waterway and sea going traffic have channel lighting comparable to streetlights in normal road traffic. Considering that all vessels are equipped with radar and most vessels nowadays are equipped with electronic chart devices, it is questioned if an expensive and energy consuming system of channel lighting still is necessary for safe navigation. A study was started to determine the contribution of the channel lighting to the safety of navigation. Design aspects like the distance, colour and flash pattern of the lights were studied. The paper describes the set-up, the results and conclusions of the study in relation to the design aspects and as seen from the river pilots perspective.

1 INTRODUCTION

Channels in the Netherlands with combined inland waterway and sea going traffic have channel lighting comparable to streetlights in normal road traffic. Considering that all vessels both inland waterway vessels and sea going vessels are equipped with radar and most vessels nowadays are equipped with electronic chart devices, it is questioned if an expensive and energy consuming system of channel lighting still is necessary for safe navigation. A study was started using a manoeuvring simulator to determine the contribution of the channel lighting to the safety of navigation. In a first phase of the study inland skippers sailed a bended channel with a four barge push convoy during night handling meetings with sea going traffic. During the simulations distances to banks, distances to other traffic and the swept path were measured together with physiological (workload) measurements like heartbeat and the capability to perform an additional secondary task. The results of the first phase showed for tight situations (160 m channel width) a strong correlation between the availability of channel lighting and the performance in terms of distances to banks, distances to other traffic and workload of the skippers. For wide channels no correlation was found between the availability of channel lighting and the performance. It was concluded that from the perspective of the inland skipper channel lighting is only necessary in tight situations (Hove, D. ten, 2014).

The first phase focussed only on the necessity of lighting for the inland skippers and studied the availability of channel lighting and the distance between the lights. As a follow up, in a second phase also river pilots sailed the same bended channel during night with a large bulk carrier and handled meetings with inland vessels and other sea going traffic. In this second phase also design aspects like the colour and flash pattern of the lights were studied. The methodology for the second phase was identical to the first phase and is based on measuring performance in terms of workload and distances to banks and other traffic during a navigation task with and without channel lighting. In case of channel lighting the following design aspects were varied:

- Distance between the lights;
- Colour of the lights;
- Flash pattern of the lights.

2 EXPERIMENT IN THE MANOEUVRING SIMULATOR

2.1 *Research question*

The goal of the experiment is to investigate the effect of channel lighting on the workload and performance of river pilots. In the experiment the river pilots sail a a large coal carrier. During the passage of the channel they twice encounter a bulk carrier. The first time at a straight part of the channel, later on a second meeting in a curve.

2.2 *Experimental setting*

Fairway

A representation of the modelled fairway is given in Figure 1. In this figure North is above. Two vessels sail a fixed southward track. The north going vessel, a coal carrier, is sailed by the participating river pilots. The run starts with a straight part. The first encounter takes place in the first stretch. The second encounter is in the curve to the left. These locations are represented with the frameworks in Figure 1. The channel is 265 m wide at the surface and 170 m wide at the bottom, at 15 m depth. The depth and cross sections are corresponding with the Noordzeekanaal in The Netherlands.

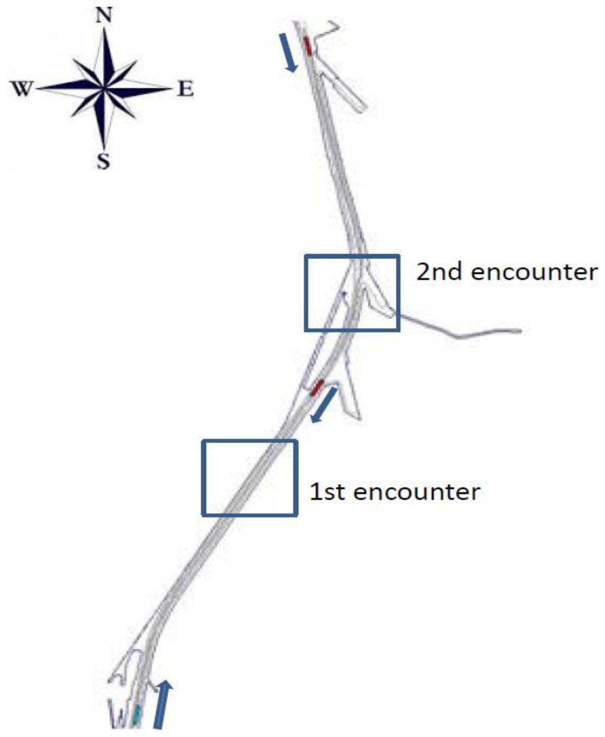

Figure 1: Representation of the fairway

Channel light

Four different lighting conditions are modelled for the river pilots:

- without channel lights;
- with white channel lights every 100 meter (Figure 2);
- with white channel lights every 200 m;
- with green 8 sec. isophase (4 sec. on, 4 sec. off) lights on the left bank and red 8 sec. isophase lights on the right bank every 200 meter (Figure 3).

Wind

Wind Beaufort 5 (mean wind speed 10 m/s) from a westerly direction is modelled. Wind gusts are introduced by a Davenport wind spectrum. Wind shielding caused by the encountering bulk carriers is taken into account. During the encounter, the coal carrier sails partly in the wind shadow of the encountering bulk carriers.

Figure 2: White channel lights every 100 m

Figure 3: Red/green isophase lights every 200 m

Vessels

The main particulars of the coal carrier ars given in Table 1. The encountering bulk carriers are respectively a Capesize bulk carrier 277x42.2x13.5 m (1st encounter) and a Panamax bulk carrier 225x32.3x12 m (2nd encounter).

Type of vessel	Coal carrier
Length overall (Loa) [m]	248
Beam [m]	32.2
Draft [m]	8
Displacement [tonnes]	50240
Deadweight [tonnes]	70000
Power [kW]	8000
Height of bridge above water level [m]	25

Table 1: Main particulars of the coal carrier (Panamax sized)

Scenarios

The coal carrier starts on the south side of the channel and sails north. The vessel speed is 8 kts.

During the simulations most river pilots maintained a slightly higher vessel speed to increase the controllability of the coal carrier in crosswind. After sailing the bend, the skipper chooses its transverse position in the fairway for the first meeting with the bulk carrier. The bulk carriers sail southwards on the centreline with a cruising speed of 6 kts. With these speeds, the first meeting is in the middle of the straight section and the second meeting in the curve to the left. Variations are in the configuration of the channel lights. Table 2 lists the different scenarios

Scenario	Channel width	Channel light	Amount of repetition (candidates)
F	265 m	None	6 (S1,S2,S3,S4,S5,S6)
G	265 m	White, every 100 m	6 (S1,S2,S3,S4,S5,S6)
H	265 m	White, every 200 m	6 (S1,S2,S3,S4,S5,S6)
I	265 m	Red/green isophase, every 200 m	6 (S1,S2,S3,S4,S5,S6)

Table 2: List of scenarios

Execution of simulations

The simulations were executed during a three days session with six experienced river pilots. Every day two candidates started with a briefing and familiarisation run and alternately sailed one of the scenarios. Every scenario is repeated by 6 river pilots (see Table 2). To avoid any learning effect, the conditions were randomly divided over the participants.

2.3 *Methodology*

To measure workload and performance in a simulator training setting, a methodology is being used that combines performance measures like distances to banks and other traffic and workload measurements with a secondary task performance (Uitterhoeve et al. 2014, Uitterhoeve et al. 2012).

Workload

Assuming that no single parameter could indicate workload and that reliability increases as more indicators point out the same, several parameters are obtained. For subjective effort rating the Rating Scale of Mental Effort (RSME) developed by Zijlstra (De Waard 1996) is used. This rating scale runs from 0 to 150 and contains levels from "absolutely no effort" till more than "extreme effort". The candidate puts a mark on this scale (see Figure 4).

To measure focus on the main task, a peripheral detection task (PDT) is added. The secondary task applied in the experiment consists of reacting to a red flash light in the peripheral view of the candidate (see Figure 5). The reaction time and missed stimuli are the indicators for spare mental capacity (Martens et al.).

Performance

The simulator delivers several time traces. In this experiment time traces of rudder angle, distance to the starboard border and distance to the encountering bulk carriers are taken into account. An overall interpretation of the workload and simulator data provides additional information about cause and effect.

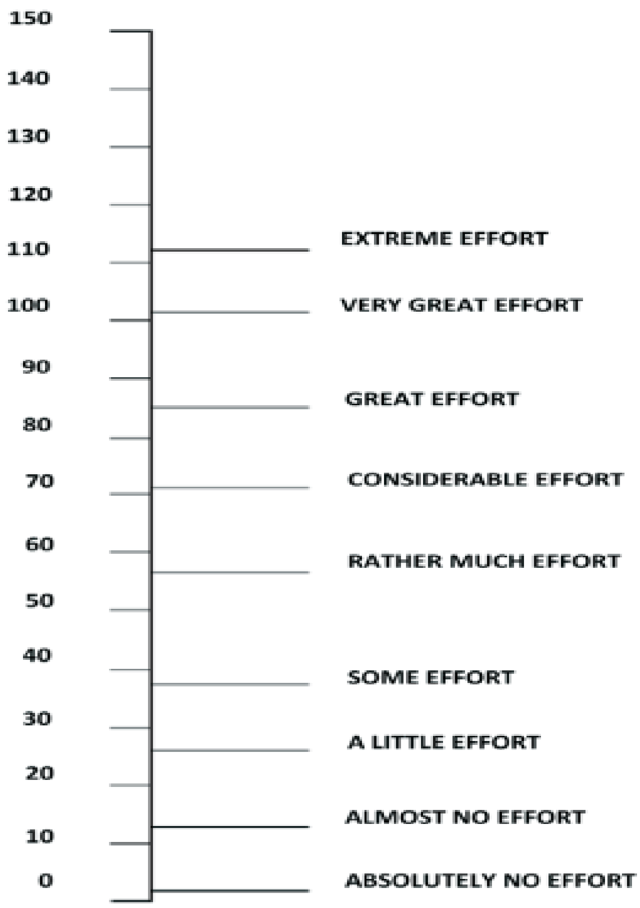

Figure 4: Rating Scale of Mental Effort (RSME)

Figure 5: Candidate wears the secondary task (PDT) helmet

Figure 6: Impression of the experimental setting

2.4 *Procedure*

Before the start of the first run, candidates (river pilots) were briefed and prepared to the test. This comprises putting on a heartbeat belt and the PDT equipment and checking the wireless connection of both systems. The heart rate and secondary task were measured during the total run, approximately 30 minutes. The RSME score is filled in twice; first during the simulation directly after the first encounter and second directly after the run after the second encounter. The runs stopped when a stable situation after the second encounter was reached. Stable in this case means that the vessel is back on its original track and that lateral movements are minimized. This was most of the times within a few minutes after the second encounter.

2.5 Data analysis

The numerical analysis is based on a comparison of the mean and the standard deviation of the following parameters: RSME-score, reaction time PDT, missed stimuli PDT, rudder angle, the distance to the starboard shore, the swept path and the distance to the bulk carriers in three successive intervals:

- Sailing the straight section before reacting on the oncoming bulk carrier;
- The meeting with the first bulk carrier in the second half of the straight section,
- The meeting with the second bulk carrier in the second bend.

The first interval begins when the coal carrier passed the first bend and lines up for the straight section to approximately a quarter of the straight section with a total length of 600 m. The second interval begins when the distance bow to bow for the coal carrier and the first bulk carrier is 5.5L (with L = 248 m, the length of the coal carrier) and ends when the sterns are at the same height. The third interval begins when the distance bow to bow for the coal carrier and the second bulk carrier is 5.5L and ends when the sterns are at the same height. In the second and third interval the coal carrier makes an evasive manoeuvre for the meeting with the first and second bulk carrier, respectively.

Data is analysed and results are discussed with regard to three topics:

- Used space: the distance to the starboard shore, the swept path and the distance to the bulk carrier;
- Controllability: the rudder angle;
- Workload: the RSME-score and the reaction time PDT.

Figure 7: Example trackplot, meeting in the second bend, scenario H

3 RESULTS

3.1 *Used space*

Based on general guidelines the following minimum distances are advised for safe manoeuvring:

- smallest distance to the shore 47.5 m;
- smallest distance to the bulk carriers 32.2 m;
- maximum path width in the straight section 48.3 m;
- maximum path width in the bend 54.7 m.

Scenario	river pilot	first meeting (straight section)		
		maximum path width [m]	smallest distance to shore [m]	smallest passing distance [m]
F	**average**	**43.8**	**62.1**	**31.3**
	1	50.8	68.1	17.0
	2	42.3	58.3	38.5
	3	39.3	60.9	34.9
	4	45.8	67.2	26.5
	5	44.4	64.3	30.1
	6	40.0	53.7	40.8
G	**average**	**42.6**	**63.2**	**30.2**
	1	39.2	70.7	28.0
	2	38.0	69.5	25.6
	3	39.8	66.9	32.9
	4	41.5	68.8	26.1
	5	38.9	53.3	41.7
	6	58.0	50.2	27.2
H	**average**	**40.5**	**62.4**	**33.7**
	1	39.9	70.2	28.1
	2	39.9	75.8	21.8
	3	39.3	48.7	47.4
	4	42.3	66.5	27.6
	5	38.0	52.5	42.9
	6	43.9	60.6	34.4
I	**average**	**41.9**	**64.7**	**30.4**
	1	40.5	62.5	34.1
	2	37.1	74.2	26.3
	3	41.3	64.5	31.8
	4	45.0	71.1	23.7
	5	46.3	61.3	28.8
	6	41.3	54.5	37.8

Table 3: Results for used space (1st meeting)

Table 3 and 4 show the maximum path width, the smallest distance to the shore, and the smallest passing distance to the bulk carriers. The results are given for each scenario and on the top line (in bold) is the average value for all river pilots and below the score for each separate river pilot. The fields that the criterion distance for safe manoeuvring is not satisfied is marked in red. The distance to the shore is marked orange if it is more than 47.5 m but less than 63.6 m.

Scenario	river pilot	second meeting (bend)		
		maximum path width [m]	smallest distance to shore [m]	smallest passing distance [m]
F	**average**	**46.8**	**62.8**	**24.5**
	1	43.0	77.3	28.1
	2	47.7	55.3	28.7
	3	44.1	63.5	27.7
	4	49.3	66.4	15.3
	5	51.2	65.1	23.2
	6	45.4	49.0	23.9
G	**average**	**49.8**	**61.0**	**26.7**
	1	42.8	57.2	22.7
	2	45.8	62.9	25.5
	3	38.6	74.0	20.5
	4	68.9	61.3	27.3
	5	47.9	48.6	38.8
	6	55.0	62.1	25.3
H	**average**	**51.8**	**61.5**	**27.2**
	1	40.3	78.3	23.2
	2	45.4	75.0	14.8
	3	56.4	48.7	26.7
	4	68.2	60.9	26.1
	5	57.3	44.2	39.8
	6	43.2	62.1	32.6
I	**average**	**54.0**	**55.5**	**24.6**
	1	41.3	58.3	24.6
	2	47.0	65.6	20.1
	3	71.6	45.2	29.2
	4	47.0	61.4	17.8
	5	61.6	49.3	35.0
	6	55.3	53.3	20.8

Table 4: Results for used space (2nd meeting)

It is clear from the tables that for all scenarios during the meeting the criterion for the smallest passing distance is exceeded. One of the reasons is that both meeting vessels stayed as close as possible to the fairway centreline and as far as possible from the banks. The difference between the scenarios with regard to the extreme values is small. Although with the white lights (scenario G and H) the vessels stayed closer to the bank. Scenario F, without channel lighting showed in general that the river pilots stayed closer to the centreline with smaller passing distances to the other vessels. The scenario with the red/green isophase lights (scenario I) was regarded as extremely annoying and confusing. The orientation was adversely affected and the passing distance became smaller.

Lining up for the straight channel section after the bend was easier with the lights along the banks. In this case there was no difference between the white lights and the red/green isophase lights.

Finally an analysis of the standard deviation of the path width, the distance to the banks and the passing distance (Figure 8) shows a significant decrease in standard deviation for the scenarios with channel lighting (G, H and I). The orientation is much better than without lights, resulting in a better control of the position relative to the banks and the other traffic.

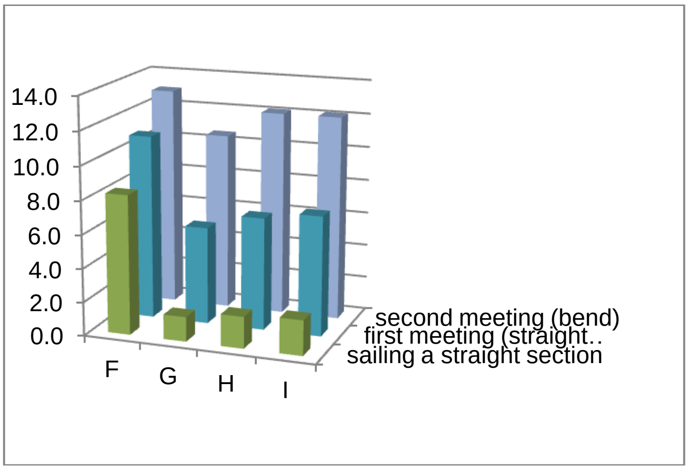

Figure 8: Standard deviation of the distance to the shore

3.2 *Controllability*

Figure 9 shows the standard deviation for the three different sections (lining up after the bend, first meeting and second meeting). The standard deviation is small indicating that the situation in all cases is easy to control. However for the straight section there is a clear trend that the standard deviation with channel lights is smaller than without channel lighting. The lighting along the bank makes it possible to detect and to react more quickly and efficiently to deviations in the rate of turn. The response of the radar alone is too slow for this. The effect was already evident in the distribution of the distance to the banks (Figure 8).

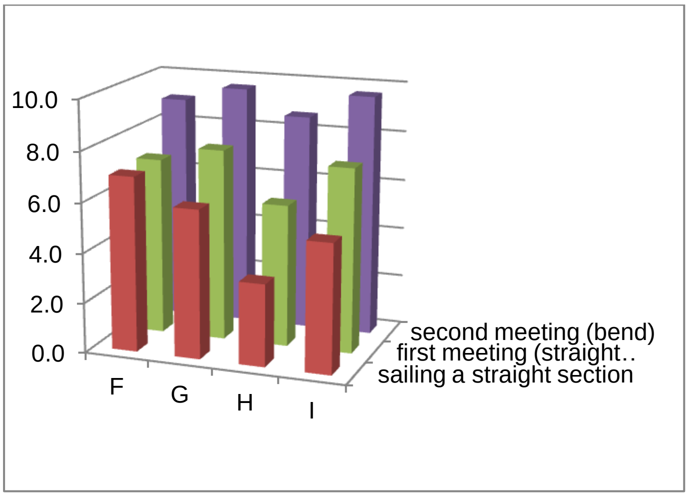

Figure 9: Standard deviation of the rudder angle [deg]

3.3 Mental workload

Figures 10 and 11 show the RSME score and the average response time in the secondary task. Together they reflect the total load of the task. The values for the RSME-score are in the range from 16 (almost no effort) to 85 (high effort). It is clear that the encounter in the bend is experienced as more difficult than the meeting in the straight section. Ranking the scenarios by the RSME score from high (much effort) to low (less effort) then the order is: F (no lights), I (red/green isophase lights every 200 m), H (white lights every 200 m), G (white lights every 100 m) with only small differences between G and H. This is consistent with the ranking the river pilots indicated in the debriefing.

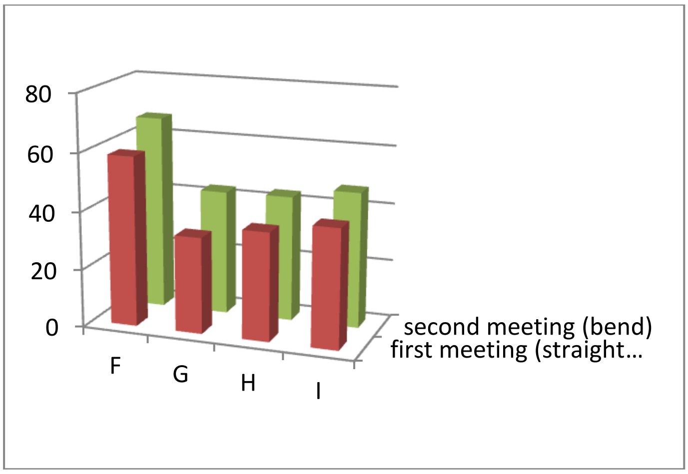

Figure 10: RSME score

Presence of white lights along the banks results in a significant reduction in response times and the number of misses which means that navigation with white lights along the bank requires much less concentration. Remarkably, the reaction times with red/green illumination are highest. They are for the straight channel section even higher than in the situation without lights and for the meetings similar to the situation without lights. Most likely this is caused by the blinking character of the lighting. Every 4 seconds the visual situation changes and the internal information processing system of the river pilots has to anticipate. This confirms the subjective assessment of the river pilots that the red/green illumination was perceived as tedious and confusing. Overall, we see that the mental workload of the situation with red/green lighting and without lighting is clearly above the mental workload with fixed white lights along the bank.

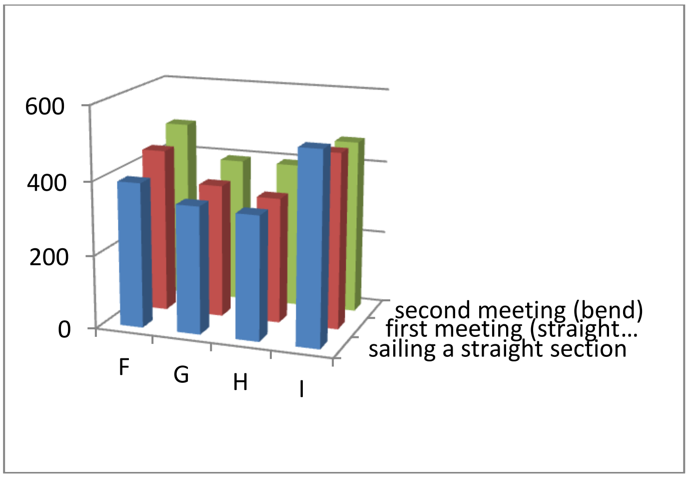

Figure 11: PDT average response time

4 CONCLUSIONS

Ranking the scenarios on used space, controllability and mental workload shows a clear difference between the scenario without light and the scenario with red/green light on the one hand and the scenarios with white lights on the other. The workload of the situations with red/green lighting or without lighting is higher than the mental workload with fixed white lights along the bank.

There is little difference between the scenarios with 100 m and 200 m separation distance. It is concluded that a separation distance of 200 m is sufficient.

A red/green isophase lighting of the banks is discouraged. A continuously lit red/green light would score better in this case, although it is better for the orientation on both sides to have the same colour of lighting.

The lighting should not be bright white, but more toward yellow with a clear illumination of the banks to the waterline to highlight a rigid separation of bank and water. A more diffuse yellow colour avoids confusion with lights of other ships and navigation marks.

The first phase of the study already concluded that from the perspective of the inland skippers in the tight situation of 160 m channel width the channel lighting is necessary for safe navigation in the dark (Ten Hove 2014). Based on a comparison of the performance measures it is concluded that from the perspective of the river pilot channel lighting contributes to safer navigation in all circumstances. A row of lights on each bank with a fixed separation distance between the lights provides very fast information on the rate of turn of the own vessel and the relative position of the own vessel to other traffic and to the banks. E.g. the river pilots indicated that in most cases a small rate of turn is detected earlier from a row of lights than from the instruments like a rate of turn indicator or the ECDIS.

It is concluded that is is particularly important that the presence of channel lighting primarily contributes to the rapid identification of abnormal movement (drift and rotation speed).

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