FLOODSTAND

FP7-RTD- 218532

Integrated Flooding Control and Standard for Stability and Crises Management

FLOODSTAND-deliverable:

Report on the method for assigning of uncertainty bounds for methods for M-A-R assessment.

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Revision	3.0
Deliverable No.	D5.5
Date	30 January 2012

SEVENTH FRAMEWORK PROGRAMME

Document identification sheet		
FLOODSTAND	**Integrated Flooding Control and Standard for Stability and Crises Management**	FP7-RTD- 218532

Title: Report on the method for assigning of uncertainty bounds for methods for M-A-R assessment.	**Other report identifications:**
Investigating partners: SSRC, BMT, BV **Authors: Y.HIFI (SSRC)** **Reviewed by**:	
[ ] **Outline** [ ] **Draft** [x] **Final** **Version number:** 3.0 **Revision date**: **Next version due:** **Number of pages**: 89	[x] **A deliverable** [ ] **Part of a deliverable** [ ] **Cover document for a part of a deliverable** [ ] **Deliverable cover document** [ ] **Other** **Deliverable number**: D5.5 **Work Package**: WP5 **Deliverable due at month**: 30
Accessibility: [x] **Public** [ ] **Restricted** [ ] **Confidential (consortium only)** [ ] **Internal (accessibility defined for the final version)**	**Available from**: http:/floodstand.aalto.fi **Distributed to**: **Disclosees when restricted:** **Comments:**

Abstract:
This deliverable describes the methods used to establish the uncertainty bounds for the MAR process as well as the assessment of the abandonment and rescue using the Casualty Calculator developed in task 5.2.

Acknowledgements
The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 218532. The financial support is gratefully appreciated.

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1 Executive summary

The aim of task 5.5 is to establish the uncertainty bounds on the Mustering, Abandonment and Rescue (MAR) process.

In addition and as explained in FLOODSTAND deliverables D5.2, D5.3 and D5.4 it was deemed more meaningful to analyse the sensitivity of the expected number of fatalities at the end of the whole Mustering-Abandonment-Rescue process rather than on each phase individually (i.e task 5.2, task 5.3 and task 5.4).

Therefore this report presents the methods used to determine the uncertainty bounds as well as a detailed analysis of the results obtained when the abandonment and rescue phases are assessed using the Casualty Calculator software developed in task 5.2.

2 Introduction

The present deliverable deals with the uncertainty bounds of the MAR process.

The sensitivity analysis as well as the overall assessment of the MAR process will also be presented in this deliverable as explained in the deliverables D5.2, D5.3 and D5.4.

Although the main aim of task 5.5 was to establish the uncertainty bounds, a large part of this report is dedicated to the analysis of the results of the assessment of the whole abandonment and rescue process using the Casualty Calculator software.

In the first part of the document the methods to assign uncertainty bounds are presented. The distinction is made here between the mustering phase of the MAR process and the abandonment and rescue phases.

The first phase was assessed using the evacuation simulation tool. The main result of the assessment was the estimated evacuation time. The uncertainty bounds corresponding to the estimated time are given as an output of the software as will be explained later in section 3.1.

For the rest of the process, namely the abandonment and the rescue which were assessed using the degradation of the human health status method (see D5.1 and D5.2), the specifically developed software to estimate the expected number of fatalities that might occur during the process also provides the uncertainty bounds that correspond to the expected number of fatalities as introduced in D5.2 and further explained in section 3.2 of this document.

In the second part of this document (section 4), the whole abandonment and rescue process is assessed using the Casualty Calculator and the impact of some relevant obstacles is evaluated and further assessed. Section 5 presents the results for the reference ships. Section 6 deals with the error propagation and finally the conclusions are presented in section 7.

3 Uncertainty bounds

3.1 The mustering phase

The assessment of the mustering phase of the MAR process and the assessment of the obstacle “Embarkation” (D5.3) were performed using Evi, the evacuation simulation tool as described in FLOODSTAND deliverable D5.2.

In Evi uncertainties are accounted for by modelling every parameter (continuous or discrete) as a random variable with a predefined distribution to capture the unpredictable aspect of human behaviour (especially under unusual circumstances such as facing an emergency).

The probability distributions for each random variable are sampled using the Monte Carlo method. The results of the different instances of the simulation execution will then exhibit a reasonable amount of variation.

The term Evacuability - $Evacuability(t, env, dist)$ can then be defined to be the probability of an environment being completely evacuated no later than a time t in a given state of the environment env (the layout and the conditions) and a given state of initial distribution $dist$ of people in the environment (including the distribution of behavioural attributes).

For the evacuation times of a number n of instances, given that the environment and the distribution remain the same, represented as a multiset $\{t_1, t_2, \cdots, t_n\}$ and by the law of large numbers, the Evacuability is expressed as:

$$E(t) = \lim_{n\to\infty} \frac{1}{n} \left(\sum_{i=1}^{n} F(t_i, t)\right)$$

Where,

$$F(a,b) = \begin{cases} 1, & a \leq b \\ 0, & otherwise \end{cases}$$

$E(t)$ can be estimated with a finite number of trials for a sufficiently large value of n.

$E(t)$ is monotonically increasing function of time as it is a cumulative probability distribution function.

More details can be found in (D.Vassalos et al.).

During the assessment of the mustering phase in task 5.2 and the embarkation obstacle in task 5.3, the results were provided in FLOODSTAND deliverables D5.2 and D5.3 with their minimum and maximum values.

3.2 The abandonment and rescue phase

The abandonment and rescue phases were assessed using the Casualty Calculator software developed in task 5.2 and described in FLOODSTAND deliverable D5.2.

The Casualty Calculator produces as output the expected number of fatalities as well as the associated standard deviation.

The uncertainties are accounted for through the computation of the "error" associated to the health vector as explained in "*Appendix A*" of FLOODSTAND deliverable D5.2.

For convenience, the explanation is reproduced below.

Standard deviation

The "error" of the output health vectors is calculated algebraically from the means and variances of the obstacle matrices. We use the following formula.

Claim:
Let A and B be two $n \times n$ matrices whose entries are independent random variables. We denote by $\langle A \rangle$ and $var(A)$ the expectation value and variance of A, respectively. Define $\tilde{A}$ to be the matrix containing the squared entries of $\langle A \rangle$ (and equivalently for B). The variance of the product of the two matrices is given by

$$var(A \cdot B) = \tilde{A} \cdot var(B) + var(A) \cdot \tilde{B} + var(A) \cdot var(B)$$

Proof:
Denote the entries of A and B by a_{ij} and b_{ij}, respectively. Using the well-known relations

$$var(x + y) = var(x) + var(y)$$
$$var(x \cdot y) = \langle x \rangle^2 var(y) + \langle y \rangle^2 var(x) + var(x) var(y)$$

for independent real-valued random variables x and y, we find for the product matrix:

$$\begin{aligned}
\left(var(AB)\right)_{ij} &= var\left((AB)_{ij}\right) \\
&= var\left(\sum_{k=1}^{n} a_{ik} b_{kj}\right) \\
&= \sum_{k=1}^{n} var\left(a_{ik} b_{kj}\right) \\
&= \sum_{k=1}^{n} \left(\langle a_{ik} \rangle^2 \cdot var\left(b_{kj}\right) + \langle b_{kj} \rangle^2 \cdot var(a_{ik}) + var(a_{ik}) \cdot var\left(b_{kj}\right)\right) \\
&= \left(\tilde{A} \cdot var(B) + var(A) \cdot \tilde{B} + var(A) \cdot var(B)\right)_{ij}
\end{aligned}$$

□

For a product of more than two matrices, the above equation is applied repeatedly.

Using this formula, it is straightforward to compute the variance of the output health vector. In particular, the variance of the expected death rate (D) is given by

$$var(D) = GH_{in}^2 \cdot var(M_{41}) + MI_{in}^2 \cdot var(M_{42}) + SI_{in}^2 \cdot var(M_{43}) \quad ,$$

where GH_{in} etc. denote the input health coefficients (which are known exactly and hence have variance zero) and M is the product of all relevant obstacle matrices.

The computation of the error through the Casualty Calculator will be presented in section 6 of the document.

4 The Abandonment and Rescue phases: Application of the Casualty Calculator and sensitivity analysis

List of abbreviations

In the rest of the document the following abbreviations will be used.

LB:	Lifeboat
LR:	Liferaft
HW obstacles:	Hardware obstacles (see D5.2 for a detailed description)
HF obstacles:	Human factor obstacles (see D5.2 for a detailed description)
MAR:	Mustering Abandonment and Rescue
LSA:	Life Saving Appliances
HHS	Human Health Status
SSx:	Sea state *x* where *x* is 3, 5 or 6
DL LR:	Davit launched Liferaft

As introduced in Deliverable D5.2, the application of the Casualty Calculator to the abandonment (except obstacle A6: embarkation which was assessed using Evi) and the rescue phases is explained in this deliverable.

A number of scenarios were defined to be tested. The relevant parameters were identified as being:

- the distribution of passengers in the different age groups,
- the different sea states,
- the exposure time and
- the availability of the Life Saving Appliances (Lifeboats).

4.1 Parameters

1. Passengers' distribution per age group

Four different distributions of passengers per age group were studied:

- two extreme cases where all passengers are in the young age group (P1) and all passengers are in the old age group (P2),
- a third case where all passengers are evenly distributed in the three age groups (P3) and
- a final case (P4) where most passengers (2/3) are in the middle age group and the rest are evenly distributed between the young and old age group.

The matrix below summarises the different proportions per age group.

	P1	P2	P3	P4
Young age group	1	0	0.33	0.17
Middle age group	0	0	0.33	0.67
Old age group	0	1	0.33	0.17

2. Sea state

Three (03) seas states were considered in this study: sea states 3, 5 and 6.

3. Exposure time

The exposure time is the time during which people will remain in the LSA waiting to be rescued. During this time they will be exposed to some health risks such as seasickness or injuries due to motions in the LSA. The periods considered in this study are 4h, 8h, 12h and 16h.

4. Number of available Lifeboats

To account for the fact that if the ship is heeling too much half of the total number of Lifeboats will not be available. Two cases were considered: (a) total number of Lifeboats is available and (b) only half of the total number of Lifeboats is available.

The number of Liferafts was deemed to always be enough (because of the excess capacity) and could accommodate for the lost capacity of the Lifeboats.

4.2 Sequence of events

In order to define a realistic scenario to assess the whole MAR process, a sequence of obstacles that passengers must face, were they to abandon the ship, needs to be defined.

In the rest of the document, the two different types of Life Saving Appliances (LSA), namely Lifeboats (LB) and Liferafts (LR) will be looked at separately as some of the obstacles are particular to only one type of LSA.

The obstacles that were deemed important to the MAR process are listed in the table below (please refer to D5.3 and D5.4 for a more detailed descriptions of the obstacles).

A2	Davit deployment/malfunction
A7	Structural failure/capsize due to premature release of LSA
A8	Structural failure due to impact against the hull
A16_LB	Failure to clear off the vessel/LB
A16_LR	Failure to clear off the vessel/LR
R6_LB	Lifeboat capsize
R6_LR	Liferaft capsize
A9_LB	Injuries due to impact of LB against hull/lowering

A10_LB	Injuries due to slamming of LB
A11	Injuries while using the escape ladders
A15_LR	Injuries while moving to seats in LR
R3-R5	Injuries while transferring Passengers
R7_LB	Injuries due to LB motions
R7_LR	Injuries due to LR motions
R8_LB	Hypothermia in LB
R8_LR	Hypothermia in LR
R9_4hours	Seasickness for specified time of exposure
R9_8hours	Seasickness for specified time of exposure
R9_12hours	Seasickness for specified time of exposure
R9_16hours	Seasickness for specified time of exposure

In defining the sequence of obstacles and as a first stage, only Human Factor obstacles were considered and they are:

A. Injuries due to:
    1. Impact of LB against the hull,
    2. Slamming of LB
    3. Using escape ladders
    4. Moving to seats in LR
    5. LSA motions
    6. Transferring passengers during rescue.
B. Hypothermia (please see below **Note**)
C. Sea seasickness

Distinction was made between "davit-launched" LR and LR boarded through ladders as it is the case for the Estonia which had both types of LRs.

The sequence of obstacles is then:

LB

A_{9LB} A_{10LB} R^{**}_{7LB} R^{**}_{8LB} $R^{*}_{9\_x\ hours}$ $R_{3\text{-}5}$

DL LR

A_{15LR} R^{**}_{7LR} R^{**}_{8LR} $R^{*}_{9\_x\ hours}$ $R_{3\text{-}5}$

LR

$A_{11}A_{15LR}$ R^{**}_{7LR} R^{**}_{8LR} $R^{*}_{9\_\ x\ hours}$ $R_{3\text{-}5}$

* Different exposure time *x*, where *x* is either 4, 8, 12 or 16 hours.
** if the exposure time is 4h then the obstacle appears only once in the sequence. If the exposure is 8h, then it appears twice in the sequence. For 12h, it appears 3 times and for 16h, 4 times.

<u>Note on Hypothermia:</u>

For this study it was assumed that the water temperature was above 5°C so no hypothermia would occur in Liferafts.
People in Lifeboats are not exposed to hypothermia whatever the water temperature as the interior of LBs is assumed to remain dry (Please refer to FLOODSTAND deliverable D5.4 for more details).

The impact of this obstacle for water temperature below 5°C was assessed for the LR only in sea state 6. The results will be presented at the end of section 4.

As a next stage, the HW obstacles were introduced in the sequence of obstacles.

HW obstacles can be separated into weather dependent obstacles and weather independent obstacles as follows:

Weather **dependent**:

- Structural failure due to impact against the hull
- Failure of LSA to clear off the vessel
- Capsize of LSA.

Weather **independent**:

- Davit deployment/malfunction
- Structural failure/capsize due to premature release of LSA

The different cases considered in this study are defined by varying the weather independent obstacles in the sequence of obstacles as follows:

- only one of the weather independent HW obstacles is present in the sequence,
- both are present and
- finally both are absent from the sequences.

For simplicity we assume that if no davit deployment/malfunction occurs for the LB it will not occur either for the davit launched LR.
The same holds for the premature release of the LSA.

As explained in Appendix A (section 5) of FLOODSTAND deliverable D5.2, in the computation of the expected number of fatalities one of the assumption was that passengers are subject to HW obstacles before HF obstacles.

The four sequences are then:

- 1st case (only A2 present)

LB	**DL LR**
A_2 A_8 A_{16LB} R_{6LB} A_{9LB} A_{10LB} R^{**}_{7LB} R^{**}_{8LB} $R^{*}_{9\_x\ hours}$ $R_{3\text{-}5}$	A_2 A_{16LR} R_{6LR} A_{15LR} R^{**}_{7LR} R^{**}_{8LR} $R_{9\_x\ hours}$ $R_{3\text{-}5}$

- 2nd case (only A7 present)

LB	**DL LR**
A_7 A_8 A_{16LB} R_{6LB} A_{9LB} A_{10LB} R^{**}_{7LB} R^{**}_{8LB} $R^{*}_{9\_x\ hours}$ $R_{3\text{-}5}$	A_7 A_{16LR} R_{6LR} A_{15LR} R^{**}_{7LR} R^{**}_{8LR} $R^{*}_{9\_x\ hours}$ $R_{3\text{-}5}$

- 3rd case (both present)

LB	**DL LR**
A_2 A_7 A_8 A_{16LB} R_{6LB} A_{9LB} A_{10LB} R^{**}_{7LB} R^{**}_{8LB} $R^{*}_{9\_ x\ hours}$ R_{3-5}	A_2 A_7 A_{16LR} R_{6LR} A_{15LR} R^{**}_{7LR} R^{**}_{8LR} $R^{*}_{9\_x\ hours}$ R_{3-5}

- 4th case (both absent)

LB	**DL LR**
A_8 A_{16LB} R_{6LB} A_{9LB} A_{10LB} R^{**}_{7LB} R^{**}_{8LB} $R^{*}_{9\_x\ hours}$ R_{3-5}	A_{16LR} R_{6LR} A_{15LR} R^{**}_{7LR} R^{**}_{8LR} $R^{*}_{9\_x\ hours}$ R_{3-5}

Although the obstacles are in a sequence it might happen that they occur simultaneously. To account for that and because matrix multiplication is generally not symmetric, it was decided to consider the mean of the different combinations of matrix multiplications corresponding to the simultaneous obstacles. This only applies when HF obstacles matrices are multiplied together. For HW obstacles the specific shape of their degradation matrices makes the multiplication symmetric.

Passengers boarding LR through the ladders are not subjected to the weather independent obstacles A2 and A7 as they are not part of the sequence of obstacles. The four cases explained above are not applicable here. For this type of LR the sequence of obstacles is as follows:

A_{16LR} R_{6LR} $A_{11}A_{15LR}$ R^{**}_{7LR} R^{**}_{8LR} $R^{*}_{9\_x\ hours}$ R_{3-5}

4.3 Results

The expected number of fatalities is computed as follows:

$$N\_fatalities_{LSA} = young\_rate_{LSA} * N\_young_{LSA} + middle\_rate_{LSA} * N\_middle_{LSA} + old\_rate_{LSA} * N\_old_{LSA}$$

Where,

$young\_rate_{LSA}$, $middle\_rate_{LSA}$ and old_rate_{LSA} are respectively the rate of fatalities for the young, middle and old age group for a particular type of LSA.

N_young_{LSA} , N_middle_{LSA} and N_old_{LSA} are respectively the total number of people in the young, middle and old age group in that particular type of LSA.

For the sensitivity analysis it was decided to study the fatality rates instead of the expected number of fatalities for the following reasons:

- The same sequence of obstacles was used for both the Estonia and the Cruise Liner, for the LB and davit launched LR.
- Fatality rates depend on the sea state and the exposure time only.

- The expected number of fatalities can be easily computed from the fatality rates as explained above.

The expected number of fatalities will be presented for both the Estonia and the Cruise Liner in the case study section (section 5).

The input matrices corresponding to the obstacles in the sequences considered in this study are as defined in D5.3 and D5.4 and are summarised for convenience in Appendix I.

4.3.1 Human Factor obstacles only

For each sea state and for the different exposure times corresponding to the sequence of obstacles defined in section 4.2, the fatality rates were computed using the Casualty Calculator software (available in Appendix II).

For the Lifeboats:

The fatality rate for the young group is constant whatever the exposure time. The rate for sea state 5 and 6 are close together with the rate for sea state 3 being a third of the rate for the sea state 6 (Figure 1).

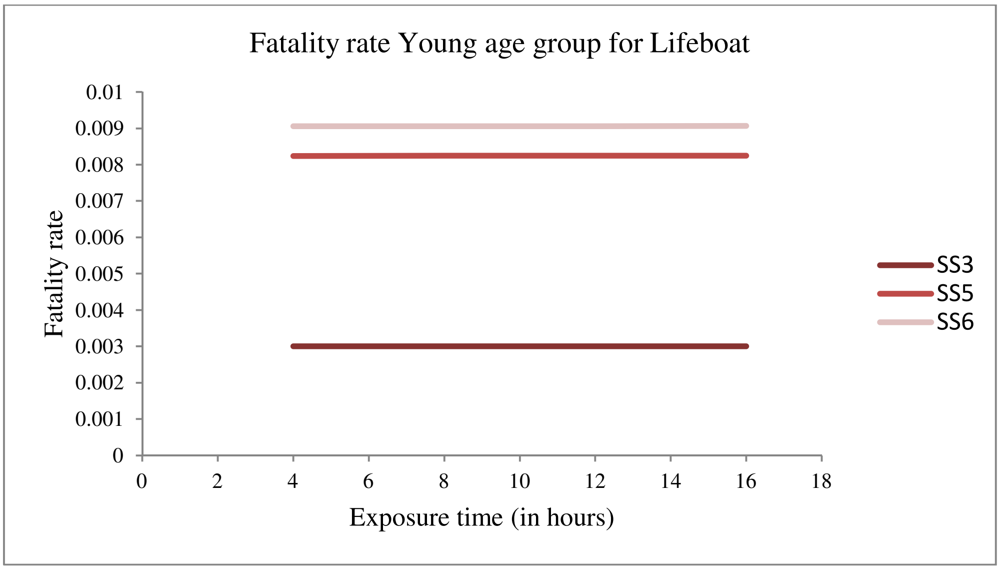

Figure 1: Fatality rate for the young age group in LB for HF obstacles only

For the middle group, the fatality rate increases linearly with the exposure time in a same manner for sea states 5 and 6. In sea state 3 the increase is linear with the exposure time but in a much smaller order of magnitude.
Compared to the young age group and for sea state 5 and 6, the fatality rate for the middle age group is almost double the fatality rate for the young group (Figure 2) but remains quite small.

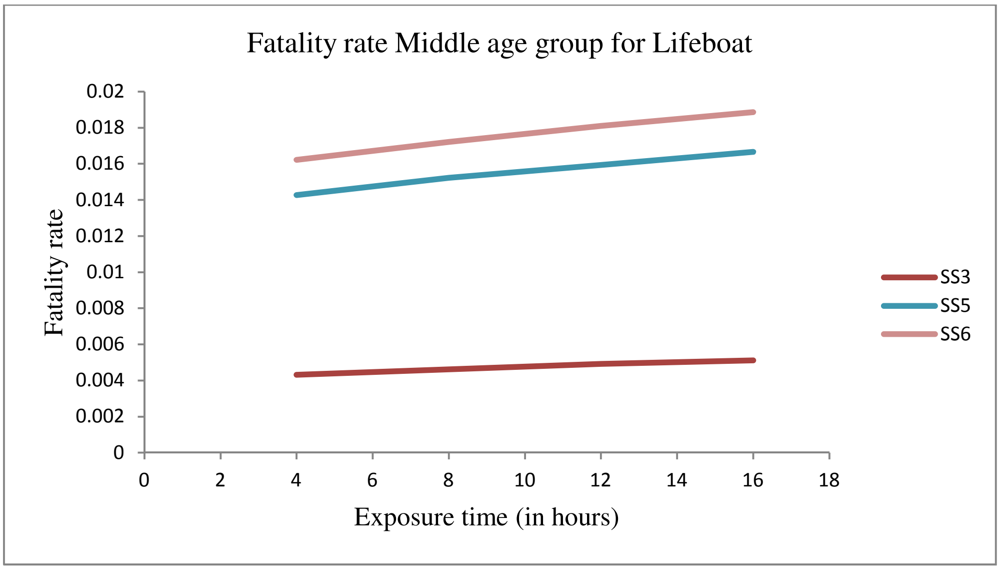

Figure 2: Fatality rate for the middle age group in LB for HF obstacles only

The same tendency as with the middle age group is observed for the old group but with higher fatality rates for all sea states. There is also a bigger gap between the fatality rates of the old age group for sea state 5 and 6 than for those of the middle age group for the same sea states (Figure 3).

Figure 3: Fatality rate for the old age group in LB for HF obstacles only

For the Davit launched Liferafts

The fatality rate for the young age group in sea state 3 is the same as the one for the Lifeboat and is constant whatever the exposure time. Sea state 5 and 6 have the same constant fatality rate whatever the exposure time which is practically equal to the fatality rate of the young age group for the Lifeboat at sea state 5 (Figure 4).

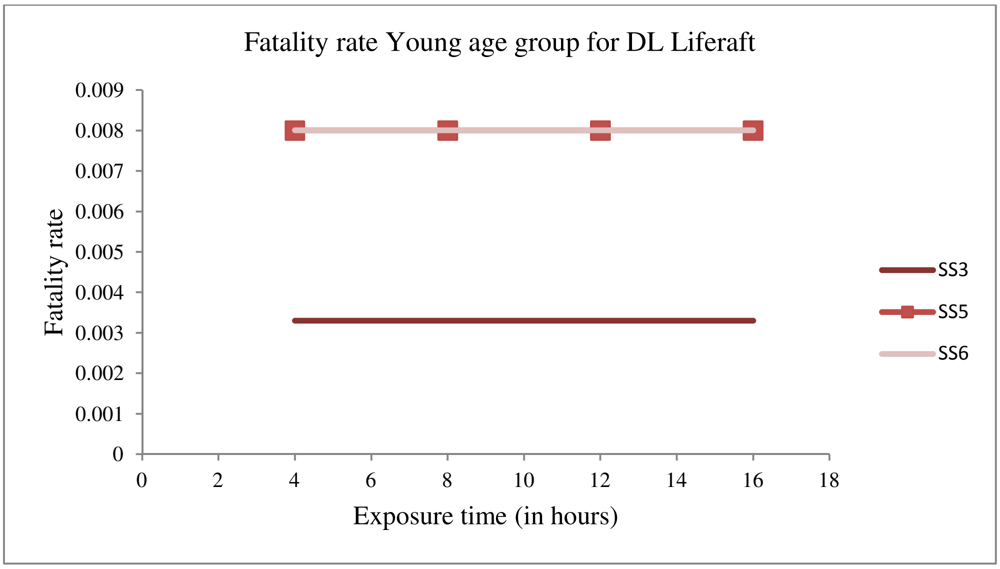

Figure 4: Fatality rate for the young age group in DL LR for HF obstacles only

For the middle age group the fatality rate increases linearly with the exposure time. Sea states 5 and 6 have almost the same fatality rates (Figure 5).

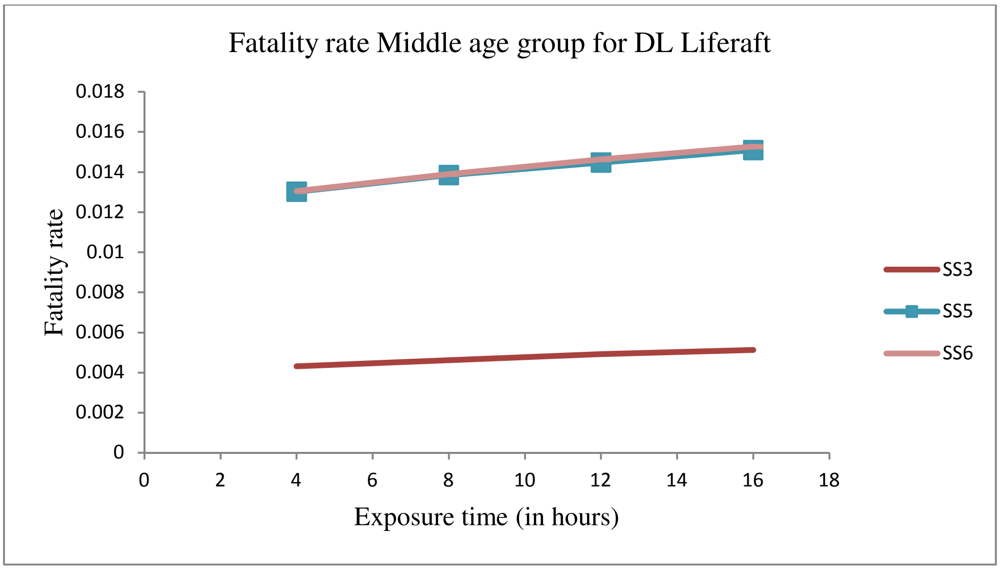

Figure 5: Fatality rate for the middle age group in DL LR for HF obstacles only

For the Old age group, again the fatality rate for sea state 5 and 6 are the same and increase linearly with the exposure time (Figure 6).

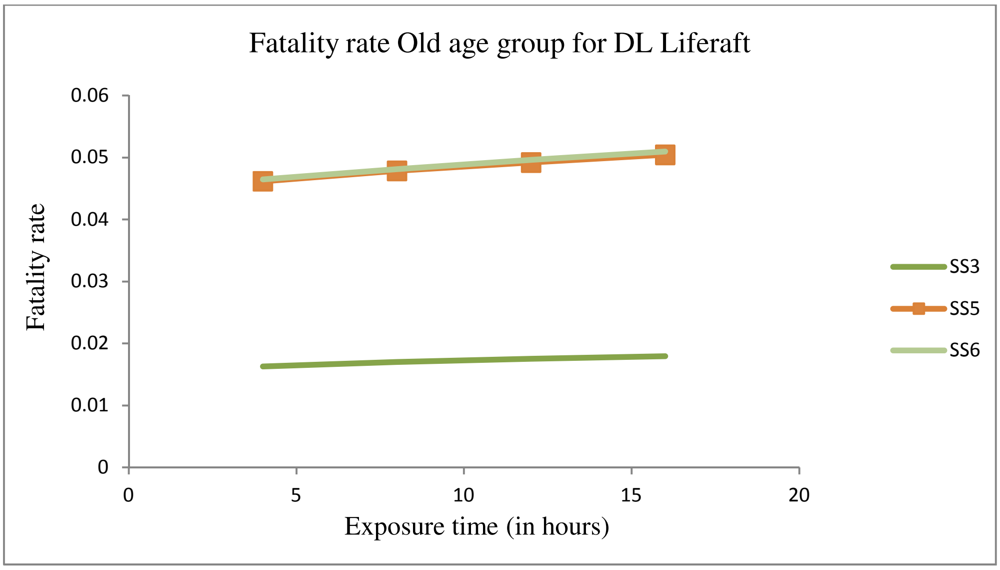

Figure 6: Fatality rate for the old age group in DL LR for HF obstacles only

For the ladder-boarded Liferafts

The difference in the sequences of obstacles between the davit launched LR and the LR boarded through ladders, is the obstacle A11.

The same kind of results as for the davit launched LR are observed here too.

The fatality rate for the young age group remains constant whatever the sea state. In addition the fatality rate for sea state 5 and 6 are the same (Figure 7).

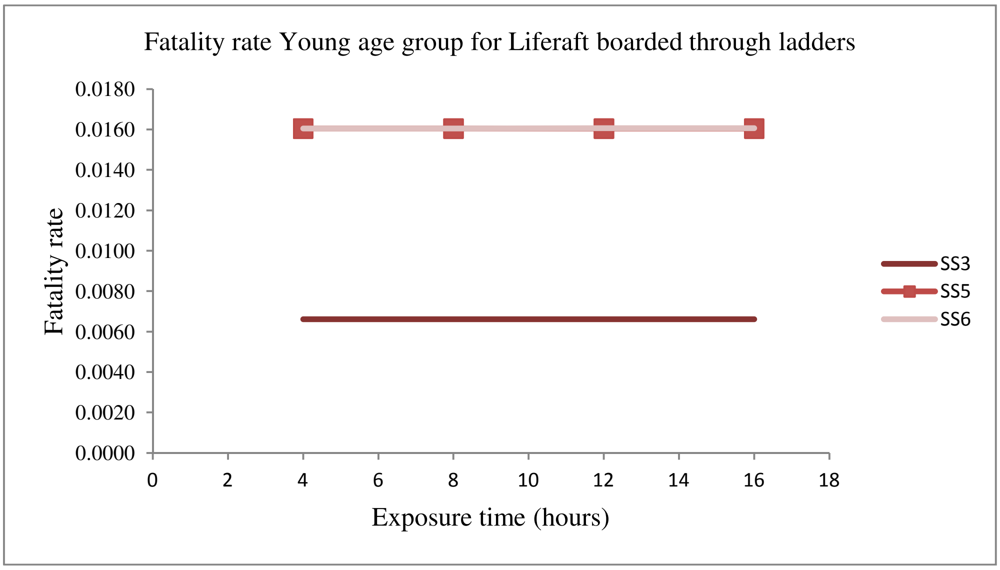

Figure 7: Fatality rate for the young age group in ladder boarded LR for HF obstacles only

For the middle age group the fatality rate increases linearly with the exposure time. Sea states 5 and 6 have almost the same fatality rates (Figure 8).

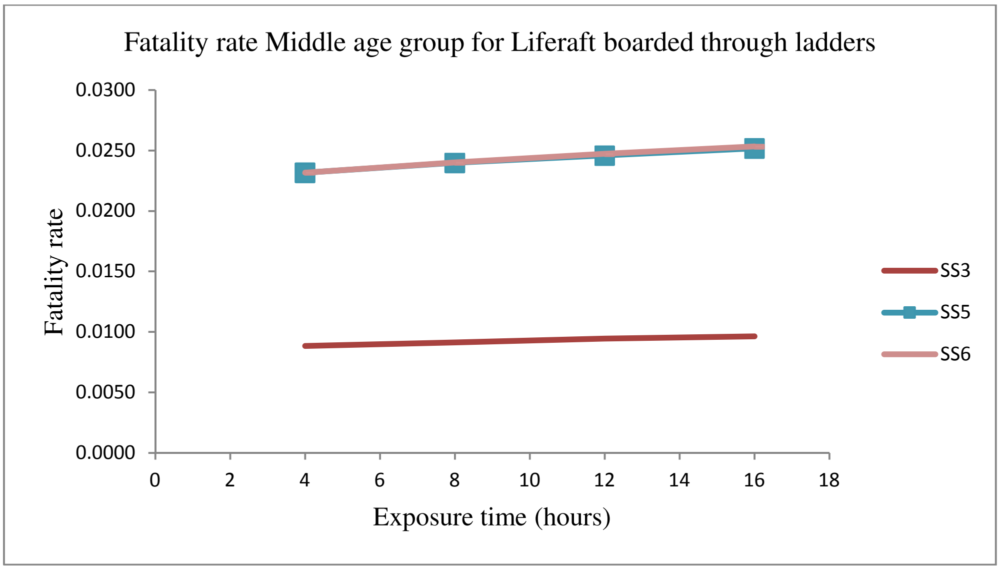

Figure 8: Fatality rate for the middle age group in ladder boarded LR for HF obstacles only

For the Old age group, again the fatality rate for sea state 5 and 6 are the same and increase linearly with the exposure time (Figure 9).

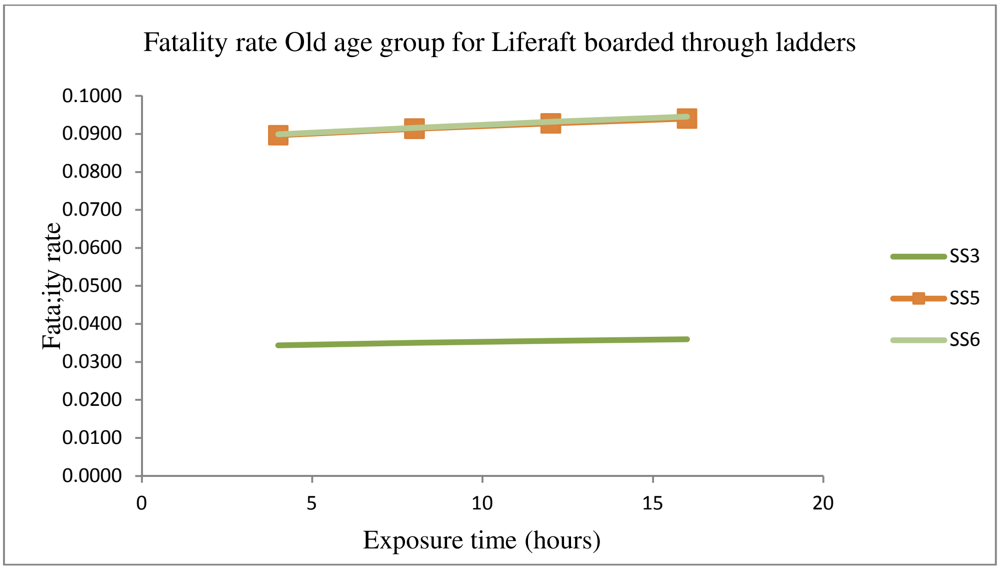

Figure 9: Fatality rate for the old age group in ladder boarded LR for HF obstacles only

The major difference between the results for the davit launched LR and the ladder boarded LR is that the fatality rates are much higher for the latter because of injuries while using the ladders.

The percentage changes in the fatality rates per age groups are shown in the tables below.

The young age group

Exposure (hours)	SS3	SS5	SS6
4	100.21%	100.57%	100.56%
8	100.21%	100.57%	100.54%
12	100.21%	100.57%	100.52%
16	100.21%	100.57%	100.50%

Table 1: Percentage change in fatality rates between DL LR and ladder boarded LR for the young age group

The middle age group

Exposure (hours)	SS3	SS5	SS6
4	87.16%	78.26%	78.16%
8	81.86%	73.68%	73.53%
12	77.27%	70.61%	69.94%
16	74.46%	67.81%	67.12%

Table 2: Percentage change in fatality rates between DL LR and ladder boarded LR for the middle age group

The old age group

Exposure (hours)	SS3	SS5	SS6
4	93.53%	93.94%	93.34%
8	89.92%	90.54%	90.01%
12	87.55%	87.97%	87.12%
16	85.74%	85.71%	84.75%

Table 3: Percentage change in fatality rates between DL LR and ladder boarded LR for the old age group

For every age group, the highest fatality rate corresponds to a 16 hours exposure time in a ladder boarded LR at sea state 6 mainly because of the high fatality rate of obstacle A_{11} (injuries when using the ladders). At these highest rates and in the respective age groups, there would be one fatality for every:

- 62 people in the young age group.
- 39 people in the middle age group.
- 11 people in the old age group

When the LSA consist only of LB and DL LR, the highest fatality rate corresponds to a 16 hours exposure time in a Lifeboat at sea state 6. This is because there is one more obstacle in the sequence of obstacles of the LBs than in the sequence of the LRs. In addition the fatality rate of obstacle R_7 is higher for the LB than it is for the LR.
At these rates there would be one fatality for every:

- 110 people in the young age group.
- 53 people in the middle age group.
- 14 people in the old age group.

4.3.2 HF and HW obstacles

Adding HW obstacles to the sequences of HF obstacles, the fatality rates change and the results for the 4 different cases defined in section 4.2 are shown below.

First the results for the Lifeboat are presented for each age group and for all four cases, where:

- **Case 1** is the sequence of obstacles with HF obstacles, weather dependent obstacles and only one (obstacle A2) of the weather independent obstacles,
- **Case 2** is the sequence of obstacles with HF obstacles, weather dependent obstacles and only the second (obstacle A7) of the weather independent obstacles,
- **Case 3** is the sequence of obstacles with HF obstacles, weather dependent obstacles and both weather independent obstacles (obstacle A2 and A7),
- **Case 4** is the sequence of obstacles with HF obstacles and weather dependent obstacles only.

The results are then compared to assess first the impact of the exposure time and second the effect of the HW obstacles as well as the weather independent obstacles (A2 and A7). For that only case 3 and case 4 are compared as they represent the extreme cases (with and without the weather independent obstacles).

The results for the Davit launched Liferaft will be presented in the same way.

For the ladder-boarded LR, as mentioned previously the four cases are not applicable, so the results will be presented at the end of the section.

Lifeboat results
Impact of exposure time

Case 1: Young age group

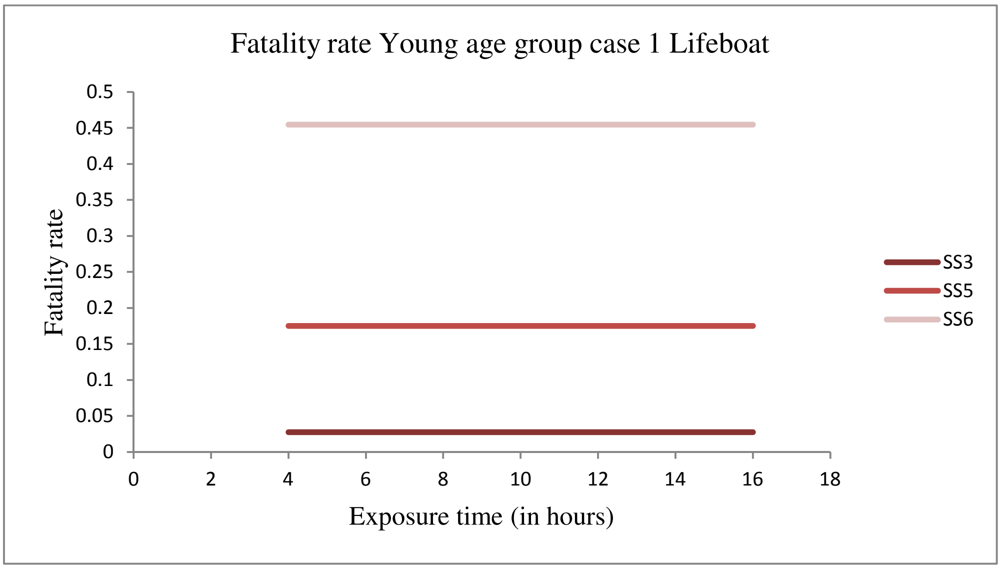

Figure 10: Fatality rate for the young age group in LB for HF+HW obstacles case1

Case 2: Young age group

Figure 11: Fatality rate for the young age group in LB for HF+HW obstacles case2

Case 3: Young age group

Figure 12: Fatality rate for the young age group in LB for HF+HW obstacles case3

Case 4: Young age group

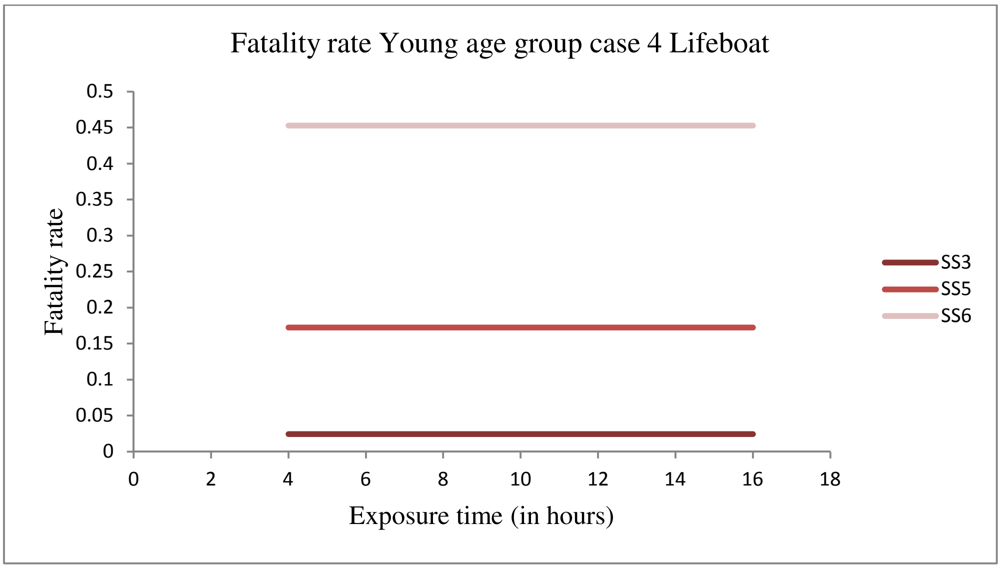

Figure 13: Fatality rate for the young age group in LB for HF+HW obstacles case4

The fatality rate for the young group remains constant whatever the exposure time in all 4 cases and in all sea states.

Case 1: Middle age group

Figure 14: Fatality rate for the middle age group in LB for HF+HW obstacles case1

Case 2: Middle age group

Figure 15: Fatality rate for the middle age group in LB for HF+HW obstacles case2

Case 3: Middle age group

Figure 16: Fatality rate for the middle age group in LB for HF+HW obstacles case3

Case 4: Middle age group

Figure 17: Fatality rate for the middle age group in LB for HF+HW obstacles case4

For the middle age group, the fatality rate is almost constant whatever the exposure time in all 4 cases and in all sea states.
The percentage changes in the fatality rate from 4 hours to 16 hours exposure time per case for each sea state are summarised in Table 4 below. The percentage change is small for sea state 3 (at the most 3%) and negligible for sea state 5 (about 1%) and 6 (about 0.3%).

	Case 1	Case 2	Case 3	Case 4
Sea state 3	2.74%	2.95%	2.63%	3.08%
Sea state 5	1.10%	1.11%	1.09%	1.12%
Sea state 6	0.32%	0.33%	0.32%	0.33%

Table 4: Percentage changes in the fatality rate for the middle group from 4h exposure time to 16h for LB

Case 1: Old age group

Figure 18: Fatality rate for the old age group in LB for HF+HW obstacles case 1

Case 2: Old age group

Figure 19: Fatality rate for the old age group in LB for HF+HW obstacles case 2

Case 3: Old age group

Figure 20: Fatality rate for the old age group in LB for HF+HW obstacles case 3

Case 4: Old age group

Figure 21: Fatality rate for the old age group in LB for HF+HW obstacles case 4

For the old age group, the fatality rate is almost constant whatever the exposure time in all 4 cases and in all sea states.

The percentage changes in the fatality rate from 4 hours to 16 hours exposure time per case for each sea state are summarised in Table 5 below.

The percentage change is bigger than for the middle age group for sea state 3 but is still a small change (about 4%). For seas state 5 the percentage change is also bigger than for the middle age group but remains a small change (2 %). For seas sate 6 it is still negligible (less than 1%).

	Case 1	Case 2	Case 3	Case 4
Sea state 3	3.80%	4.00%	3.70%	4.11%
Sea state 5	2.02%	2.04%	2.01%	2.06%
Sea state 6	0.62%	0.62%	0.62%	0.62%

Table 5: Percentage changes in the fatality rate for the old group from 4h exposure time to 16h for LB

Conclusion:

The fatality rates for the young age group are constant whatever the exposure time and that in all the four cases.

A very small change in the fatality rate as a result of the exposure time is observed for sea state 3 for the middle and old age groups.

In sea state 5 and 6 the changes to the fatality rates over the exposure time are negligible.

So the exposure time has almost no impact on the fatality rate and it can be assumed constant for all age groups.

Impact of weather independent obstacles

Whatever the age group, having both the weather independent obstacles in the sequence of obstacles (case 3) leads, as expected, to a higher fatality rate compared to when both obstacles are not in the sequence of obstacles (case 4) or when only one obstacle is present (case 1 or case 2).

For the young age group, the fatality rate for case 3 is 17.3% more than the fatality rate for case 4 in sea state 3.
In sea state 5 and 6 the fatality rate for case 3 is almost the same as the fatality rate of case 4 (only 2.06 % higher for sea state 5 and 0.52% higher in sea state 6).

Adding HW obstacles (with or without weather independent HW obstacles) to the sequence of obstacles has a significant impact on the fatality rate (Figure 22).

The fatality rates for the different sea states for the young group corresponding to HF only and HF and HW obstacles together are summarised in Table 6 below. As can be seen, the biggest impact is observed in sea state 6 as the fatality rate increases from 0.009 to 0.45.

	HF only	HF and HW case3
Sea state 3	0.0033	0.0284
Sea state 5	0.0082	0.1759
Sea state 6	0.0090	0.4554

Table 6: Comparison of fatality rates for the young age group for HF obstacles only and HF+HW obstacles for LB

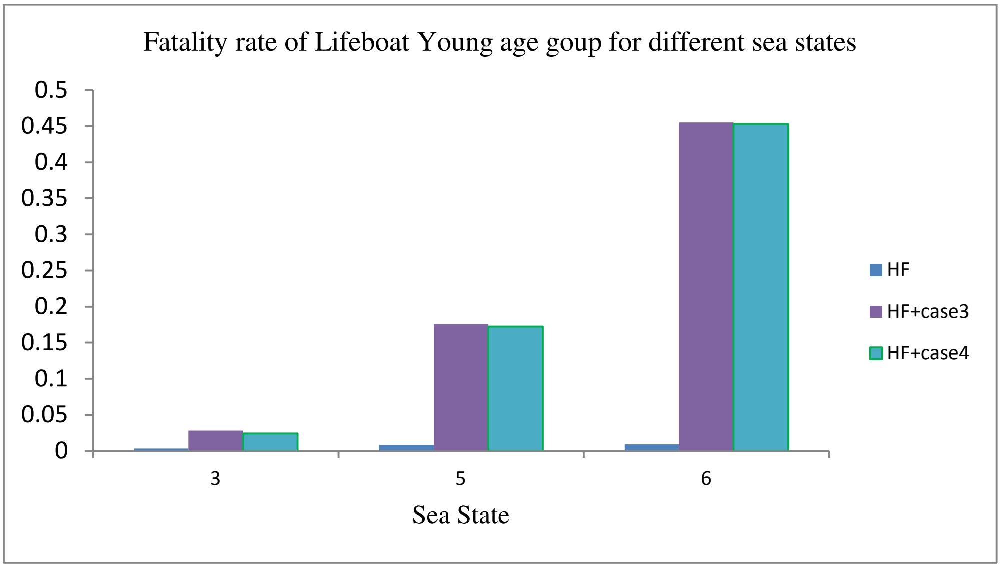

Figure 22: Comparison of fatality rates for the young age group for HF obstacles only and HF+HW obstacles case 3 and case 4 for LB

For the middle age group the results are very similar to the young age group as the fatality rate for case 3 is almost 17% more than the fatality rate for case 4 for sea state 3.
For sea state 5 and sea state 6, the fatality rate of case 3 is almost the same as the fatality rate of case 4 (only 2% higher for sea state 5 and 0.52% higher in sea state 6). Here again the fatality rate of the HF obstacles alone is negligible (Figure 23).

Adding HW obstacles has the same effect for the middle age group as the one observed for the young group.

The fatality rates for the different sea states for the middle age group corresponding to HF only and HF+HW obstacles together are summarised in Table 7 below. As for the young age group, the biggest impact is observed in sea state 6 as the fatality rate increases from to 0.0169 to 0.46.

	HF only	HF and HW case3
Sea state 3	0.0047	0.0298
Sea state 5	0.0142	0.1809
Sea state 6	0.0169	0.4594

Table 7: Comparison of fatality rates for the middle age group for HF obstacles only and HF+HW obstacles for LB

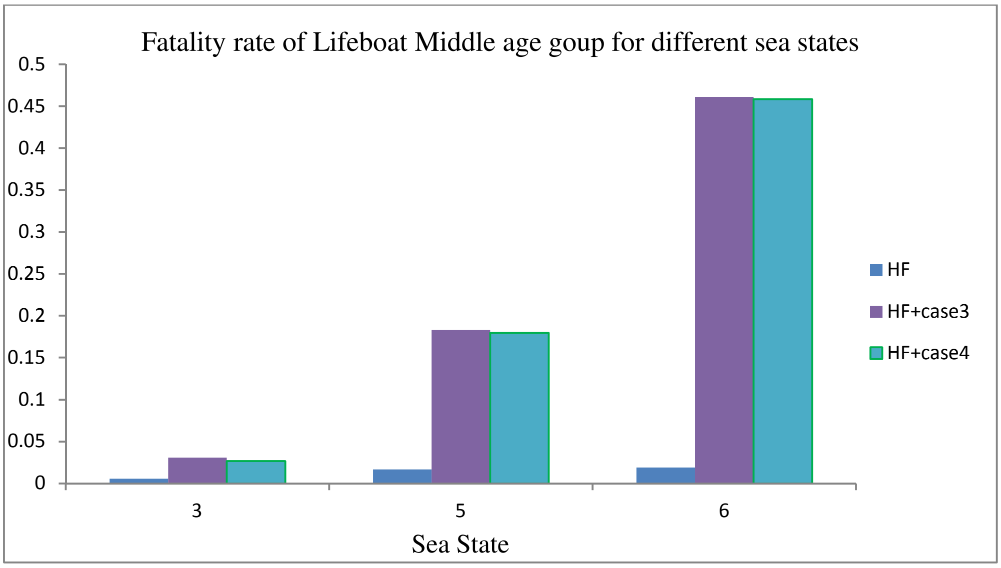

Figure 23: Comparison of fatality rates for the middle age group for HF obstacles only and HF+HW obstacles case 3 and case 4 for LB

The same tendency is observed in the results for the old age group. The fatality rate of case 3 is higher than that of case 4 for sea state 3 but the difference is less compared to the young or middle age groups as it is 11%.
For sea state 5 and sea state 6, the fatality rate for case 3 is almost the same as the fatality rate of case 4 with slightly smaller differences than for the young and middle age groups (only 1.64% higher for sea state 5 and 0.46% higher in sea state 6).

Here the fatality rate of the HF obstacles alone is not as small as for the young or middle age groups (Figure 24). Still adding HW obstacles has a big impact on the fatality rates.

The fatality rates for the different sea states for the old age group corresponding to HF only and HF+HW obstacles together are summarised in Table 8 below. For sea state 3, HW obstacles have a significant impact on the fatality rate but not as much as in the young and middle age group case as the fatality rate corresponding to HF obstacles alone is about 44% of the fatality rate corresponding to HF and HW obstacles while in the case of the young and middle age group it is 11% and 18% respectively.
For sea state 5, the fatality rate corresponding to HF obstacles alone is about 26% of the fatality rate when HW obstacles are added to the sequence of obstacles and falls to 15% for sea state 6.

	HF only	HF and HW case3
Sea state 3	0.0197	0.0434
Sea state 5	0.0553	0.2150
Sea state 6	0.0713	0.4896

Table 8: Comparison of fatality rates for the old age group for HF obstacles only and HF+HW obstacles for LB

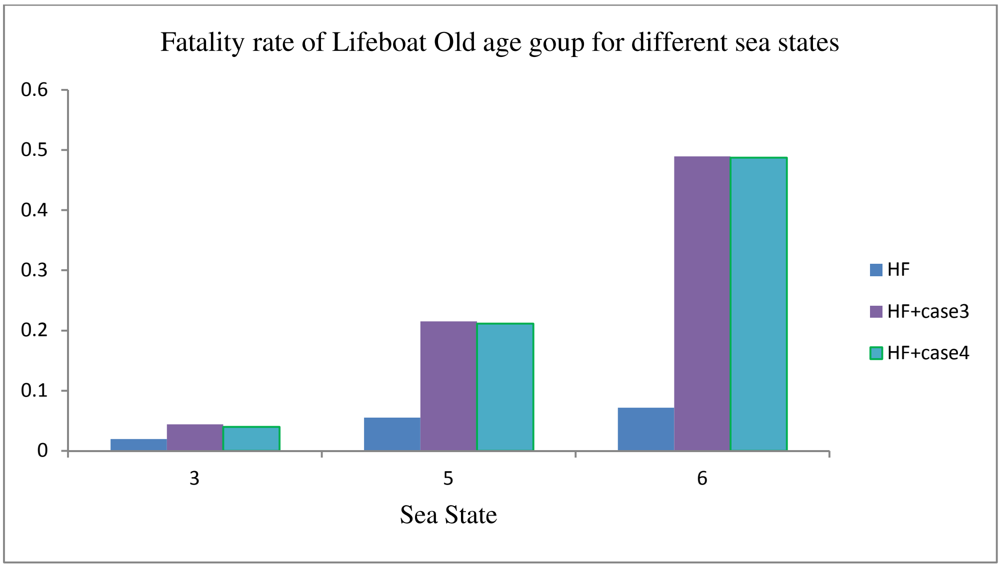

Figure 24: Comparison of fatality rates for the old age group for HF obstacles only and HF+HW obstacles case 3 and case 4 for LB

Conclusion:

In sea state 5 and 6 the weather independent HW obstacles have little impact on the fatality rate.
In sea state 3, the biggest impact is observed for the young age group as the fatality rate for case 3 is about 18% higher than that of case 4. The same difference is observed for the middle age group.
For the old age group the fatality rate for case 3 is still higher than that of case 4 but not as much as in the other two age groups.

The impact of the HW obstacles on the fatality rate is quite significant in all sea states for both the young and middle age group and in comparison the fatality rate corresponding to HF only is negligible. For the old age group, the HF fatality rate is still much smaller than that of the HW obstacles but not negligible.

In summary for the Lifeboat, the exposure time has no impact on the fatality rate and the weather dependent HW obstacles have the biggest influence on the fatality rates.

Davit Launched Liferaft results

Impact of exposure time

Case 1: Young age group

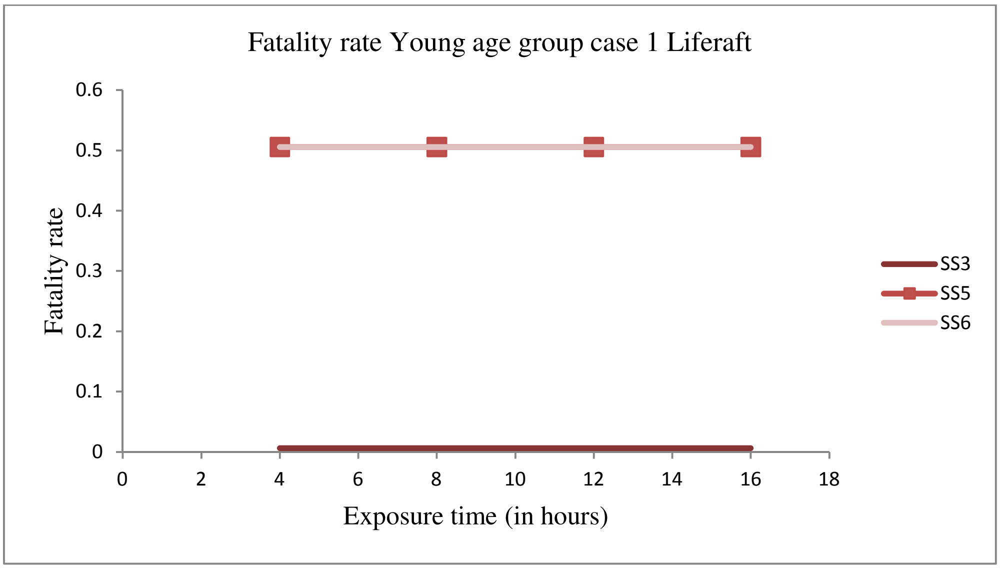

Figure 25: Fatality rate for the young age group in LR for HF+HW obstacles case 1

Case 2: Young age group

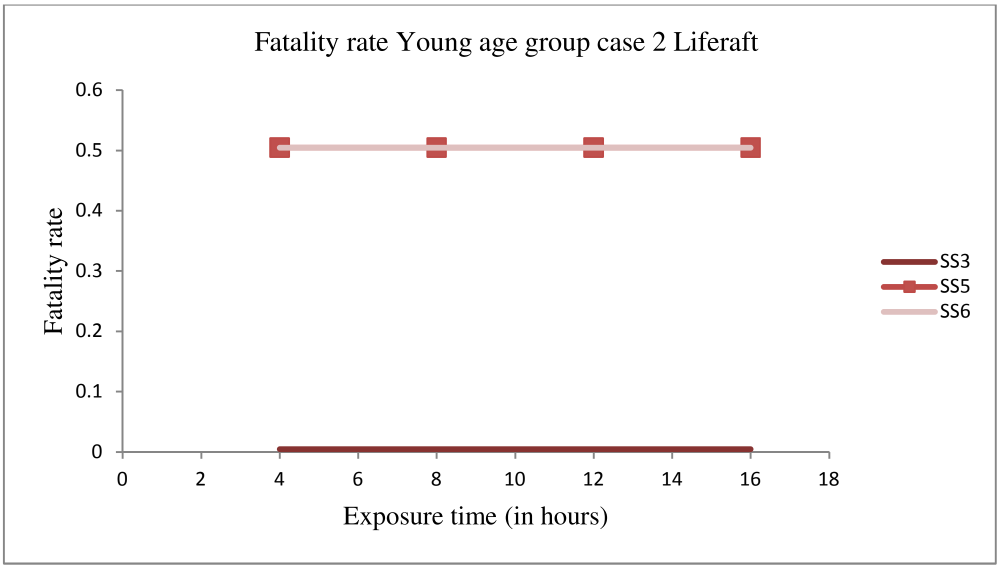

Figure 26: Fatality rate for the young age group in LR for HF+HW obstacles case 2

Case 3: Young age group

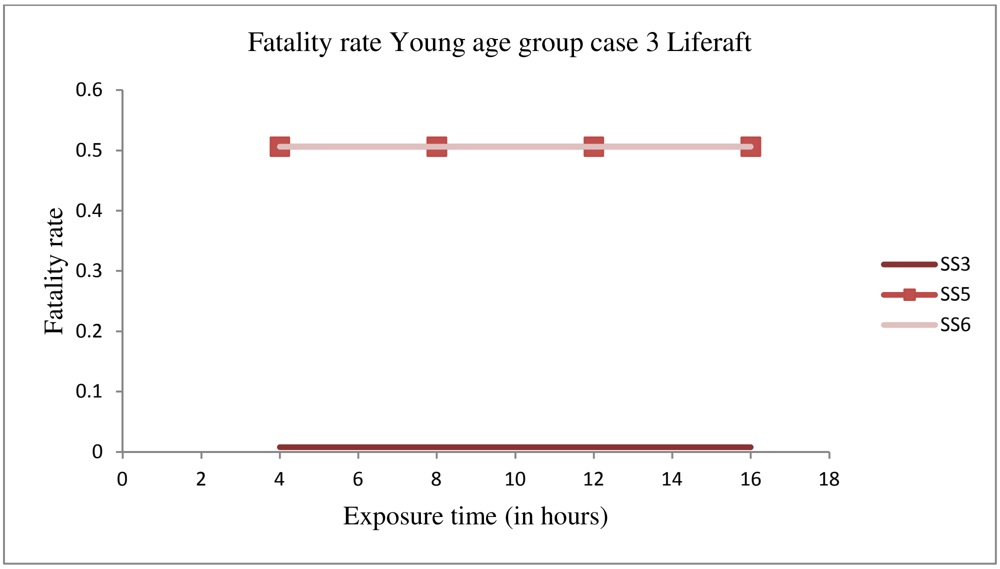

Figure 27: Fatality rate for the young age group in LR for HF+HW obstacles case 3

Case 4: Young age group

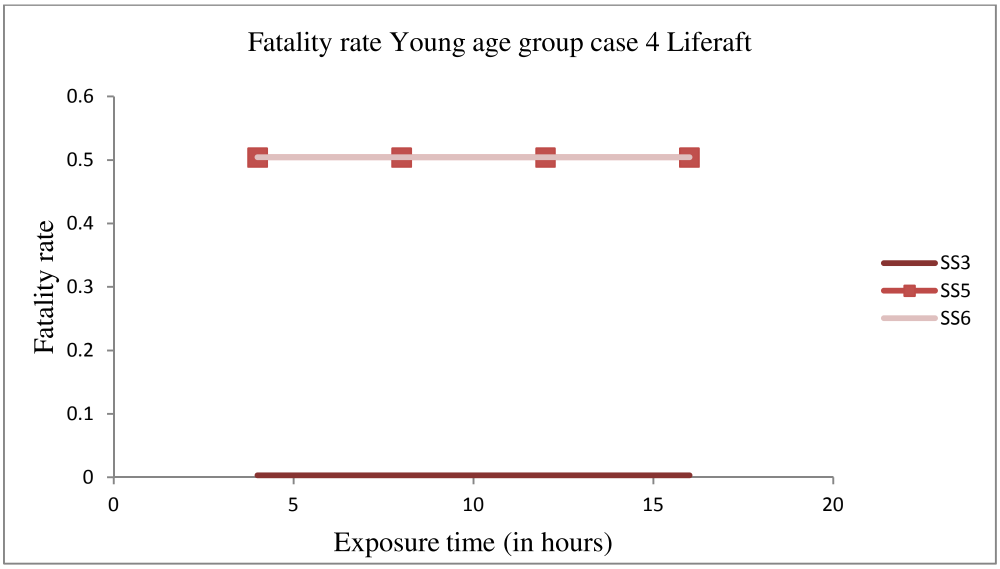

Figure 28: Fatality rate for the young age group in LR for HF+HW obstacles case 4

The fatality rate for the young group remains constant whatever the exposure time in all 4 cases and in all sea states. In addition, the fatality rate for sea state 5 and 6 are equal.

Case 1: Middle age group

Figure 29: Fatality rate for the middle age group in LR for HF+HW obstacles case 1

Case 2: Middle age group

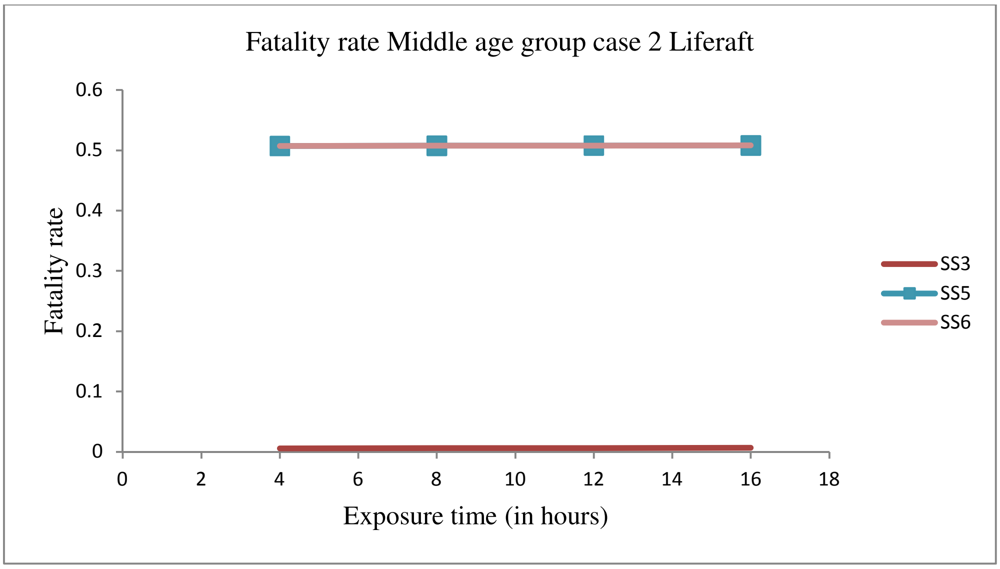

Figure 30: Fatality rate for the middle age group in LR for HF+HW obstacles case 2

Case 3: Middle age group

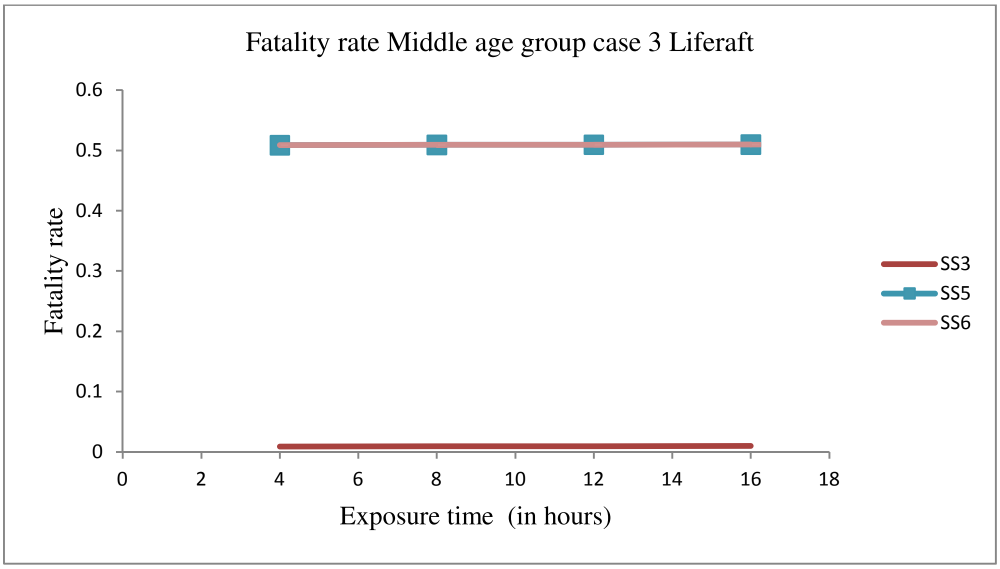

Figure 31: Fatality rate for the middle age group in LR for HF+HW obstacles case 3

Case 4: Middle age group

Figure 32: Fatality rate for the middle age group in LR for HF+HW obstacles case 4

For the middle age group, the fatality rate in sea state 5 and 6 are equal and constant whatever the exposure time in all 4 cases. The percentage change in the fatality rate from 4 hours to 16 hours exposure time is less than 0.5 %.

For sea state 3, the percentage change in the fatality rate from 4 hours to 16 hours exposure time is different for the four cases studied and is not negligible.
The percentage changes per case for each sea state are summarised in Table 9 below.

	Case 1	Case 2	Case 3	Case 4
Sea state 3	10.17%	13.87%	8.92%	17.08%
Sea state 5	0.20%	0.20%	0.20%	0.20%
Sea state 6	0.21%	0.21%	0.21%	0.21%

Table 9: Percentage changes in the fatality rate for the young group from 4h exposure time to 16h for LR

The fatality rate for sea state 3 increases in the same way in all four cases as shown in Figure 33 below.

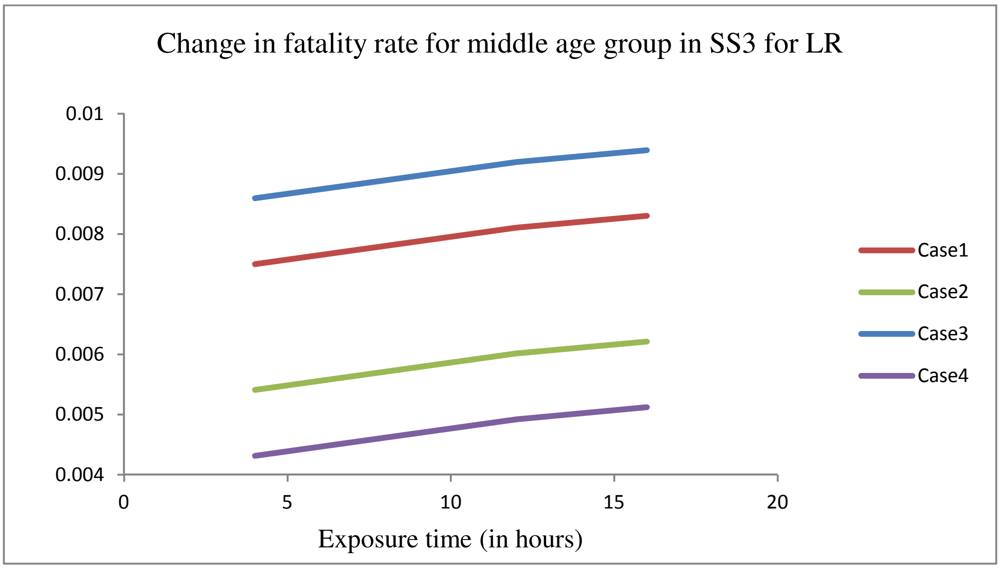

Figure 33: Percentage change in fatality rate of middle age group from 4h to 16h exposure time for LR

Case 1: Old age group

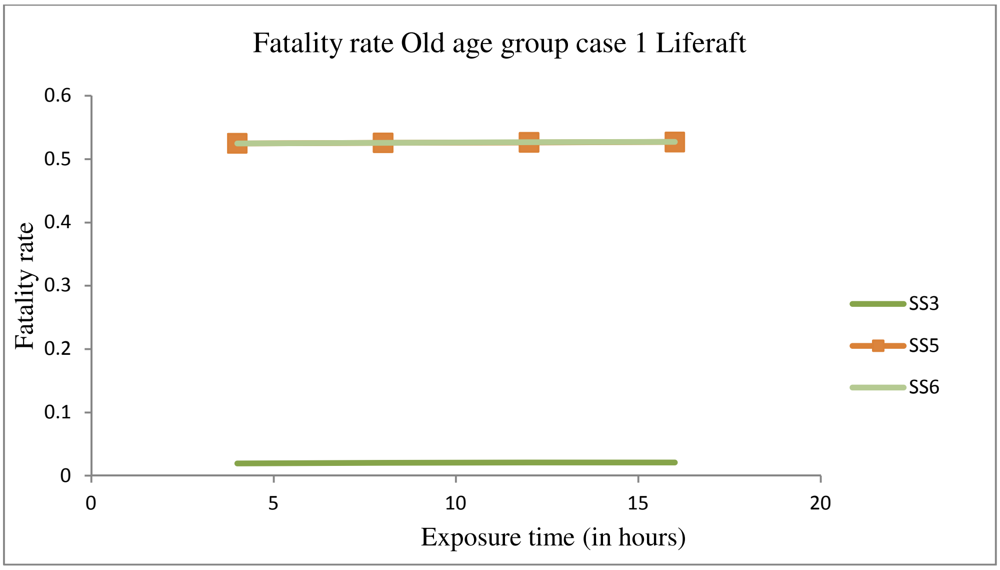

Figure 34: Fatality rate for the old age group in LR for HF+HW obstacles case 1

Case 2: Old age group

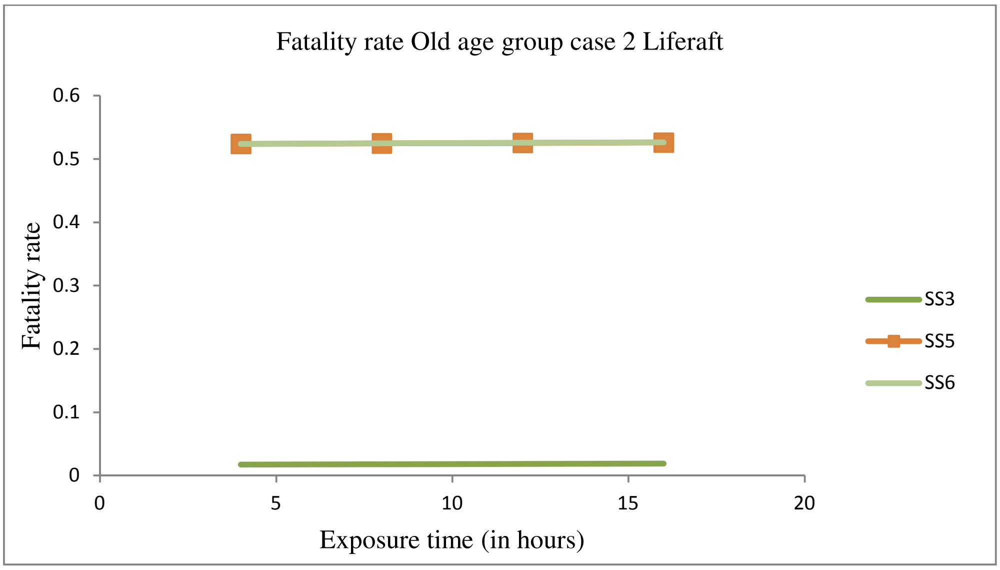

Figure 35: Fatality rate for the old age group in LR for HF+HW obstacles case 2

Case 3: Old age group

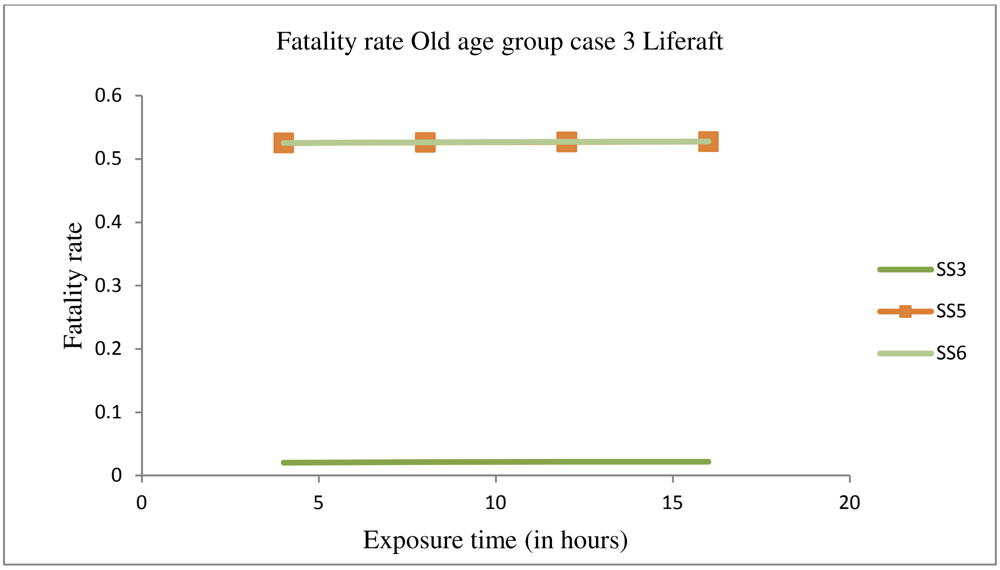

Figure 36: Fatality rate for the old age group in LR for HF+HW obstacles case 3

Case 4: Old age group

Figure 37: Fatality rate for the old age group in LR for HF+HW obstacles case 4

For the old age group, the fatality rate in sea state 5 and 6 are equal and constant whatever the exposure time in all 4 cases. The percentage change in the fatality rate from 4 hours to 16 hours exposure time is less than 0.5 %.

For sea state 3, the percentage change in the fatality rate from 4 hours to 16 hours exposure time is different for the four cases and ranges from 8% to less than 10% which is less than for the middle age group which ranges from 10% to almost 17%. The change in the fatality rate over the exposure time although smaller is not negligible in this case too.

The percentage changes per case for each sea state are summarised in Table 10 below:

	Case 1	Case 2	Case 3	Case 4
Sea state 3	7.72%	8.58%	7.33%	9.11%
Sea state 5	0.42%	0.42%	0.42%	0.42%
Sea state 6	0.44%	0.44%	0.44%	0.44%

Table 10: Percentage changes in the fatality rate for the old group from 4h exposure time to 16h for LR

Like in the middle age group the changes follow the same tendency for all cases as shown below.

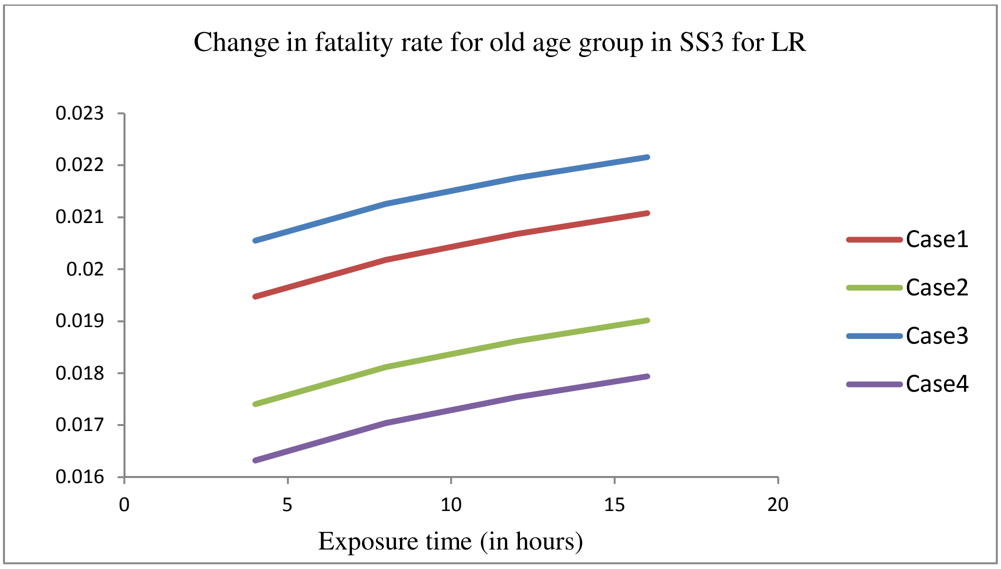

Figure 38: Change in fatality rate for old age group with exposure time in sea state 3 for LR

Conclusion:

The Exposure time has no influence on the fatality rate for all age groups and in all four cases in sea state 5 and 6.

In sea state 3, the fatality rate of the young group is not influenced by the exposure time but for the middle and old age groups the fatality rate increases with the exposure time.

Impact of weather independent obstacles

Like in the results for the Lifeboat, whatever the age group, having both the weather independent obstacles in the sequence of obstacles (case 3) leads to a higher fatality rate compared to case 1, 2 or 4.

For the young age group, and in sea state 3, adding both weather independent obstacles increases the fatality rate by almost 130%. In sea state 5 and 6 this percentage drops to 0.42% where the fatality rate for case 3 is almost the same as the fatality rate of case 4.

Adding HW obstacles (with or without weather independent HW obstacles) to the sequence of obstacles has a significant impact on the fatality rate (Figure 39).

The fatality rates for the different sea states for the young group corresponding to HF only and HF and HW obstacles together are summarised in Table 11 below. As can be seen, the biggest impact is observed in sea state 5 and 6 as the fatality rate increases from 0.0080 to 0.5064.

	HF only	HF and HW case3
Sea state 3	0.0033	0.0075
Sea state 5	0.0080	0.5064
Sea state 6	0.0080	0.5063

Table 11: Comparison of fatality rates for the young age group for HF obstacles only and HF+HW obstacles for LR

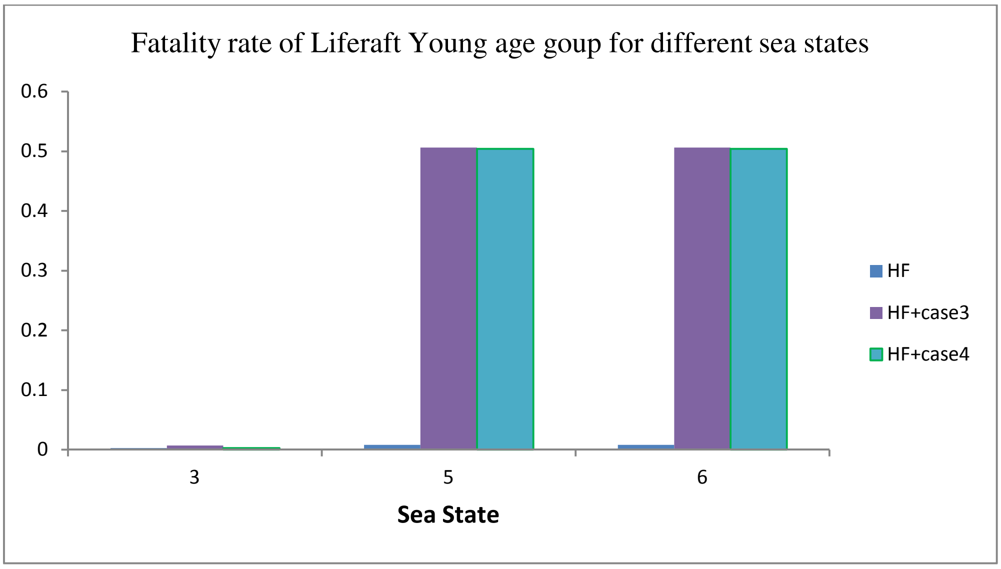

Figure 39: Comparison of fatality rates for the young age group for HF obstacles only and HF+HW obstacles case 3 and case 4 for LR

For the middle age group the influence of the weather independent obstacles is only observed in sea state 3. In higher sea states (5 and 6) the increase in the fatality rate in case 3 compared to case 4 is negligible (fatality rate of case 3 is 0.42% higher than case 4).
For sea state 3, the increase in the fatality rate depends on the exposure time. For example for 4h exposure time, the fatality rate in case 3 is 91% higher than in case 4 but for 16h exposure time it is 77% higher than case 4.

As to the effect of the HW (both weather dependent and weather independent) it is quite significant.
The fatality rates for the different sea states for the middle age group corresponding to HF only and HF+HW obstacles together are summarised in Table 12 below. Only the rate corresponding to the longest exposure time is shown in the table. Here again the biggest impact is observed in sea states 5 and 6.

	HF only	HF and HW case3
Sea state 3	0.0055	0.0098
Sea state 5	0.0150	0.5099
Sea state 6	0.0152	0.5099

Table 12: Comparison of fatality rates for the middle age group for HF obstacles only and HF+HW obstacles for LR

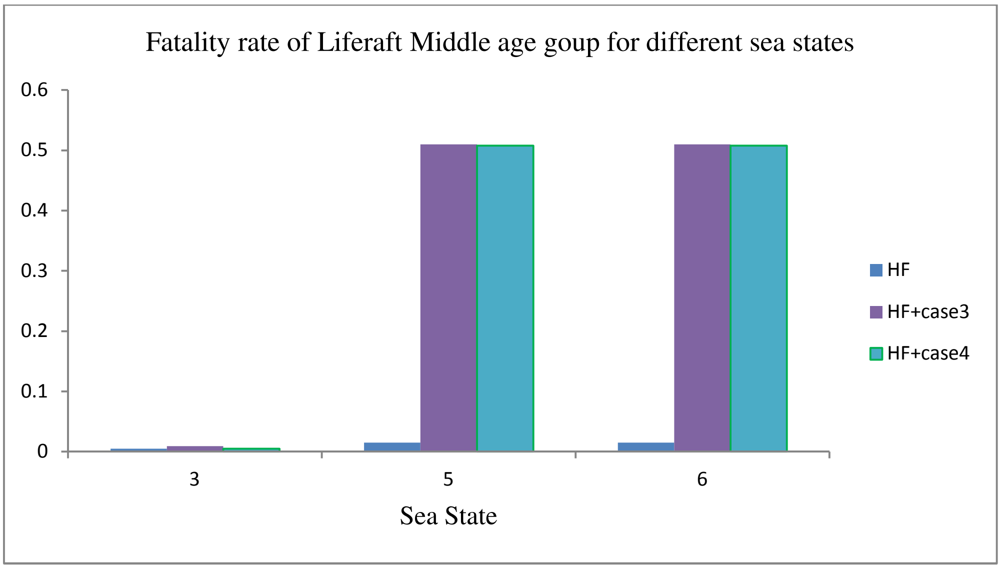

Figure 40: Comparison of fatality rates for the middle age group for HF obstacles only and HF+HW obstacles case 3 and case 4 for LR

For the old age group and in high sea states (5 and 6) the increase in the fatality rate in case 3 compared to case 4 is negligible (fatality rate of case 3 is 0.39% higher than case 4). The influence of the weather independent obstacles is only observed in sea state 3 but in a much smaller scale than what is observed for the young and middle age group.

In this case too, the increase in the fatality rate depends on the exposure time. For 4h exposure time, the fatality rate in case 3 is almost 24% higher than in case 4 and for 16h exposure time it is about 22% higher than case 4.

As to the effect of the HW (both weather dependent and weather independent) it is quite significant.
The fatality rates for the different sea states for the old age group corresponding to HF only and HF and HW obstacles together are summarised in Table 13 below. Only the rate corresponding to the longest exposure time is shown in the table. Here again the biggest impact is observed in sea states 5 and 6.

	HF only	HF and HW case3
Sea state 3	0.0193	0.0235
Sea state 5	0.0506	0.5276
Sea state 6	0.0511	0.5278

Table 13: Comparison of fatality rates for the old age group for HF obstacles only and HF+HW obstacles for LR

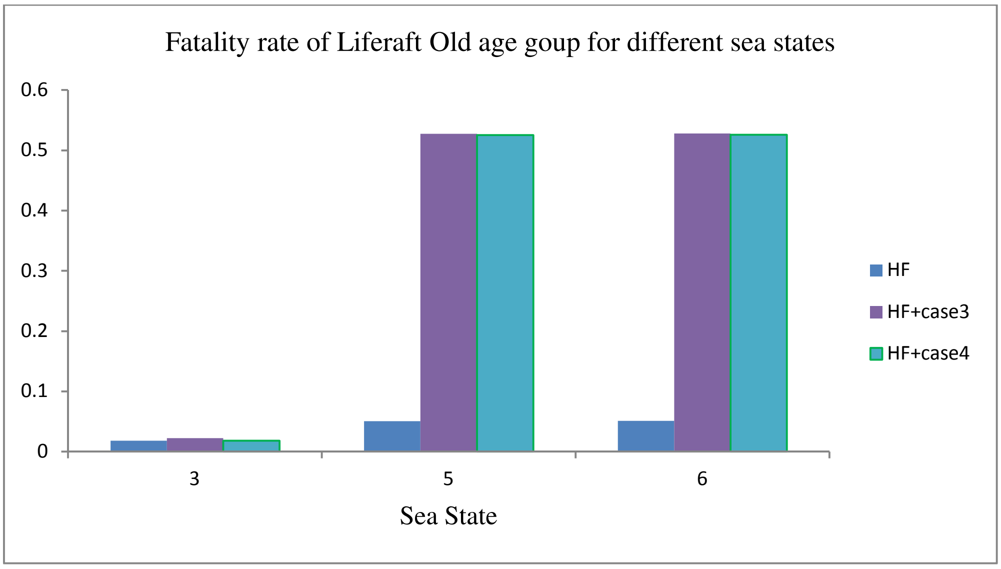

Figure 41: Comparison of fatality rates for the old age group for HF obstacles only and HF+HW obstacles case 3 and case 4 for LR

Conclusion:

In all cases and for all age groups the fatality rates for sea state 5 and 6 are (almost) equal.
In sea state 3, the fatality rates for the middle and old age group is affected by the exposure time. For the young age group the fatality rate is constant whatever the exposure time.

The weather independent obstacles have no influence on the fatality rate in sea state 5 and 6.
The biggest influence of the weather independent obstacles on the fatality rate for the Liferaft can be seen for the young age group. For the middle age group the influence is also quite big. For the old age group the influence is significant but much smaller than the other two age groups.

As for the HF compared to HW obstacles, the fatality rate for the HF obstacles only is negligible in sea state 5 and 6 and for the young and middle age group. For the old age group it is quite small but not negligible.

In sea state 3, the fatality rate associated to HF obstacles only is quite significant in the case of the old age group but less so for the middle and young age group (in this order).

Results for the ladder-boarded LR

The HW obstacles in the sequence of the ladder boarded LR are obstacles R6 and A16.

The fatality rates are as follows:

SS3	HF only			HF+HW		
Expo. time(h)	Y	M	O	Y	M	O
4	0.0066	0.0088	0.0343	0.0066	0.0088	0.0343
8	0.0066	0.0091	0.0350	0.0066	0.0091	0.0350
12	0.0066	0.0094	0.0355	0.0066	0.0094	0.0355
16	0.0066	0.0096	0.0359	0.0066	0.0096	0.0359

Table 14: Fatality rate for the ladder boarded LR in SS3

SS5	HF only			HF+HW		
Expo. time(h)	Y	M	O	Y	M	O
4	0.0161	0.0232	0.0897	0.5083	0.5119	0.5451
8	0.0161	0.0240	0.0914	0.5083	0.5123	0.5460
12	0.0161	0.0246	0.0928	0.5083	0.5126	0.5467
16	0.0161	0.0252	0.0940	0.5083	0.5129	0.5473

Table 15: Fatality rate for the ladder boarded LR in SS5

SS6	HF only			HF+HW		
Expo. time(h)	Y	M	O	Y	M	O
4	0.0161	0.0232	0.0899	0.5082	0.5118	0.5452
8	0.0161	0.0240	0.0916	0.5082	0.5122	0.5460
12	0.0161	0.0247	0.0932	0.5082	0.5126	0.5468
16	0.0161	0.0253	0.0945	0.5082	0.5129	0.5474

Table 16: Fatality rate for the ladder boarded LR in SS6

In sea state 3, the fatality rates for the HF only and HF+HW cases are equal, meaning that HW obstacles do not have an impact on the fatality rates. This is due to the fact that their associated degradation matrices are the identity matrices.

Results for sea state 5 and 6 are very similar (almost equal fatality rates).

The exposure time has no influence on the fatality rate for the young age group whatever the sea state for both the situation when the HW obstacles are in the sequence and when there are not.

For the middle age group the percentage change in the fatality rate from a 4h exposure time to 16h is about 9% in all sea state for the HF only case. When HW obstacles are added, then the percentage changes in the fatality rate from 4h exposure time to 16h are insignificant (0.2%) in sea state 5 and 6. In sea state 3, the percentage remains 9% as the HW have no impact.

For the old age group, the percentage change in the fatality rate from a 4h exposure time to 16h is about 5% in all sea states for the HF only case. For the HF+HW case the percentage changes in the fatality rate from 4h exposure time to 16h are insignificant (0.4%) in sea state 5 and 6. In sea state 3, the percentage remains 5% as the HW have no impact.

Conclusion:

For the LR boarded through the ladders, the HW obstacles do not have an impact on the fatality rates in sea state 3 as their degradation matrices are identity matrices.
As for the DL LR and the LB, the exposure time has no impact on the fatality rate of the young group in all sea states.
For the middle and old age groups the exposure time has an impact on the fatality rate only in sea state 3.

Comparing Lifeboat and Liferaft fatality rates

First the fatality rates per age group for the LB and the two types of LRs (Davit launched and boarded through ladders) when only HF obstacles are in the sequence of obstacles are presented. Then the fatality rates for the sequence of obstacles with HF and HW obstacles together corresponding to case 3 (for the LB and DL LR) are presented per age group.
In the rest of this section the LRs boarded through the ladders will be designated by LR_L.

HF only

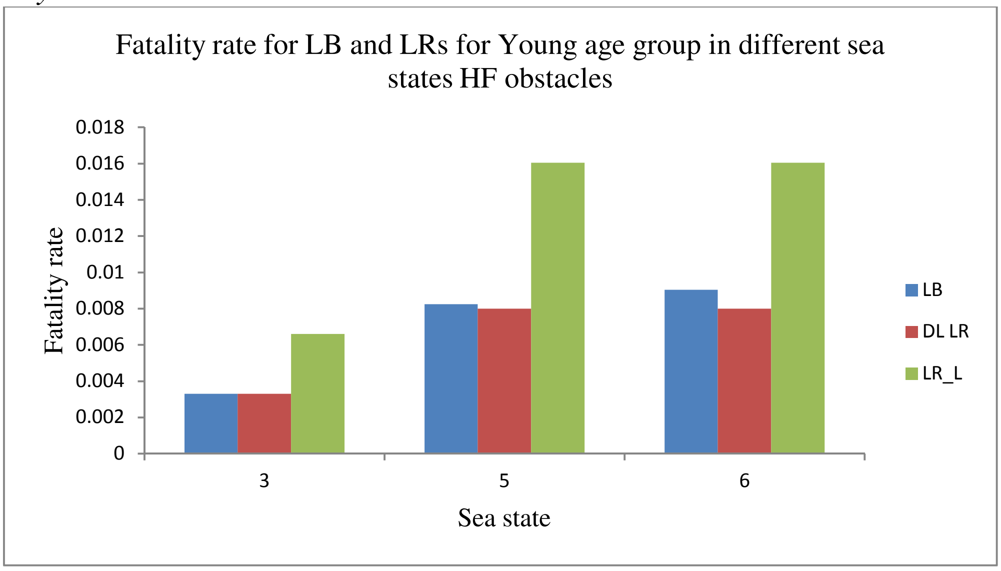

Figure 42: Comparing fatality rates of LB and LRs for young age group for HF only in different sea states.

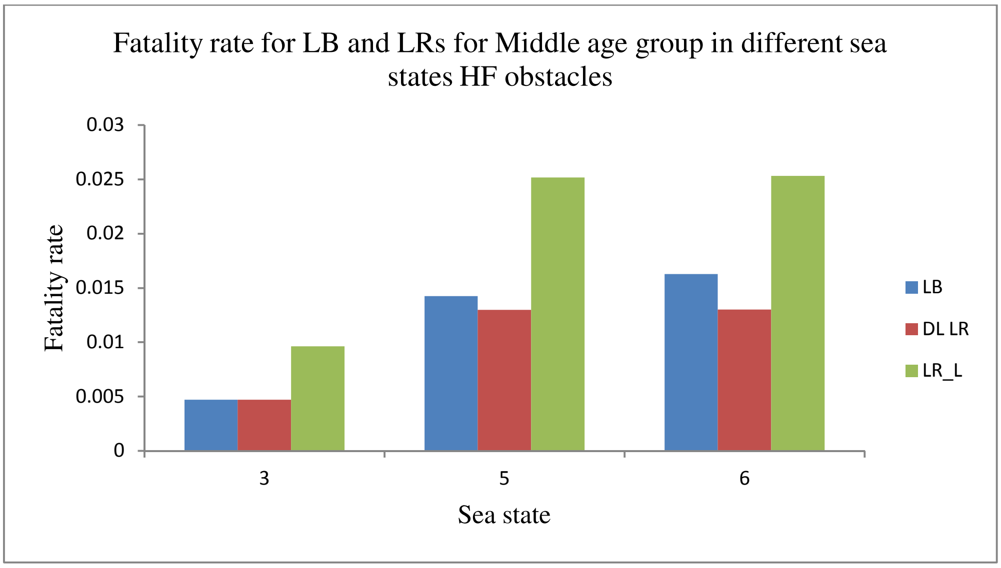

Figure 43: Comparing fatality rates of LB and LRs for middle age group for HF only in different sea states

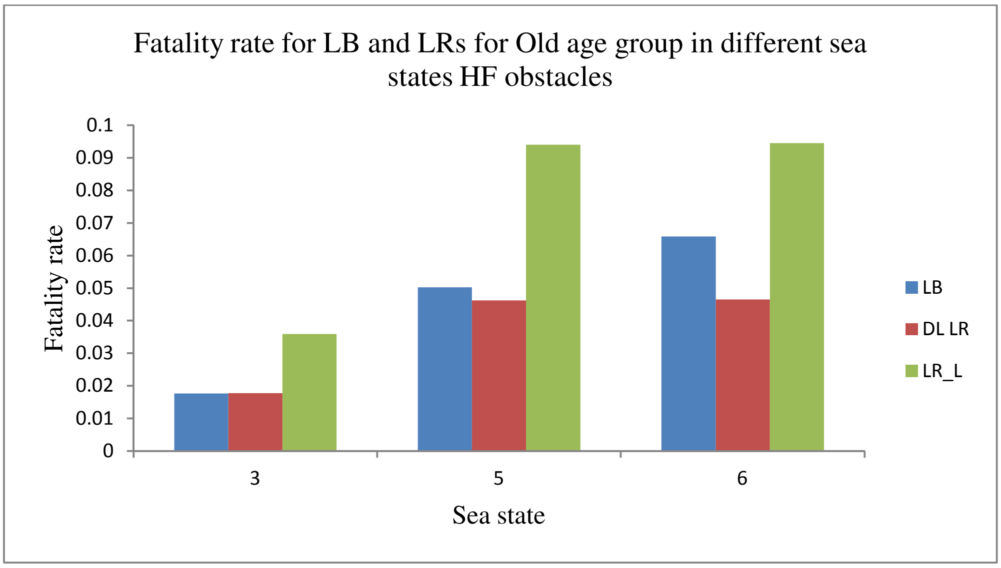

Figure 44: Comparing fatality rates of LB and LRs for old age group for HF only in different sea states

In sea state 3, Lifeboat and davit launched Liferaft have the same fatality rate in all age groups but the fatality rate for the LR boarded through ladders is double.
In sea state 5, the fatality rate of the LB is higher than the fatality rate of the DL LR for all age groups but remains smaller than the fatality rate of the LR boarded through ladders (almost half for the young age group and about 60 % for the middle and old age group).
In sea state 6 the fatality rate of the LB is still bigger than that of the DL LR and is about 56 % that of the LR boarded through ladders, for the young age group, and about 75% for both the middle and old age groups.

The fatality rates associated to the LR boarded through ladders are the dominant ones for all age groups and in all sea states when only HF obstacles are considered. This is mainly due to the fact that when comparing the sequence of obstacles corresponding to the LB, DL LR and LR boarded through ladder and the associated degradation matrices, the one with the highest values is the degradation matrix of obstacle A11 which is only in the sequence of obstacles for the LR boarded through ladders.

HF + HW obstacles

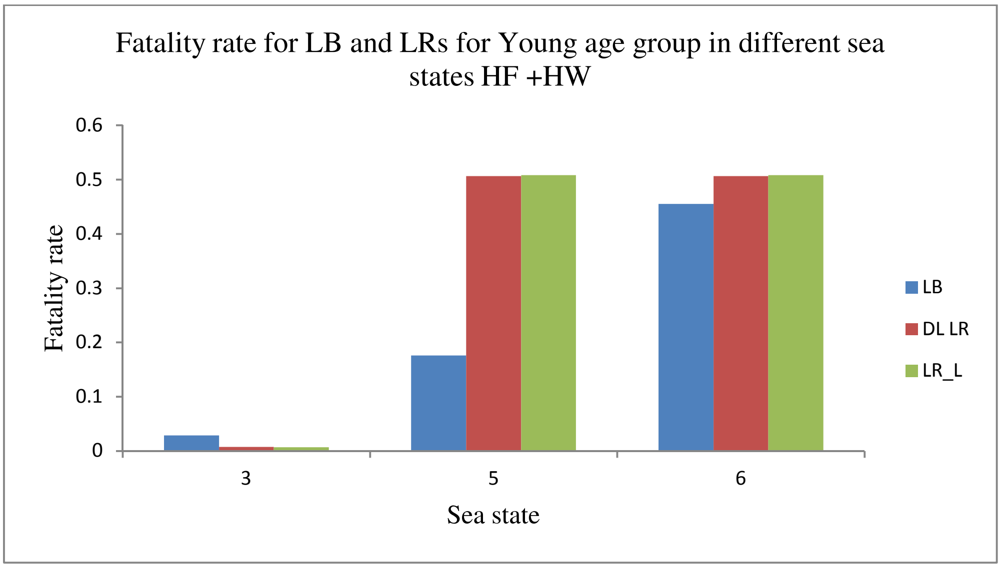

Figure 45: Comparing fatality rates of LB and LRs for young age group for HF +HW obstacles in different sea states

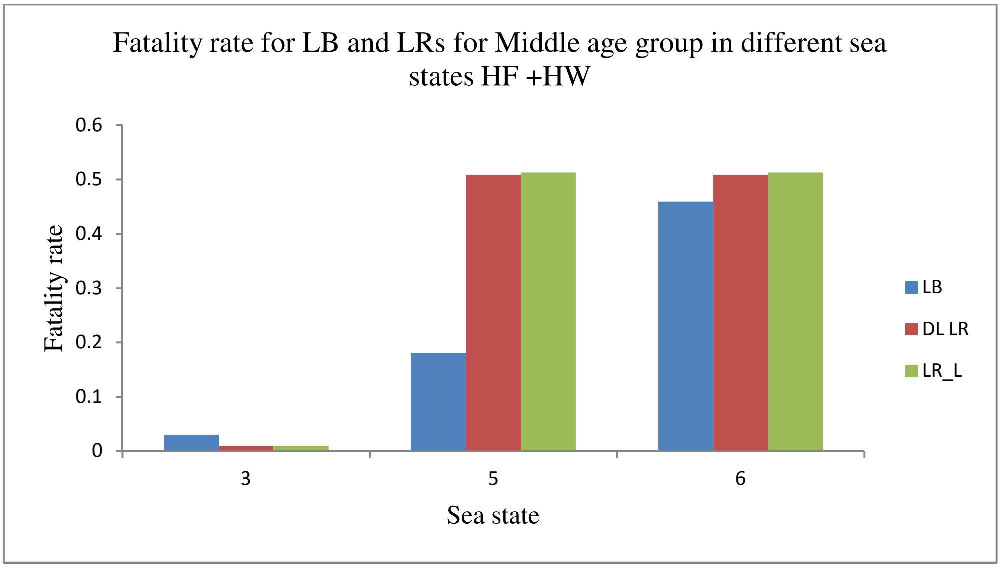

Figure 46: Comparing fatality rates of LB and LRs for middle age group for HF +HW obstacles in different sea states

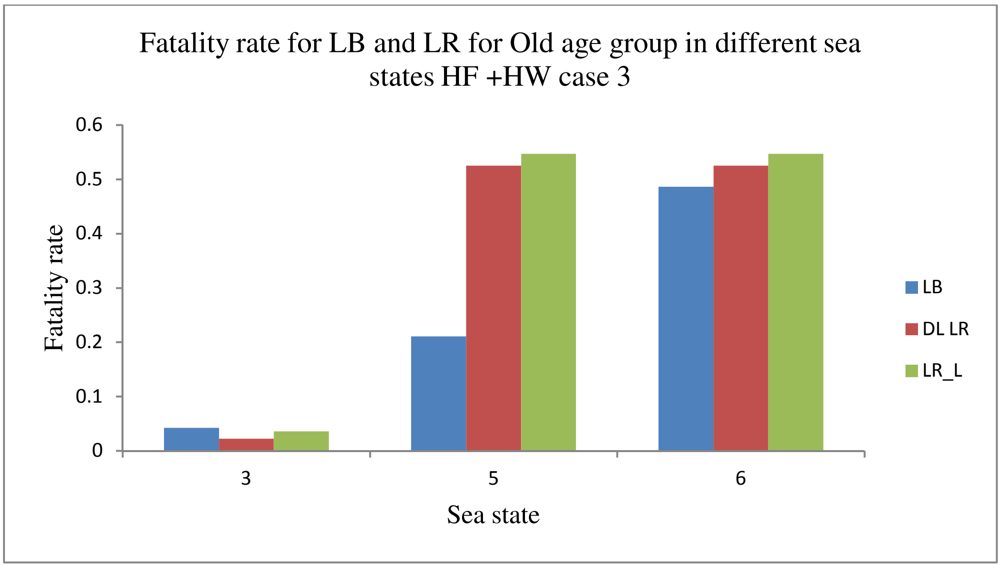

Figure 47: Comparing fatality rates of LB and LRs for old age group for HF +HW obstacles in different sea states

When HW obstacles are added to the sequence of obstacles, in sea state 3 the fatality rate of the LB becomes higher than the fatality rate of the two LR types and is almost 4 times bigger for the young age group, 3 times bigger for the middle age group and almost double the fatality rate of the DL LR, but only 1.2 times higher for the LR boarded through ladder for the old age group.

In sea state 5, the fatality rate of both types of the LR is bigger and is more than double the fatality rate of the LB for all age groups.
In sea state 6, the fatality rate of the LB is still smaller than the fatality rate of both LR types for all age groups but this time the difference is much smaller and is only about 10%.

In this case adding HW obstacles has reduced the difference between the fatality rates of both types of LRs which are almost equal.

In sea state 3, the LB has the biggest fatality rate but in sea state 5 and 6, LRs have bigger fatality rates.
This is mainly due to the fact that in these two states it is assumed that LR cannot be towed and that only half of them (in the leeward side) would be able to drift.

4.3.3 Impact of hypothermia on people in Liferafts

As introduced earlier in the document the effect of the hypothermia were studied for the LRs (both davit launched and ladder-boarded) in sea state 6.

The fatality rates when only HF obstacles are in the sequence of obstacles are as follows.

SS6	DL LR			LR_L		
Expo. time(h)	Y	M	O	Y	M	O
4	0.015101	0.022555	0.058513	0.023245	0.032769	0.101971
8	0.022216	0.03287	0.072096	0.030453	0.043122	0.115549
12	0.029346	0.043029	0.085439	0.037669	0.053315	0.12886
16	0.036488	0.053037	0.09848	0.044893	0.063351	0.141851

Table 17: Fatality rates with hypothermia in sea state 6 for HF obstacles only.

When compared to the fatality rates without hypothermia, the percentage changes in the fatality rates are quite significant as shown below.

SS6	DL LR			LR_L		
Expo. time(h)	Y	M	O	Y	M	O
4	358%	378%	231%	45%	41%	13%
8	573%	555%	293%	90%	80%	26%
12	789%	709%	353%	135%	116%	38%
16	1006%	860%	411%	180%	150%	50%

Table 18: Percentage change in fatality rates when compared to sequence of HF obstacles without hypothermia in sea state 6.

As can be seen the biggest change is for the young age group and for a 16 hours exposure time. This is mainly due to the fact that obstacle R_8 (Hypothermia) is duplicated to account for the exposure time and most of the other obstacles in the sequence of obstacles have no fatality rate for the young age group.

When HW obstacles are introduced in the sequence of obstacles, the fatality rates for the sequence of obstacles with hypothermia are as follows.

SS6	DL LR			LR_L		
Expo. time(h)	Y	M	O	Y	M	O
4	0.509862	0.513572	0.531466	0.511818	0.516578	0.551165
8	0.513403	0.518705	0.538226	0.51542	0.521753	0.557952
12	0.516952	0.523761	0.544866	0.519027	0.526847	0.564604
16	0.520506	0.528741	0.551356	0.522637	0.531863	0.571097

Table 19: Fatality rates with hypothermia in sea state 6 for HF+HW obstacles.

The percentage changes in the fatality rates when compared to the sequence without hypothermia are:

SS6	DL LR			LR_L		
Expo. time(h)	Y	M	O	Y	M	O
4	0.70%	0.93%	1.14%	0.71%	0.94%	1.10%
8	1.40%	1.86%	2.26%	1.42%	1.87%	2.19%
12	2.10%	2.78%	3.37%	2.13%	2.79%	3.26%
16	2.80%	3.70%	4.46%	2.84%	3.70%	4.32%

Table 20: Percentage change in fatality rates when compared to sequence of HF+HW obstacles without hypothermia in sea state 6

As previously found, when HW obstacles are introduced in the sequence of obstacles, the impact of the HF obstacles is insignificant. And here having the hypothermia in the sequence of obstacles would account for a 4% increase (at the most) in the fatality rate.

5 Case study

In this section the total expected number of fatalities for both the Estonia and the Cruise Liner will be presented.

The differences in the expected number of fatalities will be mainly due to the number of people in each age group using a specific LSA type.

The different passenger proportions per age group as defined previously are:

	P1	P2	P3	P4
Y	1	0	0.33	0.17
M	0	0	0.33	0.67
O	0	1	0.33	0.17

In a first case all LBs are assumed available and in a second case only half the LBs are available.

The sequence of obstacles with the highest fatality rate (case 3) was chosen to illustrate the expected number of fatalities.
No distinction was made between passengers and crew members.

5.1 Cruise Liner

In the cruise liner the total number of people on board was 3388. There are 18 Lifeboats with a capacity of 150 people each. Once all LB capacity has been used the rest of the people onboard are distributed in DL LR with a capacity of 25 persons each.
For each passenger's distribution over the age groups, the expected number of fatalities when all LB are available and then when only half the Lifeboats are available are given below.

Proportion 1

In this situation all passengers are assumed to be in the young group and because for this age group the exposure time does not influence the fatality rate, the expected number of fatalities is the same for all exposure time and is given in the tables below.

All Lifeboats available:

Sea state	LB	DL LR	Total
3	76.74	5.22	81.96
5	475.02	348.42	823.45
6	1229.59	348.36	1577.95

Table 21: Expected number of fatalities for the cruise liner when all passengers are in the young age group

When only half the Lifeboats are available the expected number of fatalities is:

Sea state	LB	DL LR	Total
3	38.37	15.45	53.83
5	237.51	1032.10	1269.61
6	614.80	1031.90	1646.70

Table 22: Expected number of fatalities for the cruise liner when all passengers are in the young age group and only half the LBs are available

When only half of the Lifeboats are available the total number of passengers having to use Liferafts will increase. In addition the expected number of fatalities for the Lifeboats will be reduced by half.

The loss of half the Lifeboats' capacity reduces the expected number of fatalities in sea state 3. The percentage change in the total expected number of fatalities is about 34%.
In contrast, in sea state 5 and 6 the total expected number of fatalities increases by 54% for sea state 5 but only by 4% for sea state 6 when only half the Lifeboats are available.
This is due to the fact that in sea state 3 for the young age group the fatality rate of the LB is higher than the fatality rate of the DL LR, while in seas state 5 and 6 the fatality rate of the DL LR is more than double the fatality rate of the LB (Figure 45).

Proportion 2

Here all passengers are assumed to be in the old age group.

The fatality rates are given below:

Sea state	Exposure time (hours)	LB	LR	Total
3	4	114.52	15.10	129.62
	8	116.39	15.59	131.98
	12	117.70	15.94	133.64
	16	118.75	16.21	134.96
5	4	569.21	361.51	930.72
	8	573.68	362.10	935.78
	12	577.33	362.58	939.91
	16	580.67	363.02	943.69
6	4	1313.89	361.54	1675.43
	8	1316.89	362.13	1679.02
	12	1319.60	362.66	1682.27
	16	1322.02	363.13	1685.15

Table 23: Expected number of fatalities for the cruise liner when all passengers are in the old age group

When only half the Lifeboats are available the expected number of fatalities is:

Sea state	Exposure time (hours)	LB	LR	Total
3	4	57.26	44.74	102.00
	8	58.19	46.20	104.39
	12	58.85	47.21	106.06
	16	59.38	48.02	107.40
5	4	284.61	1070.87	1355.47
	8	286.84	1072.62	1359.45
	12	288.67	1074.03	1362.70
	16	290.34	1075.33	1365.67
6	4	656.95	1070.96	1727.91
	8	658.45	1072.69	1731.14
	12	659.80	1074.28	1734.09
	16	661.01	1075.68	1736.69

Table 24: Expected number of fatalities for the cruise liner when all passengers are in the old age group and only half the LBs are available

Like for proportion 1, the loss of half the Lifeboats' capacity reduces the expected number of fatalities in sea state 3 and the percentage change in the total expected number of fatalities is about 21%.
In sea state 5 and 6 the total expected number of fatalities increases by about 45% in sea state 5 and by 3% in sea state 6 when only half the Lifeboats are available.

This is due to the fact that for the old age group in sea state 3 the fatality rate of the LB is higher than the fatality rate of the DL LR, while in seas state 5 and 6 the fatality rate of the DL LR is higher than the fatality rate of the LB (Figure 46Figure 46).

Proportion 3

Passengers are assumed equally distributed over the three age groups.

Sea state	Exposure time (hours)	LB	LR	Total
3	4	90.58	8.84	99.41
	8	91.47	9.07	100.54
	12	92.17	9.25	101.42
	16	92.69	9.39	102.08
5	4	510.92	353.35	864.28
	8	513.12	353.64	866.76
	12	514.89	353.87	868.76
	16	516.53	354.09	870.62
6	4	1261.27	353.32	1614.59
	8	1262.78	353.61	1616.39
	12	1264.14	353.87	1618.01
	16	1265.32	354.10	1619.42

Table 25: Expected number of fatalities for the cruise liner when all passengers are equal distributed over the age groups

When only half the Lifeboats are available the expected number of fatalities is:

Sea state	Exposure time (hours)	LB	LR	Total
3	4	45.29	26.18	71.46
	8	45.73	26.87	72.60
	12	46.08	27.41	73.49
	16	46.35	27.81	74.16
5	4	255.46	1046.71	1302.17
	8	256.56	1047.57	1304.13
	12	257.45	1048.24	1305.69
	16	258.26	1048.88	1307.15
6	4	630.63	1046.62	1677.25
	8	631.39	1047.47	1678.86
	12	632.07	1048.24	1680.31
	16	632.66	1048.92	1681.58

Table 26: Expected number of fatalities for the cruise liner when all passengers are equal distributed over the age groups and half the LBs are available.

The same is observed here as the loss of half the Lifeboats' capacity reduces the expected number of fatalities in sea state 3 where the percentage change in the total expected number of fatalities is about 28%.
When only half the Lifeboats are available, in sea state 5 and 6 the total expected number of fatalities increases by 50% and about 4 % respectively.

Proportion 4

In this proportion most passengers (2/3) are in the middle age group while the rest are equally distributed over the young and old age group.

Sea state	Exposure time (hours)	LB	LR	Total
3	4	85.52	7.51	93.04
	8	86.37	7.73	94.10
	12	87.12	7.93	95.04
	16	87.64	8.06	95.71
5	4	499.72	351.74	851.47
	8	501.88	352.03	853.91
	12	503.60	352.24	855.84
	16	505.20	352.45	857.65
6	4	1250.80	351.70	1602.49
	8	1252.32	351.98	1604.30
	12	1253.68	352.23	1605.92
	16	1254.83	352.45	1607.28

Table 27: Expected number of fatalities for the cruise liner when most passengers are in the middle age group

When only half the Lifeboats are available the expected number of fatalities is:

Sea state	Exposure time (hours)	LB	LR	Total
3	4	42.76	22.25	65.01
	8	43.19	22.91	66.09
	12	43.56	23.48	67.04
	16	43.82	23.89	67.71
5	4	249.86	1041.94	1291.80
	8	250.94	1042.78	1293.72
	12	251.80	1043.42	1295.22
	16	252.60	1044.04	1296.64
6	4	625.40	1041.80	1667.20
	8	626.16	1042.64	1668.80
	12	626.84	1043.39	1670.23
	16	627.42	1044.04	1671.45

Table 28: Expected number of fatalities for the cruise liner when most passengers are in the middle age group and half the LBs are available

For this proportion the total expected number of fatalities is still reduced in sea state 3 as a consequence of half the Lifeboats loss and the percentage change is 30%. While in sea state 5 and 6 the total number of expected fatalities increases by about 51% and 4% respectively which is quite similar to the results for Proportion 3.

5.2 Estonia

For the Estonia the total number of people on board was 989. There were 10 Lifeboats with different capacities to accommodate 692 people. Once all LB capacity has been used the rest of the people onboard are distributed in LRs with a capacity of 25 persons each. Four (4) DL LR and eight (8) LR boarded through ladders are needed.

When only half of the Lifeboats are available it is assumed that LRs boarded through ladders are used to accommodate for the lost LSA capacity. This choice has been made to consider a worst case scenario as the fatality rate of the DL LR is smaller.

The expected number of fatalities, when all Lifeboats are available and when only half the Lifeboats are available for all the different passengers' proportions is shown below.

Proportion 1

Sea state	LB	DL LR	LR_L	Total
3	19.61	0.76	1.32	21.69
5	121.40	50.64	101.16	273.19
6	314.23	50.63	101.14	466.00

Table 29: Expected number of fatalities for the Estonia when all passengers are in the young age group

When only half the Lifeboats are available the expected number of fatalities is:

Sea state	LB	DL LR	LR_L	Total
3	9.81	0.76	3.60	14.16
5	60.70	50.64	276.53	387.87
6	157.11	50.63	276.47	484.22

Table 30: Expected number of fatalities for the Estonia when all passengers are in the young age group and half the LBs are available.

In all sea states the expected number of fatalities due to DL LR is smaller than the number of expected fatalities for the LR boarded through ladders. This is mainly due to the fact that the fatality rate of the davit launched LR is smaller than that of the LR boarded through the ladder and that the total number of people using the DL LR is smaller.

The loss of half the Lifeboats' capacity does not affect the number of expected fatalities using DL LR as it is assumed that the same number of people uses the DL LR in both cases.
But losing half the LB reduces the total expected number of fatalities in sea state 3. The percentage change in the total expected number of fatalities is about 34%.
In contrast in sea state 5 and 6 the total expected number of fatalities increases by 42% for sea state 5 but only by 4% for sea state 6 when only half the Lifeboats are available.

Proportion 2

Sea state	Exposure time (hours)	LB	DL LR	LR_L	Total
3	4	29.27	2.20	6.83	38.29
	8	29.74	2.27	6.97	38.98
	12	30.08	2.32	7.07	39.47
	16	30.35	2.36	7.15	39.86
5	4	145.47	52.55	108.48	306.49
	8	146.61	52.63	108.65	307.88
	12	147.54	52.70	108.78	309.03
	16	148.39	52.76	108.91	310.07
6	4	335.77	52.55	108.49	496.81
	8	336.54	52.63	108.65	497.83
	12	337.23	52.71	108.81	498.75
	16	337.85	52.78	108.94	499.57

Table 31: Expected number of fatalities for the Estonia when all passengers are in the old age group

When only half the Lifeboats are available the expected number of fatalities is:

Sea state	Exposure time (hours)	LB	DL LR	LR_L	Total
3	4	14.63	2.20	18.67	35.50
	8	14.87	2.27	19.06	36.20
	12	15.04	2.32	19.33	36.69
	16	15.17	2.36	19.55	37.08
5	4	72.73	52.55	296.54	421.82
	8	73.30	52.63	297.00	422.94
	12	73.77	52.70	297.38	423.85
	16	74.20	52.76	297.73	424.69
6	4	167.89	52.55	296.56	517.00
	8	168.27	52.63	297.02	517.92
	12	168.62	52.71	297.44	518.77
	16	168.92	52.78	297.81	519.52

Table 32: Expected number of fatalities for the Estonia when all passengers are in the old age group and half the LBs are available

The same kind of results are observed here, but in this case in sea state 3 the percentage change of the total expected number of fatalities is only 7% while for the Proportion 1 (all people in young age group) it was 34% . This is due to the fact that for the young group the fatality rate of both types of LR is very small compared to the fatality rate of the LB (Figure 42), and even with a bigger number of people using LRs that does not compensate for the difference. While for the proportion 2 (all people in old age group) the difference between the fatality rates for both types of LRs and the LB is not too big (Figure 47).

For sea state 5 and 6 the total expected number of fatalities increases by about 37% and 4% respectively.

Proportion 3

Sea state	Exposure time (hours)	LB	DL LR	LR_L	Total
3	4	23.15	1.28	3.30	27.73
	8	23.38	1.32	3.37	28.06
	12	23.55	1.34	3.42	28.32
	16	23.69	1.36	3.46	28.52
5	4	130.57	51.36	103.83	285.76
	8	131.13	51.40	103.92	286.45
	12	131.58	51.43	103.98	287.00
	16	132.00	51.47	104.04	287.51
6	4	322.32	51.36	103.82	477.50
	8	322.71	51.40	103.91	478.01
	12	323.06	51.43	103.98	478.47
	16	323.36	51.47	104.05	478.87

Table 33: Expected number of fatalities for the Estonia when all passengers are equally distributed over the different age groups

When only half the Lifeboats are available the expected number of fatalities is:

Sea state	Exposure time (hours)	LB	DL LR	LR_L	Total
3	4	11.57	1.28	9.02	21.88
	8	11.69	1.32	9.21	22.21
	12	11.78	1.34	9.35	22.48
	16	11.84	1.36	9.46	22.67
5	4	65.28	51.36	283.84	400.49
	8	65.56	51.40	284.07	401.04
	12	65.79	51.43	284.25	401.48
	16	66.00	51.47	284.42	401.89
6	4	161.16	51.36	283.82	496.33
	8	161.36	51.40	284.04	496.80
	12	161.53	51.43	284.25	497.21
	16	161.68	51.47	284.43	497.58

Table 34: Expected number of fatalities for the Estonia when all passengers are equally distributed over the different age groups and half the LBs are available

Here the percentage changes for sea state 3 is a 21% reduction. For sea state 5 and 6, the increase is 40% and 4% respectively.

Proportion 4

Sea state	Exposure time (hours)	LB	DL LR	LR_L	Total
3	4	21.86	1.09	2.53	25.48
	8	22.07	1.12	2.59	25.79
	12	22.26	1.15	2.65	26.07
	16	22.40	1.17	2.69	26.26
5	4	127.71	51.13	102.85	281.68
	8	128.26	51.17	102.93	282.36
	12	128.70	51.20	102.99	282.89
	16	129.11	51.23	103.05	283.39
6	4	319.65	51.12	102.83	473.60
	8	320.04	51.16	102.92	474.11
	12	320.39	51.20	102.99	474.57
	16	320.68	51.23	103.05	474.96

Table 35: Expected number of fatalities for the Estonia when most passengers are in the middle age group

When only half the Lifeboats are available the expected number of fatalities is:

Sea state	Exposure time (hours)	LB	DL LR	LR_L	Total
3	4	10.93	1.09	6.91	18.93
	8	11.04	1.12	7.09	19.25
	12	11.13	1.15	7.24	19.53
	16	11.20	1.17	7.35	19.72
5	4	63.85	51.13	281.15	396.13
	8	64.13	51.17	281.38	396.67
	12	64.35	51.20	281.55	397.10
	16	64.55	51.23	281.72	397.50
6	4	159.82	51.12	281.11	492.06
	8	160.02	51.16	281.34	492.52
	12	160.19	51.20	281.54	492.93
	16	160.34	51.23	281.71	493.28

Table 36: Expected number of fatalities for the Estonia when most passengers are in the middle age group and half the LBs are available

Here the percentage change for sea state 3 is 25%.The increase is sea state 5 and 6 is 40% and 4% respectively like for the previous proportion.

Conclusion

The results are quite similar for both ships as the total expected number of fatalities is smaller when all the passengers are in the young age group. The other extreme case where all passengers are in the old age group represents the worst case with the highest number of total expected fatalities.
The biggest difference between these two proportions is observed in sea state 3 where the total expected number of fatalities for Proportion 2 is more than 1.5 times the total expected number of fatalities of Proportion 1. When only half the LBs are available it is almost double.

When passengers are distributed according to the other two proportions (P3 and P4), the computations produce quite the same total numbers of fatalities and the values are between the two extreme cases (P1 and P2).

Reducing the number of Lifeboats by half has also the same effect for both ships. In sea state 3 the total expected number of fatalities is reduced while in sea state 5 and 6 it is increased. The only difference is in the percentage changes of the expected number of fatalities for the different proportions.
For both sea states 3 and 5 the percentage changes of the total expected number of fatalities when only half the LBs are available are smaller for the Estonia than for the Cruise Liner apart for Proportion 1 and sea state 3 where the percentage changes for both ships are quite similar and are about 34%.
In sea state 6 for all proportions and for both ships the percentage change is always about 4%.

6 Error propagation

As explained in the first part of this document (section 3.2), the CasualtyCalculator produces as an output the standard deviation associated with the fatality rates. In order for the software to compute the standard deviation, it needs as input a variance matrix as well as the degradation matrix (considered as the mean) associated to each obstacle. It then produces the fatalities rates with the standard deviation associated to them.

During the assessment of the obstacles it was difficult to assign uncertainties to the different values of the obstacle matrices mainly due to a lack of data. In order to compute the error, it was decided to assign fixed values to the variances associated to the obstacles and study how this would affect the results.

For this study the sequence of obstacles used corresponds to the worst case scenario and was the one defined earlier as case 3.

First all obstacles were assigned a variance and the standard deviation of the fatality rates were computed.

Then, as obstacle A16 has the highest failure probability (and so the biggest influence on the overall fatality rate) additional values were assigned to the variance of obstacle A16 in order to study the variation.

The next section explains how the variance matrices are obtained. Then the results of the error computation for the sequence of obstacles are presented.

No variance matrices were associated to identity degradation matrices.

6.1 Variance matrices

For HW obstacles and because each column of the degradation matrix needs to add up to 1 only one value p is enough to define the degradation matrix where p is the failure probability of the HW obstacle.
The same applies to the variance matrices and only one value is enough to define it.

For example for obstacle A2, the failure probability is 0.0032 in this case the degradation matrix is defined as follows:

$$\begin{bmatrix} 0.9968 & 0 & 0 & 0 \\ 0 & 0.9968 & 0 & 0 \\ 0 & 0 & 0.9968 & 0 \\ 0.0032 & 0.0032 & 0.0032 & 1 \end{bmatrix}$$

The variance matrix (multiplying by 0.001 the value of the failure probability) is then

$$\begin{bmatrix} 3.2 \times 10^{-6} & 0 & 0 & 0 \\ 0 & 3.2 \times 10^{-6} & 0 & 0 \\ 0 & 0 & 3.2 \times 10^{-6} & 0 \\ 3.2 \times 10^{-6} & 3.2 \times 10^{-6} & 3.2 \times 10^{-6} & 0 \end{bmatrix}$$

For HF obstacles each column needs to add up to 1 as well, but in this case more values are needed to define the matrix.
For the first column only three values are needed (a_{11} is computed). For the second column 2 values are needed (a_{22} is computed) and finally for the third column only one value is needed (a_{33} is computed).

The variance matrix can be defined in the same way where one value in each column (a_{11},a_{22}, and a_{33}) is dependent of the other values in that column.

For example for obstacle A9 and for the old age group the degradation matrix is

$$\begin{bmatrix} 0.9185 & 0 & 0 & 0 \\ 0.0764 & 0.9937 & 0 & 0 \\ 0.0041 & 0.0051 & 0.9975 & 0 \\ 0.0010 & 0.0013 & 0.0025 & 1 \end{bmatrix}$$

The associated variance matrix is (in this case by multiplying by 0.001 the values of the degradation matrix):

$$\begin{bmatrix} 8.15 \times 10^{-5} & 0 & 0 & 0 \\ 7.64 \times 10^{-5} & 6.4 \times 10^{-6} & 0 & 0 \\ 4.1 \times 10^{-6} & 5.1 \times 10^{-6} & 2.5 \times 10^{-6} & 0 \\ 10^{-6} & 1.3 \times 10^{-6} & 2.5 \times 10^{-6} & 0 \end{bmatrix}$$

6.2 Fatality rates errors

As explained above the variances associated to each obstacle were assigned values equal to 0.001 time the values of the entries of the mean matrices. These values were chosen so that the changes remain in the same order of magnitude as the fatality rates (all variance matrices are presented in Appendix I).

The standard deviation associated to each fatality rate was then obtained using the Casualty Calculator.

The coefficient of variation which is defined as: $c.o.v = \frac{standard\ deviation}{mean}$, was then computed and used to analyse the results.

6.2.1 Lifeboat results

For the young and middle age groups the c.o.v. is constant for all sea states independent of the exposure time. For the old age group there is a 2% decrease in the c.o.v. of the fatality rate at 4h exposure when compared to the one at 16h exposure. Because of the difference being so small we can assume that the c.o.v of the fatality rate for the old age group is not affected by the exposure time.
In all sea states the c.o.v of the fatality rate for the young age group is higher than the other two age groups. For all age groups the c.o.v. decreases in higher sea states (Figure 48, Figure 49, Figure 50 and Figure 51).

Figure 48: c.o.v. of the fatality rate for the LB in sea state 3 for all age groups

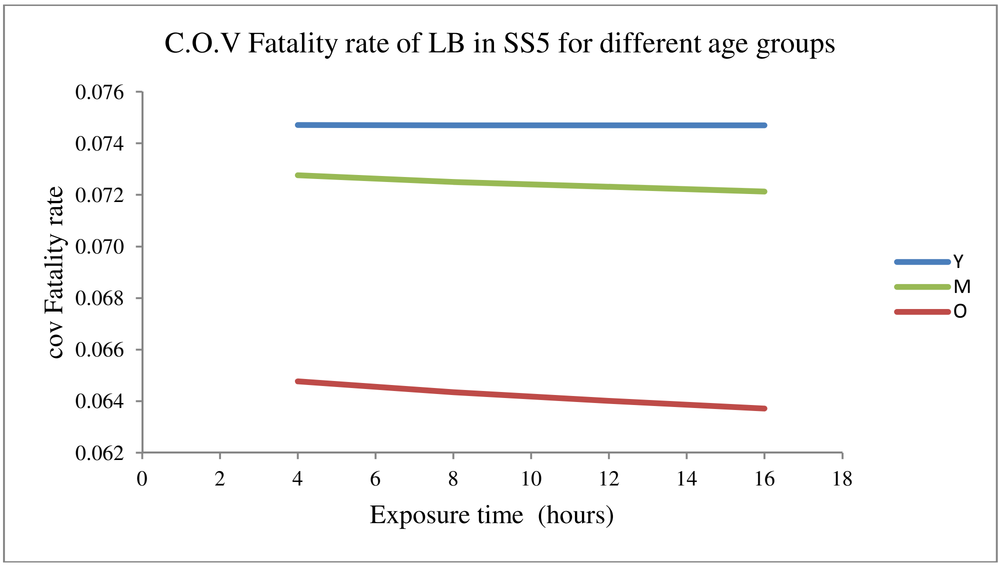

Figure 49: c.o.v. of the fatality rate for the LB in sea state 5 for all age groups

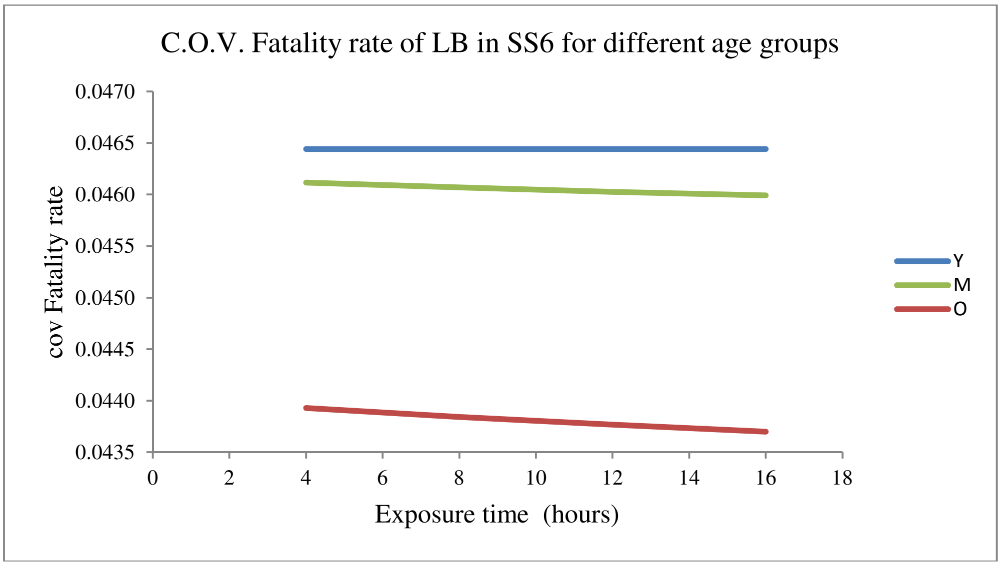

Figure 50: c.o.v. of the fatality rate for the LB in sea state 6 for all age groups

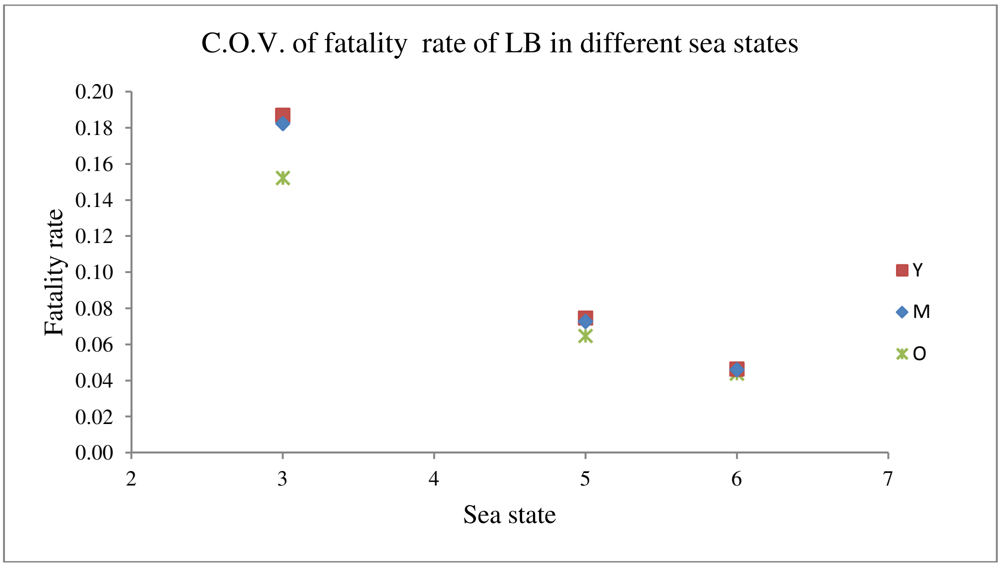

Figure 51: c.o.v. of the fatality rate for the LB in different sea states.

6.2.2 *Liferaft Results*[1]

For the LR the c.o.v. is constant for the young age group but decreases slightly (about 4%) with the exposure time for the middle and old age groups, in sea state 3. In the other two sea states the c.o.v. of the fatality rate for all the age groups is not affected by the exposure time. The old age group has the smallest c.o.v. in all situations.
In addition there are no changes in the results for all age groups from sea state 5 to sea state 6 (Figure 52, Figure 53 and Figure 54).

Here too the c.o.v of the fatality rate decreases with high sea states (Figure 55).

The main difference here when compared to the results for the LB, is the value of the c.o.v., in sea state 3 which is much higher than in sea state 5 and 6.

[1] The results shown here correspond to the davit launched LR. The LR boarded through the ladder was not investigated here.

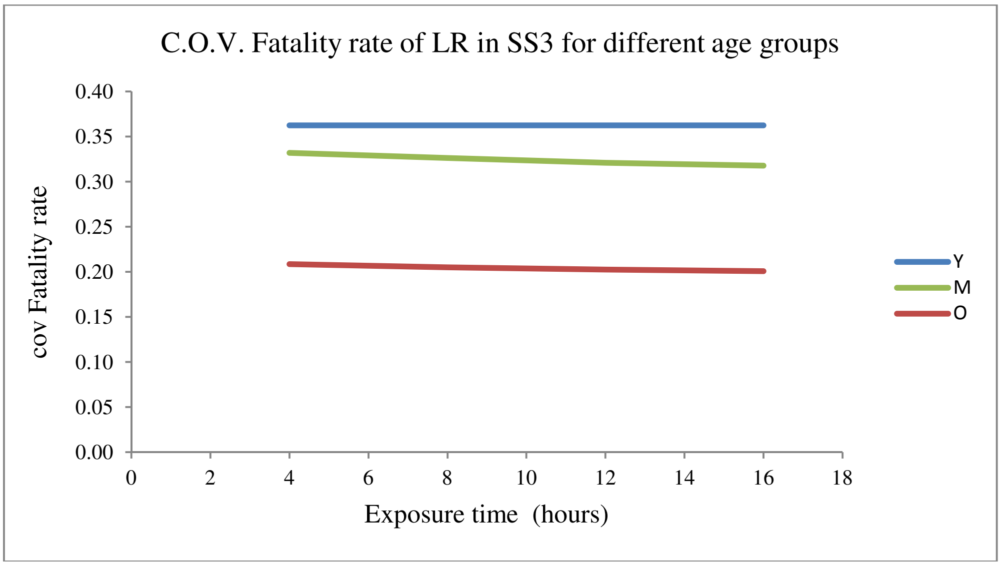

Figure 52: c.o.v. of the fatality rate for the LR in sea state 3 for all age groups

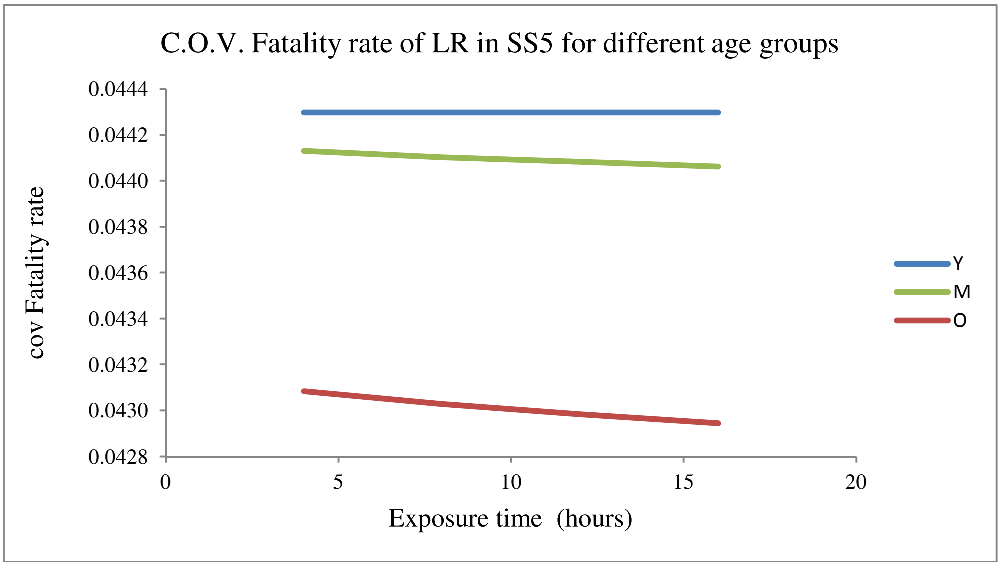

Figure 53: c.o.v. of the fatality rate for the LR in sea state 5 for all age groups

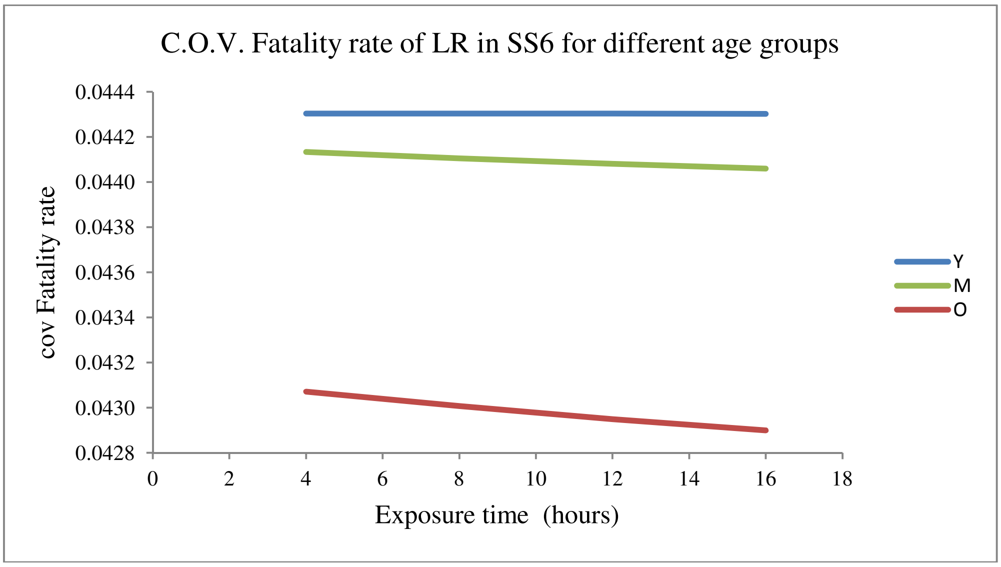

Figure 54: c.o.v. of the fatality rate for the LR in sea state 6 for all age groups

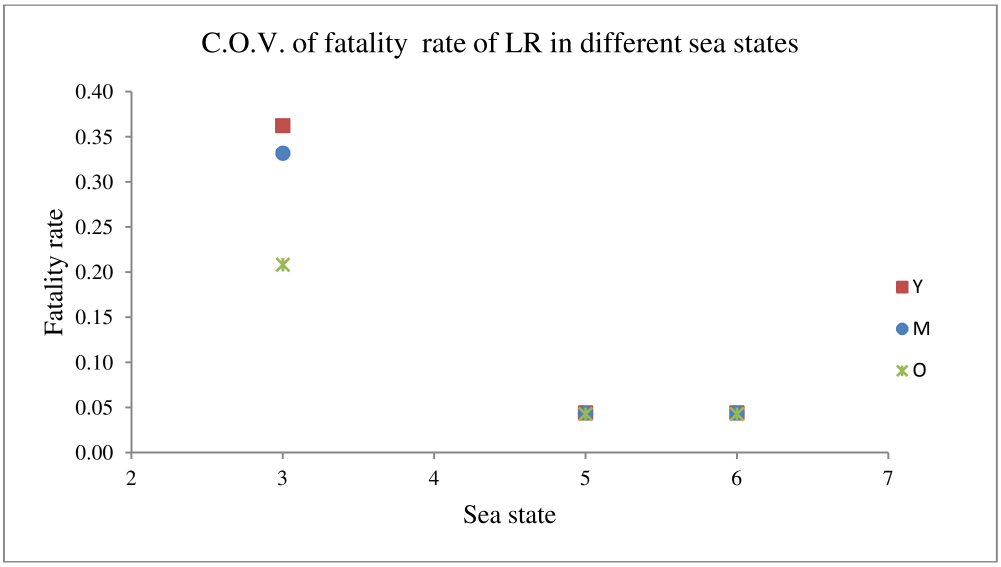

Figure 55: c.o.v. of the fatality rate for the LR in different sea states.

6.2.3 *Discussion*

These results are explained by the fact that the number of obstacles involved in the sequence varies: i.e. obstacles for which the degradation matrix is not an ID matrix (please refer to Appendix I for the degradation matrices).

The table below summarises the number of obstacles in the sequence for which the degradation matrix is not an ID matrix per age group and sea state for both LB and LR.

For the LB, the sequence of obstacles originally contains 10 obstacles without duplication[2] and for the LR the sequence contains 8 obstacles without duplication (obstacle A8 has an ID degradation matrix so is not accounted for here).

	LB (total obstacles 10)			LR (total obstacles 8)		
Sea state	Y	M	O	Y	M	O
3	4	5	5	3	4	4
5	5	6	7	5	6	7
6	7	8	10	5	6	7

Table 37: Number of obstacles for which the degradation matrix is not an ID matrix

As can be seen in the table above, in all cases the number of obstacles in the sequence is the smallest for the young age group leading to the highest c.o.v.

[2] As explained in section 4.2 of this document obstacle R7 is duplicated in the sequence of obstacles a number of times according to the exposure time (appears once for 4h exposure and 4 times for a 16h exposure).

6.2.4 Minimum and maximum values for the fatality rates

Using the standard deviation computed by the Casualty Calculator, the minimum and maximum values within 1 sigma of the mean for the fatality rates were computed and are shown in the tables below for each age group. The values correspond to the shortest exposure time (4h) for which the c.o.v. was the highest (when applicable).

Sea State 3

	Y_Min	Y_Max	M_Min	M_ Max	O_Min	O_ Max
LB	0.023	0.034	0.024	0.035	0.036	0.049
LR	0.005	0.010	0.006	0.012	0.017	0.027

Sea State 5

	Y_Min	Y_Max	M_Min	M_ Max	O_Min	O_ Max
LB	0.163	0.189	0.168	0.194	0.197	0.224
LR	0.484	0.529	0.486	0.531	0.503	0.548

Sea State 6

	Y_Min	Y_Max	M_Min	M_ Max	O_Min	O_ Max
LB	0.434	0.477	0.438	0.481	0.465	0.508
LR	0.484	0.529	0.486	0.531	0.503	0.548

6.3 Influence of A16

Different variances were assigned to this obstacle to study the impact on the fatality rate.
All other obstacles had their variances set equal to zero.

The different variances considered are:

For the LB

	SS3	SS5	SS6
Scenario 1	0.00001	0.001	0.01
Scenario 2	0.00002	0.002	0.02
Scenario 3	0.00003	0.003	0.03
Scenario 4	0.00004	0.004	0.04
Scenario 5	0.00005	0.005	0.05

For the LR

	SS3	SS5	SS6

Scenario 1	0.0001	0.01	0.01
Scenario 2	0.0002	0.02	0.02
Scenario 3	0.0003	0.03	0.03
Scenario 4	0.0004	0.04	0.04
Scenario 5	0.0005	0.05	0.05

The failure probabilities associated to obstacle A16 are as follows:

	SS3	**SS5**	**SS6**
LB	0.021	0.165	0.44
LR	0	0.5	0.5

Because obstacle A16 is a HW obstacle it affects the different age groups in the same way. The standard deviation of the fatality rates for a particular scenario and in a particular sea state will be the same for all the age groups. The standard deviation is not affected by the exposure time either.

The standard deviation of the fatality rates is as follows:

For the LB

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
SS3	0.0031	0.0045	0.0055	0.0063	0.0070
SS5	0.0315	0.0445	0.0545	0.063	0.070
SS6	0.0982	0.1388	0.1701	0.1964	0.2195

For the LR

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
SS3	0.01	0.0141	0.0172	0.0199	0.0223
SS5	0.0996	0.1408	0.1725	0.1991	0.2227
SS6	0.0996	0.1408	0.1725	0.1991	0.2227

For each scenario the coefficient of variation was computed.
First the relationship of the c.o.v. with the exposure time was investigated then its relationship with the c.o.v. of the input.

6.3.1 Relationship with the exposure time

Lifeboat Results

The c.o.v. of the fatality rate remains constant for the young age group in all 5 scenarios and in all sea states and is not affected by the exposure time.

For the middle group a 2.6% decrease in the c.o.v of the fatality rate is observed when comparing the results for 4h and 16h exposure in sea state 3. The decrease is down to 1% in sea state 5 and 0.32% in sea state 6.

For the old age group a 3.6% decrease is observed in sea state3. In sea state 5 it is 2% decrease while in sea state 6 it is down to 0.6%.

Liferaft Results

The c.o.v. of the fatality rate remains constant for the young age group in all 5 scenarios and in all sea states and is not affected by the exposure time.

For the middle group a 8.2% decrease in the c.o.v of the fatality rate is observed when comparing the results for 4h and 16h exposure in sea state 3. The decrease is down to 0.2% in sea state 5 and 6.

For the old age group a 6.8% decrease is observed in sea state3. In sea state 5 there is a 0.41% decrease while in sea state 6 it is 0.44%.

Discussion:

The changes (when not negligible) in the c.o.v. with the exposure time are explained by the fact that the fatality rate was found (section 4.3) in some cases to vary slightly with the exposure time and because the standard deviation is constant for all exposure times (see results in Appendix II), the variation in the c.o.v is only due to the variation in the fatality rate.
Also as the c.o.v. is inversely proportional to the fatality rate it decreases with the exposure time while the fatality rate was found to increase with the exposure time.

6.3.2 Relationship with c.o.v. of input

As there is only one obstacle (A16) for which the error varies, the relationship between the error in the input and the impact it has on the output error has been investigated. For simplicity only the results corresponding to a 4h exposure time were analysed.

The c.o.v. of the failure probability (input) for both the LB and LR are as follows:

For the LB

	SS3	**SS5**	**SS6**
Scenario 1	0.1506	0.1917	0.2273
Scenario 2	0.2130	0.2710	0.3214
Scenario 3	0.2608	0.3320	0.3936
Scenario 4	0.3012	0.3833	0.4545
Scenario 5	0.3367	0.4285	0.5082

For the LR

	SS3	SS5	SS6
Scenario 1	0.01	0.2	0.2
Scenario 2	0.0141	0.2828	0.2828
Scenario 3	0.0173	0.3464	0.3464
Scenario 4	0.02	0.4	0.4
Scenario 5	0.0224	0.4472	0.4472

Lifeboat results

Sea state 3

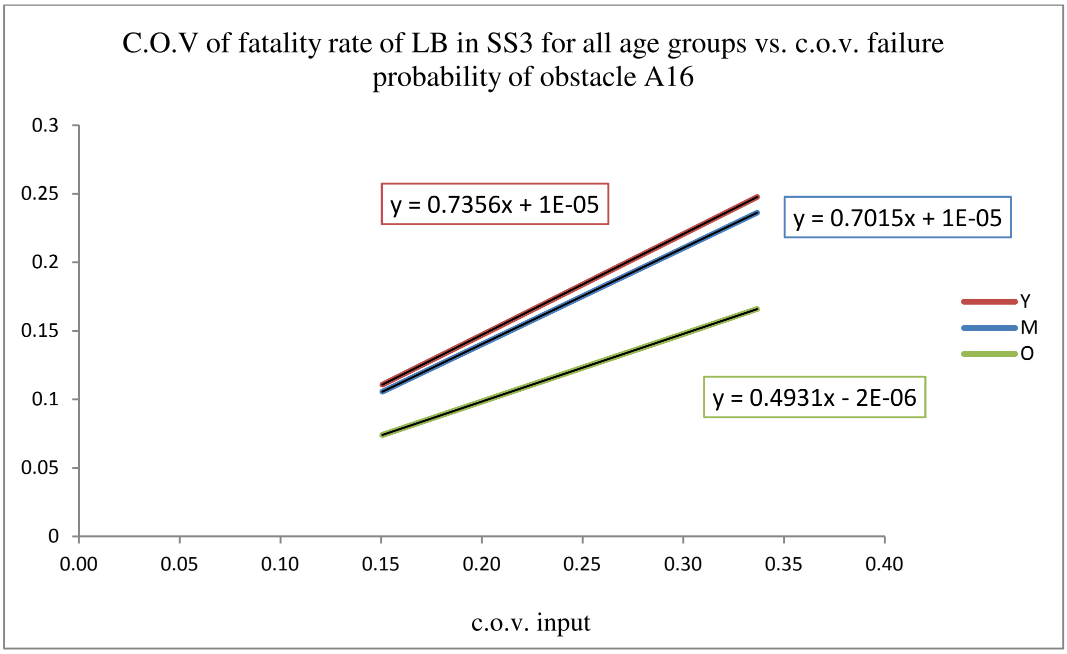

Figure 56: Relationship between c.o.v of input and c.o.v. of output in sea state 3 for the LB

Sea state 5

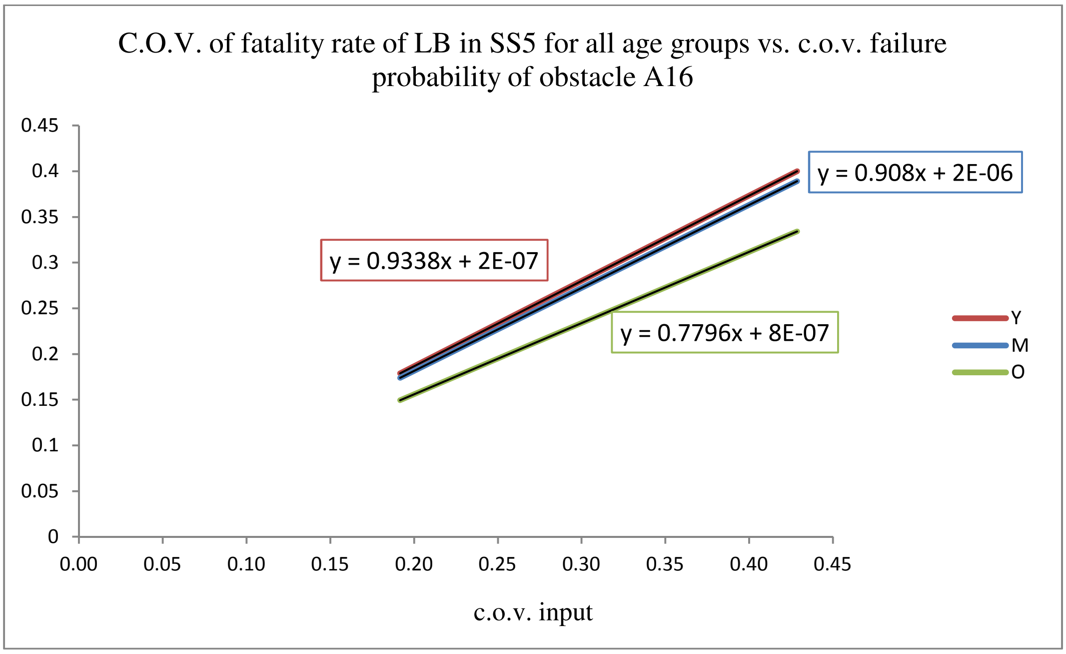

Figure 57: Relationship between c.o.v of input and c.o.v. of output in sea state 5 for the LB

Sea state 6

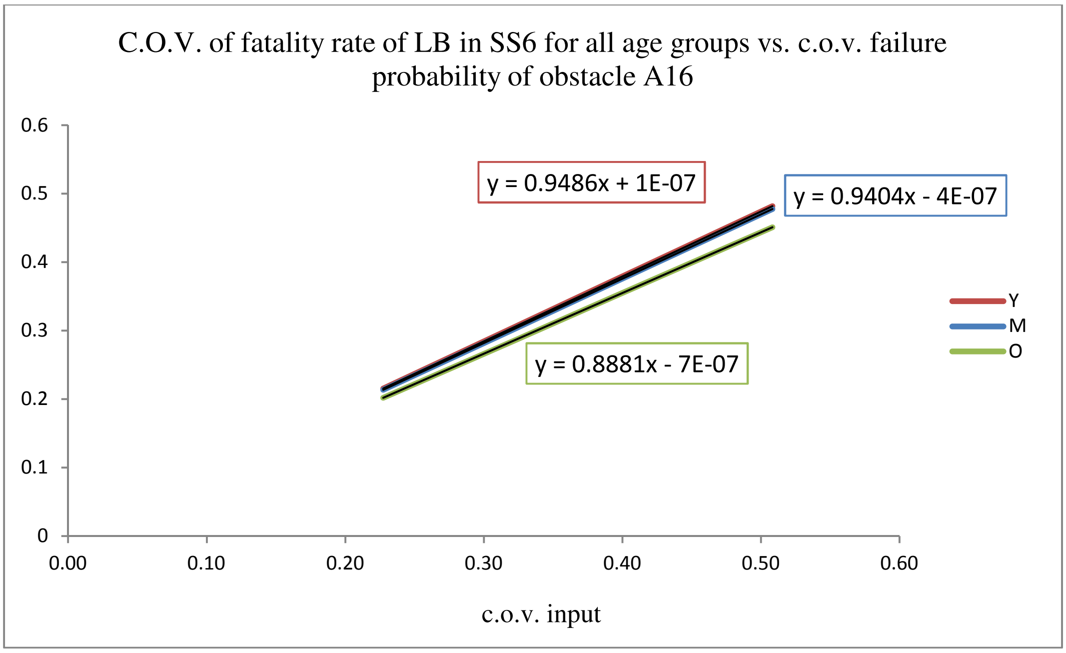

Figure 58: Relationship between c.o.v of input and c.o.v. of output in sea state 6 for the LB

Liferaft results

Sea state 3

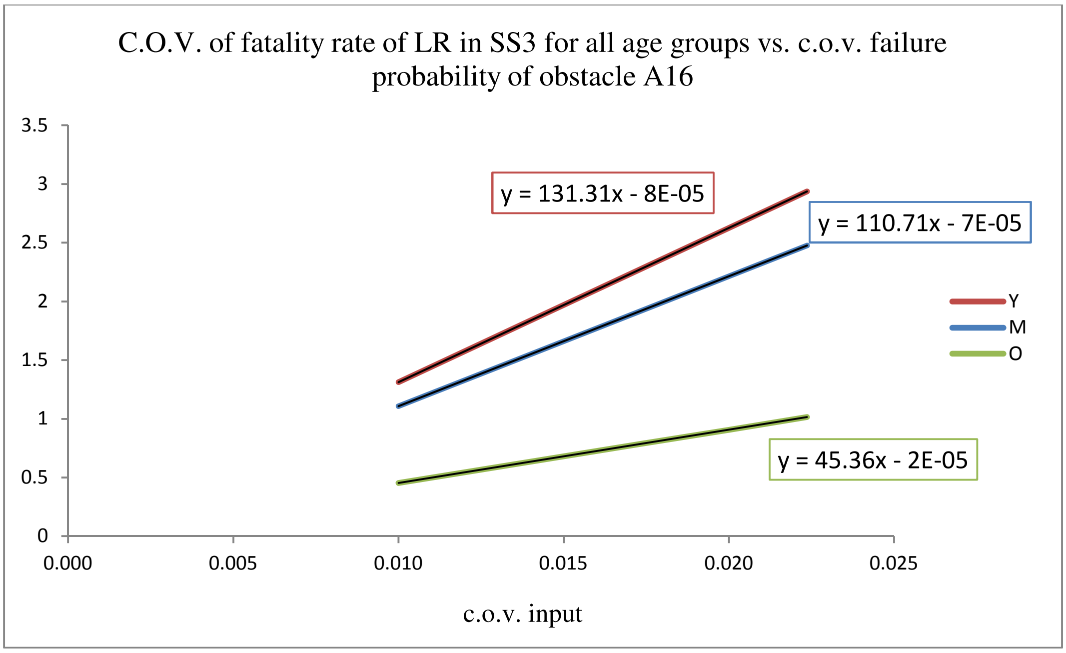

Figure 59: Relationship between c.o.v of input and c.o.v. of output in sea state 3 for the LR

Sea state 5

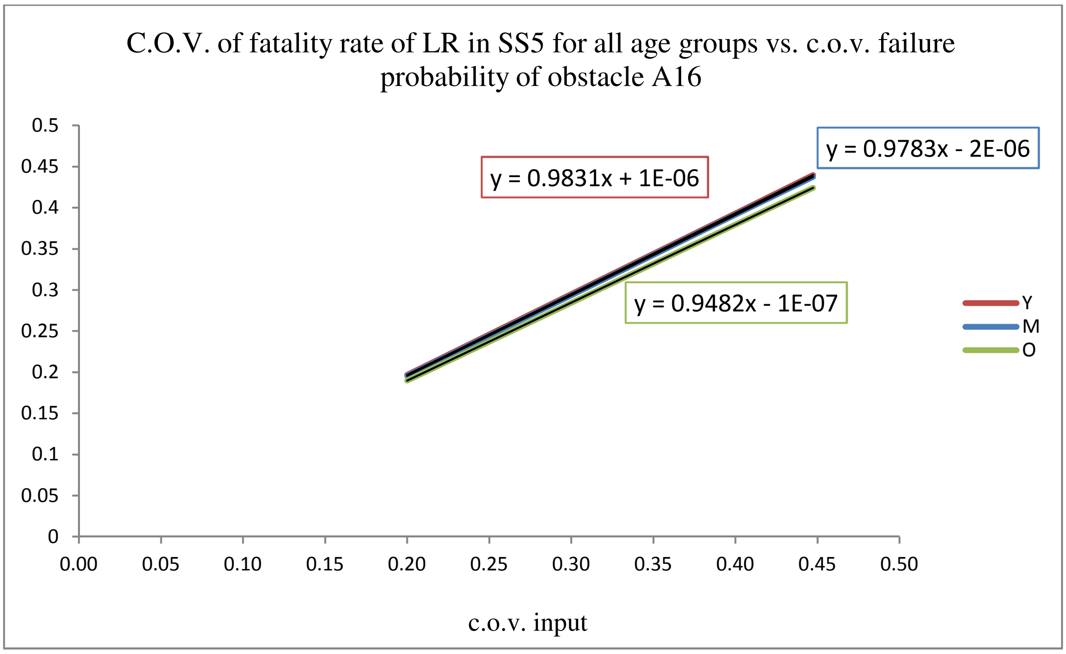

Figure 60: Relationship between c.o.v of input and c.o.v. of output in sea state 5 for the LR

Sea state 6

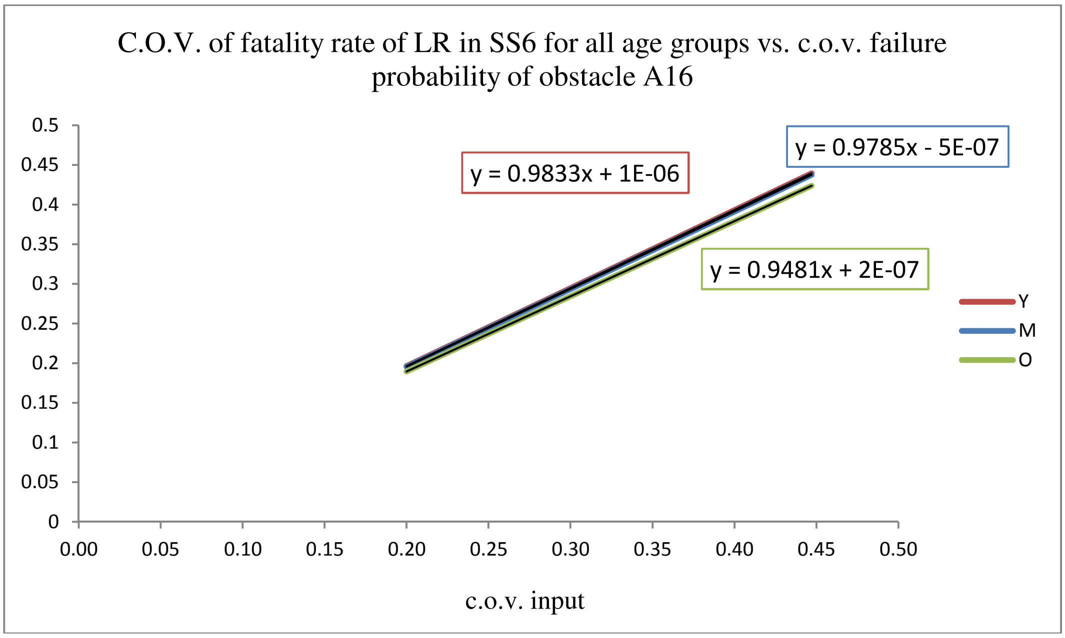

Figure 61: Relationship between c.o.v of input and c.o.v. of output in sea state 6 for the LR

Discussion:

In all cases and for both LB and LR, the c.o.v. of the fatality rate (output) increases linearly with the c.o.v. of the failure probability of obstacle A16 (the input).

In sea state 3 and for both the LB and LR the old age group has the slowest growth with a significant difference between the old age group and the other two age groups. In addition the increase of the c.o.v of the output is much higher for the LR than it is for the LB.

In sea state 5, the curves for the young and middle age group are almost parallel for the LB and almost equal for the LR. Their distance to the old age group's curve is much smaller in this sea state especially for the LR.

In sea state 6 the results for the LR are the same as in sea state 5. For the LB, the results are similar to those of sea state 5, with the curves of the middle and young age groups almost equal and the difference with the old age group even smaller.

In sea state 3, the high values of the c.o.v. for the LR are explained by the fact that the failure probability of obstacle A16 is equal to zero. In addition the number of obstacles for which the degradation matrix is not an ID matrix is very small.

For the LB the c.o.v. of the output is about 70% the c.o.v. of the input for both the young and middle age group while for the old age group it is less than 50 %.

For the LB young and middle age groups and for all age groups for the LR, in sea states 5 and 6, the relationship between the c.o.v of the input and the c.o.v. of the output can approximately be

$$c.o.v.output \cong c.o.v\ input$$

7 Conclusion

The methods to establish the uncertainty bounds for the MAR process have been presented in the first part of this document. Then the whole abandonment and rescue phase was assessed using the Casualty Calculator. To do so, a sequence of obstacles was defined and the fatality rates associated to it computed.

The impact of hardware (HW) obstacles was found to be the most significant.
The fatality rate as a result of Human Factor (HF) obstacles alone was negligible in most cases.
The exposure time was found to have almost no impact on the fatality rate for all age groups except for the middle and old age group in sea state 3 for the LR.

Weather independent HW obstacles were found to have little or no impact on the fatality rate in sea state 5 and 6 while in sea state 3 they have some impact mainly for the young and middle age groups.

When comparing fatality rate per Life Saving Appliances (LSA) types, it was found that in sea state 3, the Lifeboats (LB) had the biggest fatality rate but in sea state 5 and 6, Liferafts (LR) had bigger fatality rates.

The Error was found to be related to the number of obstacles involved in the sequence. The more obstacles are in the sequence the smaller the value of the c.o.v. is.

8 References

D.Vassalos, H. Kim, G. Christiansen and J. Majumder *“A Mesoscopic Model for Passenger Evacuation in a Virtual Ship-Sea Environment and Performance-Based Evaluation”*. Pedestrian and Evacuation Dynamics. 2001.

Appendix I: Input matrices to the CasualtyCalculator - Degradation and variance matrices.

The input degradation matrices for each obstacle used in the computations are explained in details in D5.3 and D5.4 and are summarised in this annex for convenience. The variance matrices are given next.

Obstacle A2

Same matrix for all age groups and sea states

$$\begin{bmatrix} 0.9968 & 0 & 0 & 0 \\ 0 & 0.9968 & 0 & 0 \\ 0 & 0 & 0.9968 & 0 \\ 0.0032 & 0.0032 & 0.0032 & 1 \end{bmatrix}$$

Obstacle A7

Same matrix for all age groups and sea states

$$\begin{bmatrix} 0.9989 & 0 & 0 & 0 \\ 0 & 0.9989 & 0 & 0 \\ 0 & 0 & 0.9989 & 0 \\ 0.0011 & 0.0011 & 0.0011 & 1 \end{bmatrix}$$

Obstacle A8

Below sea state 6 and for all age groups

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Sea state 6 and for all age groups

$$\begin{bmatrix} 0.986 & 0 & 0 & 0 \\ 0 & 0.986 & 0 & 0 \\ 0 & 0 & 0.986 & 0 \\ 0.014 & 0.014 & 0.014 & 1 \end{bmatrix}$$

Obstacle A16

For LB

Sea state 3

$$\begin{bmatrix} 0.979 & 0 & 0 & 0 \\ 0 & 0.979 & 0 & 0 \\ 0 & 0 & 0.979 & 0 \\ 0.021 & 0.021 & 0.021 & 1 \end{bmatrix}$$

Sea state 5

$$\begin{bmatrix} 0.835 & 0 & 0 & 0 \\ 0 & 0.835 & 0 & 0 \\ 0 & 0 & 0.835 & 0 \\ 0.165 & 0.165 & 0.165 & 1 \end{bmatrix}$$

Sea state 6

$$\begin{bmatrix} 0.56 & 0 & 0 & 0 \\ 0 & 0.56 & 0 & 0 \\ 0 & 0 & 0.56 & 0 \\ 0.44 & 0.44 & 0.44 & 1 \end{bmatrix}$$

For LR

Sea state 3

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Sea state 5 and 6

$$\begin{bmatrix} 0.5 & 0 & 0 & 0 \\ 0 & 0.5 & 0 & 0 \\ 0 & 0 & 0.5 & 0 \\ 0.5 & 0.5 & 0.5 & 1 \end{bmatrix}$$

Obstacle R6 (LB+LR)

Sea state 3

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Sea state 5

$$\begin{bmatrix} 0.9994 & 0 & 0 & 0 \\ 0 & 0.9994 & 0 & 0 \\ 0 & 0 & 0.9994 & 0 \\ 0.0006 & 0.0006 & 0.0006 & 1 \end{bmatrix}$$

Sea state 6

$$\begin{bmatrix} 0.9996 & 0 & 0 & 0 \\ 0 & 0.9996 & 0 & 0 \\ 0 & 0 & 0.9996 & 0 \\ 0.0004 & 0.0004 & 0.0004 & 1 \end{bmatrix}$$

Obstacle A9

Below sea state 6 and for all age groups

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Sea state 6

Young (<50)

$$\begin{bmatrix} 0.9694 & 0 & 0 & 0 \\ 0.0306 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Middle (50-75)

$$\begin{bmatrix} 0.9399 & 0 & 0 & 0 \\ 0.0561 & 0.9937 & 0 & 0 \\ 0.0041 & 0.0051 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Old (>75)

$$\begin{bmatrix} 0.9185 & 0 & 0 & 0 \\ 0.0764 & 0.9937 & 0 & 0 \\ 0.0041 & 0.0051 & 0.9975 & 0 \\ 0.0010 & 0.0013 & 0.0025 & 1 \end{bmatrix}$$

Obstacle A10

Sea state 3 for all age groups

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Sea state 5

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 0.8740 & 0 & 0 & 0 \\ 0.1260 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \begin{bmatrix} 0.6010 & 0 & 0 & 0 \\ 0.3990 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \begin{bmatrix} 0.6005 & 0 & 0 & 0 \\ 0.3960 & 0.9956 & 0 & 0 \\ 0.0032 & 0.0040 & 0.9992 & 0 \\ 0.0003 & 0.0004 & 0.0008 & 1 \end{bmatrix}$$

Sea state 6:

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 0.5818 & 0 & 0 & 0 \\ 0.4160 & 0.9973 & 0 & 0 \\ 0.0020 & 0.0025 & 0.9995 & 0 \\ 0.0002 & 0.0002 & 0.0005 & 1 \end{bmatrix} \quad \begin{bmatrix} 0.3205 & 0 & 0 & 0 \\ 0.6700 & 0.9883 & 0 & 0 \\ 0.0086 & 0.0107 & 0.9979 & 0 \\ 0.0009 & 0.0011 & 0.0021 & 1 \end{bmatrix} \quad \begin{bmatrix} 0.3144 & 0 & 0 & 0 \\ 0.5890 & 0.8892 & 0 & 0 \\ 0.0885 & 0.1008 & 0.9802 & 0 \\ 0.0081 & 0.0100 & 0.0198 & 1 \end{bmatrix}$$

Obstacle A11

Sea state 3

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 0.9901 & 0 & 0 & 0 \\ 0.0033 & 0.9918 & 0 & 0 \\ 0.0033 & 0.0041 & 0.9918 & 0 \\ 0.0033 & 0.0041 & 0.0082 & 1 \end{bmatrix} \quad \begin{bmatrix} 0.9877 & 0 & 0 & 0 \\ 0.0041 & 0.9898 & 0 & 0 \\ 0.0041 & 0.0051 & 0.9898 & 0 \\ 0.0041 & 0.0051 & 0.0102 & 1 \end{bmatrix} \quad \begin{bmatrix} 0.9507 & 0 & 0 & 0 \\ 0.0164 & 0.9596 & 0 & 0 \\ 0.0164 & 0.0202 & 0.9604 & 0 \\ 0.0164 & 0.0202 & 0.0396 & 1 \end{bmatrix}$$

Sea state 5 and 6

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 0.9760 & 0 & 0 & 0 \\ 0.0080 & 0.9802 & 0 & 0 \\ 0.0080 & 0.0099 & 0.9804 & 0 \\ 0.0080 & 0.0099 & 0.0196 & 1 \end{bmatrix} \quad \begin{bmatrix} 0.9702 & 0 & 0 & 0 \\ 0.0099 & 0.9754 & 0 & 0 \\ 0.0099 & 0.0123 & 0.9757 & 0 \\ 0.0099 & 0.0123 & 0.0243 & 1 \end{bmatrix} \quad \begin{bmatrix} 0.8810 & 0 & 0 & 0 \\ 0.0397 & 0.9047 & 0 & 0 \\ 0.0397 & 0.0476 & 0.9093 & 0 \\ 0.0397 & 0.0476 & 0.0907 & 1 \end{bmatrix}$$

Obstacle A15

Sea State 3

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 0.9990 & 0 & 0 & 0 \\ 0.0010 & 0.9990 & 0 & 0 \\ 0 & 0.0010 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.9990 & 0 & 0 & 0 \\ 0.0010 & 0.9990 & 0 & 0 \\ 0 & 0.0010 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.9800 & 0 & 0 & 0 \\ 0.0200 & 0.9980 & 0 & 0 \\ 0 & 0.0020 & 0.9990 & 0 \\ 0 & 0 & 0.0010 & 1 \end{bmatrix}$$

Sea States 5 and 6

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 0.9990 & 0 & 0 & 0 \\ 0.0010 & 0.9500 & 0 & 0 \\ 0 & 0.0500 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.9970 & 0 & 0 & 0 \\ 0.0030 & 0.9300 & 0 & 0 \\ 0 & 0.0700 & 0.9800 & 0 \\ 0 & 0 & 0.0200 & 1 \end{bmatrix} \begin{bmatrix} 0.9800 & 0 & 0 & 0 \\ 0.0200 & 0.9000 & 0 & 0 \\ 0 & 0.1000 & 0.9200 & 0 \\ 0 & 0 & 0.0800 & 1 \end{bmatrix}$$

Obstacle R3-R5

Sea state 3

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 0.9901 & 0 & 0 & 0 \\ 0.0033 & 0.9918 & 0 & 0 \\ 0.0033 & 0.0041 & 0.9918 & 0 \\ 0.0033 & 0.0041 & 0.0082 & 1 \end{bmatrix} \begin{bmatrix} 0.9877 & 0 & 0 & 0 \\ 0.0041 & 0.9898 & 0 & 0 \\ 0.0041 & 0.0051 & 0.9898 & 0 \\ 0.0041 & 0.0051 & 0.0102 & 1 \end{bmatrix} \begin{bmatrix} 0.9507 & 0 & 0 & 0 \\ 0.0164 & 0.9596 & 0 & 0 \\ 0.0164 & 0.0202 & 0.9604 & 0 \\ 0.0164 & 0.0202 & 0.0396 & 1 \end{bmatrix}$$

Sea state 5 and 6:

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 0.9760 & 0 & 0 & 0 \\ 0.0080 & 0.9802 & 0 & 0 \\ 0.0080 & 0.0099 & 0.9804 & 0 \\ 0.0080 & 0.0099 & 0.0196 & 1 \end{bmatrix} \begin{bmatrix} 0.9702 & 0 & 0 & 0 \\ 0.0099 & 0.9754 & 0 & 0 \\ 0.0099 & 0.0123 & 0.9757 & 0 \\ 0.0099 & 0.0123 & 0.0243 & 1 \end{bmatrix} \begin{bmatrix} 0.8810 & 0 & 0 & 0 \\ 0.0397 & 0.9047 & 0 & 0 \\ 0.0397 & 0.0476 & 0.9093 & 0 \\ 0.0397 & 0.0476 & 0.0907 & 1 \end{bmatrix}$$

Obstacle R7

For LB

Sea state 3, all age groups, 4 hours of exposure:

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Sea state 5 and 6, 4 hours of exposure:

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 0.9983 & 0 & 0 & 0 \\ 0.0017 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.9929 & 0 & 0 & 0 \\ 0.0067 & 0.9994 & 0 & 0 \\ 0.0004 & 0.0005 & 0.9999 & 0 \\ 0 & 0.0001 & 0.0001 & 1 \end{bmatrix} \begin{bmatrix} 0.9822 & 0 & 0 & 0 \\ 0.0166 & 0.9986 & 0 & 0 \\ 0.0010 & 0.0013 & 0.9997 & 0 \\ 0.0001 & 0.0001 & 0.0003 & 1 \end{bmatrix}$$

For LR

Sea state 3, all age groups, 4 hours of exposure

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Sea state 5, 4 hours of exposure

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.9998 & 0 & 0 & 0 \\ 0 & 0.9997 & 0 & 0 \\ 0.0002 & 0.0003 & 0.9999 & 0 \\ 0 & 0 & 0.0001 & 1 \end{bmatrix} \begin{bmatrix} 0.9994 & 0 & 0 & 0 \\ 0 & 0.9993 & 0 & 0 \\ 0.0005 & 0.0007 & 0.9999 & 0 \\ 0.0001 & 0.0001 & 0.0001 & 1 \end{bmatrix}$$

Sea state 6, 4 hours of exposure

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 0.9992 & 0 & 0 & 0 \\ 0.0008 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.9964 & 0 & 0 & 0 \\ 0.0033 & 0.9997 & 0 & 0 \\ 0.0002 & 0.0003 & 0.9999 & 0 \\ 0 & 0 & 0.0001 & 1 \end{bmatrix} \begin{bmatrix} 0.9911 & 0 & 0 & 0 \\ 0.0083 & 0.9993 & 0 & 0 \\ 0.0005 & 0.0007 & 0.9999 & 0 \\ 0.0001 & 0.0001 & 0.0001 & 1 \end{bmatrix}$$

Obstacle R8

All sea states and age groups for LB and LR

For water temperature above 5°C

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

For water temperature below 5°C and for 4 hours exposure

Sea state 6

Young (<50)	Middle (50-75)	Old (>75)
$\begin{bmatrix} 0.9872 & 0 & 0 & 0 \\ 0.0022 & 0.9864 & 0 & 0 \\ 0.0035 & 0.0013 & 0.9789 & 0 \\ 0.0071 & 0.0124 & 0.0211 & 1 \end{bmatrix}$	$\begin{bmatrix} 0.9865 & 0 & 0 & 0 \\ 0.0013 & 0.9864 & 0 & 0 \\ 0.0026 & 0.0013 & 0.9789 & 0 \\ 0.0096 & 0.0124 & 0.0211 & 1 \end{bmatrix}$	$\begin{bmatrix} 0.9861 & 0 & 0 & 0 \\ 0.0003 & 0.9830 & 0 & 0 \\ 0.0013 & 0.0013 & 0.9744 & 0 \\ 0.0124 & 0.0158 & 0.0256 & 1 \end{bmatrix}$

Obstacle R9

Sea State 3

	Young (<50)	**Middle (50-75)**	**Old (>75)**
4h	$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 0.9963 & 0 & 0 & 0 \\ 0 & 0.9962 & 0 & 0 \\ 0.0031 & 0.0031 & 0.9988 & 0 \\ 0.0006 & 0.0007 & 0.0012 & 1 \end{bmatrix}$	$\begin{bmatrix} 0.9957 & 0 & 0 & 0 \\ 0 & 0.9954 & 0 & 0 \\ 0.0031 & 0.0031 & 0.9976 & 0 \\ 0.0012 & 0.0015 & 0.0024 & 1 \end{bmatrix}$
8h	$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 0.9950 & 0 & 0 & 0 \\ 0 & 0.9948 & 0 & 0 \\ 0.0041 & 0.0041 & 0.9982 & 0 \\ 0.0009 & 0.0011 & 0.0018 & 1 \end{bmatrix}$	$\begin{bmatrix} 0.9940 & 0 & 0 & 0 \\ 0 & 0.9935 & 0 & 0 \\ 0.0041 & 0.0041 & 0.9962 & 0 \\ 0.0019 & 0.0024 & 0.0038 & 1 \end{bmatrix}$
12h	$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 0.9944 & 0 & 0 & 0 \\ 0 & 0.9941 & 0 & 0 \\ 0.0044 & 0.0044 & 0.9976 & 0 \\ 0.0012 & 0.0015 & 0.0024 & 1 \end{bmatrix}$	$\begin{bmatrix} 0.9932 & 0 & 0 & 0 \\ 0 & 0.9926 & 0 & 0 \\ 0.0044 & 0.0044 & 0.9952 & 0 \\ 0.0024 & 0.0030 & 0.0048 & 1 \end{bmatrix}$

16h	$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$	$\begin{bmatrix}0.9940&0&0&0\\0&0.9937&0&0\\0.0046&0.0046&0.9972&0\\0.0014&0.0017&0.0028&1\end{bmatrix}$	$\begin{bmatrix}0.9926&0&0&0\\0&0.9919&0&0\\0.0046&0.0046&0.9944&0\\0.0028&0.0035&0.0056&1\end{bmatrix}$

Sea State 5

	Young (<50)	**Middle (50-75)**	**Old (>75)**
4h	$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$	$\begin{bmatrix}0.9823&0&0&0\\0&0.9816&0&0\\0.0148&0.0148&0.9942&0\\0.0029&0.0036&0.0058&1\end{bmatrix}$	$\begin{bmatrix}0.9795&0&0&0\\0&0.9781&0&0\\0.0148&0.0148&0.9887&0\\0.0057&0.0071&0.0113&1\end{bmatrix}$
8h	$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$	$\begin{bmatrix}0.9804&0&0&0\\0&0.9795&0&0\\0.0159&0.0159&0.9926&0\\0.0037&0.0046&0.0074&1\end{bmatrix}$	$\begin{bmatrix}0.9768&0&0&0\\0&0.9750&0&0\\0.0159&0.0159&0.9855&0\\0.0073&0.0091&0.0145&1\end{bmatrix}$
12h	$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$	$\begin{bmatrix}0.9795&0&0&0\\0&0.9784&0&0\\0.0162&0.0162&0.9914&0\\0.0043&0.0054&0.0086&1\end{bmatrix}$	$\begin{bmatrix}0.9752&0&0&0\\0&0.9731&0&0\\0.0162&0.0162&0.9829&0\\0.0086&0.0107&0.0171&1\end{bmatrix}$
16h	$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$	$\begin{bmatrix}0.9788&0&0&0\\0&0.9776&0&0\\0.0163&0.0163&0.9902&0\\0.0049&0.0061&0.0098&1\end{bmatrix}$	$\begin{bmatrix}0.9739&0&0&0\\0&0.9716&0&0\\0.0163&0.0163&0.9806&0\\0.0098&0.0121&0.0194&1\end{bmatrix}$

Sea State 6

	Young (<50)	**Middle (50-75)**	**Old (>75)**
4h	$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$	$\begin{bmatrix}0.9819&0&0&0\\0&0.9812&0&0\\0.0152&0.0152&0.9942&0\\0.0029&0.0036&0.0058&1\end{bmatrix}$	$\begin{bmatrix}0.9789&0&0&0\\0&0.9775&0&0\\0.0152&0.0152&0.9883&0\\0.0059&0.0073&0.0117&1\end{bmatrix}$
8h	$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$	$\begin{bmatrix}0.9801&0&0&0\\0&0.9792&0&0\\0.0162&0.0162&0.9926&0\\0.0037&0.0046&0.0074&1\end{bmatrix}$	$\begin{bmatrix}0.9764&0&0&0\\0&0.9746&0&0\\0.0162&0.0162&0.9853&0\\0.0074&0.0092&0.0147&1\end{bmatrix}$

12h

$$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}\quad\begin{bmatrix}0.9791&0&0&0\\0&0.9780&0&0\\0.0165&0.0165&0.9912&0\\0.0044&0.0055&0.0088&1\end{bmatrix}\quad\begin{bmatrix}0.9747&0&0&0\\0&0.9726&0&0\\0.0165&0.0165&0.9826&0\\0.0088&0.0109&0.0174&1\end{bmatrix}$$

16h

$$\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}\quad\begin{bmatrix}0.9784&0&0&0\\0&0.9772&0&0\\0.0166&0.0166&0.9901&0\\0.0050&0.0062&0.0100&1\end{bmatrix}\quad\begin{bmatrix}0.9734&0&0&0\\0&0.9710&0&0\\0.0166&0.0166&0.9802&0\\0.0100&0.0124&0.0198&1\end{bmatrix}$$

VARIANCE MATRICES

As explained in this document the variance matrices were derived from the degradation matrices and are as follows. No variance matrix was associated to obstacles for which the degradation matrix was an identity matrix.

Obstacle A2

Same matrix for all age groups and all sea states

$$\begin{bmatrix}3.2\times10^{-6}&0&0&0\\0&3.2\times10^{-6}&0&0\\0&0&3.2\times10^{-6}&0\\3.2\times10^{-6}&3.2\times10^{-6}&3.2\times10^{-6}&0\end{bmatrix}$$

Obstacle A7

Same matrix for all age groups and all sea states

$$\begin{bmatrix}1.1\times10^{-6}&0&0&0\\0&1.1\times10^{-6}&0&0\\0&0&1.1\times10^{-6}&0\\1.1\times10^{-6}&1.1\times10^{-6}&1.1\times10^{-6}&0\end{bmatrix}$$

Obstacle A8

Below sea state 6 and for all age groups no variance matrix.

Sea state 6 and for all age groups

$$\begin{bmatrix} 1.1\times10^{-5} & 0 & 0 & 0 \\ 0 & 1.1\times10^{-5} & 0 & 0 \\ 0 & 0 & 1.1\times10^{-5} & 0 \\ 1.1\times10^{-5} & 1.1\times10^{-5} & 1.1\times10^{-5} & 0 \end{bmatrix}$$

Obstacle A16

For LB

Sea state 3 and for all age groups

$$\begin{bmatrix} 2.1\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.1\times10^{-5} & 0 & 0 \\ 0 & 0 & 2.1\times10^{-5} & 0 \\ 2.1\times10^{-5} & 2.1\times10^{-5} & 2.1\times10^{-5} & 0 \end{bmatrix}$$

Sea state 5 and for all age groups

$$\begin{bmatrix} 1.65\times10^{-4} & 0 & 0 & 0 \\ 0 & 1.65\times10^{-4} & 0 & 0 \\ 0 & 0 & 1.65\times10^{-4} & 0 \\ 1.65\times10^{-4} & 1.65\times10^{-4} & 1.65\times10^{-4} & 0 \end{bmatrix}$$

Sea state 6 and for all age groups

$$\begin{bmatrix} 4.4\times10^{-4} & 0 & 0 & 0 \\ 0 & 4.4\times10^{-4} & 0 & 0 \\ 0 & 0 & 4.4\times10^{-4} & 0 \\ 4.4\times10^{-4} & 4.4\times10^{-4} & 4.4\times10^{-4} & 0 \end{bmatrix}$$

For LR

Sea state 3 and for all age groups no variance matrix.

Sea state 5 and 6 and for all age groups

$$\begin{bmatrix} 0.0005 & 0 & 0 & 0 \\ 0 & 0.0005 & 0 & 0 \\ 0 & 0 & 0.0005 & 0 \\ 0.0005 & 0.0005 & 0.0005 & 0 \end{bmatrix}$$

Obstacle R6 (LB+LR)

Sea state 3 and for all age groups no variance matrix.

Sea state 5

$$\begin{bmatrix} 6\times10^{-7} & 0 & 0 & 0 \\ 0 & 6\times10^{-7} & 0 & 0 \\ 0 & 0 & 6\times10^{-7} & 0 \\ 6\times10^{-7} & 6\times10^{-7} & 6\times10^{-7} & 0 \end{bmatrix}$$

Sea state 6

$$\begin{bmatrix} 4\times10^{-7} & 0 & 0 & 0 \\ 0 & 4\times10^{-7} & 0 & 0 \\ 0 & 0 & 4\times10^{-7} & 0 \\ 4\times10^{-7} & 4\times10^{-7} & 4\times10^{-7} & 0 \end{bmatrix}$$

Obstacle A9

Below sea state 6 and for all age groups no variance matrix.

Sea state 6

Young (<50)

$$\begin{bmatrix} 3.06\times10^{-5} & 0 & 0 & 0 \\ 3.06\times10^{-5} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Middle (50-75)

$$\begin{bmatrix} 6.02\times10^{-5} & 0 & 0 & 0 \\ 5.61\times10^{-5} & 5.1\times10^{-6} & 0 & 0 \\ 4.1\times10^{-6} & 5.1\times10^{-6} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Old (>75)

$$\begin{bmatrix} 8.15\times10^{-5} & 0 & 0 & 0 \\ 7.64\times10^{-5} & 6.4\times10^{-6} & 0 & 0 \\ 4.1\times10^{-6} & 5.1\times10^{-6} & 2.5\times10^{-6} & 0 \\ 10^{-6} & 1.3\times10^{-6} & 2.5\times10^{-6} & 0 \end{bmatrix}$$

Obstacle A10

Sea state 3 for all age groups no variance matrix.

Sea state 5

Young (<50)

$$\begin{bmatrix} 1.26\times10^{-4} & 0 & 0 & 0 \\ 1.26\times10^{-4} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Middle (50-75)

$$\begin{bmatrix} 3.99\times10^{-4} & 0 & 0 & 0 \\ 3.99\times10^{-4} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Old (>75)

$$\begin{bmatrix} 3.99\times10^{-4} & 0 & 0 & 0 \\ 3.96\times10^{-4} & 4.4\times10^{-6} & 0 & 0 \\ 3.2\times10^{-6} & 4\times10^{-6} & 8\times10^{-7} & 0 \\ 3\times10^{-7} & 4\times10^{-7} & 8\times10^{-7} & 0 \end{bmatrix}$$

Sea state 6

Young (<50)

$$\begin{bmatrix} 4.182\times10^{-4} & 0 & 0 & 0 \\ 4.16\times10^{-4} & 2.7\times10^{-6} & 0 & 0 \\ 2\times10^{-6} & 2.5\times10^{-6} & 5\times10^{-7} & 0 \\ 2\times10^{-7} & 2\times10^{-7} & 5\times10^{-7} & 0 \end{bmatrix}$$

Middle (50-75)

$$\begin{bmatrix} 6.795\times10^{-4} & 0 & 0 & 0 \\ 6.7\times10^{-4} & 1.18\times10^{-5} & 0 & 0 \\ 8.6\times10^{-6} & 1.07\times10^{-5} & 2.1\times10^{-6} & 0 \\ 9\times10^{-7} & 1.1\times10^{-6} & 2.1\times10^{-6} & 0 \end{bmatrix}$$

Old (>75)

$$\begin{bmatrix} 6.856\times10^{-4} & 0 & 0 & 0 \\ 5.89\times10^{-4} & 1.108\times10^{-4} & 0 & 0 \\ 8.85\times10^{-5} & 1.008\times10^{-4} & 1.98\times10^{-5} & 0 \\ 8.1\times10^{-6} & 10^{-5} & 1.98\times10^{-5} & 0 \end{bmatrix}$$

Obstacle A11

Sea state 3

Young (<50)

$$\begin{bmatrix} 9.9\times10^{-6} & 0 & 0 & 0 \\ 3.3\times10^{-6} & 8.2\times10^{-6} & 0 & 0 \\ 3.3\times10^{-6} & 4.1\times10^{-6} & 8.2\times10^{-6} & 0 \\ 3.3\times10^{-6} & 4.1\times10^{-6} & 8.2\times10^{-6} & 0 \end{bmatrix}$$

Middle (50-75)

$$\begin{bmatrix} 1.23\times10^{-5} & 0 & 0 & 0 \\ 4.1\times10^{-6} & 1.02\times10^{-5} & 0 & 0 \\ 4.1\times10^{-6} & 5.1\times10^{-6} & 1.02\times10^{-5} & 0 \\ 4.1\times10^{-6} & 5.1\times10^{-6} & 1.02\times10^{-5} & 0 \end{bmatrix}$$

Old (>75)

$$\begin{bmatrix} 4.92\times10^{-5} & 0 & 0 & 0 \\ 1.64\times10^{-5} & 4.04\times10^{-5} & 0 & 0 \\ 1.64\times10^{-5} & 2.02\times10^{-5} & 3.96\times10^{-5} & 0 \\ 1.64\times10^{-5} & 2.02\times10^{-5} & 3.96\times10^{-5} & 0 \end{bmatrix}$$

Sea state 5 and 6:

Young (<50)

$$\begin{bmatrix} 2.4\times10^{-5} & 0 & 0 & 0 \\ 8\times10^{-6} & 1.98\times10^{-5} & 0 & 0 \\ 8\times10^{-6} & 9.9\times10^{-6} & 1.96\times10^{-5} & 0 \\ 8\times10^{-6} & 9.9\times10^{-6} & 1.96\times10^{-5} & 0 \end{bmatrix}$$

Middle (50-75)

$$\begin{bmatrix} 2.97\times10^{-5} & 0 & 0 & 0 \\ 9.9\times10^{-6} & 2.46\times10^{-5} & 0 & 0 \\ 9.9\times10^{-6} & 1.23\times10^{-5} & 2.43\times10^{-5} & 0 \\ 9.9\times10^{-6} & 1.23\times10^{-5} & 2.43\times10^{-5} & 0 \end{bmatrix}$$

Old (>75)

$$\begin{bmatrix} 1.191\times10^{-4} & 0 & 0 & 0 \\ 3.97\times10^{-5} & 9.52\times10^{-5} & 0 & 0 \\ 3.97\times10^{-5} & 4.76\times10^{-5} & 9.07\times10^{-5} & 0 \\ 3.97\times10^{-5} & 4.76\times10^{-5} & 9.07\times10^{-5} & 0 \end{bmatrix}$$

Obstacle A15

Sea State 3

Young (<50)

$$\begin{bmatrix} 10^{-6} & 0 & 0 & 0 \\ 10^{-6} & 10^{-6} & 0 & 0 \\ 0 & 10^{-6} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Middle (50-75)

$$\begin{bmatrix} 10^{-6} & 0 & 0 & 0 \\ 10^{-6} & 10^{-6} & 0 & 0 \\ 0 & 10^{-6} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Old (>75)

$$\begin{bmatrix} 2\times10^{-6} & 0 & 0 & 0 \\ 2\times10^{-6} & 2\times10^{-6} & 0 & 0 \\ 0 & 2\times10^{-6} & 10^{-6} & 0 \\ 0 & 0 & 10^{-6} & 0 \end{bmatrix}$$

Sea States 5 and 6

Young (<50)

$$\begin{bmatrix} 10^{-6} & 0 & 0 & 0 \\ 10^{-6} & 5\times10^{-5} & 0 & 0 \\ 0 & 5\times10^{-5} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Middle (50-75)

$$\begin{bmatrix} 3\times10^{-6} & 0 & 0 & 0 \\ 3\times10^{-6} & 7\times10^{-5} & 0 & 0 \\ 0 & 7\times10^{-5} & 2\times10^{-5} & 0 \\ 0 & 0 & 2\times10^{-5} & 0 \end{bmatrix}$$

Old (>75)

$$\begin{bmatrix} 2\times10^{-5} & 0 & 0 & 0 \\ 2\times10^{-5} & 10^{-4} & 0 & 0 \\ 0 & 10^{-4} & 8\times10^{-5} & 0 \\ 0 & 0 & 8\times10^{-5} & 0 \end{bmatrix}$$

Obstacle R3-R5

Sea state 3

Young (<50)

Middle (50-75)

Old (>75)

$$\begin{bmatrix} 9.9\times10^{-6} & 0 & 0 & 0 \\ 3.3\times10^{-6} & 8.2\times10^{-6} & 0 & 0 \\ 3.3\times10^{-6} & 4.1\times10^{-6} & 8.2\times10^{-6} & 0 \\ 3.3\times10^{-6} & 4.1\times10^{-6} & 8.2\times10^{-6} & 0 \end{bmatrix} \begin{bmatrix} 1.23\times10^{-5} & 0 & 0 & 0 \\ 4.1\times10^{-6} & 1.02\times10^{-5} & 0 & 0 \\ 4.1\times10^{-6} & 5.1\times10^{-6} & 1.02\times10^{-5} & 0 \\ 4.1\times10^{-6} & 5.1\times10^{-6} & 1.02\times10^{-5} & 0 \end{bmatrix} \begin{bmatrix} 4.92\times10^{-5} & 0 & 0 & 0 \\ 1.64\times10^{-5} & 4.04\times10^{-5} & 0 & 0 \\ 1.64\times10^{-5} & 2.02\times10^{-5} & 3.96\times10^{-5} & 0 \\ 1.64\times10^{-5} & 2.02\times10^{-5} & 3.96\times10^{-5} & 0 \end{bmatrix}$$

Sea state 5 and 6:

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 2.4\times10^{-5} & 0 & 0 & 0 \\ 8\times10^{-6} & 1.98\times10^{-5} & 0 & 0 \\ 8\times10^{-6} & 9.9\times10^{-6} & 1.96\times10^{-5} & 0 \\ 8\times10^{-6} & 9.9\times10^{-6} & 1.96\times10^{-5} & 0 \end{bmatrix} \begin{bmatrix} 2.97\times10^{-5} & 0 & 0 & 0 \\ 9.9\times10^{-6} & 2.46\times10^{-5} & 0 & 0 \\ 9.9\times10^{-6} & 1.23\times10^{-5} & 2.43\times10^{-5} & 0 \\ 9.9\times10^{-6} & 1.23\times10^{-5} & 2.43\times10^{-5} & 0 \end{bmatrix} \begin{bmatrix} 1.191\times10^{-4} & 0 & 0 & 0 \\ 3.97\times10^{-5} & 9.52\times10^{-5} & 0 & 0 \\ 3.97\times10^{-5} & 4.76\times10^{-5} & 9.07\times10^{-5} & 0 \\ 3.97\times10^{-5} & 4.76\times10^{-5} & 9.07\times10^{-5} & 0 \end{bmatrix}$$

Obstacle R7

For LB

Sea state 3, all age groups, 4 hours of exposure no variance matrix.

Sea state 5 and 6, 4 hours of exposure:

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 1.7\times10^{-6} & 0 & 0 & 0 \\ 1.7\times10^{-6} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 7.1\times10^{-6} & 0 & 0 & 0 \\ 6.7\times10^{-6} & 6\times10^{-7} & 0 & 0 \\ 4\times10^{-7} & 5\times10^{-7} & 10^{-7} & 0 \\ 0 & 10^{-7} & 10^{-7} & 0 \end{bmatrix} \begin{bmatrix} 1.77\times10^{-5} & 0 & 0 & 0 \\ 1.66\times10^{-5} & 1.4\times10^{-6} & 0 & 0 \\ 10^{-6} & 1.3\times10^{-6} & 3\times10^{-7} & 0 \\ 10^{-7} & 10^{-7} & 3\times10^{-7} & 0 \end{bmatrix}$$

For LR

Sea state 3, all age groups, 4 hours of exposure no variance matrix.

Sea state 5, 4 hours of exposure no variance matrix for the young age group.

Middle (50-75) **Old (>75)**

$$\begin{bmatrix} 2\times10^{-7} & 0 & 0 & 0 \\ 0 & 3\times10^{-7} & 0 & 0 \\ 2\times10^{-7} & 3\times10^{-7} & 10^{-7} & 0 \\ 0 & 0 & 10^{-7} & 0 \end{bmatrix} \begin{bmatrix} 6\times10^{-7} & 0 & 0 & 0 \\ 0 & 8\times10^{-7} & 0 & 0 \\ 5\times10^{-7} & 7\times10^{-7} & 10^{-7} & 0 \\ 10^{-7} & 10^{-7} & 10^{-7} & 0 \end{bmatrix}$$

Sea state 6, 4 hours of exposure:

Young (<50) **Middle (50-75)** **Old (>75)**

$$\begin{bmatrix} 8\times10^{-7} & 0 & 0 & 0 \\ 8\times10^{-7} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 3.5\times10^{-6} & 0 & 0 & 0 \\ 3.3\times10^{-6} & 3\times10^{-7} & 0 & 0 \\ 2\times10^{-7} & 3\times10^{-7} & 10^{-7} & 0 \\ 0 & 0 & 10^{-7} & 0 \end{bmatrix} \begin{bmatrix} 8.9\times10^{-6} & 0 & 0 & 0 \\ 8.3\times10^{-6} & 8\times10^{-7} & 0 & 0 \\ 5\times10^{-7} & 7\times10^{-7} & 10^{-7} & 0 \\ 10^{-7} & 10^{-7} & 10^{-7} & 0 \end{bmatrix}$$

Obstacle R8

All sea states and age groups for LB and LR no variance matrix.

Obstacle R9

No variance matrix for the young age group in all sea states and for all exposure times.

Sea State 3

	Middle (50-75)	**Old (>75)**
4h	$\begin{bmatrix} 3.7\times10^{-6} & 0 & 0 & 0 \\ 0 & 3.8\times10^{-6} & 0 & 0 \\ 3.1\times10^{-6} & 3.1\times10^{-6} & 1.2\times10^{-6} & 0 \\ 6\times10^{-7} & 7\times10^{-7} & 1.2\times10^{-6} & 0 \end{bmatrix}$	$\begin{bmatrix} 4.3\times10^{-6} & 0 & 0 & 0 \\ 0 & 4.6\times10^{-6} & 0 & 0 \\ 3.1\times10^{-6} & 3.1\times10^{-6} & 2.4\times10^{-6} & 0 \\ 1.2\times10^{-6} & 1.5\times10^{-6} & 2.4\times10^{-6} & 0 \end{bmatrix}$
8h	$\begin{bmatrix} 5\times10^{-6} & 0 & 0 & 0 \\ 0 & 5.2\times10^{-6} & 0 & 0 \\ 4.1\times10^{-6} & 4.1\times10^{-6} & 1.8\times10^{-6} & 0 \\ 9\times10^{-7} & 1.1\times10^{-6} & 1.8\times10^{-6} & 0 \end{bmatrix}$	$\begin{bmatrix} 6\times10^{-6} & 0 & 0 & 0 \\ 0 & 6.5\times10^{-6} & 0 & 0 \\ 4.1\times10^{-6} & 4.1\times10^{-6} & 3.8\times10^{-6} & 0 \\ 1.9\times10^{-6} & 2.4\times10^{-6} & 3.8\times10^{-6} & 0 \end{bmatrix}$
12h	$\begin{bmatrix} 5.6\times10^{-6} & 0 & 0 & 0 \\ 0 & 5.9\times10^{-6} & 0 & 0 \\ 4.4\times10^{-6} & 4.4\times10^{-6} & 2.4\times10^{-6} & 0 \\ 1.2\times10^{-6} & 1.5\times10^{-6} & 2.4\times10^{-6} & 0 \end{bmatrix}$	$\begin{bmatrix} 6.8\times10^{-6} & 0 & 0 & 0 \\ 0 & 7.4\times10^{-6} & 0 & 0 \\ 4.4\times10^{-6} & 4.4\times10^{-6} & 4.8\times10^{-6} & 0 \\ 2.4\times10^{-6} & 3\times10^{-6} & 4.8\times10^{-6} & 0 \end{bmatrix}$
16h	$\begin{bmatrix} 6\times10^{-6} & 0 & 0 & 0 \\ 0 & 6.3\times10^{-6} & 0 & 0 \\ 4.6\times10^{-6} & 4.6\times10^{-6} & 2.8\times10^{-6} & 0 \\ 1.4\times10^{-6} & 1.7\times10^{-6} & 2.8\times10^{-6} & 0 \end{bmatrix}$	$\begin{bmatrix} 7.4\times10^{-6} & 0 & 0 & 0 \\ 0 & 8.1\times10^{-6} & 0 & 0 \\ 4.6\times10^{-6} & 4.6\times10^{-6} & 5.6\times10^{-6} & 0 \\ 2.8\times10^{-6} & 3.5\times10^{-6} & 5.6\times10^{-6} & 0 \end{bmatrix}$

Sea State 5

	Middle (50-75)	**Old (>75)**
4h	$\begin{bmatrix} 1.77\times10^{-5} & 0 & 0 & 0 \\ 0 & 1.8\times10^{-5} & 0 & 0 \\ 1.48\times10^{-5} & 1.48\times10^{-5} & 5.8\times10^{-6} & 0 \\ 2.9\times10^{-6} & 3.6\times10^{-6} & 5.8\times10^{-6} & 0 \end{bmatrix}$	$\begin{bmatrix} 2.05\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.19\times10^{-5} & 0 & 0 \\ 1.48\times10^{-5} & 1.48\times10^{-5} & 1.13\times10^{-5} & 0 \\ 5.7\times10^{-6} & 7.1\times10^{-6} & 1.13\times10^{-5} & 0 \end{bmatrix}$
8h	$\begin{bmatrix} 1.96\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.05\times10^{-5} & 0 & 0 \\ 1.59\times10^{-5} & 1.59\times10^{-5} & 7.4\times10^{-6} & 0 \\ 3.7\times10^{-6} & 4.6\times10^{-6} & 7.4\times10^{-6} & 0 \end{bmatrix}$	$\begin{bmatrix} 2.32\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.5\times10^{-5} & 0 & 0 \\ 1.59\times10^{-5} & 1.59\times10^{-5} & 1.45\times10^{-5} & 0 \\ 7.3\times10^{-6} & 9.1\times10^{-6} & 1.45\times10^{-5} & 0 \end{bmatrix}$
12h	$\begin{bmatrix} 2.05\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.16\times10^{-5} & 0 & 0 \\ 1.62\times10^{-5} & 1.62\times10^{-5} & 8.6\times10^{-6} & 0 \\ 4.3\times10^{-6} & 5.4\times10^{-6} & 8.6\times10^{-6} & 0 \end{bmatrix}$	$\begin{bmatrix} 2.48\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.69\times10^{-5} & 0 & 0 \\ 1.62\times10^{-5} & 1.62\times10^{-5} & 1.71\times10^{-5} & 0 \\ 8.6\times10^{-6} & 1.07\times10^{-5} & 1.71\times10^{-5} & 0 \end{bmatrix}$
16h	$\begin{bmatrix} 2.12\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.24\times10^{-5} & 0 & 0 \\ 1.63\times10^{-5} & 1.63\times10^{-5} & 9.8\times10^{-6} & 0 \\ 4.9\times10^{-6} & 6.1\times10^{-6} & 9.8\times10^{-6} & 0 \end{bmatrix}$	$\begin{bmatrix} 2.61\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.84\times10^{-5} & 0 & 0 \\ 1.63\times10^{-5} & 1.63\times10^{-5} & 1.94\times10^{-5} & 0 \\ 9.8\times10^{-6} & 1.21\times10^{-5} & 1.94\times10^{-5} & 0 \end{bmatrix}$

Sea State 6

	Middle (50-75)	**Old (>75)**
4h	$\begin{bmatrix} 1.81\times10^{-5} & 0 & 0 & 0 \\ 0 & 1.88\times10^{-5} & 0 & 0 \\ 1.52\times10^{-5} & 1.52\times10^{-5} & 5.8\times10^{-6} & 0 \\ 2.9\times10^{-6} & 3.6\times10^{-6} & 5.8\times10^{-6} & 0 \end{bmatrix}$	$\begin{bmatrix} 2.11\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.25\times10^{-5} & 0 & 0 \\ 1.52\times10^{-5} & 1.52\times10^{-5} & 1.17\times10^{-5} & 0 \\ 5.9\times10^{-6} & 7.3\times10^{-6} & 1.17\times10^{-5} & 0 \end{bmatrix}$
8h	$\begin{bmatrix} 1.99\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.08\times10^{-5} & 0 & 0 \\ 1.62\times10^{-5} & 1.62\times10^{-5} & 7.4\times10^{-6} & 0 \\ 3.7\times10^{-6} & 4.6\times10^{-6} & 7.4\times10^{-6} & 0 \end{bmatrix}$	$\begin{bmatrix} 2.36\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.54\times10^{-5} & 0 & 0 \\ 1.62\times10^{-5} & 1.62\times10^{-5} & 1.47\times10^{-5} & 0 \\ 7.4\times10^{-6} & 9.2\times10^{-6} & 1.47\times10^{-5} & 0 \end{bmatrix}$
12h	$\begin{bmatrix} 2.09\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.2\times10^{-5} & 0 & 0 \\ 1.65\times10^{-5} & 1.65\times10^{-5} & 8.8\times10^{-6} & 0 \\ 4.4\times10^{-6} & 5.5\times10^{-6} & 8.8\times10^{-6} & 0 \end{bmatrix}$	$\begin{bmatrix} 2.53\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.74\times10^{-5} & 0 & 0 \\ 1.65\times10^{-5} & 1.65\times10^{-5} & 1.74\times10^{-5} & 0 \\ 8.8\times10^{-6} & 1.09\times10^{-5} & 1.74\times10^{-5} & 0 \end{bmatrix}$
16h	$\begin{bmatrix} 2.16\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.28\times10^{-5} & 0 & 0 \\ 1.66\times10^{-5} & 1.66\times10^{-5} & 10^{-5} & 0 \\ 5\times10^{-6} & 6.2\times10^{-6} & 10^{-5} & 0 \end{bmatrix}$	$\begin{bmatrix} 2.66\times10^{-5} & 0 & 0 & 0 \\ 0 & 2.9\times10^{-5} & 0 & 0 \\ 1.66\times10^{-5} & 1.66\times10^{-5} & 1.98\times10^{-5} & 0 \\ 10^{-5} & 1.24\times10^{-5} & 1.98\times10^{-5} & 0 \end{bmatrix}$

Appendix II: CasualtyCalculator outputs: Fatality rates and standard deviations.

The fatality rates corresponding to the different cases defined in section 4.2 are shown below.

HF obstacles only

SS3	**LB**			**LR**		
Expo. time(h)	Y	M	O	Y	M	O
4	0.0033	0.0047	0.0176	0.0033	0.0047	0.0177
8	0.0033	0.0050	0.0184	0.0033	0.0050	0.0184
12	0.0033	0.0053	0.0189	0.0033	0.0053	0.0190
16	0.0033	0.0055	0.0192	0.0033	0.0055	0.0194

SS5	**LB**			**LR**		
Expo. time(h)	Y	M	O	Y	M	O
4	0.0082	0.0143	0.0502	0.0080	0.0130	0.0462
8	0.0082	0.0152	0.0522	0.0080	0.0138	0.0480
12	0.0082	0.0159	0.0538	0.0080	0.0144	0.0494
16	0.0083	0.0166	0.0553	0.0080	0.0150	0.0506

SS6	**LB**			**LR**		
Expo. time(h)	Y	M	O	Y	M	O
4	0.0090	0.0163	0.0659	0.0080	0.0130	0.0465
8	0.0091	0.0173	0.0679	0.0080	0.0138	0.0482
12	0.0091	0.0182	0.0697	0.0080	0.0145	0.0498
16	0.0091	0.0190	0.0713	0.0080	0.0152	0.0512

HF and HW obstacles

Case1 sequence of obstacles
LB: A_2 A_8 A_{16LB} R_{6LB} A_{9LB} A_{10LB} A_{13LB} R^{**}_{7LB} R_{8LB} R_9* R_{3-5}
LR: A_2 A_{16LR} R_{6LR} A_{15LR} R^{**}_{7LR} R_{8LR} R_9* R_{3-5}

SS3	**LB**			**LR**		
Expo. time(h)	Y	M	O	Y	M	O
4	0.0274	0.0287	0.0414	0.0065	0.0079	0.0209
8	0.0274	0.0290	0.0421	0.0065	0.0082	0.0216
12	0.0274	0.0293	0.0425	0.0065	0.0085	0.0221
16	0.0274	0.0295	0.0429	0.0065	0.0087	0.0225

SS5	**LB**			**LR**		
Expo. time(h)	Y	M	O	Y	M	O
4	0.1750	0.1800	0.2100	0.5059	0.5084	0.5249
8	0.1750	0.1808	0.2116	0.5059	0.5088	0.5258
12	0.1750	0.1814	0.2130	0.5059	0.5091	0.5265
16	0.1750	0.1820	0.2142	0.5059	0.5094	0.5271

SS6	**LB**			**LR**		
Expo. time(h)	Y	M	O	Y	M	O
4	0.4548	0.4588	0.4861	0.5058	0.5083	0.5250
8	0.4548	0.4594	0.4872	0.5058	0.5087	0.5258
12	0.4548	0.4599	0.4882	0.5058	0.5090	0.5266
16	0.4548	0.4603	0.4891	0.5058	0.5094	0.5273

Case 2 Sequence of obstacles

LB: A_7 A_8 A_{16LB} R_{6LB} A_{9LB} A_{10LB} A_{13LB} R^{**}_{7LB} R_{8LB} R_9* R_{3-5}

LR: A_7 A_{16LR} R_{6LR} A_{15LR} R^{**}_{7LR} R_{8LR} R_9* R_{3-5}

SS3	**LB**			**LR**		
Expo. time(h)	Y	M	O	Y	M	O
4	0.0253	0.0267	0.0393	0.0044	0.0058	0.0188
8	0.0253	0.0270	0.0400	0.0044	0.0061	0.0195
12	0.0253	0.0273	0.0405	0.0044	0.0064	0.0200
16	0.0253	0.0275	0.0409	0.0044	0.0066	0.0204

SS5	**LB**			**LR**		
Expo. time(h)	Y	M	O	Y	M	O
4	0.1733	0.1783	0.2083	0.5048	0.5073	0.5239
8	0.1733	0.1791	0.2099	0.5048	0.5077	0.5248
12	0.1733	0.1797	0.2113	0.5048	0.5080	0.5255
16	0.1733	0.1803	0.2125	0.5048	0.5083	0.5261

SS6	**LB**			**LR**		
Expo. time(h)	Y	M	O	Y	M	O
4	0.4537	0.4576	0.4850	0.5047	0.5072	0.5240
8	0.4537	0.4582	0.4861	0.5047	0.5077	0.5248
12	0.4537	0.4587	0.4871	0.5047	0.5080	0.5256
16	0.4537	0.4591	0.4880	0.5047	0.5083	0.5263

Case 3 Sequence of obstacles

LB: A_2 A_7 A_8 A_{16LB} R_{6LB} A_{9LB} A_{10LB} A_{13LB} R^{**}_{7LB} R_{8LB} R_9* R_{3-5}

LR: A_2 A_7 A_{16LR} R_{6LR} A_{15LR} R^{**}_{7LR} R_{8LR} R_9* R_{3-5}

SS3	**LB**			**LR**		
Expo. time(h)	Y	M	O	Y	M	O
4	0.0284	0.0298	0.0424	0.0076	0.0090	0.0220
8	0.0284	0.0301	0.0431	0.0076	0.0093	0.0227
12	0.0284	0.0304	0.0436	0.0076	0.0096	0.0232
16	0.0284	0.0306	0.0440	0.0076	0.0098	0.0236

SS5	LB			LR		
Expo. time(h)	Y	M	O	Y	M	O
4	0.1759	0.1809	0.2108	0.5064	0.5089	0.5255
8	0.1759	0.1817	0.2125	0.5064	0.5093	0.5263
12	0.1759	0.1823	0.2138	0.5064	0.5096	0.5270
16	0.1759	0.1829	0.2151	0.5064	0.5099	0.5276

SS6	LB			LR		
Expo. time(h)	Y	M	O	Y	M	O
4	0.4554	0.4594	0.4866	0.5063	0.5088	0.5255
8	0.4554	0.4599	0.4877	0.5063	0.5092	0.5263
12	0.4554	0.4605	0.4887	0.5063	0.5096	0.5271
16	0.4554	0.4609	0.4896	0.5063	0.5099	0.5278

Case 4 Sequence of obstacles
LB: A_8 A_{16LB} R_{6LB} A_{9LB} A_{10LB} A_{13LB} R^{**}_{7LB} R_{8LB} R_9* R_{3-5}
LR: A_{16LR} R_{6LR} A_{15LR} R^{**}_{7LR} R_{8LR} R_9* R_{3-5}

SS3	LB			LR		
Expo. time(h)	Y	M	O	Y	M	O
4	0.0242	0.0256	0.0383	0.0033	0.0047	0.0177
8	0.0242	0.0259	0.0390	0.0033	0.0050	0.0184
12	0.0242	0.0262	0.0395	0.0033	0.0053	0.0190
16	0.0242	0.0264	0.0399	0.0033	0.0055	0.0194

SS5	LB			LR		
Expo. time(h)	Y	M	O	Y	M	O
4	0.1724	0.1774	0.2074	0.5043	0.5068	0.5234
8	0.1724	0.1782	0.2091	0.5043	0.5072	0.5243
12	0.1724	0.1788	0.2104	0.5043	0.5075	0.5250
16	0.1724	0.1794	0.2117	0.5043	0.5078	0.5256

SS6	LB			LR		
Expo. time(h)	Y	M	O	Y	M	O
4	0.4531	0.4570	0.4844	0.5042	0.5067	0.5235
8	0.4531	0.4576	0.4855	0.5042	0.5071	0.5243
12	0.4531	0.4581	0.4865	0.5042	0.5075	0.5251
16	0.4531	0.4585	0.4874	0.5042	0.5078	0.5258

Standard deviations associated to errors associated to all obstacles as explained in section 6.2 are shown below.

	LB			**LR**		
	Y	M	O	Y	M	O
SS3	0.005	0.005	0.006	0.003	0.003	0.005
SS5	0.013	0.013	0.014	0.022	0.022	0.023
SS6	0.021	0.021	0.021	0.022	0.022	0.023