FLOODSTAND Integrated Flooding Control and Standard for Stability and Crises Management

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FLOODSTAND-deliverable:

Report on validation and sensitivity testing of methods for assessing effectiveness of rescue process

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Abstract:
This report present the main results achieved through the Task 5.4 of the Floodstand project, entitled “Test/Develop rescue (R) model”. This task aims to develop requirements for a model describing the rescue process, as a part of the MAR process described in the 5.1 deliverable of the Floodstand project.
Sensitivity analysis of the whole process (including the Rescue process) was conducted in task 5.5 and presented in the deliverable 5.5.

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1. EXECUTIVE SUMMARY

This report presents the main results achieved through the Task 5.4 of the Floodstand project, entitled “Test/Develop rescue (R) model”. This task aims to develop requirements for a model describing the rescuing process, as a part of the MAR process described in the 5.1 deliverable of the Floodstand project.

The whole process has been divided in several obstacles (hardware/human factor/time related parameter) and each obstacle has then been evaluated. Specific models have been developed when needed and previous work from another European funded project has been exploited when relevant. For each hardware/human factor obstacle, one or several degradation matrices have been calculated.

According to the Description of Work, sensitivity testing was planned in each task from Task 5.2 to Task 5.4. However, it seems 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. Consequently, it has been decided to conduct the sensitivity analysis in task 5.5 and present it in the deliverable 5.5.

2. INTRODUCTION

This deliverable is divided in two parts. The first part gives an overview of the Muster Abandonment and Rescue (MAR) process and the different obstacles that define it.

An introduction to the software developed to assess the overall process is presented in the deliverable 5.2 and its Appendix A.

In the second part the rescuing process is studied in detail and the results of the assessment of this phase are presented, each obstacle is evaluated and the corresponding matrices are described.

3. PART I: MAR PROCESS AND LIST OF OBSTACLES

As introduced in Floodstand deliverable D5.1, the human health status (HHS) was chosen as the indicator to assess the risk for passengers when abandoning the ship.

The escape and rescue process (or route) was defined as a sequence of actions that passengers (and crew) need to perform in order to evacuate from their initial location to a place of safety (shore or rescuing vessel). In doing so, they would rely on Life Saving System (LSS).

Escape and rescue routes can be split up into four different phases as follows:

1. Mustering
2. Abandonment
3. Survival at sea
4. Rescue

In addition, the escape and rescue route can be defined as a series of obstacles which are characterised by the hazard they generate. These hazards can affect people directly (later referred to as Human Factor (HF) obstacle) or indirectly through the life saving appliances (later referred to as Hardware (HW) obstacles) by degrading (or not) their Health status.

So in order to define the Mustering, Abandonment and Rescue (MAR) process, the obstacles which constitute each phase needed to be identified.

Based on the findings of task 5.1 and the results of the FP6 funded project SAFECRAFTS, a first comprehensive list of obstacles for each phase of the process was produced. Then, a first review has been conducted to simplify this list and reduce it to a manageable size (for example there were 43 obstacles in the Mustering phase alone). The list of obstacles obtained after this review is presented hereafter.

In addition, during the assessment of the different obstacles, some of them were found to be less significant than previously thought. For example, obstacle A4 “Liferaft malfunction” was not relevant as Passenger ships, as a regulatory requirement (SOLAS), need to carry Life Saving Appliances (generally liferafts) in excess and the malfunction of a liferaft should not affect the spare LSA capacity. This allows to further simplify the list by ignoring some additional obstacles (shaded in the tables below).

Mustering

Id	Obstacle	Type
M1	Passengers' reaction time	N/A
M2	Passengers' location	N/A
M3	Passengers' (intrinsic) mobility	N/A
M4	Effects of heel on passengers' mobility	N/A
M5	Blocked doors	N/A
M6	Objects obstructing the passage	N/A
M7	Injuries due to the list (static)	HF
M8	Injuries due to ship motions (dynamic)	HF

Abandonment

Id	Obstacle	Type
A1	Deployment impossible	HW
A2	Davit deployment failure	HW
A3	Chute deployment failure	HW
A4	Liferaft malfunction	HW
A5	Lifeboat engine failure	HW
A6	Embarkation time	
A7	Structural failure/capsize due to premature release of the LSA	HW
A8	Structural failure due to impacts of the LSA against the hull during lowering	HW
A9	Injuries due to impacts of the LSA against the hull during lowering	HF
A10	Injuries due to slamming	HF
A11	Injuries while using the escape ladders	HF
A12	Structural failure due to impact against the hull while afloat	HW
A13	Injuries due to impact against the hull while afloat	HF
A14	Failure of the bowsing lines	HW
A15	Injuries while moving to seat	HF
A16	Failure to clear off the vessel	HW

Rescue

Id	Obstacle	Type
R1	Time to rescue passengers	N/A
R2	Impossible to transfer passengers by using the side door	HW
R3	Injuries while transferring passengers through the side door	HF
R4	Impossible to transfer passengers by using the escape ladder, pilot ladder, rope ladder	HF
R5	Injuries while transferring passengers with escape ladder, pilot ladder, rope ladder	HF
R6	Capsizing/Downflooding	HW
R7	Injuries due to LSA motions	HF
R8	Hypothermia	HF
R9	Seasickness	HF

4. PART II: THE RESCUE PHASE

The two reference ships selected by Floodstand project have been evaluated. These ships have different means of escape:

- The Estonia, a ro-pax ship has 10 davit-launched lifeboat (LB) with a total capacity of 692 people and 63 liferafts (LR) with a total capacity of 1575 people. 12 LR are davit-launched and the others are boarded using escape ladder.
- The cruise liner has 18 davit-launched 150 people capacity lifeboats (LB) and 18 davit-launched 25 people capacity liferafts.

4.1 Obstacles order and structure

The following diagram shows the obstacle structure, the interactions between them and the order in which people pass through them depending on which rescue route they will take. Time related parameters do not directly affect the health of passengers, but they represent an input for other obstacles, by influencing the duration of exposure to the hazard related to those obstacles (e.g. Time to rescue passengers (R1) corresponds to time spent at sea, hence has an influence on sea sickness (R9), hypothermia (R8)…).

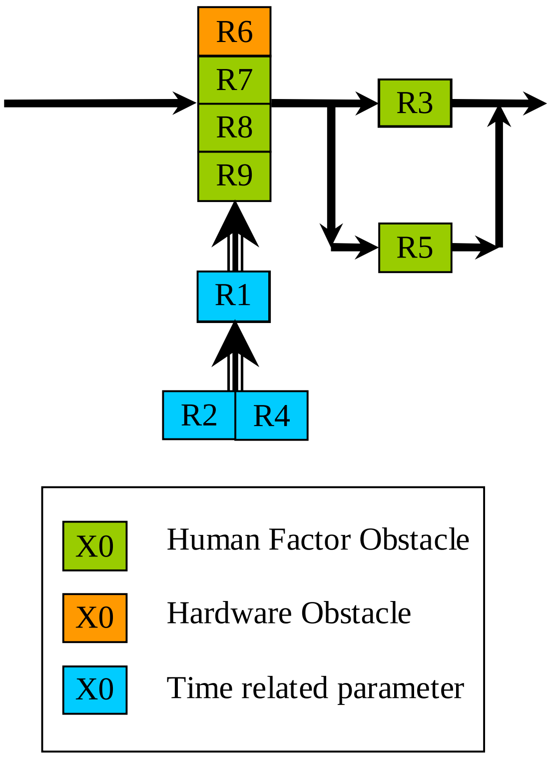


Figure 1 – Structure and order of obstacles

People pass through the obstacles from left to right, following the different paths depending on the rescue route they are taking (R3 escaping using the side door of the rescue ship or R5 using a ladder).

Some obstacles of the rescue phase have been previously studied in the FP6 funded project "*SAFECRAFTS: Safe abandoning of ships*"[1]. As lifeboats and liferafts studied in this previous project are similar in their construction to those studied here it was agreed to exploit as much as possible the results of Safecrafts for the assessment of the above obstacles, and to concentrate efforts on the assessment of the final steps of the rescue process (i.e. recovery of passengers by SAR means or passing vessels).

In the rest of the document a detailed description of the obstacles is provided as well as the assessment results.

4.2 Obstacles selection

As indicated in §3. , a comprehensive list of obstacles has been first established. Then this list has been reviewed in order to reduce the number of obstacles, as described hereafter.

The possibility to use the side doors and/or the escape ladders will determine the means of rescue that SAR organisations will be able to use. Consequently, R2 and R4 are input to R1. They are accounted for in the assessment of R1 (see §5.2) and will not be described separately.

[1] http://safecrafts.bal-pm.eu/

5. DETAILED DESCRIPTION OF OBSTACLES

5.1 Obstacle summary

A short overview of each obstacle is given in a card as shown below. A brief explanation of each cell of the card can be found in the right column.

Obstacle	Number and name of the obstacle.
Rescue route phase	Phase in which the obstacle occur (Mustering, Abandonment or Rescue).
Hardware / Human factor	Type of obstacle Hardware or Human factor.
Short Description	A short description of the obstacle, how and when it appended during the phase.
Parameter(s)	A list of parameters influencing the results of the obstacle.
Matrices to calculate	Number of matrices to compute for this obstacle, given the input parameters.
Model / Method	A short description of the model or method used to calculate the obstacle.
Results	Short explanation of the results.

5.2 R1 – Time to rescue passengers

Obstacle	R1 – Time to rescue passengers
Rescue route phase	Rescue
Hardware / Human factor	Time parameter
Short Description	The time required for SAR helicopters, rescue boats and passing vessels to rescue passengers depends on different factors such as the success or failure to keep liferafts together (towing failure for instance), the visibility (bad weather, night, daylight, etc.), the success or failure for LSAs to approach the rescue ship, etc.
Parameter(s)	Sea State, Location of the ship, available SAR means and their characteristics (speed, capacity, weather limit)
Matrices to calculate	None, this is a time-related parameter
Model / Method	A time-based simulator estimates the time needed by the means of rescue to rescue passengers.

Results	The time spent at sea waiting for rescue is strongly dependent on the location of the abandoned ship, and on the type and number of available SAR means. An example is given below.

Predicting the time needed by SAR teams to rescue passengers is a complex process. The number of variables to take into account is huge and no comprehensive data is available. In a case of large passenger ship abandonment, a number of measures will be put in place in order to rescue the passengers.

Available means of rescue:
The MRCC responsible for the concerned zone will be alerted and their available means of rescue deployed such as all weather lifeboats and helicopters.

Surrounding ships will also be alerted and may be asked to change course in order to assist the rescue operations.

Parameters:
Weather is one key parameter influencing the rescue operations. A higher sea state will slow down operations. The speed of means of rescue will be reduced; retrieving passengers will be harder, or impossible for sea states larger than 3 (see Floodstand D5.3, obstacle A11) through side doors (R2) or ladder (R4), and will thus take more time.

Method:
The method used to evaluate the time to rescue passengers is a simulation of the voyages of the means of rescue. Means of rescue that are likely to be used in case of this kind of emergency are identified. Then data about those means of rescue are collected, such as capacity, geographic position, speed on different weather, time for first launch, time to retrieve/disembark people…

Using a time-based approach, the voyages of the surrounding means of rescue is simulated. Every minute, the distance between each means of rescue and the abandoned ship is calculated. Means of rescue that have reached the rescue zone start to embark passengers and then take them back to their base.

Data collection:
Characteristics of available means of rescue could be obtained from the French MRCC for the Strait of Dover and were used to populate the database needed by the model.

Place: Name	**Type**	**Capacity** (person)	**Speed** (km/h)
Dunkerque: SNSM canot tout temps	Boat	60	42
Gravelines: SNSM vedette de 2eme catégorie	Boat	10	44
Calais: SNSM canot tout temps	Boat	60	42
Boulogne: SNSM canot tout temps	Boat	60	42
Le Touquet: helicopter Dauphin marine nationale	Helicopter	4	250
Le Touquet: helicopter sécurité civile	Helicopter	6	200
Margate: RNLI class Mersey	Boat	38	30
Ramsgate: RNLI class Trent	Boat	74	45
Douvres: RNLI class severn	Boat	138	45
Dungeness: class Mersey	Boat	38	30
Hastings: class Mersey	Boat	38	30
Eastbourne:class Mersey	Boat	38	30
RIAS ANGLIAN MONARCH	Boat	250	30
Lee on Solent: Helicopter Agusta	Helicopter	4	200
Wattisham (RAF): helicopter seaking	Helicopter	16	250

Table 1 – Means of rescue data from the French MRCC, CROSS Cap Griz-Nez

Simulator:
A simulator that uses this method and data (Table 1) has been developed in VBA. It takes as an input the distance of the accident from each base of the means of rescue as well as the number of people to be rescued. Other data is needed by the program such as the time needed to embark and disembark rescued people and time before the first launch of the vehicle.

The output is the time needed to rescue every people that are waiting for rescue as well as a curve plotting.

The example below describes the Estonia (989 people to rescue) abandoned near the Strait of Dover.

Figure 2 – Map the means of rescue in the Strait of Dover

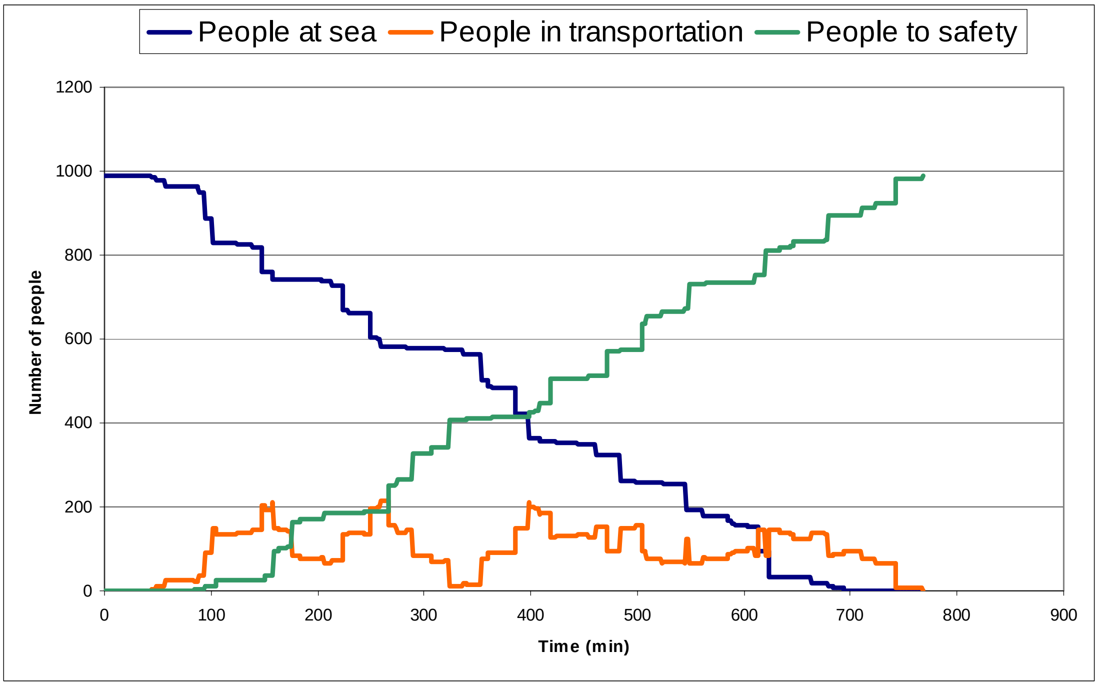


Figure 3 - Plot of the rescue process of 989 people in the Strait of Dover

The last person is retrieved after 694 min (11:34) and taken to a safe place after 768 min (12:48). For such a long duration, the model could be refined by considering the autonomy of the SAR vehicles and introducing refuelling phases, which would make the time even longer.

5.3 R3 – Injuries while transferring passengers through the side door and R5 – Injuries while transferring passengers with escape ladder, pilot ladder, rope ladder

Obstacle	R3 – Injuries while transferring passengers through the side door R5 – Injuries while transferring passengers with escape ladder, pilot ladder, rope ladder
Rescue route phase	Rescue
Hardware / Human factor	Human factor
Short Description	During the recovering phase, where people are transferred from lifeboats and liferafts, passengers may be injured, particularly the most vulnerable ones (lack of stamina, passengers already injured, etc.)
Parameter(s)	Sea State
Matrices to calculate	One matrix for each sea state
Model / Method	Literature and accident report review done in Safecrafts.
Results	Matrices for different sea states were calculated and are described below.

The cause of injuries of both obstacles is similar. People with no strength in their arm and legs will fail and get injured or be killed by the fall.

In calm weather, from experimental values based on volunteers (Steenbekkers and Beijsterveldt, 1998), we estimate that 5% of the elderly would fail to climb the ladder.

From accident review, the case of foundering of the Achille Lauro in 1994 gives a rough estimate of the casualties in moderate weather (sea state 2 later increasing to 3 perhaps 4). On the 200 people who volunteered to climb the ladder (mainly young people), two fell from it, one knocked unconscious, the other may have died two days later (the report is unclear). The proportion of falls in the young group (<50) is thus 1%.

In order to take into account the older groups of people, a multiplying factor is applied. For the 50-75 group, this factor is 1.25, and for the older group, this factor is set to 5.

Injuries resulting from a fall were considered to be equally moderate, severe or fatal. Thus a 3% fall probability results in 1% moderate injuries, 1% severe injuries and 1% deaths.

Sea state 1 to 4

<50	GH	MI	SI	D
GH	0.9910	0	0	0
MI	0.0033	0.9925	0	0
SI	0.0033	0.0041	0.9926	0
D	0.0033	0.0041	0.0082	1

50-75	GH	MI	SI	D
GH	0.9888	0	0	0
MI	0.0041	0.9907	0	0
SI	0.0041	0.0051	0.9907	0
D	0.0041	0.0051	0.0102	1

>75	GH	MI	SI	D
GH	0.9551	0	0	0
MI	0.0164	0.9632	0	0
SI	0.0164	0.0202	0.9638	0
D	0.0164	0.0202	0.0396	1

Sea state 5 and 6:

The proportion of falls for sea state 5 and 6 was raised to 2.4% for the young group. The same multiplying factor as for lower sea states are applied to other age groups. The same consequences of falls (injuries) are also assumed.

<50	GH	MI	SI	D
GH	0.9760	0	0	0
MI	0.0080	0.9802	0	0
SI	0.0080	0.0099	0.9804	0
D	0.0080	0.0099	0.0196	1

50-75	GH	MI	SI	D
GH	0.9702	0	0	0
MI	0.0099	0.9754	0	0
SI	0.0099	0.0123	0.9757	0
D	0.0099	0.0123	0.0243	1

>75	GH	MI	SI	D
GH	0.8810	0	0	0
MI	0.0397	0.9047	0	0
SI	0.0397	0.0476	0.9093	0
D	0.0397	0.0476	0.0907	1

5.4 R6 – Capsizing/Downflooding

Obstacle	R6 – Capsizing/Downflooding
Rescue route phase	Rescue
Hardware / Human factor	Hardware
Short Description	Relative motions and waves can capsize/ down flood the lifeboats/liferafts. If capsized, the LSA is deemed lost with its occupants
Parameter(s)	Sea State
Matrices to calculate	One for each Sea State
Model / Method	Seakeeping analysis and fault tree analysis.
Results	Matrices are obtained for sea state lower than 5 (no capsize or downflooding expected), sea state 5 and sea state 6.

Lifeboats:

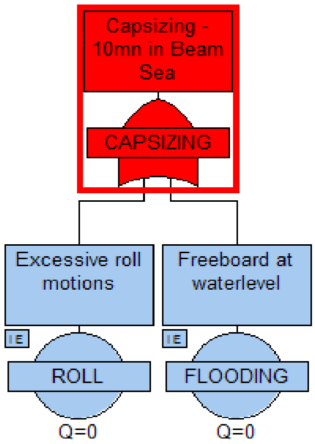
Three main events were identified as contributing to capsizing a lifeboat:

- Excessive roll motions
- Flooding (partially enclosed craft)
- Loss of dynamic stability

Seakeeping analysis was performed for lifeboat in beam seas (for which the risk of capsizing is considered maximum) and remains so for 10 minutes, while manoeuvring the lifeboat to a less dangerous wave direction (e.g. head sea). Two speeds were considered $v = 0$ knots and $v = 6$ knots in the simulations.

Further analysis of the seakeeping simulation results showed that loss of dynamic stability was negligible.

The probability of capsize was then estimated based on the remaining two events which were assumed independent: excessive roll motions and flooding. These two events were then simply combined in a fault tree with an OR gate.



The results are summarized in the table below:

Sea states	*Probability for 600s exposure time in Beam Sea*		
	P(roll>30.5°)	*P(flooding)*	*P(Capsizing)*
3	4.43×10^{-33}	6.01×10^{-31}	Negligible
5	2.09×10^{-04}	3.86×10^{-04}	5.95×10^{-04}
6	2.74×10^{-04}	8.41×10^{-05}	3.58×10^{-04}

The degradation matrices are then:

Below sea state 5

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

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

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

Liferafts:

Liferafts were assumed not to capsize but downflooding was assumed possible and because not enough data was available, the same values of lifeboat capsize were assumed to apply to the liferafts. The degradation matrices are then as above.

5.5 R7 – Injuries due to LSA motions

Obstacle	R7 – Injuries due to LSA motions
Rescue route phase	Rescue
Hardware / Human factor	Human Factor
Short Description	Because of the waves, passengers may be tossed around in the lifeboats and slide down in the liferafts, what may result in them being compressed on each other or hit hard surfaces and subsequently cause injuries.
Parameter(s)	Sea State, Time to rescue passengers (R1)
Matrices to calculate	One for each Sea state
Model / Method	The model used in this obstacle is based on a rationale developed in Safecrafts project.
Results	In calm weather no injuries are expected. In a gale, injuries and some fatalities are expected. Matrices have been calculated for a reference duration of exposure of 4 hours. The obstacle is applied as many times as necessary to cover the actual duration at sea (R1).

Assessing injuries caused by falls and slides is not an easy task and no relevant data was found in literature except for the work made in Safecrafts (WP3.1 Rescue route Quantified), which were rough numbers based on best guess.

Lifeboats:

For Sea State 3, it was assumed that no injury is to be expected as people don't get off their seats.

For other Sea States the reasoning was based on the results from the sea sickness obstacle. Sea sickness is based on the movement of the ship (RMS in x-, y- and z-axis), injuries due to lifeboat motion are based on the same movements. Following the same reasoning, for a shorter period of time of 4 hours we get the following matrices.

Sea state 1 to 3, all age categories, 4 hours of exposure:

	GH	MI	SI	D
GH	1	0	0	0
MI	0	1	0	0
SI	0	0	1	0
D	0	0	0	1

Sea state 5 and 6, 4 hours of exposure:

<50	GH	MI	SI	D
GH	0.9983	0	0	0
MI	0.0017	1	0	0
SI	0	0	1	0
D	0	0	0	1

50-75	GH	MI	SI	D
GH	0.9929	0	0	0
MI	0.0067	0.9994	0	0
SI	0.0004	0.0005	0.9999	0
D	0	0.0001	0.0001	1

>75	GH	MI	SI	D
GH	0.9822	0	0	0
MI	0.0166	0.9986	0	0
SI	0.0010	0.0013	0.9997	0
D	0.0001	0.0001	0.0003	1

Liferafts:

Liferafts present less danger as they are made of a flexible and soft material. The main hazard determined by the Safecrafts project is that raft’s rolling and pitching result in lateral forces that cause people to slide and become pressed one against the other.

Calculations were performed in Safecrafts for an exposure time of 48h. They have been adapted to the shorter reference time of 4 hours considered here. The resulting matrices are as follows:

Sea state 1 to 3, all age categories, 4 hours of exposure:

	GH	MI	SI	D
GH	1	0	0	0
MI	0	1	0	0
SI	0	0	1	0
D	0	0	0	1

Sea state 5, 4 hours of exposure:

<50	GH	MI	SI	D
GH	1	0	0	0
MI	0	1	0	0
SI	0	0	1	0
D	0	0	0	1

50-75	GH	MI	SI	D
GH	0.9998	0	0	0
MI	0	0.9997	0	0
SI	0.0002	0.0003	0.9999	0
D	0	0	0.0001	1

>75	GH	MI	SI	D
GH	0.9994	0	0	0
MI	0	0.9993	0	0
SI	0.0005	0.0007	0.9999	0
D	0.0001	0.0001	0.0001	1

Sea state 6, 4 hours of exposure:

<50	GH	MI	SI	D
GH	0.9992	0	0	0
MI	0.0008	1	0	0
SI	0	0	1	0
D	0	0	0	1

50-75	GH	MI	SI	D
GH	0.9964	0	0	0
MI	0.0033	0.9997	0	0
SI	0.0002	0.0003	0.9999	0
D	0	0	0.0001	1

>75	GH	MI	SI	D
GH	0.9911	0	0	0
MI	0.0083	0.9993	0	0
SI	0.0005	0.0007	0.9999	0
D	0.0001	0.0001	0.0001	1

5.6 R8 – Hypothermia

Obstacle	R8 – Hypothermia
Rescue route phase	Rescue
Hardware / Human factor	Human Factor
Short Description	During boarding and floating at sea, green water is likely to enter rafts, especially in gale. Combined with low air temperature, people are likely to suffer hypothermia which deteriorates health (up to death).
Parameter(s)	Sea State, Water Temperature, Time to rescue passengers (R1),
Matrices to calculate	One for each Sea State
Model / Method	Literature data on hypothermia.
Results	Matrices for various sea state ranges (≤4, 5 and 6) and water temperature (≤5°C or >5°C) for an exposure time of 4h. The obstacle is applied as many times as necessary to cover the actual duration at sea (R1).

Hypothermia will only occur for water temperature below 5°C in a wet indoor condition.

Lifeboats:

Hypothermia in lifeboat is not considered as a possibility because the inside of the lifeboat will remain dry.

All Sea state, all age categories:

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

Liferafts:

Temperature above 5°C
For water temperature above 5°C, no hypothermia is to be expected.

All Sea state, all age categories, T° above 5°C:

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

Temperature below 5°C

In calm to moderate weather (≤ sea state 4), the canopy of the liferaft will protect the people from sea water. They will remain dry and will keep each other warm (each passenger produces a heat of about 100W), hence no hypothermia is to be expected.

Sea state 4 or below, all age categories, T° below 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 sea states larger than 4, the following matrices have been derived:

Sea state 5, all age categories, T° below 5°C:

<50	GH	MI	SI	D
GH	0.9994	0	0	0
MI	0.0002	0.9986	0	0
SI	0.0003	0.0001	0.9976	0
D	0	0.0012	0.0024	1

50-75	GH	MI	SI	D
GH	0.9996	0	0	0
MI	0.0001	0.9986	0	0
SI	0.0003	0.0001	0.9976	0
D	0	0.0012	0.0024	1

>75	GH	MI	SI	D
GH	0.9986	0	0	0
MI	0.0000	0.9980	0	0
SI	0.0001	0.0001	0.9964	0
D	0.0012	0.0018	0.0036	1

Sea state 6, all age categories, T° below 5°C:

<50	GH	MI	SI	D
GH	0.9872	0	0	0
MI	0.0022	0.9864	0	0
SI	0.0035	0.0013	0.9789	0
D	0.0071	0.0124	0.0211	1

50-75	GH	MI	SI	D
GH	0.9865	0	0	0
MI	0.0013	0.9864	0	0
SI	0.0026	0.0013	0.9789	0
D	0.0096	0.0124	0.0211	1

>75	GH	MI	SI	D
GH	0.9861	0	0	0
MI	0.0003	0.9830	0	0
SI	0.0013	0.0013	0.9744	0
D	0.0124	0.0158	0.0256	1

5.7 R9 – Seasickness

Obstacle	R9 – Seasickness
Rescue route phase	Rescue
Hardware / Human factor	Human Factor
Short Description	Deterioration of passengers' health due to seasickness: seasickness would generally only create discomfort although severe dehydration caused by vomiting, and loss of will to survive LOWTS) can endanger an individuals' life. Especially for the elderly, additional dangers of continued vomiting are heart failure and suffocation in unexpelled puke…
Parameter(s)	Sea State, Time to rescue passengers (R1)
Matrices to calculate	One for each sea state
Model / Method	A model developed by McCauley to estimate the proportion of seasick people. It's consequence on human health has then been derived from literature.
Results	A matrix for each sea state and several duration of exposure (4, 8, 12 and 16 hours) has been determined.

The health status degradation is calculated following 3 successive steps: LSA seakeeping calculations, evaluation of the number of sea sick passengers and finally assessment of the consequence of sea sickness on their health. Details of the model and matrices are developed in Appendix A. .

6. CONCLUSIONS

The objective of WP5 is to develop models for the assessment of the risk to human associated with the whole Muster Abandonment and Rescue (MAR) process. The methodology developed in Task 5.1 to perform such an assessment is based on two concepts: a decomposition of the whole process into a succession of obstacles that people have to pass and the Human Health Status (HHS), which gives the proportion of people in Good Health / Minor Injury / Sever injury / Dead categories. The impact of passing a given obstacle on the health of people is translated by a modification of the HHS vector after the obstacle. This modification is calculated by multiplying the HHS vector before the obstacle by a "degradation" matrix, specifically determined for this obstacle.

In this context, and according to the Description of Work, Task 5.4 focused on the Rescue phase of the MAR process. First, the obstacles relevant for the Rescue phase have been identified, resulting in a list of 9 obstacle. Then, each obstacle has been analysed and the corresponding degradation matrix/matrices (or time for time related parameters) have been determined. These analyses and results are presented in this report.

The matrices have been input into the Casualty Calculator program (developed within Task 5.2 and described in D5.2).

The sensitivity analysis of the expected number of fatalities with the input parameters relevant to the Rescue phase is included with the global sensitivity analysis performed in Task 5.5 and presented in D5.5.

7. REFERENCES

TNO Human Factors, Safecrafts Deliverable 3.1, *Passengers Health along the Rescue Route*, 2006

Louis Boer Consult, Safecrafts update to Deliverable 3.1, *The Rescue Route in terms of Passenger Health*, June 2007

Louis Boer, *Passengers Health Estimates Revised and Evaluated*, November 2008

Floodstand Deliverable 5.3, *Report on validation and sensitivity testing of methods for assessing effectiveness of abandonment process* 2011

Peter Tikuisis, John Frim, Defense and Civil Institute of Environmental Medicine (Canada), *Prediction of survival time in cold air*, June 1994

A. APPENDIX A.

Motion sickness mathematical model

In his technical report, M. E. McCauley (McCauley, Royal, Wylie, O'Hanlon, & Mackie, 1976) describes a mathematical model for predicting the effect of vertical sinusoidal acceleration based on experimental values. This model gives MSI (MSI is the percentage of subjects who vomit in the specified time that subjects are exposed to the motions) given three parameters: frequency (f [Hz]), rms acceleration (a [g]) and time of exposure (t [min]).

The model

The model is a two-dimensional normal distribution which can be simplified as:

$$MSI = 100.\Phi(z_a).\Phi(z'_t)$$

where

$$\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-\frac{x^2}{2}} dx = \frac{1}{2}\left[1 + erf\left(\frac{z}{\sqrt{2}}\right)\right]$$

(the standardized cumulative normal distribution function)

$$z_a = \frac{\log_{10}(a) - \mu_a(f)}{\sigma_a}$$

$$z_t = \frac{\log_{10}(t) - \mu_t}{\sigma_t}$$

$$z'_t = \frac{z_t - \rho.z_a}{\sqrt{1-\rho^2}}$$

with

$$\mu_a(f) = 0.87 + 4.36\log_{10}(f) + 2.73(\log_{10}(f))^2$$

$$\sigma_a = 0.47$$

$$\mu_t = 1.46$$

$$\sigma_t = 0.76$$

$$\rho = -0.75$$

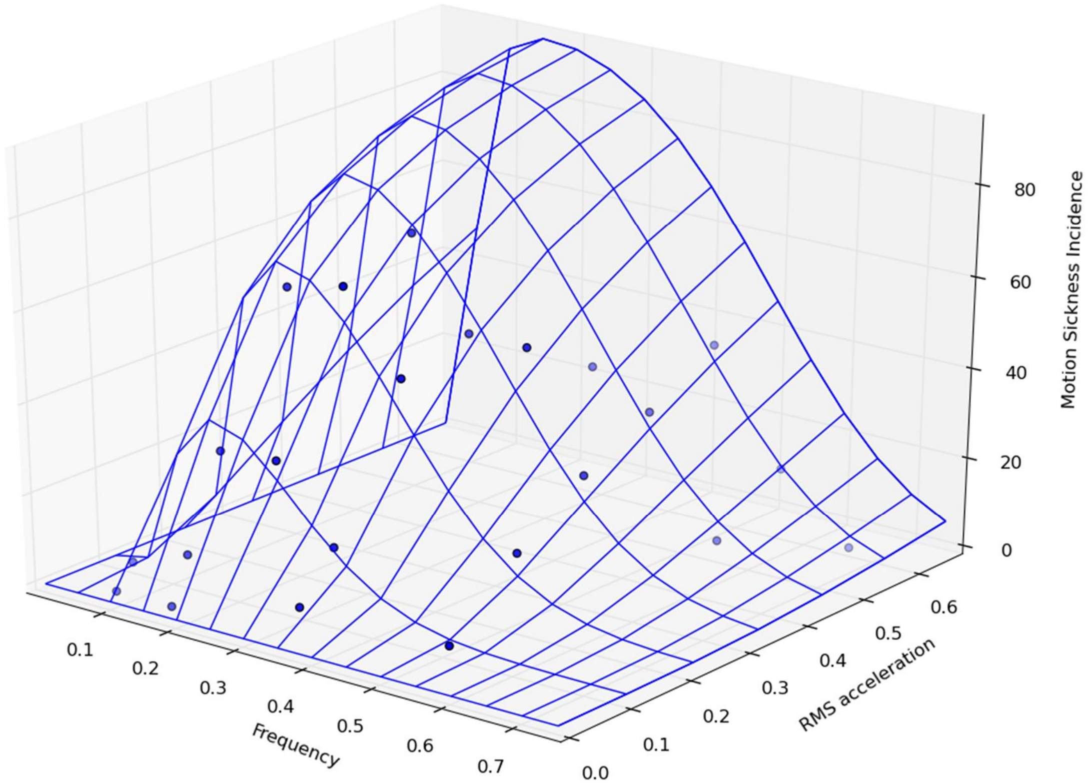


Figure 4 - 3D plot of the model for a 2h exposure, dots represent experimental values

Limits of the model

As this model is based on experimental data, it can't be used to predict values outside the values of experimentation (see Figure 5 for validity area of the model). With respect to the time variable, the experimentation did not measure time of exposure above 2h. The model has to be taken with care for time of exposure that is above 2h. It does not take into account any habituation effects that will certainly occur.

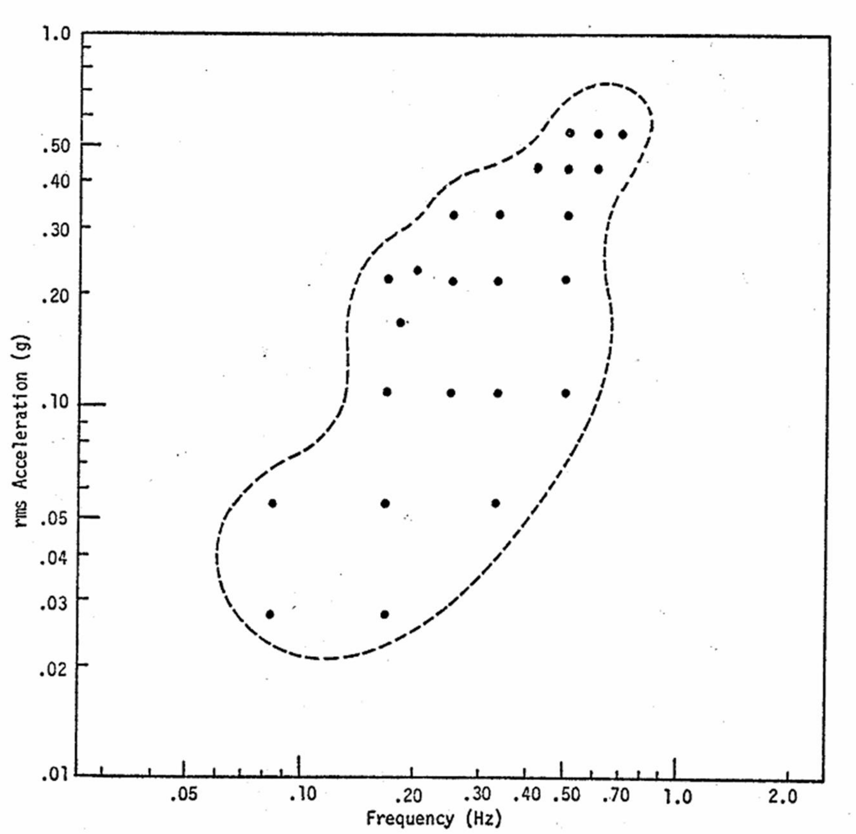


Figure 5 - Area of validity of the mathematical model

Motions of the Lifeboat and Liferaft

In order to use the model described above, accelerations and frequency have to be evaluated. In this purpose, seakeeping calculations have been made in Safecrafts project, with the following results:

Calculation conditions

LB: 18050kg displacement
ISSC spectrum
SS3 (Hs=0.88m, Tp=7.5s)
SS5 (Hs=3.25m, TP=9.7s)
SS6 (Hs=5m,TP=12.4s)
Beam sea v= 0 knots and head sea V= 6 knots
LB position with respect to vessel: free floating (no vessel influence)

Calculation point

	G	mdps
X/transom (m)	4.19	7.2
Y/axis (m)	0	1.8
Z/keel (m)	1.43	1.3

mdps : most distant passenger seat

Results

	free floating _ beam sea V = 0 knots						
	calculation point	G			mdps		
		X acc	Y acc	Z acc	X acc	Y acc	Z acc
SS3	RMS (m/s²)	0.00	0.26	0.34	0.00	0.26	0.30
	T2 (s)	2.12	4.10	3.43	2.26	4.08	4.07
SS5	RMS (m/s²)	0.00	0.68	0.84	0.01	0.68	0.77
	T2 (s)	2.12	4.52	3.71	2.50	4.48	4.41
SS6	RMS (m/s²)	0.00	0.72	0.87	0.01	0.72	0.81
	T2 (s)	2.12	4.91	3.98	2.75	4.86	4.74

	free floating _ head sea V = 6 knots						
	calculation point	G			mdps		
		X acc	Y acc	Z acc	X acc	Y acc	Z acc
SS3	RMS (m/s²)	0.27	0.00	0.74	0.28	0.00	1.07
	T2 (s)	3.17	0.00	2.57	3.13	0.00	2.31
SS5	RMS (m/s²)	0.71	0.00	1.78	0.73	0.00	2.49
	T2 (s)	3.50	0.00	2.68	3.45	0.00	2.38
SS6	RMS (m/s²)	0.76	0.00	1.77	0.78	0.00	2.42
	T2 (s)	3.82	0.00	2.79	3.76	0.00	2.43

Most distant passenger seat values are the worst case.

Consequences of Sea Sickness

Dehydration

The model of sea sickness gives the proportion of people getting sick. These people will vomit will not be able to hydrate themselves or take oral medication. Dehydration is the first threat to life to consider.

Loss of will to survive

Seasick people are more incline to give up all hope, this mental condition increases the risk of injuries and hypothermia. They will also be less active when there is a need to do something. In Safecrafts WP3.1 – Rescue Route Quantified, they estimate that 50% of the passengers suffering from seasickness will also loose the will to survive.

Fatalities

Number of fatalities is hard to estimate due to lack of data in this domain. Based on the above reasoning, they assumed the following fatalities:

For passengers below 50 years old, we assume no fatalities.

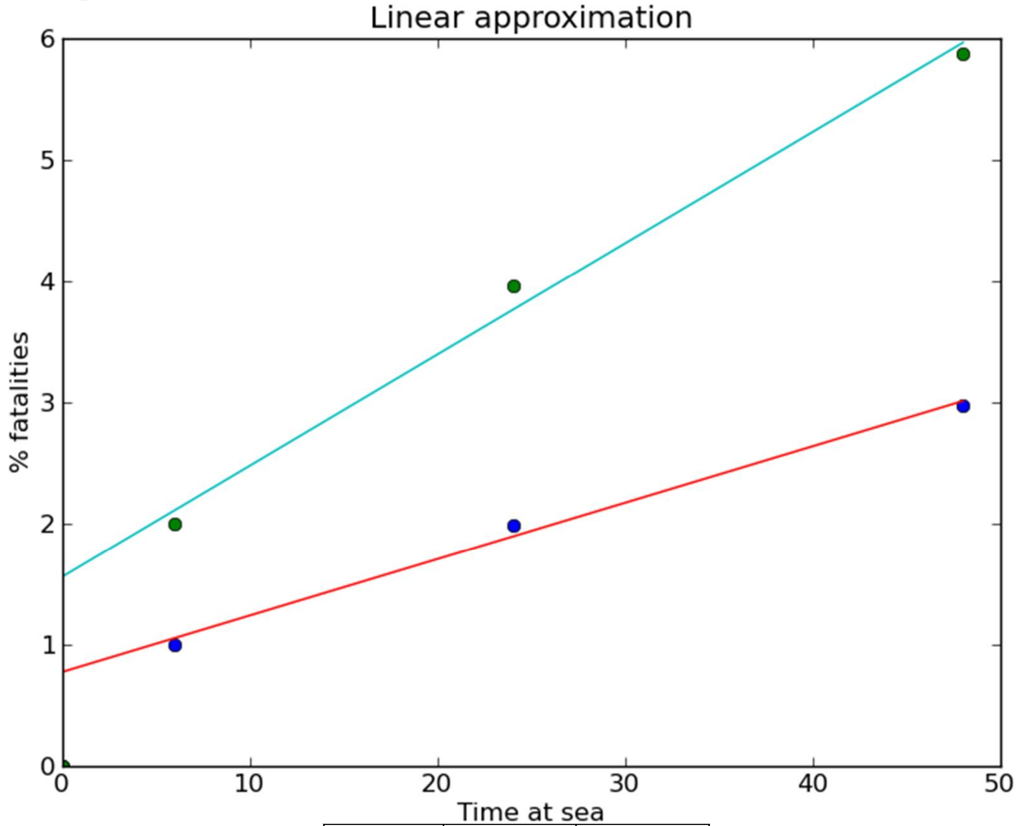
For passengers between 50 and 75 years old, we assume that $f = 1\%$ of the population that is sick after 6 hours (s_6) will die.

Then another $f = 1\%$ of the population that is sick (and alive) after 24h ($s'_{24} = s_{24} \times (1 - f)$) will also die, so at that time there will be $s_6 \times f + s_{24} \times f \times (1 - f)$ fatalities.

And finally another $f = 1\%$ of the population that is sick (and alive) after 48h will also die. So after 48h, there will be $s_6 \times f + s_{24} \times (1 - f) \times f + s_{48} \times (1 - f)^2 \times f$.

For passengers above 75 years old, the same reasoning is assumed with $f = 2\%$.

This reasoning was done to estimate fatalities after 48 hours at sea. In our model we aim at a more precise model which estimates fatalities after x hours at sea. A linear approximation based on the previous statement has been done:



a.x+b	a	b
50	0	0
50-75	0.0466	0.7756
>75	0.0917	1.5619

Figure 6 - Graph and equation parameters of the linear approximation

For a conservative approach, we also assume that 50% of seasick people aged above 50 years old will be in a state of dehydration which will need special medical care (severe injury).

Habituation

Literature states that there is an effect of habituation, people tend to get less sick over time. To model this phenomenon we will assume that the proportion of sick people will stop to increase after 16 hours of exposure.

Results

Calculations of MSI for different Sea States, times at sea, positions of the passenger and speeds of the lifeboat are given in the table hereafter.

Sea State	Hs (m)	Tp (s)	V (knots)	Point	RMS (m/s²)	T2 (s)	MSI 4h (%)	MSI 8h (%)	MSI 12h (%)	MSI 16h (%)
3	0,88	7,5	0	G	0,34	3,43	2,3475E+00	3,4616E+00	3,9843E+00	4,2704E+00
3	0,88	7,5	0	mdps	0,3	4,07	2,9668E+00	4,2433E+00	4,8171E+00	5,1227E+00
3	0,88	7,5	6	G	0,74	2,57	4,6590E+00	6,2808E+00	6,9476E+00	7,2833E+00
3	0,88	7,5	6	mdps	1,07	2,31	6,2887E+00	8,1507E+00	8,8681E+00	9,2147E+00
5	3,25	9,7	0	G	0,84	3,71	1,9809E+01	2,2212E+01	2,2887E+01	2,3155E+01
5	3,25	9,7	0	mdps	0,77	4,41	2,2712E+01	2,5070E+01	2,5700E+01	2,5943E+01
5	3,25	9,7	6	G	1,78	2,68	2,6870E+01	2,9116E+01	2,9679E+01	2,9887E+01
5	3,25	9,7	6	mdps	2,49	2,38	2,9652E+01	3,1799E+01	3,2316E+01	3,2502E+01
6	5	12,4	0	G	0,87	3,98	2,3464E+01	2,5805E+01	2,6423E+01	2,6660E+01
6	5	12,4	0	mdps	0,81	4,74	2,6196E+01	2,8462E+01	2,9036E+01	2,9250E+01
6	5	12,4	6	G	1,77	2,79	2,9470E+01	3,1624E+01	3,2144E+01	3,2331E+01
6	5	12,4	6	mdps	2,42	2,43	3,0333E+01	3,2454E+01	3,2960E+01	3,3141E+01

The worst case of each calculation is the most distant passenger seat with a 6 knot speed. For a conservative approach, we decided to use this value for all passengers. Using the linear approximation described above, we can derive the number of fatalities and severe injured people for each sea state and time at sea:

			50-75		50	
Sea State	Time at sea (h)	MSI (%)	Severely Injured	Deceased	SI	Deceased
3	2	3,9880E+00	1,9940E-03	3,4648E-04	1,9940E-03	6,9603E-04
3	4	6,2887E+00	3,1444E-03	6,0498E-04	3,1444E-03	1,2129E-03
3	6	7,4680E+00	3,7340E-03	7,8802E-04	3,7340E-03	1,5773E-03
3	8	8,1507E+00	4,0754E-03	9,3603E-04	4,0754E-03	1,8710E-03
3	12	8,8681E+00	4,4340E-03	1,1837E-03	4,4340E-03	2,3610E-03
3	16	9,2147E+00	4,6073E-03	1,4017E-03	4,6073E-03	2,7912E-03
5	2	2,5019E+01	1,2510E-02	2,1737E-03	1,2510E-02	4,3666E-03
5	4	2,9652E+01	1,4826E-02	2,8525E-03	1,4826E-02	5,7189E-03
5	6	3,1150E+01	1,5575E-02	3,2870E-03	1,5575E-02	6,5793E-03
5	8	3,1799E+01	1,5900E-02	3,6518E-03	1,5900E-02	7,2996E-03
5	12	3,2316E+01	1,6158E-02	4,3135E-03	1,6158E-02	8,6035E-03
5	16	3,2502E+01	1,6251E-02	4,9442E-03	1,6251E-02	9,8452E-03
6	2	2,5704E+01	1,2852E-02	2,2331E-03	1,2852E-02	4,4861E-03
6	4	3,0333E+01	1,5166E-02	2,9180E-03	1,5166E-02	5,8503E-03
6	6	3,1816E+01	1,5908E-02	3,3572E-03	1,5908E-02	6,7199E-03
6	8	3,2454E+01	1,6227E-02	3,7271E-03	1,6227E-02	7,4499E-03
6	12	3,2960E+01	1,6480E-02	4,3995E-03	1,6480E-02	8,7749E-03
6	16	3,3141E+01	1,6570E-02	5,0414E-03	1,6570E-02	1,0039E-02

Matrices can then be derived from the previous table:

Sea State 3:

	4h				**8h**				**12h**				**16h+**			
<50	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000
	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000
50-75	0.9963	0.0000	0.0000	0.0000	0.9950	0.0000	0.0000	0.0000	0.9944	0.0000	0.0000	0.0000	0.9940	0.0000	0.0000	0.0000
	0.0000	0.9962	0.0000	0.0000	0.0000	0.9948	0.0000	0.0000	0.0000	0.9941	0.0000	0.0000	0.0000	0.9937	0.0000	0.0000
	0.0031	0.0031	0.9988	0.0000	0.0041	0.0041	0.9982	0.0000	0.0044	0.0044	0.9976	0.0000	0.0046	0.0046	0.9972	0.0000
	0.0006	0.0007	0.0012	1.0000	0.0009	0.0011	0.0018	1.0000	0.0012	0.0015	0.0024	1.0000	0.0014	0.0017	0.0028	1.0000
>75	0.9957	0.0000	0.0000	0.0000	0.9940	0.0000	0.0000	0.0000	0.9932	0.0000	0.0000	0.0000	0.9926	0.0000	0.0000	0.0000
	0.0000	0.9954	0.0000	0.0000	0.0000	0.9935	0.0000	0.0000	0.0000	0.9926	0.0000	0.0000	0.0000	0.9919	0.0000	0.0000
	0.0031	0.0031	0.9976	0.0000	0.0041	0.0041	0.9962	0.0000	0.0044	0.0044	0.9952	0.0000	0.0046	0.0046	0.9944	0.0000
	0.0012	0.0015	0.0024	1.0000	0.0019	0.0024	0.0038	1.0000	0.0024	0.0030	0.0048	1.0000	0.0028	0.0035	0.0056	1.0000

Sea State 5:

	4h				**8h**				**12h**				**16h+**			
<50	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000
	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000
50-75	0.9823	0.0000	0.0000	0.0000	0.9804	0.0000	0.0000	0.0000	0.9795	0.0000	0.0000	0.0000	0.9788	0.0000	0.0000	0.0000
	0.0000	0.9816	0.0000	0.0000	0.0000	0.9795	0.0000	0.0000	0.0000	0.9784	0.0000	0.0000	0.0000	0.9776	0.0000	0.0000
	0.0148	0.0148	0.9942	0.0000	0.0159	0.0159	0.9926	0.0000	0.0162	0.0162	0.9914	0.0000	0.0163	0.0163	0.9902	0.0000
	0.0029	0.0036	0.0058	1.0000	0.0037	0.0046	0.0074	1.0000	0.0043	0.0054	0.0086	1.0000	0.0049	0.0061	0.0098	1.0000
>75	0.9795	0.0000	0.0000	0.0000	0.9768	0.0000	0.0000	0.0000	0.9752	0.0000	0.0000	0.0000	0.9739	0.0000	0.0000	0.0000
	0.0000	0.9781	0.0000	0.0000	0.0000	0.9750	0.0000	0.0000	0.0000	0.9731	0.0000	0.0000	0.0000	0.9716	0.0000	0.0000
	0.0148	0.0148	0.9887	0.0000	0.0159	0.0159	0.9855	0.0000	0.0162	0.0162	0.9829	0.0000	0.0163	0.0163	0.9806	0.0000
	0.0057	0.0071	0.0113	1.0000	0.0073	0.0091	0.0145	1.0000	0.0086	0.0107	0.0171	1.0000	0.0098	0.0121	0.0194	1.0000

Sea State 6:

	4h				8h				12h				16h+			
<50	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000
	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1.0000
50-75	0.9819	0.0000	0.0000	0.0000	0.9801	0.0000	0.0000	0.0000	0.9791	0.0000	0.0000	0.0000	0.9784	0.0000	0.0000	0.0000
	0.0000	0.9812	0.0000	0.0000	0.0000	0.9792	0.0000	0.0000	0.0000	0.9780	0.0000	0.0000	0.0000	0.9772	0.0000	0.0000
	0.0152	0.0152	0.9942	0.0000	0.0162	0.0162	0.9926	0.0000	0.0165	0.0165	0.9912	0.0000	0.0166	0.0166	0.9901	0.0000
	0.0029	0.0036	0.0058	1.0000	0.0037	0.0046	0.0074	1.0000	0.0044	0.0055	0.0088	1.0000	0.0050	0.0062	0.0100	1.0000
>75	0.9789	0.0000	0.0000	0.0000	0.9764	0.0000	0.0000	0.0000	0.9747	0.0000	0.0000	0.0000	0.9734	0.0000	0.0000	0.0000
	0.0000	0.9775	0.0000	0.0000	0.0000	0.9746	0.0000	0.0000	0.0000	0.9726	0.0000	0.0000	0.0000	0.9710	0.0000	0.0000
	0.0152	0.0152	0.9883	0.0000	0.0162	0.0162	0.9853	0.0000	0.0165	0.0165	0.9826	0.0000	0.0166	0.0166	0.9802	0.0000
	0.0059	0.0073	0.0117	1.0000	0.0074	0.0092	0.0147	1.0000	0.0088	0.0109	0.0174	1.0000	0.0100	0.0124	0.0198	1.0000

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