TECHNICAL REPORT

ICELANDIC MARITIME ADMINISTRATION

RISK ASSESSMENT OF FERRY BAKKAFJARA - VESTMANNAEYJAR

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DET NORSKE VERITAS

TECHNICAL REPORT

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Summary:
DNV has performed a risk assessment between a planned new ferry route between Bakkafjara and Vestmannaeyjar. The risk for people, property and environment is measured as the frequency of fatalities, property damage and oil spills. The risk of the new ferry is compared with the an existing ferry operating between the habour of Thorlakshofn and Vestmannaeyjar.

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1 CONCLUSIVE SUMMARY

A lot of research has been performed to evaluate the passage from Bakkafjara to Vestmannaeyjar, which is 7 nm long and passing a shallow sandbank with depth 5-6 meters with breaking waves during strong winds. This report contains a risk assessment requested by the Icelandic Maritime Administration (IMA). The risk is quantified and compared with the existing route Thorlakshofn – Vestmannaeyjar and risk reducing measures are proposed. Personnel risk is in focus, but also property and environmental risk is discussed.

The risk for the sailing is considered low, both when risk is measured in terms of fatalities, serious property damage and oil spills. The low risk statement is based on the estimated return periods and by comparing especially the fatality frequency with acceptance criteria than is common to apply /1/.

Compared to the existing ferry route the risk for the new route is assessed as lower.

Risk control options beyond what is already planned for in the Bakkafjara – Vestmannaeyjar project is thus not required based on the risk assessment. However, some measures may prove cost effective and should be evaluated (no cost benefits analysis of the measures is preformed as part of this assessment):

- Statistically, loss of propulsion/steering leads to approximately 15% of the global collision, contact and grounding incidents. I addition comes serious failures reported under HME which have not resulted in further events. An important risk controlling measure to avoid an escalating accident is thus to avoid a drifting vessel. A normal anchor is likely not to be sufficient for the sandy seabed outside Bakkafjara. Hence, it is recommended to that a sand anchor is installed onboard.
- Due to the heavy winds and waves, currents and the possibility for breaking waves outside Bakkafjara the probability for touching the pier entrance is high. This is in most cases regarded to give non-serious damages only. Still there might be operational interruptions due to inspections and minor repairs. To reduce the extent of any damage to the vessel it is recommended to apply fenders at the pier entrance. Fenders giving the necessary protection might be quite wide and the entrance width should be adjusted according to the width lost due to the fenders.
- Use of autopilot while approaching harbour in heavy seas should be avoided because manual steering is usually better in case of regaining control subsequent to loss of manoeuvrability due to breaking waves.
- When crossing shallow waters with a sandy seabed there might be a chance for sand and spawn to enter the engine cooling water system, which consequently might lead to an engine failure. To avoid this it is common to apply cooling water inlet on the vessel side (not water inlet at vessel bottom only) and ensure satisfactory inspection and maintenance frequency to avoid clogging of filters.
- If other ships use the Bakkafjara harbour, routines should be established to avoid that they arrive/departure at the same time as the ferry. This to avoid an increasing collision risk.

- To ensure a low probability for serious vessel fires as possible, the tug located at Vestmannaeyjar or any other stand-by vessel should have an acknowledged fire-fighting capability.
- Clear procedures for passenger movements on deck during heavy sea conditions should be applied to reduce the probability for occupational accidents.
- Issues like window sizes and position on the vessel, emergency routines including passenger/crew assembly area and life saving appliances, stability, hull strength etc. is assumed covered by class society requirements. Hence, it is recommended that the vessel is registered with an acknowledged ship classification society.
- Propulsion pods are not recommended. This recommendation is based on pod failure frequencies onboard cruise ships assessed by DNV /6/. A failure frequency of 0.18 per ship-year is estimated, and out of service time can be expected in a large portion of these incidents. In addition the failures are estimated to lead to a serious accident in 0.4% of the cases. This gives a serious accident frequency of 7.2E-04, which is similar to the total HME serious damage frequency given in Table 7. Although not directly comparable, this gives an indication of the challenges. Due to the relative high touching sandbank frequency and the whirling of sand at Bakkafjara the failure frequency is likely to be even higher for the ferry.

2 INTRODUCTION

2.1 Background

Improvement of the contact between Vestmannaeyjar and the Iceland mainland has been discussed for many years on Iceland. The existing transport is performed by a ferry between Vestmannaeyjar and Thorlakshofn using 2hr 45min, and by small taxi aircrafts. Several solutions for improved communication are discussed, including an 18 km underwater tunnel and a shorter ferry route from Bakkafjara. It is according to IMA likely that the Icelandic authorities will go forward with the latter option.

A lot of research has been performed to evaluate the passage from Bakkafjara to Vestmannaeyjar (see e.g. reference /7/-/10/), which is 7 nm long and passing a shallow sandbank with depth 5-6 meters with breaking waves during strong winds. More studies are needed before the Bakkafjara harbour construction can start, including a risk assessment of the passage, which the Icelandic Maritime Administration has requested from DNV. This report contains this risk assessment.

2.2 Objective and scope

The objective of the risk assessment is to strengthen the project and establish a better foundation for evaluating the ferry alternative by identifying and assessing the risk of the planned route Bakkafjara – Vestmannaeyjar.

The scope is to carry out a quantitative risk assessment. Personnel risk will be in focus, but also property and environmental risk will be discussed.

- Personnel risk will be quantified as fatality frequency.
- Property risk will be quantified as the frequency of damage to the ferry.
- Environmental risk will be quantified as the frequency of oil spills.

The risk of the ferry will be compared with the existing ferry route Thorlakshofn – Vestmannaeyjar and where risk reducing measures are appropriate they will be suggested.

The risk related to the whole ship in operation cycle all year around will be included. Factors causing risk both external and internal to the ferry will be addressed. However, occupational accidents are not included.

3 METHODOLOGY

The risk assessment process follows the FSA (Formal Safety Assessment) main stages as recommended by IMO. This is illustrated in Figure 1.

This project will not include a cost-benefit assessment, although economical considerations will be made in the recommendations.

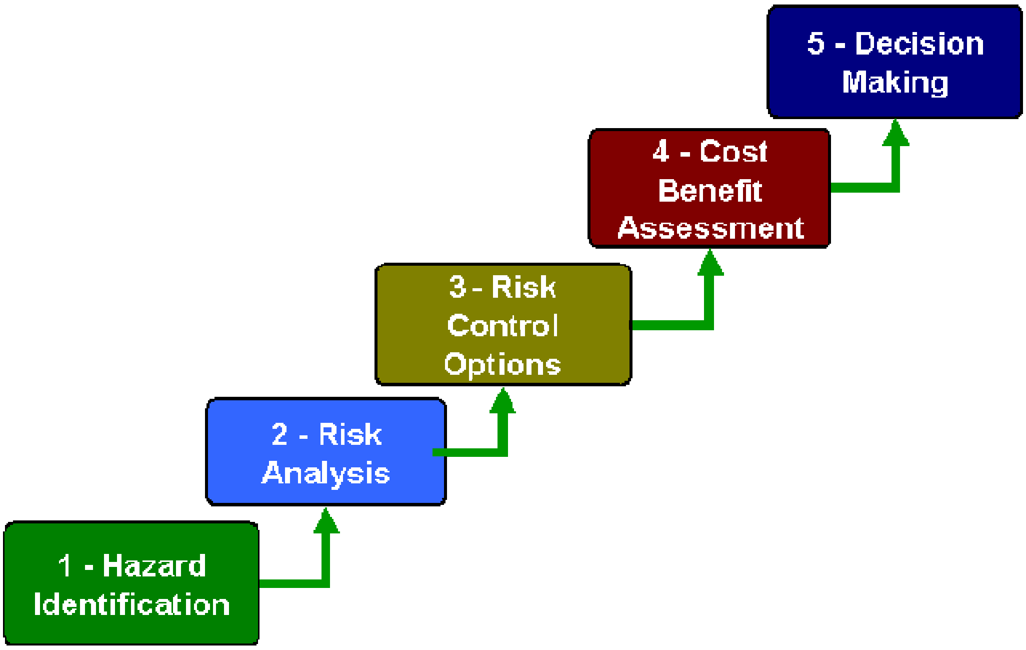

Figure 1 Risk assessment main steps

The main inputs to the study will be:

- Risk analysis of generic vessels, distributed on all accident types, including risk for personnel, property and environment.
- Local geographical, environmental and other data and considerations.
- Experience from other ships operating in the area and the existing ferry in particular.
- DNV has visited both IMA, Bakkafjara and Vestmannaeyjar and sailed the planned route to gather information and make site specific judgements.

Risk for personnel should include crew, passengers and people ashore. In this project risk for people ashore is considered negligible. Hence, focus is on crew and passengers. The personnel risk metrics calculated are the expected overall number of:

- Fatalities per ship year
- Fatalities per year
- Fatalities per sailing

Property risk will also be discussed, although not to the level of detail as for personnel risk. The property risk metrics are the expected overall number of damages per ship year, year and per sailing. Property risk will be divided into the following three categories listed below. They are further explained in Table 2.

- Total loss
- Serious damage
- Non-serious damage

Also environmental risk will be discussed. The environmental risk metrics are expected number of oil spills per ship year, year and per sailing.

Based on the previously Formal Safety Assessments (FSA) performed by DNV all types of accidents are categorised the categories explained in Table 1. The assessment of risk will be performed for each of these categories. The categories missing vessel and War loss are not included as they are regarded as irrelevant for the Icelandic coastal waters.

Table 1 Explanation of accident categories

Accident categories	**Explanation**
Collision (CN)	Striking or being struck by another ship, regardless of whether under way, anchored or moored.
Contact (CT	Striking or being struck by an external substance but not another ship or the sea bottom.
Foundering (FD)	Includes sinking due to heavy weather (capsizing), springing leaks, breaking in two and not as a consequence of the other categories.
Fire/explosion (FX)	Where fire/explosion is the first event reported (except when first event is a hull/machinery/equipment failure leading to fire/explosion)
Hull/Machinery/Equipment (HME)	Includes ships lost or damaged as a result of hull/machinery damage or failure which is not attributable to the other categories.
Grounding (GR)	Includes ships reported stuck and cases of reported touching bottom and bumping over bars.

Hazards that are identified throughout the project are categorised according to these accident categories.

Table 2 Explanation of the property damage consequence categories

<table>
<tr><th rowspan="2">Accident categories</th><th colspan="2">Property consequence categories</th></tr>
<tr><th>Serious and Non-serious damage differentiation</th><th>Total loss</th></tr>
<tr><td>Collision (CN)</td><td>Repairs needed before ship could continue sailing: serious</td><td rowspan="6">Refers to a ship which has ceased to exist, either by virtue of the fact that the ship was irrecoverable or was broken up as a consequence of that casualty.</td></tr>
<tr><td>Contact (CT</td><td>Patch over a gouge up to 1 m/slight leakage: non-serious
Bent/distorted bottom/side plating or tank internals that are straightened at a much later point: non-serious
Flooding of any compartment: serious</td></tr>
<tr><td>Foundering (FD)</td><td>All incidents are serious damage or total loss</td></tr>
<tr><td>Fire/explosion (FX)</td><td>Any ship towed into port: serious
For extent of damage to make an incident serious it would be necessary the ship to be taken out of service for at least some days.</td></tr>
<tr><td>Hull/Machinery/ Equipment (HME)</td><td>Any ship towed or shore assistance rendered due to loss of propulsive or electrical power, steering gear failure or rudder damage: Serious</td></tr>
<tr><td>Grounding (GR)</td><td>Lightening/refloating without ship damage: non-serious
Tug used although no damage reported: non-serious
Patch over a gouge up to 1 m/slight leakage: non-serious
Bent/distorted bottom/side plating or tank internals that are straightened at a much later point: non-serious
Flooding of any compartment: serious
Immediate dry-docking: serious
Repairs needed before ship could continue sailing: serious</td></tr>
</table>

4 NEW FERRY AND ROUTE INFORMATION

4.1 Ferry

A new ferry is likely to be built for the planned route. The vessel will be designed according to classification requirements to meet the conditions in the area where it is intended for operation. See Figure 2 for illustration of the vessel that is likely to be built. The main dimensions are given in Table 3. In this risk assessment it is assumed that this ferry or a ferry with similar characteristics will be used for the sailing.

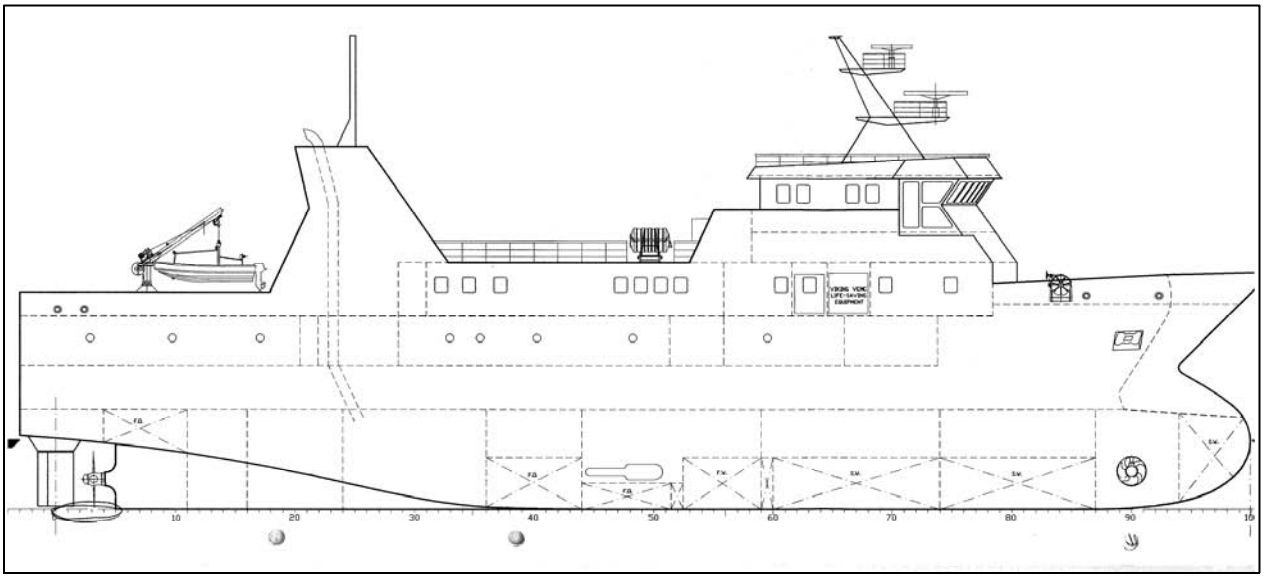

Figure 2 Drawing of planned ferry

Table 3 Ship information

Length overall	LOA	62 m
Length between PP	LPP	60 m
Beam	B	15 m
Draught	T	3,3 m
Passenger capacity	#	>250
Crew	#	7-10
Car capacity	#	50-55
Service speed		15 knots

Number of passengers onboard is on average estimated to 100. This is based on 1000 passengers/day (IMA estimates 738 passengers/day in 2010 and 1051 passengers/day in 2020) and 10 sailing/day. This gives an average passenger capacity exploitation of approximately 30-50%. In high seasons the vessel passenger capacity is expected to be fully exploited. In the adjustment factors applied to the FSA generic RoPax risk figures it is conservatively assumed full capacity exploitation as this is also assumed in the generic FSA.

Propulsion is provided by two propellers with power from two 1.500 kW main engines. In addition the vessel will be equipped with three independent auxiliary engines each capable of supplying necessary power to a bow thruster at full power. The ferry will have full propulsion redundancy according to the requirements of the DNV voluntary class notation redundant propulsion (RP or RPS) or similar. Due to the two propeller system and the bow thrusters the vessel has a short turn radius; approximately two ship lengths ~120 m.

Pods are not recommended for propulsion. It is referred to section 8 for discussion and recommendations regarding this.

The ferry will be equipped with ECDIS and since it is a new vessel it will have modern bridge design.

4.2 Ferry operation

The ferry will be in full time service between Bakkafjara and Vestmannaeyjar, a distance of 7 nm, travel time 0.5 hours and departure frequency every 2 – 2.5 hours for each leg.

A risk controlling measure to be introduced is the wave height operational limit. It is initially proposed that the ferry will not operate if the wave height (Hs) exceeds 3.4 meters plus 20% of the tidal elevation. The minimum wave height will therefore be 3.4 meters and the maximum wave height at tidal elevation of 2.64 meters will then reach 3.4 + 0.2x2.64 = 3.93 meters.

This will be monitored by the wave buoy and data will be transferred online to the ferry bridge.

The vessel will also always have 2 crewmembers on the bridge, although the second person does not necessarily have formal navigational skills (lookout).

4.3 Traffic in the area

Vessels passing between Vestmannaeyjar and the mainland are mainly fishing vessels. Domestic ship traffic, cruise ships and ships to and from Reykjavik – Northern Europe will tend to pass in this area. There will be maximum one oil tanker to Reykjavik per month likely to pass in the area. Other tankers are passing SW off Vestmannaeyjar.

- Cruise arrivals 2004 (increasing): 57 (114)
- Foreign trade arrivals 2004: 68 (136)
- Approximately 9000 fishing vessel arrivals in the harbours closest to the ferry route. Based on this it is assumed that 5000 vessels/year will cross the ferry route.

It should be noted that fishing is prohibited in the area.

4.4 Harbour

The existing Vestmannaeyjar harbour is already in use as a passenger ferry harbour. The operation of the new ferry will not change the harbour conditions, hence it is not further described here.

The new harbour at Bakkafjara will be dimensioned according to the local conditions. An illustration of the harbour is given in Figure 3. A 70 meter wide and 5.5 – 6 meter deep sailing lane is proposed (sand seabed). Breakwaters will extent approximately 500 meters from the inner harbour, hence wave reflection is not regarded as an issue. Harbours depth will be monitored and dredging performed when considered necessary.

It is assumed no other regular traffic in the harbour during departure and arrival of the ferry.

Navigational lights will be located on each side of the harbour entrance and centre leading lights/marks installed at the harbour inner end.

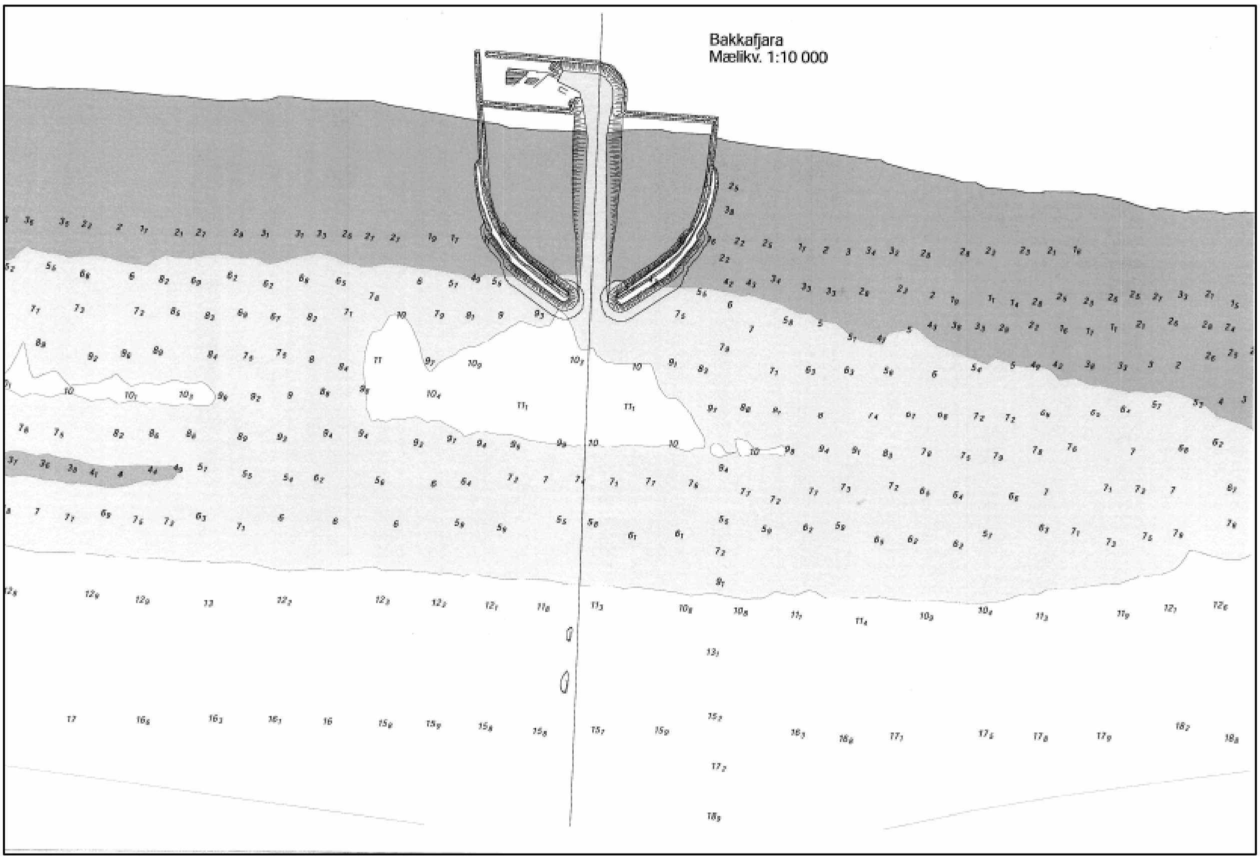

Figure 3 Illustration of Bakkafjara harbour

4.5 Environmental data

4.5.1 Seabed

There are shallow waters at Bakkafjara. The seabed consists of sand. As can be seen from Figure 3, the shallowest area is a sandbank with a minimum depth of approximately 5.5 meters some 350 – 500 meters from the harbour entrance. The sandbank is however varying with respect to depth and position with time and tends to become deeper subsequent to storms (e.g. in July 2003 the minimum depth in the same area was 6.5 meters and in October 2002 is was 7.3 meters).

Inside the sandbank the waters become deeper (10 – 11 meters) before it becomes shallower (7 – 9 meters) close to the harbour entrance.

It is assumed that inside the port the sea depth will be monitored and dredged when required. It is further assumed that the depth of the sandbank is closely monitored, to avoid crossing sandbanks at a place the depth is less than 5.5 meters.

Ship and equipment for monitoring the sea depth will be available and depth monitoring will be performed on a regular basis when the weather permits it.

Between the Bakkafjara sandbank and Vestmannaeyjar there is mainly open sea with no shallow areas. The route will pass the isles Ellidaey and Bjarnarey at a distance of at least 0.3 and 0.6 nm respectively. On the other side is Faxasker which is passed at a distance of 0.4 – 0.5 nm.

The harbour entrance at Vestmannaeyjar has a width of at least 0.1 nm, with the headland of Kleftsnef as the most critical point. The harbour entrance is marked by signal lights.

The figure below shows a map of the passage.

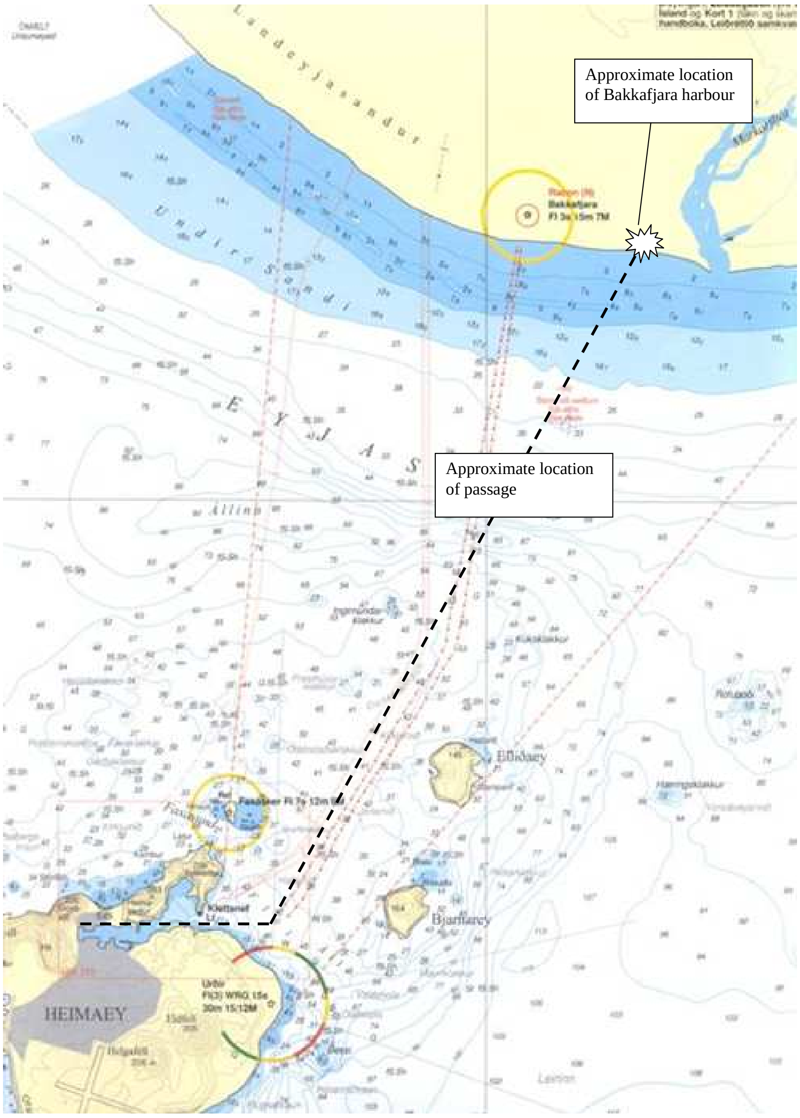

Figure 4 Map of the Bakkafjara – Vestmannaeyjar passage

4.5.2 Waves, wind and currents

Long term wave statistics from Bakkafjara buoy is presented in Table 4. The wave data from Bakkafjara is collected in the period from November 2003 to January 2006. As can be interpreted from the table the significant wave height is below about 3,7 meters 96% of the time ($Hs_{97\%}$=3,7 m).

Table 4 Bakkafjara wave statistics

% of time	Return period (y)	Bakkafjara buoy	
		Hs (m)*	Tp (s)#
60		1,8	10
90		3,1	11
98		4,3	13
99		4,7	15
	1	6,7	16
	10	7,6	18
	100	8,4	20

* Hs = Significant wave height
\# Tp = Wave period

There will be limitations on when the ferry will operate based on the significant wave height (Hs) criteria. The critical significant wave height is according to IMA Hs = 3.4 + 0.2 times the tidal elevation.

- MHWS 2.6 m Hs= 3.9 m
- MHWP 2.0 m Hs= 3.8 m
- MSL 1.4 m Hs= 3.7 m
- MLWP 0.8 m Hs= 3.6 m
- MLWS 0.1 m Hs= 3.4 m

As can be seen from the table the Hs limitation of around 3.7 meter at MSL gives availability for the ferry of around 96%.

4.5.3 Visibility

According to the official authorities no relevant visibility monitoring is being performed. The visibility monitoring on Vestmannaeyjar airport is high above sea level and not considered relevant for this crossing.

According to an interview with one of the captains onboard the existing ferry, a sailing has never been cancelled due to low visibility. It is not known of any sailing restrictions due to low visibility on Iceland.

Still, visibility can be limited both for the human eye and the radar, especially due to snow showers winter time. Based on the information above, this is however not regarded as an important safety issue.

4.6 Surveillance and emergency preparedness

A tug is located at the Vestmannaeyjar with speed 12 knots, and 30 ton bollard pull, which is regarded as satisfactory to tow the new ferry. The tug is assumed to have a max. response time of 15 minutes and is able to get from Vestmannaeyjar to Bakkafjara within some 40 minutes. This is under the assumption that there is an around the clock duty system.

All vessels entering Icelandic waters report to the Icelandic Maritime Traffic Service (IMTS). Information is logged. Traffic is monitored based on AIS data, meaning that a traffic overview for most vessels are available (all vessels above 300 BT is required to have AIS within July 2007).

There is no radar surveillance in the area and the AIS traffic information is not continuously observed by a dedicated person.

In case of an emergency the situation will be managed by an emergency team based at the IMTS. Available rescuing resources, in addition to the above mentioned tug, are:

- Other vessels in the area that can be requested to assist.
- Helicopter at Keflavik/Reykjavik.
- Vessels and personnel from the Icelandic Lifesaving Association.

5 IDENTIFICATION OF HAZARDS

Based on general DNV experience (world fleet formal safety assessment studies for various ship types), information about local conditions, information about the planned ferry, input from IMA and interviews with local experienced captains sea personnel, the following hazards have been identified (the hazards are grouped within the standard accident categories normally applied in FSA studies):

- Collision
  - With other vessel
    - In Bakkafjara harbour
    - In Vestmannaeyjar harbour
    - In open sea
- Contact
  - Pier entrance at Bakkafjara
  - Quay
  - Breakwater or protecting sand
- Hull/Machinery/Equipment (HME) failure
  - Hull fatigue
  - Sand in cooling water leading to engine failure
  - Other engines and rudder failures leading to loss of propulsion or manoeuvrability
- Foundering
  - Capsizing in breaking waves at sandbank or
  - Capsizing in wave exposed area approx. halfway between Bakkafj. and Vestman.
  - Vessel break-up
- Fire/explosion
  - Galley
  - Cabins
  - Engines
- Grounding
  - Powered grounding
    - Touching sandbank
    - Rock bottom
  - Drift grounding
    - Touching sandbank
    - Stranding on beach
    - Rock bottom

6 RISK ANALYSIS

6.1 Accident statistics

As a basis for quantifying the risk of the ferry the Lloyds Register Fairplay accident database (LRFP) and Lloyds World Fleet Statistics (LWFS) is applied*. These two databases allow for differentiation on ship types. In this study incident and fleet information for RoPax vessels (roll on/roll off/passenger vessels) are applied as a basis for developing a generic risk picture which is subsequently adjusted according to the local conditions at Bakkafjara - Vestmannaeyjar and the specific ferry planned to operate the route.

Also experience from incidents related to the existing ferry operating Thorlakshofn – Vestmannaeyjar is taken into account when assessing probabilities. But in general there are too few events to establish any statistics.

6.2 Personnel risk

6.2.1 Fatality frequency

<u>The generic FSA</u>

DNV has performed FSA studies for several generic ship types based on world fleet accident statistics (LRFP) and the world fleet (LWFS). The vessel type RoPax is assessed separately and is regarded to be the ship type category that the Bakkafjara – Vestmannaeyjar ferry would fall within. The RoPax FSA is used as a basis for the ferry risk assessment.

The fatality frequency for people onboard the generic RoPax vessel is presented in Table 5 /2/. The frequency is given per ship-year and per person-year.

Table 5 Annual fatality frequency for a generic RoPax vessel

Accident type	Fatalities/ Ship-year	Fatalities/ person-year
Collision	7.7E-03	1.2E-05
Contact	4,2E-05	6.8E-08
Foundering	5.7E-02	9.2E-05
Fire/explosion	1.1E-02	1.8E-05
Hull/Machinery/Equipment	1.6E-04	2.6E-07
Wrecked/Stranded	5.5E-05	8.8E-08
Total, excl. occupational acc.	**7.6E-02**	**1.2E-04**

Note that this is the frequency for fatalities, not for fatal accidents, meaning that an accident with e.g. two fatalities is counted twice in the table. The number of crew fatalities is not given

* The databases are released annually. The 2005 database in applied in this study.

explicitly in the LRFP database. Only the total number of fatalities can be found, which represents both crew and passenger fatalities. Hence, the fatalities/ship-year is divided by the sum of crew and passengers onboard (620 for the global fleet average) to derive at fatalities/person-year.

Adjustments to the generic FSA

The new ferry and the ferry route will have some characteristics that will differ from the generic, average world fleet situation that will influence the risk picture. Factors that are taken into account when adjusting the generic risk picture are given below. The factors are discussed within the subsequent assessments performed for each accident category.

- Less number of people onboard
- Low traffic density, but crossing traffic
- Open waters without nearby grounds or reefs
- Rougher weather conditions
- Breaking waves at sandbank
- Sandy seabed 50% of the route
- Narrow harbour entrance width
- No/little submerged objects
- New vessel with acknowledged class
- Short sailing leg thus few cabins and small galley
- Propulsion redundancy
- Modern onboard navigational support equipment and bridge design
- Anchoring in sand capabilities
- Tug boat availability

No adjustments are made for human factors like boredom and fatigue on the bridge are included in the adjustments as no arguments have been found that may differentiate the ferry from the global average situation.

To what extent the factors influence the risk picture are reflected through adjustment factors that are applied to each accident category in the generic RoPax FSA (by multiplying the adjustment factor with the generic FSA risk figures). The adjustment factors are discussed and summarised below.

Collision risk adjustments

In generic collision risk models collisions are regarded as possible if ships pass within an encounter area defined as a square of 1 nm /3/. A collision probability is then calculated based on visibility and collision probability for visibility categories. If 5000 vessels crossing the ferry route per year is assumed and these crossings are randomly distributed in time the encounter probability is calculated to be 1.4E-04. The collision risk in the Bakkafjara harbour is regarded to be zero as it is assumed no traffic when the ferry is operating. Given an encounter the collision probability is lower than the order of magnitude 1.0E-04 in clear visibility and 1.0E-03 in poor visibility /3/. Based on this, the collision probability should be lower than 1.0E-07 if the Heimey harbour is not taken into account. Also including Heimey, with a higher encounter probability, the collision probability is conservatively set to 1.0E-06. This is about 3 -4 times less than the FSA frequency of total losses due to collisions. Based on this an adjustment factor of 0.25 is applied.

Also the use of modern navigational support systems like ECDIS and modern bridge design will contribute to a lower collision frequency than the global average, however this benefit is assessed to be offset by the local weather conditions regarded to be worse than the world average RoPax route.

Contact risk adjustments

The frequency of contact incidents are likely to be higher for the ferry compared to what is given by the world average figures. The reason for this being a quite narrow harbour entrance combined with wind, currents and waves. However, most of these incidents will only be minor impacts not causing fatalities. Hence, the contact frequency increase is in principal reflected in the property risk and not in the fatality risk.

However, if the vessel looses its' ability to manoeuvre due to breaking waves and does not regain control before it is too late, the resulting contact can result in a fatal accident. On the other hand the vessel is protected from direct pier contact due to sandy grounds around the pier and permanent fenders at the harbours entrance may protect from severe impacts. Also, due to the good vessel manoeuvrability (turn radius ~120 m) and the distance from where the sea is breaking to the harbour (300 – 500 m), such an event is, based on DNV expert judgements, considered to be unlikely.

Engine problems are given as the cause in almost 20% of the contact incidents in the LRFP database. Hence, propulsion redundancy will reduce the frequency of these events. DNV has applied an adjustment factor of 0.5 when correcting for this for other ship types, e.g. tankers /4/. Combined with a sufficient sand anchor the probability for drift contact is considered as unlikely.

An important contact event in the LRFP database is contact with (unidentified) submerged objects. Such events are considered unlikely on the Bakkafjara – Vestmannaeyjar route.

In total a fatality risk adjustment factor of 0.5 is applied.

Foundering risk adjustments

According to the LRFP accident database foundering incident generally happen to old vessels. No vessel below 10 years of age has been registered with a foundering incident while under operation. Since a new ferry is planned for the route an adjustment factor of 0.1 is applied.

Loading of cars are not regarded to affect stability to a degree that makes this an issue for foundering. It is assumed that the vessel will be equipped with stabiliser fins.

Fire/explosion risk adjustments

According to DNV experience the most important areas where fires are initiated are the galley and passenger/crew cabins. Since the new ferry will only operate short legs the need for a galley and cabins are minor and regarded to be less than for the average RoPax vessel. As the number of important fire initiation points are reduced, so is also the risk.

The new vessel will also have modern fire detection and suppression systems compliant with modern rules and requirements. If the LRFP database fire frequency of young (age 0-10 years) and old vessels (age above 10 years) are compared the frequency of the younger ships are about 30% lower (young and old fleet size taken into account).

In total a fatality risk adjustment factor of 0.7 is applied.

HME risk adjustments

Hull failure due to fatigue constitutes 20% of the HME incidents. Breaking windows in heavy weather also causes fatalities according to the statistics (30% of fatalities, however the number of HME fatality incidents are few). For a new vessel build to acknowledged class rules these are regarded as unlikely events. A fatality risk adjustment factor of 0.4 is applied.

Accidents caused by machinery and steering failure will to a very little extent lead to fatal accidents as long as the event does not develop into a grounding, contact or collision accident. Hence, no personnel risk adjustments are made for these types of incidents.

Grounding risk adjustments

Grounding is divided into two separate sub-categories: 1) touching sandbank (vessel not stuck or hull ruptured); 2) hitting rocks or stuck in sand. The first is not regarded to influence the fatality risk. For other routes operating in shallow waters with sandy seabed, e.g. the Scandline Rødby – Putthaven ferries, this is an event occurring quite frequently.

The route is partly in open waters with no risk of grounding and partly in areas with sandy beaches (Bakkafjara side) where the consequence (with respect to fatalities) of a grounding event is limited. According to the LRFP database most fatalities occur while running aground on rocks. Redundancy and sand anchor are adjusted for and the factor takes into account a lower probability for drift grounding incidents.

A fatality risk adjustment factor of 0.1 is applied.

Factors affecting all categories

When fatality risk is expressed as number of fatalities per ship-year, per year or per sailing, the number of people onboard (crew + passengers) will affect the risk result. The generic RoPax vessel from the FSA study has approximately 600 people onboard (based on capacity, capacity exploitation is not taken into account). The Bakkafjara – Vestmannaeyjar ferry will have approximately half the capacity. Thus an adjustment factor of 0.5 is applied to all accident categories when risk is expressed in the above mentioned metrics.

When calculating fatalities per ship-year into fatalities per year the time the vessel is in operation must be taken into account. The ferry is assumed to be operating 5/24 of the time (5 hours of sailing and on/off loading per day). The generic RoPax vessel is assumed to be operating 12/24 of the time. Hence an adjustment factor of 5/12 is applied when performing the above mentioned calculation.

Fatality risk profile for ferry

The original FSA data, the applied adjustment factors and the estimated fatality risk are given in Table 6. The fatality frequency is dominated, in order of priority, by fire/explosion, foundering, grounding and collision events, which represents respectively 41%, 29%, 20% and 10% of the personnel risk for the vessel (occupational accidents excluded). In average, one fatality is expected for every 99th ship-year. With 10 half-hour sailings per day this equals a return period of approximately every 238 year or every 0.86 million sailing.

According to the LRFP accident statistics about 30% of the worst accidents (10 or more fatalities per accident) constitute approximately 75% of the fatalities. This means that the return period of an accident causing one or more fatality will be far less frequent than what is given in the table. A very severe accident (10 or more fatalities) can be expected about 100 times less frequently than the fatality risk shown in Table 6.

Table 6 Annual fatality frequency for the vessel

Accident type	Global RoPax FSA-data Fatalities/ Ship year	Ferry operation adjustment factor	B - V ferry Fatalities/ Ship year	B - V ferry Fatalities/ year	B - V ferry Fatalities/ sailing
Collision	3.9E-03	0,25	9,8E-04	4,1E-04	1,1E-07
Contact	4.2E-05	0,5	2,1E-05	8,8E-06	2,4E-09
Foundering	2.9E-02	0,1	2,9E-03	1,2E-03	3,3E-07
Fire/explosion	0.6E-02	0,7	4,2E-03	1,8E-03	4,8E-07
Hull/Machinery/Equipment	0.8E-04	0,4	3,2E-05	1,3E-05	3,7E-09
Grounding	2.0E-02	0,1	2,0E-03	8,3E-04	2,3E-07
Total, excl. occupational acc.	**5,9E-02**		**1,0E-02**	**4,2E-03**	**1,2E-06**
Return Period			**99**	**238**	**0,86 mill.**

It should be noted that the figures shown in the table above must be adjusted according to the number of people onboard. The adjustment shall be made proportionally, e.g. if the number over passengers are reduced by 50%, so shall also the fatality frequency. The figures are representative for a ferry fully exploited with respect to passenger capacity (300 passengers and crew assumed). If the capacity for number of people onboard is changed considerably the figures also need to be recalculated.

It is also important to note the assumption of a fully exploited capacity (worst case). This will not be the case in a real situation. A passenger a prognosis from IMA indicates a passenger capacity exploitation of about 30%. If this is considerably lower that what is the case for the world fleet average applied in the FSA study this should be adjusted for as well. It is however not done here due to lack of information about the world fleet. To make the fatality risk independent of the number of people onboard the risk can be expressed as an individual risk given as fatalities per person-year (as done in the third column in Table 5). To do this the number of people onboard must be separated into crew and passengers. If it is assumed that the average passenger uses the ferry once per day, and the average crew is onboard the whole time, the individual fatality risk for crew is 10 times higher for the crew compared to passengers. The number of crew members onboard during a sailing is on average approximately 1/10 of the number of passengers. In total the individual risk for crew and passengers are approximately the same or slightly lower for crew because the crew are more experienced and will behave more rationally in case of an accident.

Occupational accidents are not assessed in detail because these incidents are not affected by the route in which the vessel operates. Occupational accidents are defined as events affecting the crew without damaging the ship. They include falls, falling overboard, asphyxiation, electrocution, and being struck by moving objects, falling objects, mooring ropes and waves etc. The fatality frequency regarding these types of accidents is a worldwide, ship type independent estimate of 2.6E-05 per person-year /5/ or 2.6E-04 per ship-year for the ferry with a crew of 10 (passengers occupational accidents not included).

6.3 Property damage

As described in section 3 the property consequence is divided into three categories; Non-serious damage, serious damage and total loss. For non-serious damages underreporting is expected in the accident database. It is therefore decided not to apply adjustment factors to the frequency of this consequence, except for the accident categories contact and grounding. For contact accidents the frequency is increased due to a higher probability of contact with pier entrance than what can be expected for a generic RoPax vessel. Grounding accidents are increased due to the probability of touching the sandbank (if most shallow area is 5-6 meters). The contact frequency with a non-serious damage is based on the combined probability of breaking waves, loosing manoeuvring control in breaking waves and pier contact due to loss of manoeuvrability. The grounding frequency is based on the combined probability of high waves, heave/pitch in high waves, and a 5-6 meter depth at the sandbank.

For serious damages the same adjustment factor as described in the previous section is applied for all accident categories except grounding. Where the adjustment factor is increased from 0,1 to 0,9 due to the fact that it is expected that the touching sandbank incident will in 1 of 10 cases result in a serious damage to the ship bottom of propeller.

The frequency for the ferry operation property damage expressed a number of accidents per year is illustrated in Table 7. The table indicated a non-serious accident every 3^{rd} year. A serious casualty can be expected approximately every 30 years, i.e. once during the vessel's life time. Total loss is about 100 times less likely than a serious casualty.

For non-serious damage and serious damage contact incidents are by far the most important event category (approximately 80% of incidents). This includes contact both with quay and pier entrance. Grounding is the second most important event category with about 10% of the events, mainly caused by touching the seabed when crossing the sandbank in heavy seas. Touching the seabed should not necessarily be categorised as a grounding event, but it is the case in this study to enable the same accident categories as in the generic FSA studies.

Table 7 Annual property damage frequency for the vessel (accidents/year)

Accident type	**Non-serious damage**	**Serious damage** (excl. total loss)	**Total loss**
Collision	5,4E-03	2,1E-04	8,5E-06
Contact	2,7E-01	2,8E-02	-
Foundering	-	6,7E-06	1,4E-05
Fire/explosion	1,5E-03	1,1E-03	2,4E-04
Hull/Machinery/Equipment	6,7E-03	7,7E-04	1,4E-05
Grounding	3,1E-02	4,1E-03	3,1E-05
Total	**3,2E-01**	**3,4E-02**	**3,1E-04**
Return Period (year)	**3**	**29**	**3269**

6.4 Environment

Incidents leading to environmental impact (pollution) is inadequately reported in the LRFP database. Hence, the global statistics cannot be applied in the same manner as for risk for personnel and property.

To be able to derive a quantitative figure it is assumed that only serious property damage incidents has the potential to further develop into an pollution incident (oil spill from bunker tanks).

Taken into account that the hull/tank most be penetrated to cause an oil spill the probability is considered low. If it is assumed that all larger oil spills are included in the LRFP database a significant oil spill will occur in 2% of the serious damage incidents. Underreporting is expected for these event, thus the actual percentage is likely to be higher. Oil spill in 10% of the serious damages is considered as a representative value. This gives a large oil spill frequency of approximately 3.0E-03 oil spills per year or a return period of approximately 300 years. A large oil spill is here as a worst case regarded as one full fuel tank.

Other minor oil spill occurring more frequently is regarded to have an insignificant impact on the environment.

7 COMPARISON WITH EXISTING FERRY ROUTE

7.1 Existing route description

The list below summarises some of the main characteristics of the existing route/vessel:

- Route: Thorlakshofn – Vestmannaeyjar
- Sailing time: 2 hours 45 minutes
- Number of sailings per day: 4
- Capacity: 500 passengers, 60 cars
- Machinery and equipment: ECDIS and propulsion redundancy (although no redundancy class notation)

7.2 Risk comparison

The risk of the new and existing ferry is compared per sailing.

The existing vessel has a total sailing time of 2 hours and 45 minutes, whilst the new one will have 0.5 hours. The sailing time affect the risk for the accident categories foundering, HME and fire/explosion, and the existing ferry will have an accident frequency that is 5.5 times higher for these categories when only considering the sailing time. The same factor is applied to fatality (both crew and passengers), property damage and oil spill frequency.

The existing vessel has a passenger capacity that is approximately twice the new one. Although there might be some difference in the capacity exploitation, there is not sufficient information available to take this into account. In general it is however assumed that there will be more passengers onboard the existing vessel than the new one per sailing. Accidents with few fatalities are not likely to increase with respect to number of fatalities due to more passengers onboard. However, the major accidents causing many fatalities are regarded to be proportional to the number of passengers onboard. According to the LRPF database accidents with more than 10 fatalities (regarded as major fatal accident) caused 75% of the fatalities. Such major fatal accidents have occurred for all accident categories except contact and HME. Hence the fatality frequency is for the existing ferry is 0.75*2 = 1.5 times higher for the affected accident categories when only considering the number of passengers onboard. The number of crew onboard is regarded to approximately the same and is not affected by this aspect.

As the existing ferry is quite new (built year 1992), the age difference is not considered to be an issue for differentiation. Neither is the propulsion redundancy or navigational systems like ECDIS or bridge design.

Collision

The collision risk during sailing is regarded to be similar for transit at open sea and in the Vestmannaeyjar harbour. The existing ferry is operating in a harbour with other traffic (Thorlakshofn) while the new one will operate in a harbour (Bakkafjara) free of other vessels.

This is assessed to result in a slightly higher risk (both for personnel, property and environment) for the existing ferry than the new one. A factor of 1.1 is applied.

Contact

The new ferry main contributing factor for contact is the event of contact with pier while entering the Bakkafjara harbour. The main reason for a relatively high contact frequency is the combination of rough sea and narrow harbour entrance. Compared to Bakkafjara the harbour at Thorlakshofn has no easier sailing conditions. In fact the $Hs_{95\%}$ is 5 meters outside Thorlakshofn and 3.6 meters off Bakkafjara and the distance where waves break along the navigation is about 480 meters at Thorlakshofn and 250 meters at Bakkafjara /7/. The pier entrance width is 90 meters at Thorlakshofn while it is planned to be 70 – 90 meters at Bakkafjara. At Thorlakshofn there is also a large probability for beam sea while entering the harbour.

The probability for contact incidents in Vestmannaeyjar during a sailing is considered the same for the two vessels.

Fatalities caused by contact events are assessed very unlikely to happen. Due to this, the difference in fatality risk is considered insignificant. This also accounts for oil spills.

Because of the above mentioned difference in sailing entrance conditions the property damage risk is expected to be slightly higher for the existing ferry. A factor of 1.1 is applied.

Foundering

The existing ferry route is operating in less protected waters with rough weather and wave conditions, and is not subject to the same wave height sailing restrictions. This leads to a slightly higher capsizing probability and thus a higher fatality, property and environmental risk. A factor of 1.1 is applied.

Fire and explosions

According to the risk assessment there is only a minor reduction in the fire/explosion probability for the Bakkafjara ferry compared to the world RoPax fleet average (adjustment factor of 0,7). Hence, it can be justified not to make any significant adjustments for the existing ferry fire/explosion probability. The fire suppressions and detection systems are assumed equally good for the two vessels. Consequently, the fatality and property risk are considered equal when assessing the new and existing vessel’s technical systems only.

HME

Hull fatigue causing an accident is considered to contribute insignificantly to the risk for both the existing and the new ferry. This is because both vessels are new, classed within an IACS class society and is managed by a professional ship operating company.

Machinery and steering failure frequency are also considered to be similar for the two vessels. The slightly higher level of propulsion redundancy for the new ferry is regarded as negligible. Hence a factor of 1 is applied.

Grounding

The new ferry main contributing factor for grounding is the event of touching the sandbank outside the Bakkafjara harbour. This is not actual grounding, but more touching seabed, which has generally low consequences. The main reason for a relatively high grounding frequency is the combination of rough sea (even with wave cut-off) and shallow waters. The existing ferry from Thorlakshofn has similar sandbanks to cross, even higher waves and a larger low water neap (1,06 m at Thorlakshofn compared to 0,8 m at Bakkafjara). At Thorlakshofn the ferry will enter the harbour in beam sea . This will cause worse navigational conditions (affecting contact accidents) but is likely to give less hive/pitch. Summarised the combinations of shallow waters and high/breaking waves are slightly worse at Thorlakshofn while the ship vertical movement due to hive/pitch can be marginally larger at Bakkafjara. These two aspects are assessed to balance each other and a factor 1 is applied when looking isolated at the harbour conditions.

The existing ferry will have slightly more potential grounding points. However both vessels will operate in easy open waters with low probability for grounding and have similar navigational support equipment and procedures and propulsion redundancy. Hence, the base grounding frequency related to aspects discussed under this grounding heading is considered similar for the two vessels.

Risk comparison per sailing

The human, property and environmental risk for the new ferry compared to the existing ferry is summarised in Table 8. Note that the comparison is per sailing. The result relative difference between the new and existing ferry will change if another risk metrics is applied, e.g. per year (which should be applied for crew fatality frequency).

The table shows that the fatality risk per sailing is considerably lower for the new ferry compared to the existing one (factor 6.5 in difference). The main reasons for this being shorter sailing distance and the lower number of people onboard the vessel.

The property and environmental risk will have a minor decrease with the new ferry compared to the existing one (factor approximately 1.3 in difference). Note that the property damage frequency then only includes the sum of serious damages and total loss. Non-serious damages are not included.

Table 8 Comparison of the risk of new and existing ferry (per sailing)

	Passenger fatality risk of existing ferry relative to new (factor higher)	**Property risk of existing ferry relative to new' (factor higher)**	**Oil spill risk for existing ferry relative to new (factor higher)**
Collision	1,65	1,10	1,10
Contact	1,00	1,10	1,00
Foundering	9,08	6,05	6,05
Fire/explosion	8,25	5,50	5,50
HME	5,50	5,50	5,50
Grounding	1,50	1,00	1,00
Total	**6,49**	**1,36**	**1,28**

* Property risk is here the sum of serious damage and the total loss frequencies.

Risk comparison per year

As the crew will experience their exposure not per sailing but through the sailing time and number of sailings per work day, the fatality frequency for crew should be measured per day (or any longer time period). Table 9 compare the crew fatality frequency of the existing and new ferry per year. For information also passenger fatality frequency is estimated per year. As seen from the table the difference in crew fatality frequency is small, with the existing ferry being a factor 1.7 higher than the new one. The difference in passenger fatality frequency is reduced by approximately 50% when calculating per year in stead of per sailing.

The main changer when calculating from per sailing to per year is that:

- The number of crew members onboard must be taken into account when estimating crew fatality frequency. A factor 1 is applied (instead of the factor 1.5 as applied for passenger fatality frequency).
- The number of arrivals and departures affecting contact, grounding and to a lesser extent collision frequency must be taken into account. The existing vessel has 8 arrival/departures per day and the new one 20. Hence the existing ferry will have an accident frequency that is 8/20 = 0.4 times the new one for these categories when only number of departures/arrivals are considered. The same factor is applied to fatality frequency for both crew and passengers,
- The total sailing time must be taken into account, not the sailing time per leg. The existing vessel has a total sailing time of 11 hours/day, whilst the new one will have 5 hours per day. The sailing time affect the risk for the accident categories foundering, HME and fire/explosion, and the existing ferry will have an accident frequency that is 11/5 = 2.2 times higher for these categories when only considering the sailing time. The same factor is applied to fatality frequency for both crew and passengers and replaces the factor 5.5 applied when calculating per sailing.

Table 9 Comparison of fatality frequency of new and existing ferry (per year)

	Crew fatality frequency of existing ferry relative to new (factor higher)	**Passenger fatality frequency of existing ferry relative to new (factor higher)**
Collision	0,44	0,66
Contact	0,40	0,40
Foundering	2,42	3,63
Fire/explosion	2,20	3,30
HME	2,20	2,20
Grounding	0,40	0,60
Total	**1,73**	**2,60**

8 CONCLUSIONS AND RECOMMENDATIONS

The risk for the sailing is considered low, both when risk is measured in terms of fatalities, serious property damage and oil spills. The low risk statement is based on the estimated return periods and by comparing especially the fatality frequency with acceptance criteria than is common to apply /1/.

Compared to the existing ferry route the risk for the new contact is assessed as lower.

Risk control options beyond what is already planned for in the Bakkafjara – Vestmannaeyjar project is thus not required based on the risk assessment. However, some measures may prove cost effective and should be evaluated:

- Statistically, loss of propulsion/steering leads to approximately 15% of the global collision, contact and grounding incidents. I addition comes serious failures reported under HME which has not resulted in further events. An important risk controlling measure to avoid an escalating accident is thus to avoid a drifting vessel. A normal anchor is likely not to be sufficient for the sandy seabed outside Bakkafjara. Hence, it is recommended to that a sand anchor is installed onboard.
- Due to the heavy winds and waves, currents and the possibility for breaking waves outside Bakkafjara the probability for touching the pier entrance is high. This is in most cases regarded only to cause non-serious damages. Still there might be operational interruptions due to inspections and minor repairs. To reduce the extent of any damage to the vessel it is recommended to apply fenders at the pier entrance. Fenders giving the necessary protection might be quite wide and the entrance width should be adjusted according to the width lost due to the fenders.
- Use of autopilot while approaching harbour in heavy seas should be avoided because manual steering is usually better in case of regaining control subsequent to loss of manoeuvrability due to breaking waves.
- When crossing shallow waters with a sandy seabed there might be a chance for sand and spawn to enter the engine cooling water system, which consequently might lead to an engine failure. To avoid this it is common to apply cooling water inlet on the vessel side (not water inlet at vessel bottom only) and ensure satisfactory inspection and maintenance frequency to avoid clogging of filters.
- If other ships use the Bakkafjara harbour, routines should be established to avoid that they arrive/departure at the same time as the ferry. This to avoid an increasing collision risk.
- To ensure a low probability for serious vessel fires as possible, the tug located at Vestmannaeyjar or any other stand-by vessel should have an acknowledged fire-fighting capability.
- Clear procedures for passenger movements on deck during heavy sea conditions should be applied to reduce the probability for occupational accidents.

- Issues like window sizes and position on the vessel, emergency routines including passenger/crew assembly area and life saving appliances, stability, hull strength etc. is assumed covered by class society requirements. Hence, it is recommended that the vessel is registered with an acknowledged ship classification society.
- Propulsion pods are not recommended. This recommendation is based on pod failure frequencies onboard cruise ships assessed by DNV /6/. A failure frequency of 0.18 per ship-year is estimated, and out of service time can be expected in a large portion of these incidents. In addition the failures are estimated to lead to a serious accident in 0.4% of the cases. This gives a serious accident frequency of 7.2E-04, which is similar to the total HME serious damage frequency given in Table 7. Due to the relative high touching sandbank frequency and the whirling of sand at Bakkafjara the failure frequency is likely to be even higher for the ferry.

9 REFERENCES

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