A framework for investigating the potential for operational measures in relation to intact stability

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ABSTRACT

Operational safety measures are an important aspect of a holistic safety approach for intact stability. With the aim to facilitate and further investigate potential operational measures this research aims to describe a framework for prioritizing intact stability issues suitable for being addressed with operational safety measures. The proposed framework identifies that there are different potentials and uncertainties in relation to operational safety measures dependent on the operation type under study. It is demonstrated that there is not one solution that facilitates operational measures and the reliability of potential measures varies.

Keywords: *Probabilistic and risk-based assessment; intact stability; operational stability management; reliability; safety measures*

1. INTRODUCTION

Engineering approaches to improve safety are developed under the assumption that there is a link between the technical solutions implemented and the safety level during operation. There is also a link between how the ship is operated and the safety level during operation. However, this second link is often hidden to engineers because traditional engineering approaches and tools typically do not describe how risk decisions taken on-board affect safety (Kuo, 2007). As discussed within the intact stability community and at previous conferences, operational guidance or limitations are an important aspect of a holistic safety approach for intact stability. However, such operational measures also introduce new uncertainties.

With the aim to facilitate and further investigate potential operational measures this paper proposes a framework for prioritizing intact stability issues suitable for being addressed with operational safety measures and for discussing how sufficient safety can be achieved. Focus is put on pin-pointing uncertainties and how they affect the reliability of the safety efforts.

A safety level is here understood in the same way as presented in the Formal Safety Assessment (FSA) IMO (2013). FSA is an approach that investigates the risk level (and thus implicitly the safety level) in ship operations. The risk investigated in the FSA is the final risk during operation independent on whether the safety barrier is implemented in technology, crew training or operations.

2. THEORY AND METHOD

Here safety is understood as the “ability of individuals or organisations to deal with risks and hazards so as to avoid damage or losses yet still achieve their goals” (Reason, 2000). Reason also describes that effective safety work requires informed participants that can operate close to unacceptable danger without passing over the edge.

Particularly in areas with few but severe incidents, it is difficult to develop safety measures from negative outcomes (historic incidents) (Kuo, 2007). The traditional approach to safety in maritime design and operation is to implement prescriptive regulations. Such regulations are suitable for routine activities but devolve responsibility and innovation which makes them less suitable for new developments (IMO, 1994, Kuo, 2007). In a dynamic world prescriptive codes should be complemented with an effective safety culture. An effective culture knows that hazards and threats will not go away, “they anticipate the worst and equip themselves to cope with it” (Reason, 2000). However, according to Parker et al. (2006) a desirable safety culture does not just emerge, it is a result of many aspects, particularly: formal regulations and processes; competence and training; and shared risk awareness throughout the organisation.

Risk is a common approach for measuring the absence of safety. Risk is typically defined as a function of the probability of an incident and the resulting consequences. Which type of consequences to measure depend on the case studied. The FSA focus on fatalities and serious injured (IMO, 2013). The aim with risk management is most often to avoid unnecessary risks with cost effective measures (IMO, 2013). The FSA focus on the safety during operation including both proactive and reactive measures for risk reduction as illustrated by the bow tie diagram in Figure 1.

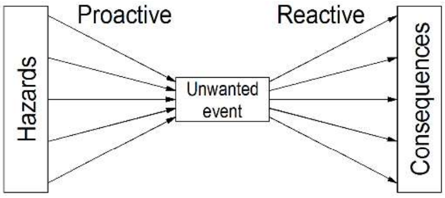

Figure 1 Bow tie diagram showing that risk controls can be applied proactively and reactively, developed from (Rausand & Bouwer Utne, 2009).

The bow tie diagram in Figure 1 show that there could be safety issues that can be eliminated long before the event with design measures, but also closer to the event and also after the unwanted event. In this work *operational safety measures are understood as measures that during operations reduce the probability of unwanted events and or the consequences of unwanted events*. Operational measures here include operational guidance and operational limitations as discussed within the work with the second generation intact stability criteria (Peters et al., 2011, Umeda & Francescutto, 2016).

Safety can be increased with different types of measures. Möller and Hansson (2008) describe four principles for engineering safety measures according to Table 1. Often, systems are designed with a combination of the principles and some applied approaches can be said to belong to more than one principle (Möller & Hansson, 2008). The principles in Table 1 will here be used to categorize different types of safety measures in general and in relation to the *reliability of the safety system, i.e., the ability of the total set of safety measures to maintain a suitable level of safety (successful performance) during operation*[1].

Table 1 Principles for engineering safety (Möller & Hansson, 2008).

#	Principle
(1)	Inherently Safe Design, which means that potential hazards or threats are excluded
(2)	Safety Reserve, safety factors or safety margins
(3)	Safe Fail, systems that fails safely
(4)	Procedural Safeguards, procedures and training is used to enhance safety

2.1 Acceptable safety level

Bačkalov et al. (2015) states that “the likelihood of an intact stability failure is typically required to be at acceptable probability levels, which can be very low”. Acceptable probabilities for incidents are for example presented by Bačkalov (2012) and Peters (2010). They both explicitly assumes a relationship between the safety level and the probability of capsize as defined by the probability of reaching a specific heel angle. Such a relationship is not straight

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[1] The definition developed from Andrews and Moss (2002b).

forward as exemplified for cruise ships by Hinz (2015).

Acceptable incident probabilities assumed by Bačkalov (2012) is once in 20 years of operation for river-sea ships, but he also states that “an appropriate safety level ... is open to discussion”. The approach assumes that the probability of a specific heel angle is proportional to the risk posed by capsizing. There could be different reactive solutions affecting the resulting safety level. Bačkalov (2012) also illustrates how such a probability can be used to calculate the safety level introduced by a rule (more formal and complete assessments include IMO (2008a, 2008b) on damage stability). Also Peters (2010) discusses tolerable risk in relation to intact stability. The approach defines a maximum probability for the ship to reach a specific heel angle (capsize angle) based on British levels of acceptable risk. The maximum allowable probability for large heel angles is by Peters calculated to be $1 \cdot 10^{-4}$.

The FSA define negligible number of fatalities in relation to societal risk and individual risk, risks below that level do not need to be reduced further. For accidents with multiple fatalities societal risk is the most relevant measure (Pedersen, 2010, Skjong, 2009). Negligible societal risk is a function of the value the activity presents to the society and IMO (2013) describes that the negligible level should be calculated based on acceptable Potential Loss of Life given by the number of occupational fatalities per Gross National Product and the economic value of the activity. The negligible risk level is given by the number of fatalities and the upper limit of the number of fatalities, i.e. the maximum number of persons on-board. For details of the calculations see IMO (2013) and Skjong (2009).

Therefore, if the fatalities associated with a capsize is known the maximum probability of capsize can be calculated. If the capsize probability is lower than that there are no safety reasons for reducing it further. How the probability of capsize level corresponds to a maximum annual large heel angle probability (such as discussed by Peters (2010)) depends on the system’s recoverability after large heel angles.

However, also for operations with negligible levels of capsize risk may it be suitable to improve intact stability. One example of other reasons for introducing operational measures and intact stability knowledge on-board is presented by Huss (2016). Huss’ example illustrates the power of operational measures with the aim to increase the quality of service for Pure Car and Truck Carriers (PCTC).

2.2 The second generation intact stability criteria

The work in regard to the second generation intact stability criteria is based on three alternative assessment procedures: Level 1 vulnerability assessment, Level 2 vulnerability assessment; and Direct stability assessment. Compliance with Level 1, 2 or the Direct stability assessment fulfils the requirements of the intact stability criteria. It is also proposed that alternatively, ship-specific operational limitations or operational guidance can be developed for conditions failing to fulfil the criteria (Peters et al., 2011, Umeda & Francescutto, 2016).

The work within the second generation intact stability criteria so far has focused on “passive” safety measures described by the level 1 and 2 assessments (Bačkalov et al., 2015). These are typically *Principle (2) Safety Reserve* as defined by Table 1. However, the operational environment and the operation itself is not static, this may lead to that safe passive design measures need to be far reaching in order to exclude unsafe operations. This is the reason for introducing operational limitations or operational guidance within the second generation intact stability criteria.

2.3 Operational aspects of safety

The personnel need to be able to take informed decisions. This includes avoiding surprises in operation (Cleary, 1975), such as sudden loss of stability without prior large ship motions (Mata-Álvarez-Santullano & Souto-Iglesias, 2014). Stensson and Jansson (2014) call this needed awareness of safety issues *edge awareness*, i.e., the awareness needed to take informed decisions to avoid accidents.

From Reasons (2000) definition of safety it follows that operations without incidents is not a proof of safe operation. Especially for these types of rare events discussed here. Also, crews sometimes are underestimating risks in dangerous situations where they have been successful in the past (Schröder-Hinrichs et al., 2012). Therefore, other types of feedback are needed to distinguish between safe and unsafe operation. The traditional prescriptive regimes typically do not inform the crew enough (Kuo, 2007). An operational measure regime must therefore be designed to inform the crew.

Operational limitations prescribe safe combinations of aspects such as sea state, heading and speed and operational guidance dynamically introduce limitations (Bačkalov et al., 2015). This typically aims towards avoiding hazards, i.e., an operational version of *Principle (1) Inherently Safe Design* (Table 1) that could be called *Inherently Safe Operations.*

Principle (4) Procedural Safeguards (Table 1) in regard to ship safety can be exemplified by, but are not limited to, prepared procedures for the crew if the ship is experiencing cargo shift or other risk driving events. Typical *Principle (3) Safe Fail* (Table 1) equipment on ships include lifesaving equipment, such as survival suites, life vests and life rafts, that can save crew and passengers if there is an accident. However, such equipment typically does not save the operation, the cargo or the ship.

Increased system reliability is another form of *Principle (3) Safe Fail* (Table 1) and can be achieved with redundancy, segregation and diversity (Möller & Hansson, 2008). Redundancy and segregation are important concept in designing for intact stability. However, typical engineering redundancy and segregation require the operational conditions to be within the design conditions and therefore the diversity of the concept can be low. Operational measures introduce other possibilities than designed engineering solutions and therefore increase the diversity of the safety system, i.e., solutions that “avoid common cause failures” (Möller & Hansson, 2008). They have the power to change the operational conditions. This means that such safety measures add reliability, i.e., reduces uncertainty to the systems as a whole even though there are uncertainties in the measure itself (Andrews & Moss, 2002a, Möller & Hansson, 2008). Operational measures are specifically important for operations with large uncertainties where procedural safeguards are ineffective (Oltedal, 2018).

3. DATA AND ANALYSIS

To widen the understanding of the risks in relation to intact stability Table 2 presents 36 intact stability incidents at sea.

Table 2 is not a complete list of incidents and therefore not intended to be used for calculating probabilities or frequencies. The list is in this study used to highlight:

- the different types of conditions and different stability failure modes that lead to an intact stability incident,
- the often severe consequences that follow with an intact stability incident, and
- the large variations in the operational conditions.

The aim here is to discuss qualitative aspects of intact stability risk. Most of the incidents described are serious accidents, i.e., leading to one or more fatality, damage to the vessel that interrupt the service or vessel lost (IMO, 2008b).

Table 2 Example of intact stability incidents at sea and documented causes. Documented or investigated in academic publications within the stability community (AIBN, 2016, Bass & Wong, 1994, Borlase, 2002, BSU, 2009, France et al., 2002, Guldhammar, 1986, Hofman & Bačkalov, 2007, Hua & Rutgersson, 1994, Huss, 2016, Kan et al., 1986, Kluwe & Krüger, 2007, Kure & Bang, 1975, MAIB, 2016, Marón et al., 2006, Mata-Álvarez-Santullano & Souto-Iglesias, 2014, NTSB, 2006, Pérez Rojas et al., 2007, Pérez Rojas et al., 2006, Sadakane, 2000, Sagarra & Puig, 1997, Shin, 1997, Swedish Accident Investigation Authority, 2008, Taguchi et al., 2015, Taguchi et al., 2003, Taylan, 2005, Umeda et al., 2006, van Walree & de Kat, 2006, Vorobyov & Sizov, 2006).

Year	Ship	Ship type	Crew + Passengers	Fatalities	Other consequences	Sea state	Down flooding	Over loaded/loaded incorrect	Cargo shift	Water on deck	Rudder forces	Free surface in tanks	Technical. error	Parametric rolling*	Forced oscil. low damping*	Flaw due to design	Poor stab. in design cond.	Stab. sensitive to waves*	Limited knowledge
2000	Ryuho Maru No.5	Fishing vessel	18	14	Ship lost	Moderate	☒	☒	☒	☒	☒								
2014	Viking 7	Pleasure craft	7	1	Boat damaged	Moderate	☒	☒								☒			
1990	Straits Pride II	Fishing vessel	6	3	Ship lost	Severe	☒		☒	☒									
1987	Herald of free enterprise	RoPax	≈590	193	Ship lost	Moderate	☒			☒									
2001	Arctic Rose	Fishing vessel	15	15	Ship lost	Severe	☒			☒		☒							
1982	Akebono Maru	Fishing vessel	33	32	Ship lost	Severe	☒			☒	☒								
1974	MFV Gaul	Fishing vessel	36	36	Ship lost	Severe	☒												
2006	-	Fishing vessel	-	-	Ship lost	Severe													
2007	-	Fishing vessel	-	-	Ship lost	Severe		☒		☒								☒	
2004	Enrique el Morico	Fishing vessel	>2	1	Ship lost	Severe		☒		☒									
2004	O Bahía	Fishing vessel	10	10	Ship lost	Severe		☒		☒									
<1997	-	General cargo	14	0	Ship lost	Calm		☒											
2015	Hoegh Osaka	PCTC	24	0	1 injured, cargo and ship damaged	Calm		☒											
2006	Lady D	Passenger vessel, small	25	5	4 injured	Moderate		☒									☒		
2006	Cougar Ace	PCTC	-	0	Cargo and ship damaged	Moderate		☒											
<2000	-	Tanker, Chem.	-	-	Ship lost	Moderate			☒	☒	☒	☒					☒		
1993	-	Fishing vessel	>1	>1	Ship lost	Severe			☒	☒									
1980	Zenobia	RoRo	≈140	0	1 injured, cargo and ship damaged	Calm			☒		☒		☒						
1988	Vinca Gorthon	RoRo	≈14	0	Ship lost	Moderate			☒										
1980	Zenobia	RoRo	≈140	0	-	Severe			☒										
2006	Finnbirch	RoRo	14	2	Ship lost	Severe			☒								☒	☒	
1993	Jan Heweliusz	RoPax	-	55	Ship lost	Severe			☒										
2003	-	Sailboat	12	7	Ship lost	Severe										☒	☒		
1950	SS Fidamus	General cargo	-	-	Ship lost	Severe				☒							☒	☒	
1951	SS Irene Oldendorff	General cargo	-	-	Ship lost	Severe				☒							☒	☒	
<1975	Edith Terkol	Tanker, small	>2	≥1	Ship lost	Moderate								☒					
2008	-	PCTC	-	0	-	Moderate								☒					
<2016	-	Large PCTC	-	0	-	Severe								☒					
1998	-	Container, post panamax	-	0	800 containers lost or destroyed	Severe								☒					
1981	RF2	Rescue Boat	6	6	Boat damaged	Severe										☒			
1976	Rechitsa	General cargo	-	-	Ship lost	Severe													☒
2013	No.38 Sankyo Maru	Tug boat	3	2	Ship lost	Severe					☒					☒			
2004	Nuevo Pilín	Fishing vessel	>5	5	Ship lost	Severe											☒	☒	
2008	Chicago Express	Container	35	1	5 injured	Severe									☒				
1969	-	Tanker, LPG	>17	17	Ship lost	Severe										☒	☒		
1950	MV Lohengrin	General cargo	-	-	Ship lost	Severe											☒	☒	
		Total:	**>1174**	**>408**	**Number of incidents:**		**8**	**9**	**9**	**13**	**5**	**2**	**1**	**4**	**1**	**5**	**9**	**7**	**1**
		Median:	**14**	**3**															

*) The causes of the accidents are summarized based on the accident descriptions studied. The five intact stability failure modes: dead ship condition, parametric rolling, pure loss of stability, surf riding/broaching and excessive accelerations were not found to be suitable categories for describing the causes of the accidents.

The 36 incidents in Table 2 add up to more than 408 fatalities. The median number of persons on-board is 14 and the median number of fatalities per accident is 3 (13 and 6 respectively if the ship capsized or sunk). In all but 11 cases the ship was lost as a result of the accident.

The incidents described in Table 2 can all most often be contributed to a combination of causes and for many of the accidents the cause is uncertain.

Many of the incidents in Table 2 (approximately 20 out of 36) are cases were the operational condition and ship state was not according to design. For example, vessels that are over loaded and/or operated in heavy weather with hatches open potentially in combination with forces from fishing gear (Mata-Álvarez-Santullano & Souto-Iglesias, 2014). Cargo shift is also common in Table 2. These conditions lead to a poor recoverability after large heel angles.

For cargo vessels the cargo and ship status is generally changed under controlled circumstances (often at port). There is a potential for a high level of internal and external control. Therefore, a high level of detail in the data on the ship status is possible. On the other hand, vessels such as fishing vessels are an example of an operation where the ship status is changed at sea dynamically without external control which lead to large uncertainties. The conditions are described by Mata-Álvarez-Santullano (2015) who show that, in stability accidents involving Spanish fishing vessels from 2008 to 2014, more than 75% of the accidents can be contributed to lack of safety culture, lack of safety awareness or lack of training. The investigation also show that the stability regulation does not give enough support for operational stability management for these kind of operations.

The difference in potential control over the ship's loading condition produce different conditions for safety work, different reliability of the passive safety designed into the craft, and different reliability as well as different need for operational safety measures. However, knowledge on safe operations, based on knowledge about the vessel's limitations and weaknesses (edge awareness) could increase the reliability of the crew decisions taken on-board in relation to intact stability especially for ships and vessels that relatively often operate beyond the operational conditions defined during the design. Therefore, operational safety measures can be an effective approach to reach acceptable levels of safety, especially for operations with large uncertainties.

4. PROPOSED FRAMEWORK AND DISCUSSION

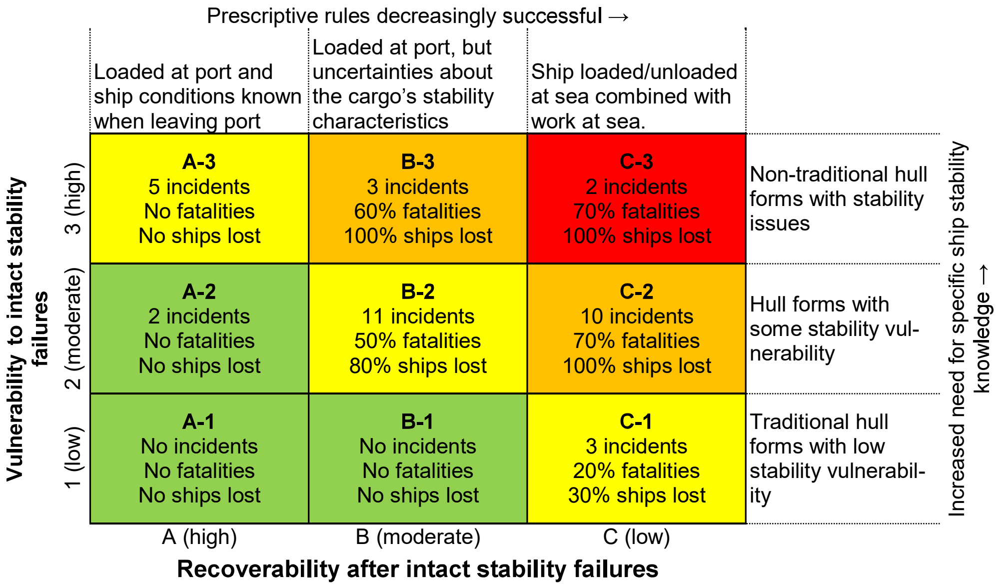
As described in Section 2.1 the probability of capsize need to be low, how low depends on what other (reactive) safety measures are implemented. Also, it is here argued that based on Table 2 the conditions for operational measures differs between ship types as a result of different types of operations and different conditions for implementing the measures on-board. Therefore, it is here proposed that there is an important distinction between a ship's general likelihood for intact stability incidents such as large roll motions (*vulnerability* to intact stability failures) and if the ship at a specific situation will not, when it experience an intact stability incident, return to a safe mode (*recoverability* after intact stability failures). Vulnerability is then typically a result of ship design whereas recoverability can be a result of ship design as well as operational aspects such as decisions taken on-board in relation to loading or unclosed hatches. Figure 2 present a framework distinguishing between the ships vulnerability and recoverability to stability incidents including the data from Table 2.

In relation to operational measures the framework aims to serve as a tool for differentiating between different types of operational safety measures. As identified among the top half of the incidents in Table 2 the safety introduced by design measures can deteriorate by lower control of ship condition (large uncertainties) and the resulting operations outside the design conditions.

The second-generation intact stability rules mainly investigate the vulnerability to intact stability failure for ships operating within the operational conditions. However, as shown in Section 2 the safety level is by IMO primarily assessed in number of fatalities and injured. Therefore, the ships recoverability to intact stability failure as well as other life saving measures need to be included if the safety effects of high vulnerability to intact stability failure is to be assessed. It is still not identified that high vulnerability alone is enough to introduce a safety problem according to IMOs definitions of safety (as can be seen for the incidents with high recoverability in Figure 2).

Ships with high recoverability and high vulnerability (A-3 in Figure 2) includes for example modern PCTC with high possible control and specialized hull forms (that lead to vulnerability to specific intact stability failure modes) and superstructures that can contribute to high recoverability after large heel angles (Hofman & Bačkalov, 2007). For such ships high-end on-board simulations can be an effective way of supporting the master's decisions about routing as well as manoeuvres to avoid intact stability incidents. However, as mentioned above, such on-board operational guidance is not necessarily needed to meet IMO's safety level ambitions according to the FSA and should if that is the case not be mandatory. The operational safety measures are motivated by the aim to increase effectiveness and quality of service, i.e. with the aim to reduce injuries to personnel and damages to cargo during the incident. Suitable operational measures for these ships need to be ship specific and supported by support tools, i.e., operational guidance. Therefore, the exchange of stability knowledge between the design phase and the development of stability management support systems, as described by (Huss, 2016), should be facilitated by the IMO rules.

For ships with high control and standard configuration (A-1 in Figure 2) standard operational safety measures is enough.



Prescriptive rules decreasingly successful →

Vulnerability to intact stability failures	Loaded at port and ship conditions known when leaving port	Loaded at port, but uncertainties about the cargo's stability characteristics	Ship loaded/unloaded at sea combined with work at sea.	Increased need for specific ship stability knowledge →
3 (high)	**A-3** 5 incidents No fatalities No ships lost	**B-3** 3 incidents 60% fatalities 100% ships lost	**C-3** 2 incidents 70% fatalities 100% ships lost	Non-traditional hull forms with stability issues
2 (moderate)	**A-2** 2 incidents No fatalities No ships lost	**B-2** 11 incidents 50% fatalities 80% ships lost	**C-2** 10 incidents 70% fatalities 100% ships lost	Hull forms with some stability vulnerability
1 (low)	**A-1** No incidents No fatalities No ships lost	**B-1** No incidents No fatalities No ships lost	**C-1** 3 incidents 20% fatalities 30% ships lost	Traditional hull forms with low stability vulnerability
	A (high)	B (moderate)	C (low)	

Recoverability after intact stability failures

Figure 2 Framework for identifying severity of stability incidents as a function of recoverability and vulnerability. The incident data from Table 2 are distributed to their respective categories and the average percentage of fatalities in relation the number of persons on-board and percentage of ships lost is given for each category based on the data in Table 2.

For ships with moderate recoverability and moderate to high vulnerability (B-2 and B-3 in Figure 2) the effective approach could be found in dealing with the recoverability uncertainties in regards to the cargo. This typically, given the examples in Table 2, include identifying the dynamic characteristics of the cargo and putting effort into tending to the problems before or while the cargo is loaded on-board. This could include efforts such as to a larger extent inspect how cargo is secured in trailers and containers, improve cargo lashing and limit the amount of cargo taken on-board for specific cargos. In total this means that the stability uncertainties introduced by the cargo is reduced. Only after such uncertainties are reduced can operational guidance, such as on-board stability simulations be reliable.

For ships with low recoverability and moderate to high vulnerability (C-2 and C-3 in Figure 2) the uncertainty in relation to the effectiveness of engineering solutions is high (because the conditions defined during design cannot be assumed to be valid). The effective approach is most likely found in making sure that risk drivers, such as open hatches and overloading, are reduced, especially in situations when the ship is more vulnerable to intact stability incidents. In such situations decisions support, such as operational guidance, can be ineffective as a result of the limited possibility to take in the information presented by such support (Oltedal & Lützhöft, 2018). Identifying and tending to risk drivers is a work that has to be performed by the whole crew by strengthening risk knowledge and risk awareness onboard thru safety management. Operational safety measures are a precondition for safe operations for this type of ships. Specific knowledge and risk management could be the primary choice for safety assurance (compare with the UK Safety Case approach for the offshore industry (Kuo, 2007) and the risk based approach for the Norwegian offshore industry (Rausand & Bouwer Utne, 2009)).

For ships with low control and standard configuration (C-1 in Figure 2) the potential for operational safety measures is high in terms of safety and effectiveness. However, the operational measures do not need to be ship specific (are not cost effective to develop).

The framework captures the different types of accidents covered in Table 2 and also articulate how the different conditions and varying uncertainties affect the consequences of the incidents, the need for operational measures and also the requirements on the measures. The framework therefore identifies that strengthening the on-board competence should be a prioritized operational safety measure approach that also increases the reliability of the safety work as it affects operational aspects that cannot be affected by design. However, this cannot be done without further knowledge about the human factors aspects involved including aspects such as safety management and human element aspects (Kuo, 2007, Oltedal & Lützhöft, 2018).

A wider understanding of the terms for operational measures is needed, especially in relation to a ship's recoverability after intact stability incidents. They cannot be judged in the same way as passive engineering solutions for safety. Such a view takes away the strength of safety solutions in the ship operation. However, the acceptable level of uncertainty varies between types of ships and especially with the ship's recoverability after stability incidents.

The work within the second-generation intact stability criteria has so far mainly considered vulnerability and has only to a limited extent considered a ship's actual recoverability after large heel angles and how that recoverability affects the risk level. This means that the relation to the safety level is not fully investigated and the operational aspects of the recoverability not fully understood. Such operational aspects include the knowledge about the potential of, and need for, operational safety measures. If the list in Table 2 is representative the potential for operational measures is high and should not be limited to operational limitations and operational guidance as defined by the forms so far discussed within the intact stability community.

The vulnerability can largely be classified based on ship dynamics. However, the tools available for investigating the recoverability are not as developed and the recoverability is largely a function of the specific ship conditions at the time of the incident. Therefore, in order to categorize a ship's recoverability more work, and multi-disciplinary studies, is needed especially in relation to operational stability management and safety culture during challenging operational situations. It is likely that intact stability recoverability must be addressed with regulations both in relation to ship dynamics and in relation safety management.

5. CONCLUSIONS

The work with the framework identifies that there are different potentials and uncertainties in relation to operational safety measures. Therefore, there is not one solution that facilitates operational measures and the reliability of potential measures varies. The work within the second generation intact stability criteria has so far mainly considered vulnerability and has only to a limited extent considered a ship's recoverability to large heel angles and how that recoverability affects the risk level. This means that the relation between a ship's intact stability vulnerability and the safety level is not fully investigated because the recoverability is not fully understood. Therefore, in order to categorize a ship's recoverability more work is needed especially in relation to challenging operational conditions.

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