Factors Affecting Ship's Stability Due To Cargo Liquefaction: Nickel Ore and Bauxite

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Abstract:
The stability of a ship is one of the most crucial and critical aspects of its safety and navigational safety, and maritime laws and maritime ordinances govern it. The research outlines vital elements of liquefaction of bulk cargoes loaded on ships, leading to loss of ship stability and severe consequences for the crew's safety and the vessel itself. International Maritime Solid Bulk Cargoes Code divides bulk cargoes into three categories. The first category is cargoes which may liquefy. Cargo liquefaction is a severe issue for solid bulk cargo carriers. The motion of ships, especially rolling, engine, and deck equipment vibration will trigger the cargo to liquefy along with the moisture content of the cargo during the voyage. There have been 21 cases documented between 2005 and 2017, resulting in bulk carriers due to cargo liquefaction. This research aims to identify and evaluate the factors that assist in the loss of ship stability when shipping the liquefiable cargo, especially nickel ore and bauxite. The data was collected based on a questionnaire created with Google Forms and given to mariners to complete. After that, factor analysis assesses the elements contributing to the ship's stability loss due to cargo liquefaction. The most significant value found in this research is human error, and mariners should be mindful of the causes identified. More cautions should be exercised when carrying liquefiable products to avert the accidents in the future
Keywords: Ship stability, cargo liquefaction, nickel ore, bauxite.

Introduction

The stability of a ship is one of the most crucial and critical aspects of its safety and navigational safety, and maritime laws and maritime ordinances govern it. The ship's stability is based on naval architecture and design that deals with how the ship reacts at sea and whether it is stable or not. The loss of the ship's stability is the main threat to the safety of navigation that should be aware of the navigators. It could lead to increased accidents and catastrophic implications following the events. As a result, serious consequences such as damage to the commodities, loss of the vessel, and loss of lives may occur.

Solid bulk liquefaction has procured to the occurrence of many major incidents in the bulkshipping industry. Solid bulk materials like nickel ore and bauxite liquefy after being loaded aboard a ship and swiftly transition from solid to semi-liquid conditions. This event resulted inincreasedmoisture content in the cargo hold, which may have been triggered by the ship's motion and disturbances from the engine compartment. Consequently, the cargo shift within the holds affects the vessel's stability and leads to the capsize. (Moustafa, 2017).

On January 1, 2021, the IMSBC Code 5th amendment was mandatory for all vessels that load solid bulk cargoes. Bauxite fines have been included in Group A and nickel ore cargoes because cargoes may liquefy. It also mentioned a method for calculating bauxite cargoes' transportable moisture limit (TML). The primary purpose of the IMSBC Code is to facilitate the safe stowage and shipment of solid bulk cargoes. The code provides precise information about the intended solid bulk cargo and guidance about the hazards and risks of the ship's associated cargoes.

Materials and Methods

The mixed-method approach was used in answering the research questions. Mixed methods research assists in complementing one method with another even where these methods originated from different methodological orientations. Mixed methods research is highly effective for resolving gaps between quantitative and qualitative results.

Quantitative method

Numbers and graphs are used in the quantitative method. It is designed to test or confirm theories and assumptions. For this research study, all the data from questionnaires are tabulated under the factors contributing to the cargo liquefaction.

Qualitative method

Qualitative methods are used in achieving objective 2. All the factors are evaluated in factor analysis to identify the relationship between factors and all the variables. In this method, factors have a more significant number as the most contribute to the unstable when carrying the liquefied cargo.

Correlation matrix

The correlation matrix is a table that displays the correlation coefficient for different variables.The matrix represents the correlation between all the possible pairs of values in a table. It is a powerful tool for summarizing a large dataset and identifying and visualizing trends in the data.

Factor analysis

The factor analysis will help identifythe relationship between the factors and all the variables. A method for reducing a vast amount of data into smaller data sets will be more manageable and understandable.

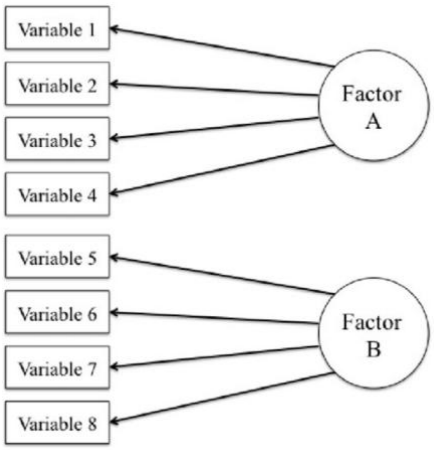

Figure 1 Factor analysis

Results and Discussion

1. Human error factor

The questionnaire regarding the human error that affects cargo liquefactionis as follows:

i. The cargo was loaded with excessive content of the moisture and continued the voyage
ii. The shipper did not provide the Master with the agreed data pertaining to the cargo's moisture content and flow test as required by the SOLAS Convention
iii. Master or Chief Officer not aware of the problem or the simple 'can' or shake test that can be performed to check the risk of cargo liquefaction
iv. Master loaded the minerals without insisting on the provision of the data concerning the moisture and flow tests
v. Master not aware of the information that is entitled to receive from shippers
vi. The owner of the vessel did not have clear instructions on the care and handling of such cargoes as specified in its Safety Management System
vii. The Officers do not follow the IMSBC Code's guideline and recommendation of carrying a basic "Can Test strictly."
viii. Ship officers do not closely check the condition of cargo before loading
ix. Ship officers not monitoring the condition throughout the loading operation
x. Officer did not become aware thatthe overturning moment exceeds the restoring moment,which leads to an unstable vessel

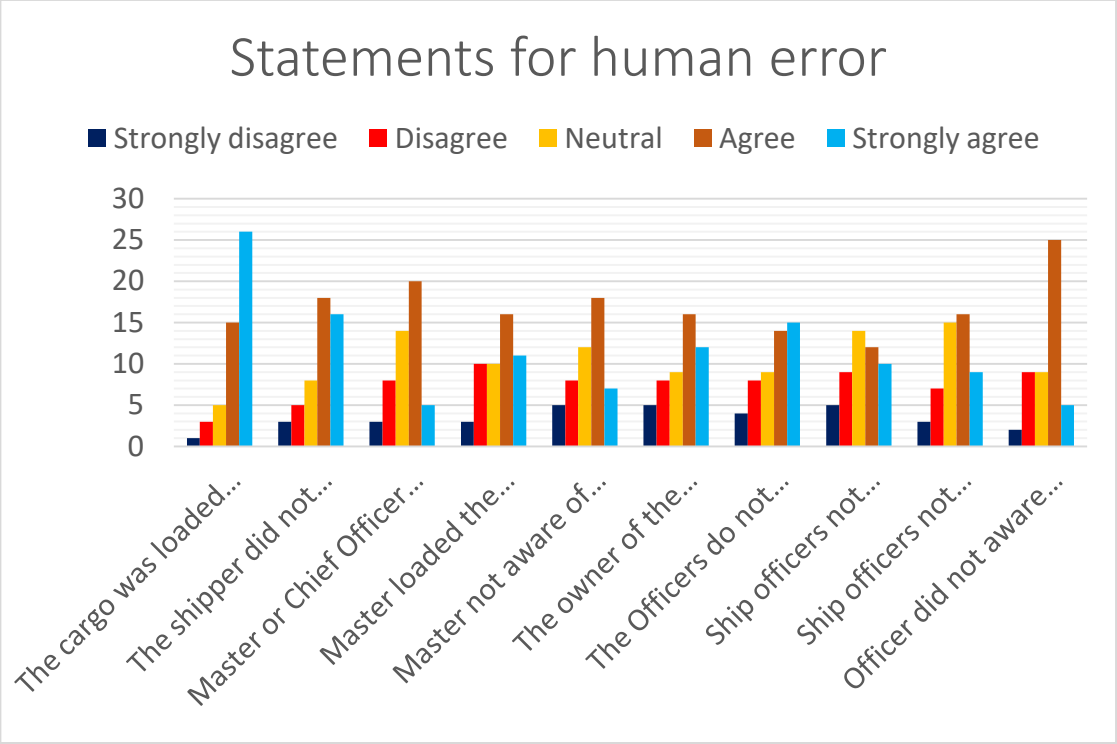

Figure 2: Graphs for statements of human error

Statistics	Variables	The cargo was loaded with excessive content of the moisture and continue the voyage	The shipper did not provide the Master with the agreed data pertaining to the cargo's moisture content and flow test as required by the SOLAS Convention	Master or Chief Officer not aware of the problem or of the simple 'can' or 'shake' test that can be performed to check the risk of cargo liquefaction	Master loaded the minerals without insisting on the provision of the data concerning the moisture and flow tests	Master not aware of the information that are entitled to receive from shippers	The owner of the vessel did not have clear instruction on the care and handling of such cargoes as specified in its Safety Management System	The Officers do not follow strictly the IMSBC Code's guideline and recommendation of carrying a basic "Can Test"	Ship officers not closely check condition of cargo before loading	Ship officers not monitoring the condition throughout loading operation	Officer did not aware of overturning moment exceeds the restoring moment that leads to unstable vessel
Correlation	The cargo was loaded with excessive content of the moisture and continue the voyage	1.000	.631	.562	.650	.403	.483	.382	.452	.434	.350
	The shipper did not provide the Master with the agreed data pertaining to the cargo's moisture content and flow test as required by the SOLAS Convention	.631	1.000	.612	.580	.477	.397	.521	.450	.454	.365
	Master or Chief Officer not aware of the problem or of the simple 'can' or 'shake' test that can be performed to check the risk of cargo liquefaction	.562	.612	1.000	.730	.766	.475	.492	.534	.416	.466
	Master loaded the minerals without insisting on the provision of the data concerning the moisture and flow tests	.650	.580	.730	1.000	.714	.756	.618	.604	.533	.623
	Master not aware of the information that are entitled to receive from shippers	.403	.477	.766	.714	1.000	.551	.595	.615	.577	.575
	The owner of the vessel did not have clear instruction on the care and handling of such cargoes as specified in its Safety Management System	.483	.397	.475	.756	.551	1.000	.531	.429	.318	.553
	The Officers do not follow strictly the IMSBC Code's guideline and recommendation of carrying a basic "Can Test"	.382	.521	.492	.618	.595	.531	1.000	.584	.716	.681
	Ship officers not closely check condition of cargo before loading	.452	.450	.534	.604	.615	.429	.584	1.000	.843	.648
	Ship officers not monitoring the condition throughout loading operation	.434	.454	.416	.533	.577	.318	.716	.843	1.000	.697
	Officer did not aware of overturning moment exceeds the restoring moment that leads to unstable vessel	.350	.365	.466	.623	.575	.553	.681	.648	.697	1.000

Table 1: Correlation matrix for human error

2. Knowledge factor

The questionnaire regarding knowledge factorsthat affect cargo liquefaction is as follows:

i. Insufficient knowledge about 4 test methodsaccording to mineral cargoes as implemented by IMSBC Code
ii. No test to specifically ascertain the transportable moisture limit (TML) of the minerals
iii. The appearance of the surface of the cargo should be checked regularly
iv. Cargo was stowed in open space prior to loading
v. Incorrect or inadequate cargo documentation
vi. Certificate presented cargo being tested but does not have the record of TML and FMP value

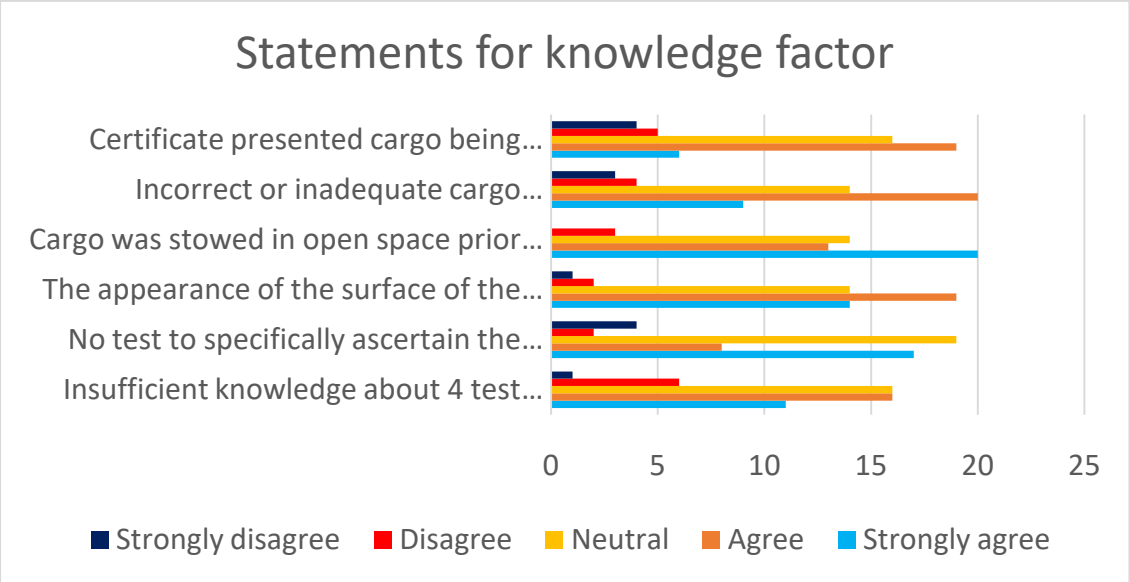

Figure 3: Graphs for knowledge factor

		Insufficient knowledge about 4 test method according mineral cargoes as implemented by IMSBC Code	No test to specifically ascertain the transportable moisture limit (TML) of the minerals	The appearance of the surface of the cargo should be checked regularly	Cargo was stowed in open space prior loading	Incorrect or inadequate cargo documentation	Certificate presented cargo being tested but does not have the record of TML and FMP value
Correlation	Insufficient knowledge about 4 test method according mineral cargoes as implemented by IMSBC Code	1.000	.628	.422	.204	.355	.333
	No test to specifically ascertain the transportable moisture limit (TML) of the minerals	.628	1.000	.571	.413	.421	.376
	The appearance of the surface of the cargo should be checked regularly	.422	.571	1.000	.511	.400	.328
	Cargo was stowed in open space prior loading	.204	.413	.511	1.000	.314	.136
	Incorrect or inadequate cargo documentation	.355	.421	.400	.314	1.000	.684
	Certificate presented cargo being tested but does not have the record of TML and FMP value	.333	.376	.328	.136	.684	1.000

Table 2: Correlation matrix for knowledge factor

3. Cargo factor

Questionnaires regarding cargo that affect cargo liquefaction are as follows:

i. Insufficient knowledge of the characteristics of nickel ore or bauxite
ii. Nickel ore makes the transportable moisture limit testing difficult because of its characteristics
iii. Bauxite contains a high proportion of fires capable of retaining significant moisture
iv. As bauxite declared Group C, shippers do not provide the required TML and moisture certification

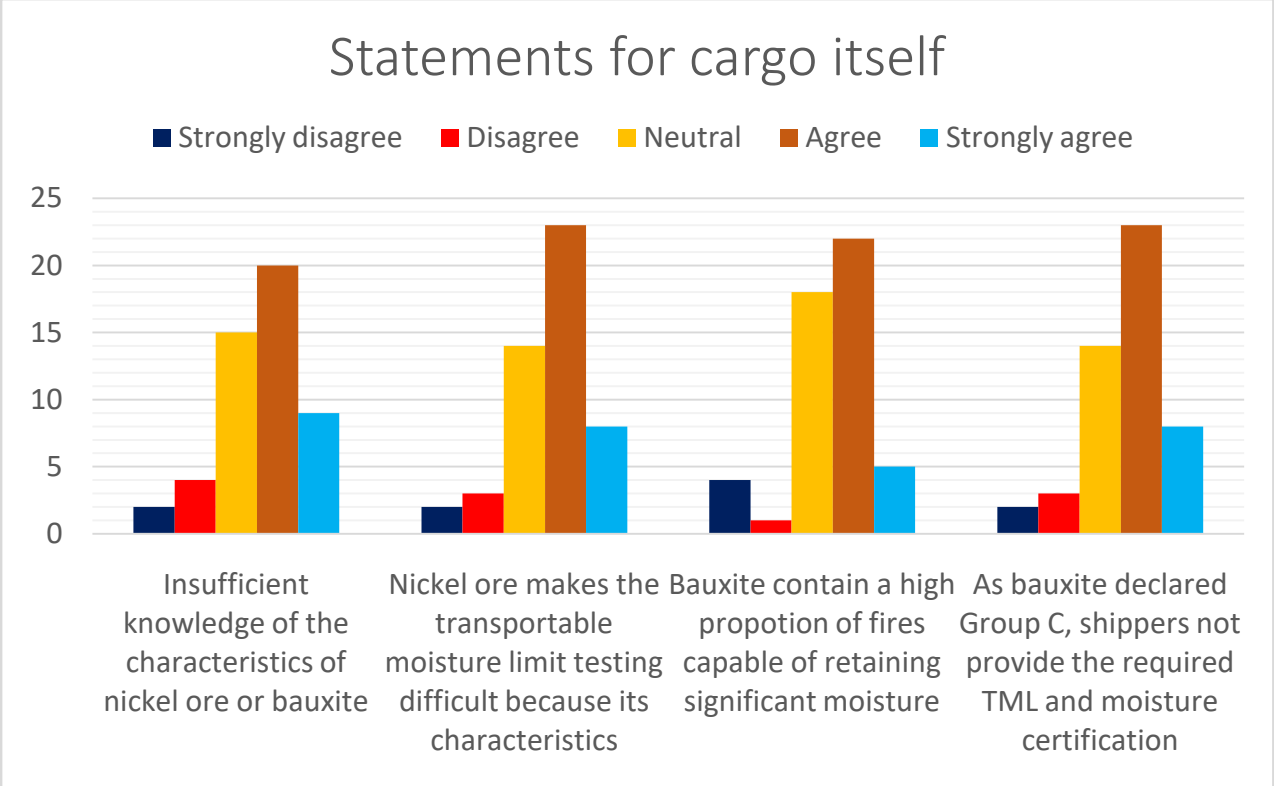

Figure 4: Graphs for cargo factor

		Insufficient knowledge of the characteristics of nickel ore or bauxite	Nickel ore makes the transportable moisture limit testing difficult because its characteristics	Bauxite contain a high propotion of fires capable of retaining significant moisture	As bauxite declared Group C, shippers not provide the required TML and moisture certification
Correlation	Insufficient knowledge of the characteristics of nickel ore or bauxite	1.000	.562	.451	.625
	Nickel ore makes the transportable moisture limit testing difficult because its characteristics	.562	1.000	.538	.692
	Bauxite contain a high propotion of fires capable of retaining significant moisture	.451	.538	1.000	.624
	As bauxite declared Group C, shippers not provide the required TML and moisture certification	.625	.692	.624	1.000

Table 3: Correlation matrix for cargo factor

4. Weather factor

Questionnaires regarding the weather that affects cargo liquefaction are as follows:

i. Heavy weather makes additional moisture to the cargo
ii. Tropical climate change of the region where the respective bulk carriers
iii. Climate and weather lead to frequent large rainfalls
iv. Wave impact makes the engine vibrations harder, and cargoes start to liquefy
v. Rain while loading the cargo in open space or during transit port

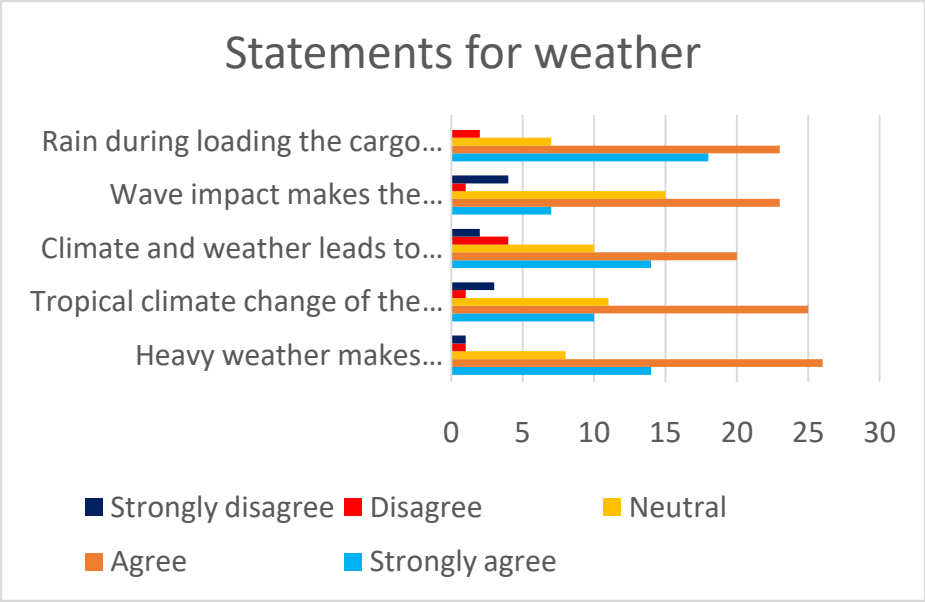

Figure 5: Graphs for weather factor

		Heavy weather makes additional moisture to the cargo	Tropical climate change of the region where the respective bulk carriers	Climate and weather leads to frequent large rainfalls	Wave impact makes the engine vibrations harder and cargoes to start liquefy	Rain during loading the cargo in open space or during transit port
Correlation	Heavy weather makes additional moisture to the cargo	1.000	.368	.411	.408	.324
	Tropical climate change of the region where the respective bulk carriers	.368	1.000	.736	.685	.143
	Climate and weather leads to frequent large rainfalls	.411	.736	1.000	.528	.246
	Wave impact makes the engine vibrations harder and cargoes to start liquefy	.408	.685	.528	1.000	.246
	Rain during loading the cargo in open space or during transit port	.324	.143	.246	.246	1.000

Table 4: Correlation matrix for weather factor

Analysis data

1. Human error factor

The factor analysis in SPSS analyzed the data. All four aspects had been measured for each factor. In factor analysis, this research lookup at the component score matrix, KMO sampling adequacy, and Bartlett's test.Based on the human error factor analysis, the highest value (0.147) is the Master loaded the minerals without insisting on the data. The higher the component score matrix value, the higher the factor assists unstable

vessels. The value for KMO sampling adequacy is aworthy result because in between 0.80~0.90. Bartlett's test is significant due to below than <0.05.

Item	Component score matrix	KMO sampling Adequacy	Bartlett's test
Cargo was loaded with excessive content of the moisture	*.113*	*.819*	*<0.01*
The shipper did not provide the Master agreed data as required	*.117*		
Master is not aware of the problem simple can or shake test	*.131*		
Master loaded minerals without insisting on the data	*.147*		
Master not aware of information receive from shipper	*.136*		
The owner did not have clear instructions on handling cargo	*.118*		
Officers do not follow strictly IMSBC Code guideline	*.132*		
Ship officers do not closely check conditions cargo	*.134*		
Ship officers not monitoring Condition throughout loading	*.130*		
Officer not aware of overturning moment	*.129*		

2. Knowledge factor

The higher the component score matrix value, the higher the factor assists the unstable vessel. Based on the analysis of the knowledge factor, the highest value (0.266) is no test specifically ascertaining the TML of the minerals. The value for KMO sampling adequacy is the average result because in between 0.70~0.80. Bartlett's test is significant due to below than <0.05.

Item	Component score matrix	KMO sampling Adequacy	Bartlett's test
Insufficient knowledge about 4 test method	*.228*	*.733*	*<0.01*
No test specifically ascertains TML of the minerals	*.266*		
The appearance of the surface of the cargo	*.249*		
Cargo was stowed in open space prior loading	*.189*		
incorrect or inadequate cargo documentation	*.243*		
Certificate presented cargo being tested but not have TML and FMP value	*.218*		

3. Cargo factor

The higher the component score matrix value, the higher the factor assists in the unstable vessel. Based on the analysis of cargo factor, the highest value (0.325) is as bauxite declared group C; the shipper does not provide TML and moisture certification. The value for KMO sampling adequacy is aworthy result because in between 0.80~0.90. Bartlett's test is significant due to below than <0.05.

Item	Component score matrix	KMO sampling Adequacy	Bartlett'stest
Insufficient knowledge of the characteristics nickel ore and bauxite	*.287*	*.802*	*<0.01*
Nickel ore makes the transportable limit difficult	*.308*		
Bauxite contains a high proportion of fire	*.284*		
As bauxite as Group C, shipper not provide TML and moisture certification	*.325*		

4. Weather factor

The higher the component score matrix value, the higher the factor assists the unstable vessel. Based on the analysis of weather factors, the highest value (0.316) is tropical climate change of the region bulk carrier respective. The value for KMO sampling adequacy is a worthy result because in between 0.80~0.90. Bartlett's test is significant due to below than <0.05.

Item	Component score matrix	KMO sampling Adequacy	Bartlett's test
Heavy weather makes additional moisture	*.242*	*.710*	*<0.01*
Tropical climate change of the region	*.316*		
Climate and weather lead frequent large rainfalls	*.307*		
Wave impact makes the engines Harder	*.300*		
Rain during loading cargo in open space	*.159*		

Comparisonof all the four highest values in each factor

Based on the analysis, comparing all the highest values in each factor, no test specifically ascertains TML of the minerals is dominant. The value for the component score matrix is 0.365. This means that the knowledge factor greatly impacts the ship's stability. The ship's crew is qualified and experienced before loading, especially nickel ore and bauxite. The guidelines from IMSBC Code should be stricter to prevent the scenario of cargo liquefaction occurs in the future.

Item	Component score matrix	KMO sampling Adequacy	Bartlett's test
Master loaded minerals without insisting on the data	*.322*	*.730*	*<0.01*
No test specifically ascertains TML of the minerals	*.365*		
As bauxite as Group C, shipper not provide TML and moisture certification	*.322*		
Tropical climate change of the region	*.269*		

Conclusion

In conclusion, many factors contribute to transporting the liquefied cargo, especially nickel ore and bauxite. In this study, the factors are categorized into human error, knowledge factor, weather, and cargo itself. The research showed the factors that are likely to occur while shipping the liquefied cargo that leads to the loss of the vessel. Recommendations have been made to minimize the number of accidents. It can raise awareness of the risks of cargo liquefaction on ships and describe what mitigating actions may be taken to reduce such risks.

According to the SOLAS Convention, the seafarers should properly load solid bulk cargoes for human error. Master should be aware of all the documents received from the shipper before allowing them to load the cargo, specifically the cargoes that may be liquefied. Officers must notice the appearance of cargo when voyaging and take appropriate action to avoid vessels becoming more unstable.

A certified and competent ship crew is fundamental for solid bulk carriers to avoid accidents. For the knowledge factor, the ship's crew must know all the basic terms to counter when this scenario happens. Insufficient knowledge about the method that needs to undergo a lab about cargo minerals before voyage leads to loss of lives and vessels.

For the cargo factor, the regulation should be stricter regarding solid bulk cargoes. All the shippers and mariners should knowcargo liquefaction. Lastly, the Master must always monitor meteorological conditions before loading or unloading the cargo minerals for the weather factor.

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