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Original article

Hazards Analysis of Routine Ship Towage operations in Indian Coastal Waters*

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Abstract

Main cause of accidents is just not always bad luck. Literature on safety has emphasised on the facts that accident finally leads to unfortunate consequence. The first step of risk assessment is to identify the hazards that are present. The Routine Ship Towage, also called harbour towage, is potentially a hazardous operation.

The main objective of this research is to identify and quantify the important factors impacting on the safety of routine ship towage operations in Indian coast. In doing so, initially, the existing literature on factors influencing safety of harbour towage operation was analysed to design questionnaire. Rest necessary data was collected through questionnaires. Finally, the factor analysis (Principal Component analysis) was applied to find grouped dimensions from identified hazard variables from literature and subsequently the critical analysis of incident type frequency, cause and consequences to get a clear picture of critical safety risk factors. As a result, the research found 20 criteria in 6 dimensions safety risk factors such as Crew Incompetency, Rough Weather, Poor Work Process, Suitability of Tug Type, Poor Safety Management System, and Poor Navigational Risk Assessment.

Keywords: Ship Towage, Tug Operation, Hazards

I. Introduction

In the seamanship a very seldom mentioned and elaborate category of small ships exist known as Tugboats. They are considered as 'workhorses of ports', very useful for assisting other vessels in mooring and un-mooring activities and providing tow service in manoeuvring within the ports and on all seas. In literature, the significance of these small ships on the whole maritime economy is often neglected but in fact their value is of paramount importance especially in manoeuvring during bad weather conditions in limited areas of world ports in particular. Now-a-days tugs are the important representative of port infrastructure in harbours worldwide and it is almost irremovable part of the business at some port in international relations without their utilization (BTA, 2010).

Accidents don't just happen on its own but they are cumulative results of series of unsafe events, in context to ports such as unsafe water conditions, human error, machinery and equipment failure - anyone or a combination of these can turn random events into accidents, sometimes with fatalities (Alert!, 2008).

Ship Towage Operation involves one of the potentially hazardous operations i.e. mooring and unmooring of vessels at ports. These operations require an efficient team work as a prerequisite to secure safety. Crew members indulging in this operation must be efficiently trained and equipped. They must possess ample understanding of their role and responsibilities of their own as well as other team members (ETA, 2012).

From past four decades, researches have been conducted in order to have a better understanding of the effects on tug operations which are leading to many accidents in recent times. It is a point of consideration that there are different ways in operation of tug in towage operation and these mainly differ from place to place. Basically there are two methods to assist a ship, one is to push or pull a ship with tug fastened alongside the ship. In this method interaction forces have very small contribution. The other method is towing a ship on a line the tug is fastened to bow or stern to make a connection with towline near the bow in particular, in this interaction forces contributes in a major proportion (IMPA, 2013). The purpose of this research paper is to identify hazards associated with mooring and unmooring operations in routine ship towage in Indian coastal waters.

1.1. Traffic at Indian Ports

The port sector of India can be divided into two categories namely Major Ports and Non-Major Ports. Major ports are those ports which are run and governed by an act of Indian Parliament while on the other hand Non Major ports includes private ports, captive ports, ports which are owned by state government. In total there are 12 major ports in India along with 176 Non major ports stretched over 7,212 kilometres of the coastal line of India.

Ninety percentage of India's international trade by volume and seventy percentages by value are represented by Major and Non-major ports in India. Data shows that 975 million tonnes of total traffic was handled by Indian ports in 2013-14, whereas 40% of the total traffic was handled by Non Major ports. There are other coastal vessels which are also contributing to this high traffic.

To handle this high volume of traffic, tugs play a vital role in providing safe mooring and unmooring operations and assistance to vessels coming alongside. Tug activities has increased tremendously in these ports and so is the risk to safety in these towage operations (Mantrana Report, 2014).

II. Literature Review

To formulate questionnaire extensive review of international literature was done to identify prevailing safety factors around the world. There is high risk when ship is having high speed and tug is operating near bow of ship having headway (Henson, 2012). In addition Merkelbach and Van Wijnen (2013) in their extensive global survey report emphasized both on ‘safe speed’ and safe operating procedure when making connection of towline. Dand (1975) model test report stated that there is most likely the tug may drive itself under the bow near the fore body of a ship as there are large interaction forces which influence the manoeuvrability of tugs, these forces is directly proportional to square of the speed.

The safety report published by Australian Transport Safety Board statistics shows those consequences of accidents involving tugs were collisions, contact damage and capsizing (ATSB, 2011). An accident reported by International Tugowners Association reveals hydrodynamics sphere of influence on tug sailing close to bow of ship was the main reason of fatal collision with vessel, and tug capsized. The tug failed to maintain safe distance due to interaction force around bulbous bow (ITA, 2012).

The significance of tow planning to prevent Routine Ship Towage accidents was well described by Transport Accident Investigation Commission of New Zealand (TAIC, 2001). The associated risk of Girting was mentioned in circular of British Tug Association where barge while berthing capsized and foundered due to wrong operational procedure by tug. The tug was acting as resistant that lead uncontrolled yawing of barge (BTA, 2010).

In British Tugowners Association’s Safety delegates Seminar emphasized the significance of training and expressed concern over poor seamanship and incompetency of tug crew that are leading to high number of safety incidents occurrence (BTA, 2012). The same was stressed by Livingstone (2012) for adoption of simulator based training that would boost tug masters confidence by increasing their competency in efficient operation of their tug.

Henson, Merkelbach and Van Wijnen (2013) recognised the significance of competency which is attribute to skills, great teamwork and experiential comprehensive training for tug captains, pilots, ship’s master and crew involved in towage operations. Importance of following standard operating procedure was emphasized by Stockman (2010) report, in which there was incident of near girting and ultimately could also have led to capsize of tug.

In Marine Safety Information Bulletin published by United States Coast Guard underlines the significance of Tug Handling techniques in reducing down streaming conditions (USCG, 2009). In one of accident where tug was assisting vessel in a narrow channel collided, British Tugowner Association in its report emphasized on hazards associated with lack of manoeuvring space which may also arise due to navigational obstacle in harbour towage operations (BTA, 2010). The EMSA (2010) stressed over the tug approach manoeuvres, stating that Pilots and tug masters need to be very careful in towage operations.

Choosing a Tug type for efficient and safe towage operation is critical as mentioned by Henson (2011) in Safe Tug Procedures. Tugs with propulsion units aft are more prone to safety risk as the tug's stern will come closer to the ship bow that will lead to increase of suction forces and consequently the high risk of heavy contact with the bow. He also pointed out that proper tow planning can give opportunity to choose right tug type, he proposed greater use of tugs with propulsion unit forward as they are less affected by interaction forces and are much safer to operate as bow tug.

The poor maintenance of tug propulsion engine that led to collision between bulk carrier and tug was reported as the main cause by Australian Transport Safety Board (ATSB, 2006). Details of report mentions about breakdown of main engine, due to seepage of clutch oil from discharge pipe, this led to loss control over tug propulsion and it made heavy contact with starboard ship hull and damaging shell plating.

TAIC, New Zealand (2000) reported issue of poor communication between crew of ship and tug led to safety incident involving man overboard and near capsize of tug. There was inadequate communication between bridge and crew at mooring station; and also between pilot and tug master.

European Tugowners Associations (2011) stressed on safety culture and human factor in tug operating companies, highlighting casual attitude of company staff and tug crew due to lack of enforcement legislation for safety management system as they fall below 500 GT for many international conventions. Another example Maritime Labour Convention 2006 (ILO, 2013) which has provision for suitable hours of rest for seafarers but this cannot be applied to mariners engaged on tug boats (ABS, 2002).

III. Research Methodology

This research was aimed at identification and quantification of independent variables i.e. Hazards causing threat to dependent variables i.e. safety of routine ship towage. The main challenge faced at the time of research was to establish a control group who are involved in safety incidents. The best method was to adopt an experimental approach but that would not be ethical and practical to have accidents in controlled circumstances to determine the risk factors involved in towage operation. Therefore, analytical survey was chosen. The methodology would be required for statistically skewed distributions as sample population studied represented a particular segment.

This research was not subjected to extremely structured deductive approach and not able to control variables in order to generate data for analysis because it is an exploratory non-experimental research. Therefore a phenomenological approach is adopted to gather relative experiences of people and used active experiences as an open ended enquiry.

Questionnaire survey method was adopted to assess the practitioners' professional experience in this research. To compare independent variables and to cross check the results, Likert Style questionnaire was utilised (Bryman, 2004). It was aimed at generating particular contemporary data in order to identify model of types of safety incidents, their frequency and criticality, cause and results (Loughborough, 2010). Questionnaire was designed in such a way that most questions were closed, containing measurable factual information; also there was an option of providing additional descriptive information and facts.

3.1. Process

A Pilot survey was carried out by draft questionnaire to verify comprehension, structure and precision of the questionnaire prior to the actual survey, by having response of five non-participants. In order to achieve target participation, the questionnaire was circulated to a stratified set of involved organizations and individuals. Total questionnaire distributed were 250 to group of Tug Master, Class Surveyors, Ship's crew, Master Mariners, Maritime Administrators, Harbour Master, Towage Enterprise Manager, Safety officers, Pilots, Tug Shipbuilders.

IV. Survey Results

Each and every Questionnaire was given a unique number for reference and the collected data was optimized and cleaned (checking for obvious errors and ineligibility). The data was then organized and coded for analysis on an Excel spread sheet.

The Likert element was taken as ordinal data & considered for analysis separately; four significance levels have been used, so that respondents could distinguish the difference between next levels, as equidistant. Ordinal data gathered from Likert responses has been analyzed using non-parametric testing. One hundred and forty three questionnaires were received by various data collection sources mentioned above; forty of these were given by Tug Masters, thirty by vessel Pilots and forty by Master Mariners.

Responses were received from nine states and most of them taken as valid. Gujarat (38), Maharashtra (33), Karnataka (14), Kerala (7), Tamil Nadu (15), Andhra Pradesh (13), Orissa (7), Delhi (11) Goa (5); Total (143). The collected data was not statistically Normally Distributed by analysing Mean, Median, Mode and Standard Deviation; however plotting the histogram of risk factor frequency shows a positive skew. Questionnaires Survey depicts that the most frequently occurring risk factors (>50%), Refer figure 1, which attributes to risks were:

- Poor Training;
- Human Factors;
- No Tow Planning;
- Poor Tug Handling;
- Communication Procedure;
- Substandard Tug Equipment;

- Tug Approach Maneuvers;
- Interaction;
- Safety Culture;

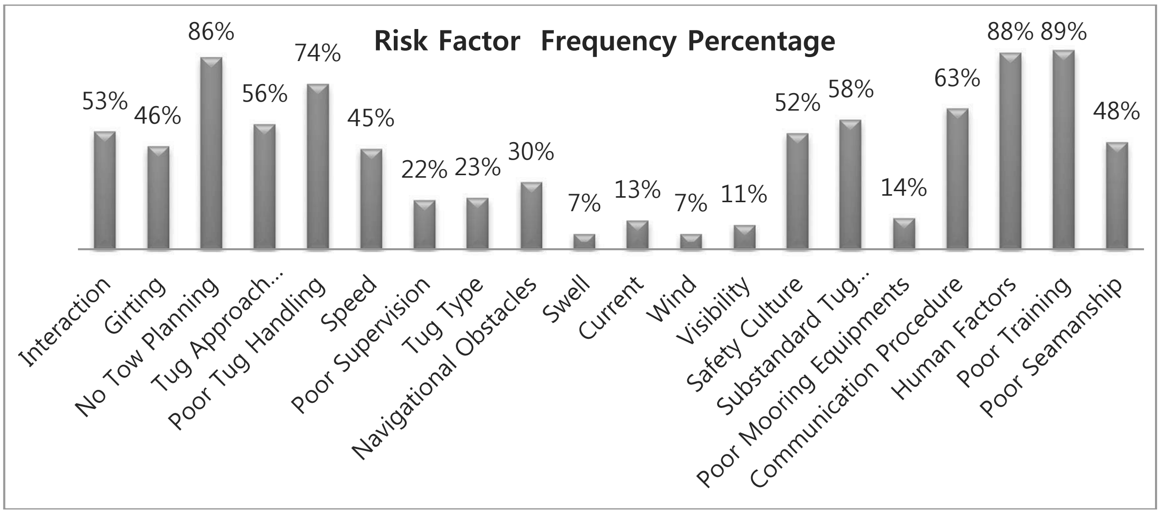

Figure 1: Risk Factor Frequency Percentage

A statistical tool Pearson's r significant number test was used to assess relationship between Risk Factors & Consequence severity significance. The test acknowledged a Strong relationship ($r > 0.39$) for four factors:

- Human Factor;
- Poor Training;
- Poor Safety Culture;
- Substandard Tug Equipment

The following guiding principle were used for inferring positive or negative correlations (Pearson's r).

If r = +.70 or higher Very strong positive relationship
+.40 to +.69 Strong positive relationship
+.30 to +.39 Moderate positive relationship
+.20 to +.29 weak positive relationship
-.19 to +.19 No or negligible relationship
-.20 to -.29 weak negative relationship
-.30 to -.39 Moderate negative relationship
-.40 to -.69 Strong negative relationship

The test showed a moderate positive relationship (r value between 0.30 - 0.39) for Three Risk Factors:

- Tug Type
- Poor Tug Handling
- Poor Training

Weak Positive relationship in Tow Planning, whereas negligible relationship was found in eleven remaining factors (*See Table 1*). Severity of consequences was calculated following risk assessment guidelines.

Table 1: Pearson's r Significant Number Test for analysing relationship between Consequence Severity and Risk Factor (SPSS Software output)

	Pearson Correlation [Sig.(2-tailed)]	Consequence	Relationship
Interaction	0.000	0.168**	Negligible
Girting	0.000	0.099**	Negligible
Tow planning	0.031	0.201*	Weak Positive
Tug Approach Manoeuvres	0.044	0.07*	Negligible
Poor Tug Handling	0.000	0.393**	Moderate Positive
Speed	0.000	0.165**	Negligible
Poor Supervision	0.040	0.145*	Negligible
Tug type	0.036	0.322*	Moderate Positive
Navigational Obstacle	0.004	0.034*	Negligible
Swell	0.031	0.01*	Negligible
Current	0.000	0.015**	Negligible
Wind	0.001	0.01**	Negligible
Visibility	0.004	-0.040	Weak Negative
Safety Culture	0.040	0.472*	Strong Positive
Substandard Tug Equipment	0.003	0.447**	Strong Positive
Poor Mooring Equipment	0.024	0.083*	Negligible
Communication Procedure	0.000	-0.387	Moderate Negative
Human factor	0.041	0.464*	Strong Positive
Poor Training	0.001	0.496**	Strong Positive
Poor Seamanship	0.041	-0.060	Negligible
** .Correlation is significant at the 0.01 level (2-tailed).			
*.Correlation is significant at the 0.05 level (2-tailed).			

V. Analysis - Factor Analysis Results (Principal Component Analysis Method)

Statistical analyses Data were analysed using SPSS 16.0. Factor analysis using PCA (Principal Components Analysis) Extraction Method and varimax rotation is applied to analyse the association between various risk factors. A factor analysis is useful to identify common underlying dimensions (factors) that consist of items (in this case concerns) that are strongly interrelated (Neill, 2013). The selection of factors was based on Eigen values (>1 as threshold), while factor loadings were used to interpret the meaning of the resulting factors. Cronbach's alpha was used to decide and interpret upon internal reliability consistency. Threshold value for acceptable construct is 0.6, which denotes that the dissimilar items measure one single construct and therefore may be grouped. Aggregation was done through averaging the scores across issues assigned to a specific factor.

PCA is a method used for altering the variables in a multivariate data set, A_1, A_2, A_3….Ap into new variables, B_1, B_2, B_3…Bp which are uncorrelated with each other and account for decreasing proportions of the total variance of the original variables defined as:

$$B1=x_{11}A_1+x_{12}A_2+x_{13}A_3+\ldots+x_{1p}A_p$$
$$B2=x_{21}A_1+x_{22}A_2+x_{23}A_3+\ldots+x_{2p}A_p$$
$$B3=x_{21}X_1+x_{22}X_2+x_{23}X_3+\ldots+x_{2p}X_p$$

With the coefficients being preferred; so that B_1, B_2, B_3…Bp are accounted for decreasing magnitudes of the total variance of the original variables A_1, A_2, A_3….Ap. (Everitt et al.,2001; Gaspersz, 2007; Mulyono et al., 2009).

5.1. Data Screening

The data was screened for univariate outliers. From overall data, five out-of-range values, due to clerical or data collection errors, were identified and logged as missing data. The minimum sample size for factor analysis was identified, with absolute sample size of 143 (using list wise omission), with over 8 cases per variable.

5.2. Factor Analysis

Before proceeding to Principal Component Analysis following assumptions need to be checked. The factorability of the 20 items was examined. We have multiple variables with ordinal values derived from 4 point Likert scale. There was also need to have a linear relationship between all constructs. This is because PCA is based on Pearson correlation coefficients, and there needs to be a linear relationship between the construct. Linearity was tested using a matrix scatterplot, which was selected randomly for just a few possible relationships between variables and tested.

Some well-known criteria for the factorability of a correlation were used. Firstly, 15 out of the 20 items correlated at least 0.30 with at least one other item, signifying rational factorability. Secondly, the Kaiser-Meyer-Olkin measure of sampling appropriateness was 0.699, above the suggested value of 0.6, and Bartlett's Test of Sphericity was significant (χ^2 (335) = 5.091E3, $p < .05$). The diagonals of the anti-image correlation matrix were mostly over 0.5, supporting sampling adequacy i.e. the inclusion of most of the item in the factor analysis.

The determinant value of sample data is 3.33E-02 (which is 0.0333) which is more than the required value of 0.00001. Hence, multicollinearity is not a found in these data. To sum up, none of the questions in the Questionnaire have correlation coefficients particularly high and all of them correlate fairly well; therefore, there is no need to consider excluding any questions at this stage.

There are no significant outliers for ordinal values of Likert scale of 4 point used. Outliers are important because these can have a disproportionate influence on the results. Viewing at the mean values, we can conclude that crew incompetency is the most important risk factor that accounts maximum impact on safety; and it has two variables of Human Factor & Poor Training. It has the highest mean of 2.67 & 2.63 respectively.

Internal consistency for variables from questionnaire was assessed using Cronbach's alpha. The alpha is acceptable 0.733. Finally, the communalities were all above 0.3; further confirming that each item shared some common variance with the other items. Given these overall indicators, factor analysis was conducted with all 20 items. Communalities values show how much of the variance in the variables has been accounted for by the extracted factors. For instance over 86% of the variance in Human Factor is accounted for while 64.1% of the variance in Girting is accounted for.

Principle components analysis was used because the primary purpose was to identify and compute composite coping scores for the factors underlying the Hazards in Routine Ship Towage. The initial Eigen values showed that the first factor explained 22.66% of the variance, the second factor 15.14% of the variance, the third factor 12.48% of the variance, the fourth factor 10.49% of the variance, the fifth factor 8.93% of the variance and a sixth factor 5.18% of the variance. All the six factors had Eigen values of just over one, each factor explaining 12.4%.

All Six factor solutions were assessed in factor loading matrix using both varimax and oblimin rotations. The identified six factors explained 74.92% of the variance and its 'levelling off' of Eigen values on the screen plot, and subsequently the inadequate number of primary loadings and difficulty of interpreting the Seventh factor and succeeding factors. There was minor dissimilarity between the varimax and oblimin solutions, thus both solutions were assessed in the subsequent analyses before determining Varimax rotation for the final solution.

Table 2: Total Variance (SPSS Software output)

	Total Variance Explained								
	Initial Eigenvalues			**Extraction Sums Of Squared Loadings**			**Rotation Sums of Squared Loadings**		
Component	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	4.532	22.662	22.662	4.532	22.662	22.662	3.438	17.190	17.190
2	3.030	15.149	37.811	3.030	15.149	37.811	3.095	15.477	32.667
3	2.496	12.482	50.293	2.496	12.482	50.293	2.931	14.655	47.322
4	2.100	10.499	60.792	2.100	10.499	60.792	2.327	11.633	58.954
5	1.788	8.939	69.731	1.788	8.939	69.731	2.143	10.715	69.670
6	1.038	5.189	74.920	1.038	5.189	74.920	1.050	5.251	74.920
Extraction Method: PCA									

During analysis, one of the items was disregarded because it did not contribute to a simple factor structure and failed to pass a requisite minimum criteria of having a primary factor loading of 0.4 or above, and no cross-loading of 0.3 or above. The item "Speed" did not load above 0.3 on any factor. It had a primary factor loading of 0.48 on the third component (which was well defined by 4 other items) and a cross-loading of 0.32 on Sixth component for the varimax solution. In addition, this item had a floor effect, with 55% of the participants not reporting this Risk factor as hazard.

The principle-components factor analysis of the remaining 20 items, using varimax and oblimin rotations was conducted, with the six factors explaining 74.9% of the variance. A varimax rotation provided the best defined factor structure. All items had primary loadings over 0.5 and only one item had a cross-loading above 0.3 (Speed). The factor loading matrix for this final solution is presented in Table 3.

Factor loadings and communalities based on a principle components analysis with Varimax rotation for 20 items depicting Risk factors qualified for Hazards (N = 143)

Table 3: Rotate Component Matrix (SPSS Software output)

	Component					
	1	2	3	4	5	6
Human factor	0.963	0.026	0.167	0.027	-0.066	-0.028
Poor Training	0.93	0.029	0.165	0.075	-0.027	0
Tow planning	0.893	0.053	0.086	-0.061	-0.138	0.064
Poor Seamanship	-0.868	0.019	0.057	-0.058	0.1	0
Swell	0.024	0.918	-0.109	0.019	-0.135	0.142
Wind	0.024	0.918	-0.109	0.019	-0.135	0.142
Visibility	0.004	0.852	0.275	-0.002	0.044	-0.138
Current	0.042	0.789	0.32	0.098	0.064	-0.205
Interaction	0.084	0.086	0.916	0.142	-0.116	-0.017
Girting	0.13	0.035	0.728	0.157	-0.174	0.195
Poor Tug Handling	0.064	0.009	0.721	0.001	-0.321	0.01
Communication Procedure	-0.045	0.087	0.603	0.125	-0.179	-0.031
Speed	0.102	0.069	0.484	0.311	0.227	-0.322
Tug Type	0.004	-0.056	-0.081	0.92	0.023	-0.005
Substandard Tug Equipment	0.043	0.046	0.208	0.837	0.072	0.042
Poor Mooring Equipment	0.026	0.093	0.047	0.742	-0.087	0.044
Poor Supervision	-0.153	-0.078	-0.097	0.002	0.947	0.086
Safety Culture	-0.153	-0.078	-0.097	0.002	0.947	0.086
Tug Approach Manoeuvers	0.052	0.076	0.303	-0.106	0.002	0.642
Navigational Obstacle	0.005	0.06	0.11	-0.192	-0.171	-0.609

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization

VI. Discussion and Conclusion

Overall, these analyses indicated that Six distinct factors were underlying maximum threat to Routine Ship Towage safety namely Crew incompetency, Poor Work Process, Rough Weather, Suitability of tug type, Navigational Obstacle and Poor Safety Management System. *(Refer Table 4)*

Table 4: Result

Extracted Risk Factor	Risk Factors	Frequency Percentage	Relationship Between Risk Factor & Consequences
Crew Incompetency	Poor Training	89%	STRONG
	Human Factor	88%	STRONG
	Poor Tow Planning	86%	NONE
	Seamanship	48%	NONE
Rough Weather	Wind	13%	NONE
	Visibility	7%	NONE
	Current	11%	NONE
	Swell	7%	NONE
Poor Work Process	Poor Tug Handling	74%	MODERATE
	Communication Procedure	63%	MODERATE
	Girting	46%	NONE
	Interaction	53%	NONE
Suitability of Tug Type	Tug Type	23%	MODERATE
	Tug Equipment	58%	STRONG
	Mooring Equipment	14%	NONE
Poor Safety Management System	Safety Culture	52%	STRONG
	Poor Supervision	22%	NONE
Poor Navigational Risk Assessment	Navigational Obstacle	30%	NONE
	Tug Approach Manoeuvering	56%	NONE

The most potential safety event in RST operations is Collision (eighty two percentage) followed by Grounding (fifty two percentage) and Capsize / Foundering (forty eight percentage). The most potential consequence is Damage (ninety one percentage) followed by Injury (seventy six percentage) and Pollution (fifty nine percentage). There is also indication of a noticeable risk of Loss of Life (sixty percentages).

As it was evident from analysis that there is a correlation between frequency of Risk Factor & consequence significance, the interpretations need to be optimized due to complexity of association between factors (a lesser number of Safety Risk Factors can underlie the most disastrous accidents).

The data was not normally distributed hence the test was not carried out to assess whether Safety Risk Factor magnitude had any effect, a simple plot of Safety Factor frequency against accident severity showed some increase, however there were:

- fluctuations;
- significant maximum Safety Risk Factor frequencies in average ranked incidents;
- A smaller amount of Safety Risk Factor frequency for the most catastrophic incidents.

Poor training and Poor Tow Planning which are attributed to crew incompetency showed substantial amount of risk frequency, in fact Human factor which represents the issue related to human element also exhibited high frequency. Moreover, issues related to poor training and human element shows strong relationship between risk factor and consequences.

The Tug type involved in Routine ship towage operation though shows small risk factor frequency but it shows moderate relationship with consequences whereas substandard tug equipment shows high risk factor frequency and strong relationship with consequences. Hence, Suitability of tug type as identified risk factor significantly contributes to threat to RST.

Poor work process components like communication procedure and poor tug handling and interaction are with high risk factor frequency and moderate relationship with consequences. Poor Safety Management System which is an attribute of poor implementation of safety culture accounting high risk factor frequency and strong relationship with consequences are main cause to threat to RST operation. However, Poor navigational risk assessment and rough weather though carrying low risk factor frequency and no relationship with consequences were also identified as threat to RST operation.

Safety Risk Factor identified in Indian coastal waters by this Questionnaire survey can be further validated by researchers with the help of other data collection tool such as studying secondary data i.e. accident and investigation reports relevant to Indian coastal waters or extensive interviews of experts & professionals from RST industry.

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