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Risk Analysis and Human Factor in Prevention of CRG Casualties

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ABSTRACT: CRG casualties create one of the major type casualties in shipping. Prevention of CRG casualties is an important issue, especially because of the number of CRG casualties has increased almost twice during recent years. For the great majority of all CRG casualties human factor responsible, and the increasing number of these casualties might be attributed to poorer qualifications of ship masters who have not enough experience in handling very large ships put into operation presently. Risk analysis is a modern method for assessment of safety level of technical systems. This tool may be the used to investigate causes of casualties and to find out most effective prevention measures. Risk analysis is widely used in many areas; in case of marine technology it is used routinely in off-shore technology.
The author investigates possibilities to apply risk analysis in the area of ship handling with the focus on human factor. This is preliminary study where possible methodology for hazards identification and risk assessment in respect of CRG casualties are investigated and risk control options are suggested. Various aspects of the influence of human factor in collision avoidance are listed and in particular the effect of training is stressed.

1 INTRODUCTION

During last three decades attention of the maritime world has been focused on safety of shipping. Amongst other causes of accidents at sea casualties related to manoeuvrability happen quite often and analysis of casualties shows that CRG casualties (Collisions-Ramming-Groundings) constitute about 53% of all serious accidents leading to ship loss (Payer 1994). Data on CRG casualties for the year 1982 analysed on the basis of sources provided by LRS and DnV revealed that their frequency was rather high as it is seen from the Table 1.

Table 1. Data on CRG casualties

Source	Mean number of ships during the year	Number of CRG casualties	Frequency of casualties [%]
DnV	2816	120	4.3
LRS	3391	170	5.0

The data showed that 1 ship in 22 took part in CRG casualty this year (Samuelides 1984). CRG casualties occur more often with increasing speed and size of vessels and such casualties may cause more serious consequences. Collisions may also happen more often in restricted waterways and canals and in particular in areas where additional external factors, as e.g. current, make handling of ships more difficult.

Statistics of CRG casualties in the following years showed considerable decrease in percentage, however it revealed quite alarming increase of the number of accident during last few years. As it is seen from Fig.1 the number of such casualties has increased almost twice from the year 2000. The reason of this effect is not clear – it may be, however, to be attributed to increase of the size of ships, in particular container ships operated, to the increase of the density of traffic, but most probably to the lower level of performance of crew members which were recruited from many different countries.

This situation requires serious attention and prevention of CRG casualties must be treated as a priority.

2 SAFETY SYSTEM OF PREVENTION OF CRG CASUALTIES

In order to achieve safe operation of ships and preventing casualties holistic and system approach is necessary. System approach consists of looking at the problem as assembled of the number of sub-problems mutually interrelated. In this approach the process of achieving main goal is exactly defined and related to sub-problems in accordance to the adopted plan.

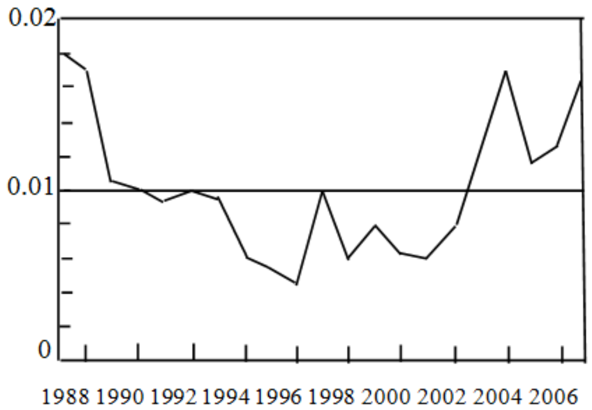

Figure 1.Percentage of CRG casualties during years 1988-2006

The system of safety against CRG casualties is rather complex, because of numerous interrelations between various sub-systems and because of that, its analysis is difficult. It would be, however, necessary to take into account in this system at least the following sub-systems:

- Traffic pattern
- Environment
- Human factor
- Equipment
- Legislation

3 GOAL ORIENTED APPROACH

The weak point of the present legislative status of safety requirement in general was duly noticed by highest IMO (International Maritime Organization) bodies and quite recently the Marine Safety Committee (MSC) recommended adoption of the concept of goal-based approach to safety requirements. The goal-based approach does not include prescriptive regulations or standards that must be complied with, but sets goals that allow alternative ways of achieving safety (Hoppe 2006). Goal-based standards are for some time considered at IMO and appraised by some authors (Vassalos 2002), and they were introduced in some areas, albeit not in the systematic manner. Marine Safety Committee commenced in 2004 (IMO 2004) its work on goal-based standards in relation to ship construction adopting five-tier system (Table 2).

IMO MSC committee agreed in principle on the following Tier I goals to be met in order to build and operate safe and environmentally friendly ships: “Ships are to be designed and constructed for a specific design life to be safe and environmentally friendly, when properly operated and maintained under specified operating and environmental conditions, in intact and specified damage conditions, throughout their life” (IMO 2004).

In the opinion of the author goal oriented holistic approach appears to be the best solution in preventing the increase of the number of CRG casualties. Goal oriented approach involves apart of prescriptive requirements, also risk analysis and system approach. Therefore to investigate the possibilities of application of risk analysis to safety against CRG casualties and to investigate possible risk control options and associated requirements is an important issue.

Table 2. Five-tier system for goal-based requirements

Tier I:	Goals
Tier II:	Functional requirements
Tier III:	Verification criteria of compliance
Tier IV	Technical procedures and guidelines, classification rules and industry standards
Tier V	Codes of practice and safety and quality systems for shipbuilding, ship operation, maintenance, training etc

4 PRESCRIPTIVE VERSUS RISK-BASED APPROACH

The basic dichotomy in the conception of safety requirements consists of prescriptive approach and risk-based approach (Kobyliński 2007)

Traditional regulations were of prescriptive nature and they are formulated in the way where a certain standards related to ship construction or operation must be complied with. Prescriptive regulations could be developed on the basis of experience (experts opinions) statistics, analytical methods, computer simulation, model tests and full-scale trials. Deterministic or probabilistic calculations may be employed when developing the criteria, although, as a rule, deterministic approach is used in most cases.

Prescriptive regulations have many advantages. They are formulated in a simple language, which is easily understood by everybody, they are easy in application, they also make checking adherence to the requirements easy. The main shortcoming of prescriptive regulations is that they are bounding designers or operators and they do not allow introduction of alternative solutions. They are based on experience gained with existing objects and they are not suitable for novel types of ships or uncommon operational and emergency situations. Usually they were amended after serious casualties happened. The risk involved with the application of prescriptive regulations is not known.

At the opposite of the prescriptive regulations, there is risk-based requirements. The risk-based requirements are based on risk analysis where and the main object is to assess eventually accept the risk. The advantages of risk-based requirements is that they are not binding designers or operators requesting to satisfying or obeying adopted fixed rules and standards, but offering the possibility of applying a variety of solutions provided they ultimately allow to keep risk within acceptable limits. Human factor could be taken into account, which is extremely important because the majority of CRG casualties may be attributed to human fault.

Risk is defined as a product of hazard probability and hazard severity (consequences):

R = PxC

To facilitate the ranking and validation of ranking IMO recommended defining consequence and probability indices on a logarithmic scale (IMO 2002). The risk index may therefore be established by adding the probability (frequency) and consequence indices. We have then:

Log(risk) = Log (frequency) + Log(consequence)

Risk-based approach according to IMO recommendation is formalized (FSA methodology) and includes the following steps (IMO 2002):

1 Identification of hazards
2 Risk assessment
3 Risk control options
4 Cost-benefit assessment, and
5 Recommendations for decision making

FSA methodology was recommended by IMO for general evaluation of safety requirements; in particular cases strict adherence to this methodology may not be possible. However, in all cases risk analysis must lead to risk assessment and acceptance. For this purpose, and taking into account specifics of ship operation at sea, risk assessment matrix (Table 3) may help to evaluate risk and to take appropriate action. In this matrix hazard probabilities are divided in five groups, as below:

- *A. Frequent* – always occurring, once or more yearly (greater than10^{-3}-10^{-4})
- *B. Probable* – few times during ship's lifetime (10^{-4}-10^{-5})
- *C. Occasional* – once during the lifetime of the ship, few times in the lifetime of the fleet (10^{-5}-10^{-7})
- *D. Remote* – little probable, but possible during the lifetime of the ship, once during the lifetime of the fleet(less than 10^{-7})
- *E. Extremely improbable* – such a small probability that it may not be taken into account (10^{-9} – 10^{-10})

and hazard severities (consequences) into four groups (Halebsky):

1 *Catastrophic* – loss of vessel, fatalities
2 Critical hazardous effect - dangerous degradation in handling, need outside rescue operation
3 *Marginal major effect* – significant degradation in handling but not preventing to complete safely journey
4 *Negligible minor effect* – slight degradation in handling, need for slight modification of operating procedures

Table 3. Risk assessment matrix

	Hazard probability (hourly) ←**Low** **High**→				
	E.	**D.**	**C.**	**B.**	**A.**
I Catastrophic	**Z**	**Y**	**X**	**X**	**X**
II Critical hazardous effect	**Z**	**Z**	**Y**	**X**	**X**
III Marginal major effect	**Z**	**Z**	**Z**	**Y**	**Y**
IV Negligible minor effect	**Z**	**Z**	**Z**	**Z**	**Z**

In the table 3: Z- action to reduce hazard if economically feasible. Y-action to reduce hazard probability, X action to eliminate hazard

5 RISK ANALYSIS AND SAFETY AGAINST CRG CASUALTIES

At present there are numerous requirements included into various legislative instruments that were, however, developed at different times by different bodies, some of them being compulsory, some others have only status of recommendations and in general, they are not consistent in many points. Most of them were developed by the International Maritime Organization, but in spite of that, holistic system approach was not used in their development. The list of different legislative instruments where requirements applicable to safety against CRG casualties are included is shown below:

- IMO manoeuvring standards,
- SOLAS convention requirements related to steering gear, and machinery
- COLREG convention requirements
- Pilotage requirements
- Separate traffic routes
- STCW Convention (Personnel qualifications)

– SOLAS Equipment Chapter Port authorities requirements.

The above list is not exhaustive and is provided as an example only. Requirements included in all of the above instruments are of prescriptive character.

Because of the complicity of the system of legislative instruments and requirements included therein, direct application of risk analysis to the system as a whole at this stage seems to be extremely difficult and requiring thorough study that is beyond the scope of this paper. Risk analysis might be, however, applied for example to the requirements related to the following subsystems:

– Ship design – (manoeuvring characteristics)
– Harbour and traffic lanes design
– Effect of human factor.
– Navigational aids
– Performing safe manoeuvers

The above subsystems are strongly interconnected, but in order to bring practicable solution they may be separated at the first step.

6 APPLICATION OF RISK ANALYSIS TO PERFORMING SAFE MANOEUVRES

The first step of the risk analysis is identification of hazards and assessment of their probabilities. Analysis of CRG casualties reveals that the causes of casualty may be attributed to:

– functional aspects resulting from reliability characteristics of the technical system, therefore manoeuvring characteristics of the ship,
– operational aspects resulting from the way the ship is operated in traffic routes, from harbour lay-outs and facilities, cargo handling etc,
– human factor, i.e. aspects resulting from action of the personnel handling the system, therefore crew members but also ship management, marine administration and owners company organization
– external causes resulting from factors independent from designers builders and operators of the technical system therefore from ship environment and climatology
– decision support systems helping the master or pilot to take appropriate decisions, *inter allia* radar. ARPA, electronic maps, computer programs for manoeuvres prediction, etc.

IMO resolution included general guidance on the methodology of hazard identification. With respect to manoeuvrability, hazard identification could be achieved using standard methods involving evaluation of available data in the context of functions and systems relevant to the type of ship and mode of its operation.

– Hazard identification is carried-out using hazard identification and ranking procedure (HAZID). According to general recommendation the method of hazard identification comprised mixture of creative and analytical techniques. Creative element was necessary in order to ascertain that the process is proactive and is not limited to hazards that happened in the past. Analytical techniques are used in order to evaluate, separately or in combination:
– statistical data concerning causes of accidents
– historical data including detailed description of accidents
– conclusions resulting from model tests and computer simulations
– event and fault trees method
– opinions of experts

In particular the last method is much of use, provided that collation and analysis of expert opinions is properly organized – for example by using Delphic method (IMO 2002a).

US Coast Guard (USGC 1981) provided some indication on the posible causes of CRG casualties. This is shown in the table 4.

Table 4.Causes of CRG casualties (according to USGC 1981)

	Cause	Percentage [%]
Insufficient ship controllability	Wind & current	9
	Turning ability	7
	Tugs	4
	Stopping	4
	Bank suction	3
	Sterring failure	2
	Control while stopping	2
	Control while backing	2
Direct human error		33
Unavoidable		34

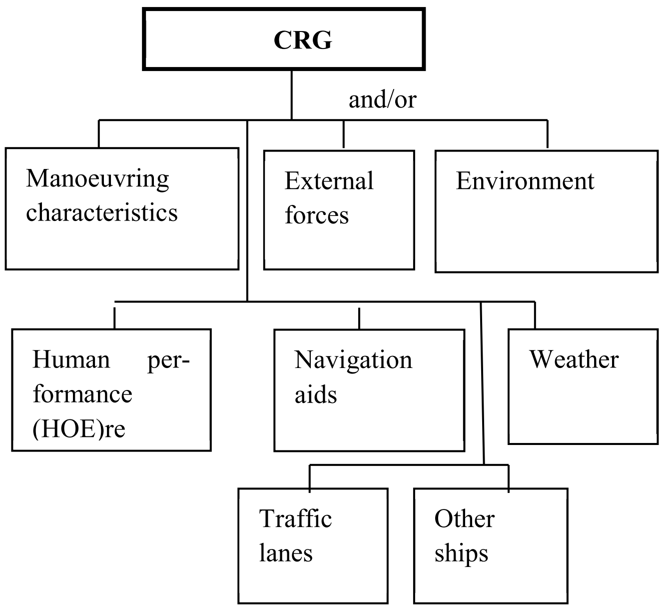

Figure 2. First level fault tree for CRG casualties

The classification shown in Table 4 is, however, not particularly useful for the purpose of risk assessment because large percentage of casualtied was classified as unavoidable. This is certainly wrong, because there is always some cause behind the casualty and it is probably that human and organisation errors (HOE) or heavy weather and perhaps other causes qualified by marine courts as "*force majeure*" are hidden in this category.

As an example of application of this methodology the list of hazards in respect to CRG casualties is shown in Fig. 2. In this example ranking of hazards is not shown, moreover the sketch could be considered as the first level of the fault tree leading to CRG. Hazards identified as relevant to safety against CRG are all strongly interconnected, moreover, human factor understood as performance of an individual (in most cases the master) plays important part in each case. Hazards identified should be further decomposed preferably using fault trees and/or events trees reproducing various scenarios of CRG casualty. The set and combination of fault trees and event trees as developed for all hazards identified and all scenarios (defined as risk contribution trees – RCT) is a basis for HAZOP (hazard and operability study) procedure that allows also assessment of frequencies (probabilities) of hazards required for risk assessment. This is rather tedious task bearing in mind the multitude of possible scenarios. This problem, however, is not discussed here.

7 EFFECT OF HUMAN FACTOR

As human and organization errors (HOE) are major causes of CRG casualties they require a special attention. HOE may be the result of design and construction faults (bad manoeuvring characteristics of ships) and *force majeure*, that are responsible for about 20% of all HOE casualties (Payer,1994), the rest may be attributed to operational factors that include the following:

- society and safety culture
- organization
- system
- individual

Society and its culture has important effect on safety. Economic factors tend to limit safety requirement, because enhancement of safety cost more; from the other hand lower safety level results in higher cost of increased number of accidents. There exists certain optimum from the purely economic point of view, but if fatalities are resulting from accidents the pure economic point of view is no more valid and crucial point is how high risk may be acceptable by the society. The risk is much lover in developed countries in comparison with the countries that are not yet developed.

The society culture is strongly related with safety culture. High safety culture helps to avoid a large percentage of accidents. The enquiry by the RINA amongst a number of naval architects did show, that the majority of them recognized safety culture as the most important factor in safety (The Naval Architect 1999).

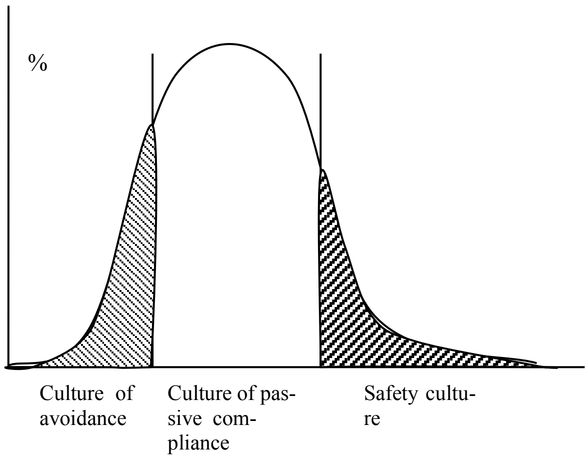

Figure 3. Effect of safety culture on accidents rate

Organization. A great number of accidents is caused by bad management or bad organization. Bad organization could mean lack of supervision, lack of procedures, lack of instructions, lack of activity by marine administration, lack of policy for safety management or lack of motivation. One important factor is also culture of shipping company. For example the dominant culture of company might be tendency to achieve gain without considering risk (flirting with risk) or forcing excessive strain leading to over-fatigue and in consequence may appear to be opposite with the aim of the company.

System. The following system faults influence operator behaviour: complexity, faulty signalization, small tolerances, difficult operation, inaccessibility, high demands in operation, wrong alarms, bad visibility, incomplete software, etc.

Individual. Operator's error is the most common cause of accident. However it is very difficult to identify the real reason of the operator action. There is a long list of possible causes as shown in table 5.

It is really impossible to attach probabilities to all factors listed in Table 5, because the relevant statistical data do not exist and there is no chance that such statistics will be ever available. However all the above factors may be divided in three groups:

1 individual character of the operator- integrity, reliability, morale
2 physical predispositions – health, endurance, immunity
3 knowledge – education, training, experience

Limiting to the above three groups it would be possible to construct the risk contribution tree (fault tree) for HOE as shown in fig 4.

Table 5. Human error factors (Bea 1994)

Fatigue	Wishful thinking	Bad judgement
Negligence	Mischief	Carelessness
Ignorance	Laziness	Physical limitations
Panic	Violations	Boredom
Greed	Drugs	Inadequate training
folly	Inadequate communication	Inadequate education
Ego	Alcoholism	Hidden illness

For the risk analysis it is necessary to attach probabilities to every group at the first stage. This could be done on the basis of statistics or expert opinions. Currently published statistics is not available, although major shipping companies certainly have such data. If probabilities attached to each of the above groups are known then conclusions with regard to risk o may be drawn.

Risk control options constitute an important step in the risk analysis. If we assume that probabilities are equally distributed between three groups, then concentrating on group three for example, one risk option would be stressing importance of training. Amongst other effects, it is well known, that training affects considerably the ability to handle critical situations (Bea 1984).

8 CONCLUSIONS

Risk analysis is an excellent method for analyzing safety of complex systems to which system of safety against CRG casualties at sea also belongs. However application of risk analysis to CRG casualties poses serious difficulties because of the complexity of the system and strong interrelations between different subsystems.

In particular, human factor, playing predominant part in a great majority of CRG accidents, requires special attention in the risk analysis. This is, however, difficult because of lack of reliable statistical data on the influence of various individual characteristics of the man at control on safe performance of manoeuvres. There are intuitive conclusions that training, for example affects ability of the man at control considerably, but respective statistical data are not available.

Nothwithstanding the difficulties, even at this stage, risk analysis could provide useful results when applied to various subsystems of safety against CRG casualties and in particular it may allow to assess the impact of various risk control options. This may be, in particular, relevant to human and organization errors (HOE) as shown in the paper.

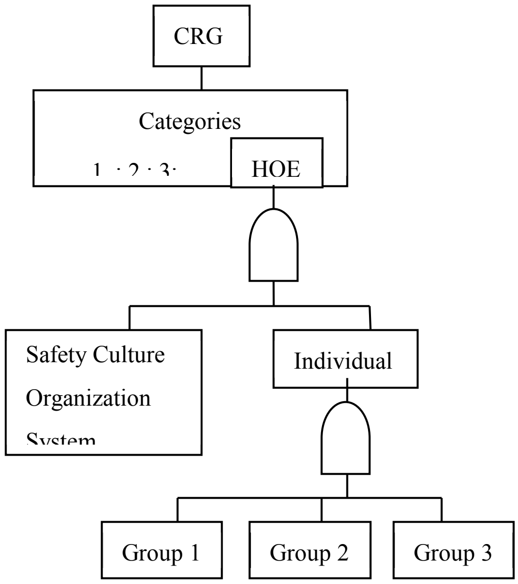

Figure 4. Simplified fault tree for HOE

REFERENCES

Bea, G.R. (1994). The role of human error in design, construction and reliability of marine structures. *Ship Structure Report* SSC-378

Hoppe H. (2006). Goal based standards – a new approach to the international regulations of ship construction. *IMO News* Issue 1

IMO (2002). Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process. *Doc. MSC/Circ. 1023;*

IMO (2002a). Guidance on the use of human element analyzing process (HEAP) and formal safety assessment (FSA) in the IMO rule making process. *Doc. MSC/Circ. 1022;*

Kobyliński, L. (2006). Appraisal of risk assessment approach to stability of ships. *8th International Ship Stability Workshop*, Istambul

Kobyliński, L. (2007). Goal–based standards. *9th International Ship Stability Workshop.* Hamburg

Payer, H. (1994). Schffssicherheit und menschliche Versagen. *Hansa-Schiffahrt-Schiffbau-Hafen* 131 Jahrgang, No.10

Samuelides, E., Frieze, P. (1984). Experimental and numerical sikulation of ship collisions. *Proc 3rd Congress on Marine Technology (IMAEM.* Athens

The Naval Architect (1999) March issue.

US Coast Guard (1995) Preventing through people. *Quality action team report*

US Coast Guard (1981). *Report M-8-81*

Vassalos, D. (2002). Total ship safety – a life-cycle risk-based DOR for safety. *The Stability Research Centre NAME. Universities of Glasgow and Strathclyde.* Report.