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HUMAN RELIABILITY ASSESSMENT, THE SOPHISTICATED TOOLS FOR MINIMIZING HUMAN ERRORS IN MARITIME DOMAINS

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ABSTRACT

Although, the maritime modernization and shipping technological improvement, maritime accidents still occur and according to European Maritime Safety Agency EMSA report 2015, accidents moderately increased during the last four years. Therefore, great efforts exerting to improve the ship construction and whole system reliability. Over decades, diversity of researches and reports proposed that human errors are the major reason contributing to maritime casualties. This promote a great concern to the research and improvement of innovative safety assessment regardless the availability of human failure statistics in the maritime domains, which is scarce.

Human reliability assessment HRA tools/ methods, which proven valuable tools since they used in nuclear industry and aviation, involves the use of qualitative and quantitative methods to assess the human contribution to risks in maritime safety "critical" domains, typically like nuclear industry and aviation, and they aimed to minimize the probability of accidental events. The paper reveals the contraption of human element in marine accident, and reviews widely used HRA tools of first and second generations, which developed by human reliability experts and by carrying out a comparison based on elastic criteria, it reveals a vision for assessors to extricate the proper tool for a task assessment. In addition, to describes why HRA second-generation tool "CREAM" is appropriate for maritime domains.

KEYWORDS: HRA – CREAM – THERP - Common Performance Conditions

INTRODUCTION

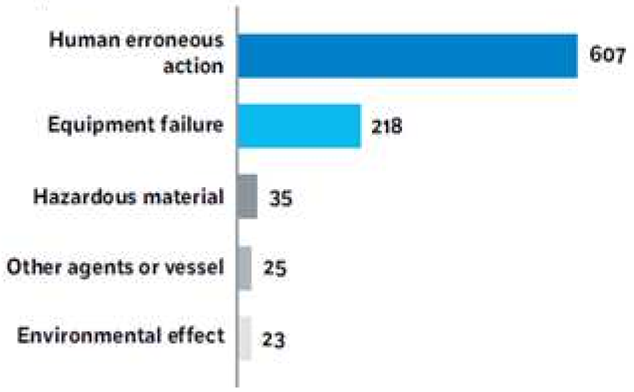
The international tendency of ship fatalities is in a decline, the maritime transport system is four times riskier than air transport causing 33% deaths per 100 million person. Over the last four decades, the shipping industry has concentrated on developing ship structure and the reliability of ship systems in order to decrease the rate of casualties and increase proficiency and productivity. In addition to the improvements in hull design, propulsion systems stability, and navigational equipment, until ship's systems turn out to be technologically advanced and highly reliable, the maritime casualty rate is still high with all these enhancements because ship structure and system reliability are a relatively small part of the safety equation. The spine of maritime system or any organization is a human system.

As far as human operation carried on in a complex environment, errors will occurs, and its possibility increased particularly under the Maritime critical situations. Despite the high qualifications of seafarers nowadays, human errors, "human failure", still powerfully contributed in casualty situations. About 75-96% of marine casualties caused, at least in part, by some sort of human errors. The contribution of human errors, which are Part of the total failure in major maritime accidents, was observed as following:

- 84-88% of tanker accidents.
- 79% of towing vessel groundings.
- 89-96% of collisions.
- 75% of fires and explosions.

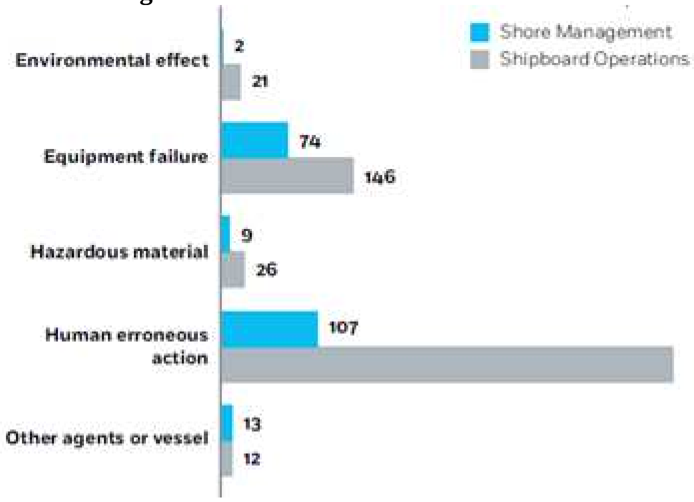
Such mishaps include capsizing, collision, and fire, and often result in pollution. Enough concern has generated that scientists around the world have developed the study of the human factor and presumption of human errors into an independent scientific discipline, and making greater strides towards reducing the number and severity of maritime casualties. Moreover, emphasis on assessing the significant forms of human errors that cause casualties in maritime domains especially during the critical maritime operations.

Over the period, 2011-2014, more than 390 persons lost their lives and 3250 were injured; around two thirds of the total existences directly involved damages to a ship, whereas one third was about mishaps to persons on board. While the majority of ships that sank were fishing vessels, cargo ships represented 44% of all ships involved it is important to mention that 67% of accidents in the mentioned period related to human erroneous activities.



Source: EMSA, 2015

Figure 1: Number of Accidental Events



Source: EMSA, 2015

Figure 2: Relation between Accidental Events and the Main Contributing Factors

Figure 1 and 2 illustrates the accidental events and participation factors that led to the accidents in the of period.2011-2014, and Human erroneous actions in relation with shipboard operations signified by extreme the main accidental event with 55% of the total of 908 accidental events assessed during the investigations. Despite the increase of the technology in maritime domains, the frequency of mishaps that human factor is the main cause, increased through the period 2011-2015. (EMSA, 2015)

Since the human factor plays corner stone as a fundamental concern of safety and total safety standards, human reliability assessment HRA, is the way to recognizes how reliable the operator to achieve a given action/task without failure, and estimate the probability of human errors for a certain task or operation. Applying the HRA conceders sophisticated tools to minimize the human errors particularly for maritime high-risk operation that evolves causalities and loss of lives.

Human Reliability Assessment- HRA

Humans are contribute in all life stages of most technical systems, from design through construction, operation, management, maintenance, and system upgrade. Humans have a tendency to make mistakes and it is repeatedly said “to err is human". Human error is a foremost provider to the risks and reliability of systems, as over 90% in the nuclear industry over 80% in the chemical and petro-chemical industries, over 75% of marine casualties and over 70% of aviation accidents; so that human requires a suitable respond to mitigate such failures . (French et al, 2009)

- **Human error:** An out-of-tolerance action, or deviation from the norm, where the limits of acceptable performance defined by the system.
- **Human reliability:** The probability that a person:
- Correctly performs some system-required activity in a required time period (if time is a limiting factor)
- Performs no extraneous activity that can degrade the system.(Rausand, 2013)
- **Human error Probability HEP**

“Is the probability that an action will be performed out of tolerance during observation period”. (Havlikova et al, 2014)

The human error can be quantifies as

- ***HEP*** **= n / N**
- **n** is the number of incorrectly managed tasks,
- **N** is the total number of managed tasks.
- On the other hand, the probability for an action to perform successfully during an observation is called “Human Success Probability”
- **HSP, (HSP = 1-*HEP*).**

The Attributes of HRA tools

A human reliability assessment HRA originally titled “probabilistic risk assessments PRAs”, because it deals with human errors assessment and prediction. These tools developed to meet the requirements of probabilistic risk assessment (PRA). It is a methodical identification and valuation of the human potential errors, which made, by operators, maintenance personnel, and other operating personnel in organization during operations, to perform one task on the failure probabilities of successive tasks.

Moreover, HRA tools designed to support the assessment and minimization of risks associated with human failures. HRA may be qualitative or quantitative; it aims to decrease the harmful and negative effects resulting from human errors and failures through the operations performance affecting the safety of lives. In addition, HRAs use to recognize phases or activities in a process that targeted for modifications that could reduce the probability of human error.

Furthermore, the importance of HRA in maritime operations appears when predicting human errors likelihood of high-risk shipboard, critical, operations and maritime critical operation as a general application in order to reduce accidents circumstances as it is working through over all human performance in operation activities. (Kirwan, 1997)

The number of HRA tools approaches are exceeds 50 techniques nowadays, but the widely uses tools about 14 tools/ techniques, those tools are defers in a number of key aspects, in general HRA tools estimate the probability of human error for a certain tasks or operation considering the influence of Performance Shaping Factor PSF. A Performance Shaping Factors PSFs are the factors that can affect (Influences) the ability of the person to carry out a task.

External PSFs are out of the individual’s control such as (design of the task, tools and equipment, environmental factors, and procedures)

Internal PSFs are human characteristics carried to the task by the person that, in some cases, influenced by the person such as (skills, knowledge, abilities, attitudes). When PSFs are recognized, their impact on the potential human error is determined so that the basic human error rate can be adjusted per the explicit circumstances. (NASA, 2006)

The HRA Basic Process

The general process of HRA is concise in phases (Figure 3):

Problem Definition

The problem definition is the first phase in the process and it uses to determine the scope of the analysis, including what type of analysis (qualitative or quantitative).

Task Analysis

Task analysis is a methodical way to identify, list, and decompose each task into “steps and sub-steps” that describe the required human activities in terms of physical actions and cognitive procedures through a range of techniques to understand what humans are required to do in order to achieve a system goal. The Hierarchical Task Analysis HTA is to expresses a job or task in terms of “aims, operations and plans”. The task analysis begins after a functional analysis ended

Error Identification

Human error identification is the significant phase of HRA process as the aim of HRA is to estimate the potential contributions to hazardous events. The analysis must identify and the dissimilar types of human errors that can affect the operation. Human actions and interactions within a system categorizes into two main forms of fundamentals, a cognitive reaction or a physical action, and their correlated errors.

Representation

Representation or Human error modeling is to gain perception into the reasons, susceptibilities, recoveries, and possible risk mitigation plans associated with various operation scenarios. Each scenario starts with an Initiating Event; an Initiating Event commonly settled and supplied to the model as a frequency from the sources outside the scenario. The Human errors denotes as a contributor to an Initiating Event.

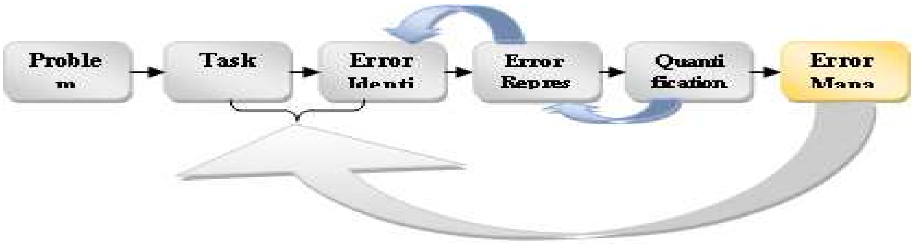
Quantification

Quantification is the process used to designate probabilities to the human errors, and it achieved as a screening analysis or as a detailed HRA. The HEPs integrates into the PRA to afford inclusive accident-sequence quantification and allow the analysts to determine which human errors were the most substantial providers to system and operation risk. The ways to get quantitative data are historical records, collected data, estimation techniques, and judgement and experience. Anyway, quantification steps depending upon the method being used.

Error Management and Reduction

Human error management and Reduction is philosophy accepts that humans will persist imperfect. Even when well-trained crew will cause errors. However, the viewpoint specifies that probable human errors can be recognized; some errors eliminate and minimize others.

In addition to lessen the negative impact of most of those lasting. Human error management strive for developing a system that minimizes errors and tolerates those that persist to provide the assurance, which the system will not experience, a disastrous failure or a major accident, despite the human errors that may arise. (Kirwan, 1994)



Source: Kirwan, (1994), NASA, (2006)
Figure 3: The Process of HRA Phases

Generational Approaches and DEVELOPMENT oF Hra Tools

The human errors prediction mission originally comes from nuclear power industry, through the tools and experts judgments techniques developed. HRA techniques or approaches divided essentially into two categories: first and second generation in addition to other classification categories of those tools that are using database, and those using experts' opinions, even the tools use database need expert's opinions in reality. (Kirwan, 1997)

HRA First Generation Tools

The first generation class of HRA tools, techniques, were developed after the second world war due to extensive acceleration in military equipment and weapons, then the primary method of HRA was in the year 1970s and 1980s, they have been strongly influenced the probabilistic safety assessment (PSA). The tools initially developed to help the risk assessor in predicting possibility of the human errors, utilizing a simple error categorization, they emphasis the skill and rule based level of human activity, and they encouraged the assessor to decompose a task into component parts, then deliberate the potential impact of adjusting factor such as time pressure, equipment design, and stress to determines the potential nominal human errors.(Julie, 2009)

The limitations of the first generation tools can only emphasis on the inherent defect, nevertheless of the decision of the individuals and environmental factors affecting human performance, but the second generation of HRA that included advanced evaluation tools the problems were solved. (Maddah et al, 2015)

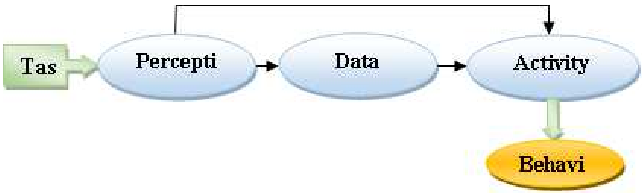


Figure 4: Human Behavior in HRA Tools of First Generation

Table 1: Broadly Used Hra Tools of the First Generation

Tool/Method	Full Name	Description	Creators
THERP	Technique for Human error Rate prediction	A tool for predicting human error rates and for assessing the humiliation of a human-machine system which caused by human errors .The method exploits performance-shaping factors to make judgments about particular situations.(swain, 1989)	Swain & Guttman, 1983
HEART	Human Error Assessment and Reduction Technique	Comparatively quick to apply and understood by assessors and human factors specialists. This tool positively used in various activities, including the nuclear, chemical, aviation, rail, and medical.(Williams, 1986, 1988, 1992)	Williams, 1986; 1988
ASEP	Accident Sequence Evaluation Program	A short version of THERP. (swain, 1987)	swain, 1987
SPAR-H	Standard Plant Analysis Risk HRA Method	SPAR-H applied to over 70 U.S. nuclear power plants. SPAR-H was originally developing as a screening methodology, but later the tool was extended for occupied HEP quantification. (Julie, 2009)	Gertman, Blackman, Marble, Byers, Haney &Smith, 2005

The first generation tools have restrictions in the analysis of Human errors in that they are missing a well-defined systems taxonomy, an understandable model, and precise image of dynamic system relations. Most of them describe each operator action with a success or failure path. Moreover, the representation of PSFs emphases the human performance is somewhat poor, and the tools are quantitative rather than qualitative with, high level of uncertainties. These deficiencies are fundamental reasons for the development of the second generation of human reliability assessment tools. (Myrto et al, 2006)

Technique for Human Error Rate prediction THERP

THERP is inclusive HRA tool/method, that developed by Swain & Guttmann for assessment of human reliability in nuclear power plants. It is the most composite and comprehensive effort made to produce data for the methodical assessment of human error. THERP is the most commonly practical tool for human performance reliability likelihood. It is a method for predicting human error rates and for assessing the humiliation of a human-machine system likely caused by human errors. It uses as a screening or a detailed analysis tool. Moreover, it uses performance-shaping factors PSF to make judgments about specific task. In some cases, it may be difficult to provide all factors that considers significant.

THERP has the advantage of simplicity but it does not account for a dependency of human performance reliability with time. This tool/method uses in circumstances of composite work. There are many types of human errors that the prospective event identified by this method. THERP required an enormous human reliability database containing Human Error Probabilities HEPs, that based upon both system data and expert judgments. The method does not consider human performance reliability in time. The method contains the following phases:

- Describe the system or procedure.
- List all the human operations performed and their associations to the system or tasks procedure.
- Predict the error rates for each human operation or group of operations.
- Determine the effect of human errors on the system or process, including the consequences of the error not detected.
- Improve and recommend changes that will reduce the procedure failure rate.

THERP tool/method determine the probability which an error “class of errors” will caused a system or process failure, the error which governs a system failure is stated as HEP_i , the Human Success Probability (HSP)

$$\mathbf{HSP = 1- \mathit{HEP_i}}$$

Probability that a class of errors will cause process failure given by

$$\mathbf{Q_i = 1-(1-\mathit{HEP_i})}$$

When $\mathbf{Q_i}$ is the partial probability of errors

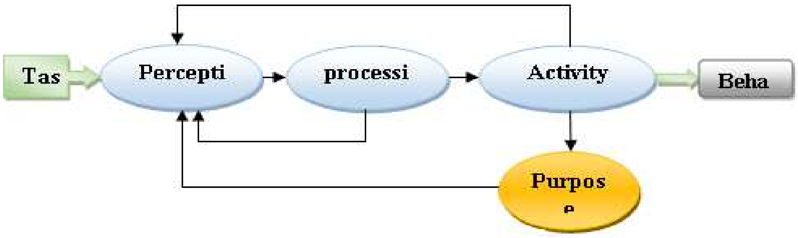
$$\mathbf{Q_{HUMAN} = Q_T = 1-} \left[\left(\prod^{n} \mathbf{(1-Q_i)}\right)\right]$$

The calculation of the total probability $\mathbf{Q_T}$ based on the nominal values of HEP_i and choosing the rate of the error factor depends on the formerly completed qualified valuation.

Q_{HUMAN} is the probability which one or more failure conditions will product of errors in at least one of the (n) failure classes. (Havlikova, 2014)

HRA Second-Generation Tools

The second-generation tools utilizes a concept that based on error classification, the concept matches with the human behavior cognition. To expedite errors identification, and quantification, it develops elaborate match scenarios and conceders the cognitive behaviors of the human element (operator). The second-generation tools developed in the year 1990. (Havlikova et al, 2014)



Source: (Havlikova Et Al, 2014)
Figure 5: Human Behavior in HRA Tools of Second Generation

Table 2: Broadly Used HRA Tools of the Second-Generation

Tool	Full Name	Description	Creators
ATHEANA	A Technique for Human Event Analysis	"ATHEANA is the product of a multi-phase research sponsored by the U.S. Nuclear Regulatory Commission. The initial effort started in 1992, aiming for more comprehensive coverage of operator response in the PRAs of nuclear power plants, particularly EOCs. It contains a detailed search process that promises to determine cognitive vulnerabilities in crews that may not be discovered when applying other HRA methods".	Barriere, Bley, Cooper, Forester, Kolaczkowski, Luckas, Parry, Ramey-Smith, Thompson, Whitehead & Wreathall, 2000
CREAM	Cognitive Reliability and Error Analysis Method	"CREAM established for general applications and based on the Contextual Control Model. It used as a screening analysis or a detailed analysis. CREAM does not provide specific guidance on all steps of the HRA process described earlier. CREAM requires the analyst to perform task decomposition that breaks the task down into subtasks. Each subtask matched to one of the pre-specified cognitive activities in the list. For each subtask, the activity further classified as an observation, interpretation, planning, or execution activity". (Hollnagel, 1993)	Hollnagel, 1998

Cognitive Reliability and Error Analysis Method CREAM

In 1998 HRA tool/method CREAM developed by "Eric Hollnagel". It represents a second-generation HRA tool/ method with developed applicability and accuracy compared to most of the first generation methods. It is broadly used tool of the second generation HRA, and based on three primary areas of work; task analysis, prospects for decreasing errors and possibility to deliberate the human performance with respects to overall safety of a system. It takes dissimilar approaches to modeling human reliability. There are two methods of this tool, "basic and extended method". CREAM uses for mutually "prospective and retrospective" assessment. Prospective estimate the human errors expected through a certain task, whereas retrospective quantifies errors that already happened.

Table 3: Control Mode

Control Mod	Hep	Cii Value
Strategic	$0.00005<p<0.01$	-7 to -4
Tactic	$0.001<p<0.1$	-3 to 1
Opportunistic	$0.01<p<0.5$	2 to 5
Scrambled	$0.1<p<1.0$	6 to 9

CREAM Basic Method

The purpose of basic method is to determine initial screening the human interaction with the task and its segments under four-control mode that linked with different failure probability intervals, table3. CREAM tool/method determined from contextual control mode COCOM. The purpose of COCOM is to offer theoretical and applied basis to improve operator performance in operations. (Hollnagel, 1993)

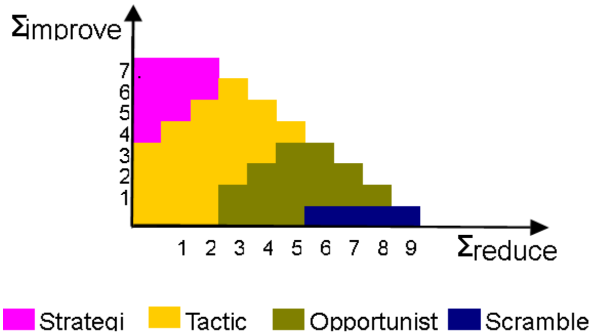


Figure 6: Operator Control Modes

CREAM identifies Common Performance Conditions CPCs, which provides the bases of conditions under the performance is expected, table (4), the control mode chosen according to combined CPCs.

CPCs expected to be “reduced, no significant, or improved” the combined score of CPCs is counting the number of reduced minus number of improved.

If the number of reduced minus number of improved is called Context influence index CII.

$$\mathbf{CII} = \sum_{\mathbf{reduced}} - \sum_{\mathbf{improved}}$$

The value of CII uses to find the control mode takes from the figure (6), then use table 3 to find HEP interval, the basic method is a qualitative process and it is imperative source for CREAM extended method. Moreover, it is a screening way that manage the assessor to evaluate the task and decided if continue to more detailed and precise method by continuing to the extended method.

Table 4: CPCS and Performance Reliability

Cpcs	CPC Levels	Effects
Adequacy of organization	Very efficient	Improved
	Efficient	Not significant
	Inefficient	Reduced
	Deficient	Reduced
Working conditions	advantageous	Improved
	compatible	Not significant
	Incompatible	Reduced
Table (4): Cond		
Adequacy of human-machine interaction and operational support	Supportive	Improved
	Adequate	Not significant
	Tolerable	Not significant
	Inappropriate	Reduced
Availability of the procedures / plans	Appropriate	Improved
	Acceptable	Not significant
	Inappropriate	Reduced
Number of simultaneous goals	Fewer than capacity	Not significant
	Matching current capacity	Not significant
	More than capacity	Reduced
Available time	Adequate	Improved
	Temporary inadequate	Not significant
	Continuously inadequate	Reduced
Time of day when the task is performed	Day time (adjusted)	Not significant
	Night time (unadjusted)	Reduced
Adequacy of training and preparation	Adequate high experience	Improved
	Adequate low experience	Not significant
	Inadequate	Reduced
Level of cooperation and interaction among department staff. . or Crew collaboration quality (BREAM)	Very efficient	Improved
	Efficient	Not significant
	Inefficient	Not significant
	Deficient	Reduced

The Realistic Criteria for Selecting of HRA Tool

Studding of common used tools through (1^{st} & 2^{nd} generations) and literature reviews, the four widely utilizes tools has evolved table (5) illustrates a comparison based on important factors consider a context to select an appropriate tool for the of human error probability, to assess quantitative risk. Consequently, the choice of the proper tool of assessing human errors for a certain task, should base on accessible data. The chosen tool applies by experts in the field, so it should be accurate and complete results with flexibility in practical application and this matter reveals a fact “the determination of human errors probability is an integration of art, science and practical experience”. (Maddah et al, 2015)

Table 5: Comparison Between Commonly Utilizes HRA Tools “Through Elastic Criteria”

Tools				Factors	Criteria
1st Generation		2nd Generation			
THERP	HEART	CREAM	ATHENA		
1	1	1	2	Number of assessors	Resources required
High	low	High	High	Time consideration	
*	*	*		Job descriptions	Output through the assessment period time
			*	Describes the background	
			*	Analytic Model	
		*	*	Experts judgement	
			*	Scenario descriptions	The assessment output
		*		Task analysis	
			*	Error type	
				Outcomes (results) errors	
		*	*	Psychological considerations	
		*		Probability of human error	
		*		Risk or success/ failure process	
				Opportunities to compensate for the error	
				Proposals or strategies to reduce and prevent errors	
		*	*	Screening	

To assessment human action to expect errors probability occurrence for a certain task, it is essential to select the proper HRA tool. There are pragmatic criteria, which are precise and accurate to select HRA tool to quantifying errors as following:

- The accuracy in defining the risks
- Comprehensive method
- Compatibility
- The resources required for the process
- Outputs during the period of assessment and final outcomes.(NEA, 2015)

However, HRA tools are critical elements of PRAs since the tool used to assess the effects of various phases of human performance on risk; they have limitations in assessing human action. The basic limitations are insufficient data, operational limitations related to prejudice of assessment and expert judgment, and uncertainty concerning the actual behavior of human element particularly during accident conditions.

HRA and High-Risk Maritime Domains

The maritime domains is the sort of work performed on board any kind of vessel. It is probable to describe five maritime work tasks:

- Navigation.
- Propulsion.
- Cargo handling (including passengers).
- Platform maintenance.
- Ship management. (Koester, 1999)

Human factor plays an important role in the safety of various maritime operation even on board ships (shipboard operations) or on shore operations. Applying a HRA tools to control the human errors before high-risk maritime operations, require decision-making errors made before such operations.

The development of maritime modern technology, human work has changed as well, from manual skills to more cognitive nature, also the first generation of HRA offerings some deficiencies, mentioned before, so HRA tools/methods must be updated. Second-generation human reliability assessment tools that developed in order to overcome the deficiencies in first generation are appropriate since they can assess cognitive processes tools such as CREAM an examples of second-generation human reliability assessment. CREAM specifically is a flexible tool/method; it has been applied for some maritime domains and for general working tasks.

The International Maritime Organization IMO in the guidelines of Formal Safety Assessment FSA confirmed the utilizing of HRA into FSA process, IMO stated, “The proposed HRA guidance should be used wherever an FSA is conducted on a system which involves human action or intervention which affects system performance”. (IMO, 2002)

Moreover, in the FSA guidelines of IMO, mentioned THERP and HEART, as appropriate tools/methods for maritime field, but Hollnagel, the presenter of second generation HRA methods CREAM, stated that “in modeling human behavior the event tree approach used in THERP does not make sense, because cognitive acts cannot be separated into subtasks as easily as manual actions”. He disapproved the detached use of Performance Shaping Factors PSFs that would submit context independency, so the effects of context on human behavior should include in a model identifying human performance. (Hollnagel, 1998)

HRA CREAM tool is suitable for maritime operations, because the tool can utilize with both qualitative and quantitative data to influence safety measures of maritime operations, and the limitation of CPCs can be used to predict the potential human errors of critical maritime operations/Tasks in progress (prospective)

The identification of the nine CPCs in both basic and extended methods of prospective quantification could use as questionnaire to judge the levels of CPCs by experts, so in some high risk critical operation, task required to be judged to get accurately CPCs levels. CREAM built on Cognitive Control Model based on four control modes depending on time-availability and context of the operation.

CONCLUSIONS

Statistics of 2015, reveal the increase the rate of accident due to human errors, even with the power of the international treaties held by IMO, it is a clue declares that human actions (reliability) in need to assess because human factor plays a main part in maritime causalities, and to reduce the plausible operational human failure. The paper illustrates the Human Reliability Assessment- HRA different tools with its first and second generations, its importance as probabilistic risk assessments PRA, and HRA process. In addition to an example for both generations, and comparison between commonly utilizes HRA tools “over compliant criteria” that could help assessor to choose a proper tool/ method for a certain task. Moreover, the study shows the suitability of the second-generation HRA tools for maritime operations tasks particularly HRA CREAM, which is a flexible tool, and the model include cognitive acts to subtasks providing detailed assessment of context and therefore gives complex depiction that meets the requirement of maritime domains.

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