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RELIABILITY ASSESSMENT OF ARCTIC EER SYSTEMS

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ABSTRACT

Methodologies for the assessment of offshore installation EER systems have been developed utilizing various risk analytic network and simulation approaches. In this paper, the extension of a highly developed network and Monte Carlo simulation methodology to consider Arctic ice conditions impact on the emergency escape, evacuation, and rescue from floating and bottom founded installations is described. Essentially, open water EER simulation is augmented by the inclusion of cold weather and ice conditions together with estimates of their effects on human and mechanical performance of the EER system and its components. Following a description of the EER simulation principles and processes, selected Arctic and open water scenarios are described and representative results of reliabilities of different EER system configurations under a range of open water and Arctic conditions are presented. Conclusions and recommendations for further work are given.

INTRODUCTION

Current focus in the regulatory, design, and operational areas on performance rather than prescription has augmented the need for tools for the assessment of performance characteristics (Bercha 2004, 2003a). Such performance characteristics include reliability, availability, risk, and safety. Both human and mechanical performance and its interaction must be considered. There is a paucity of full-scale data even for controlled EER operations such as evacuation trials, and only anecdotal accounts of such operations for emergency situations exist. Accordingly, quantification of performance targets for emergency situations needs to be carried out largely analytically usually utilizing computer simulation techniques. The same applies even more emphatically for polar EER emergencies. No publicly available full-scale, even drill, data for EER in ice conditions exist. To keep pace with the current development of Arctic EER performance-based standards (Bercha 2003a, 2004), there is an increased demand for ways of quantifying and setting realistic but safe performance goals for all aspects of escape, evacuation, and rescue.

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EER PERFORMANCE ASSESSMENT

The principal steps of EER modeling are illustrated in the block diagram in Figure 1. Essentially, following assimilation of data (Step 1) and assessment of the key accident scenarios (Step 2) the modeling of the escape process (Step 3) is conducted. The escape process entails movement of personnel from their location at the time of the alarm to a Temporary Refuge (TR) or muster point. The evacuation process (Step 4) entails movement from the TR to a lifeboat or other device, and its launch and movement to a safe distance from the installation or vessel. Step 5 involves the rescue, which consists of survival until a rescue platform is available and subsequent transfer of evacuees to that rescue platform. In the final step (Step 6), the results of the individual component models are integrated to give an overall EER reliability or success probability for the EER system.

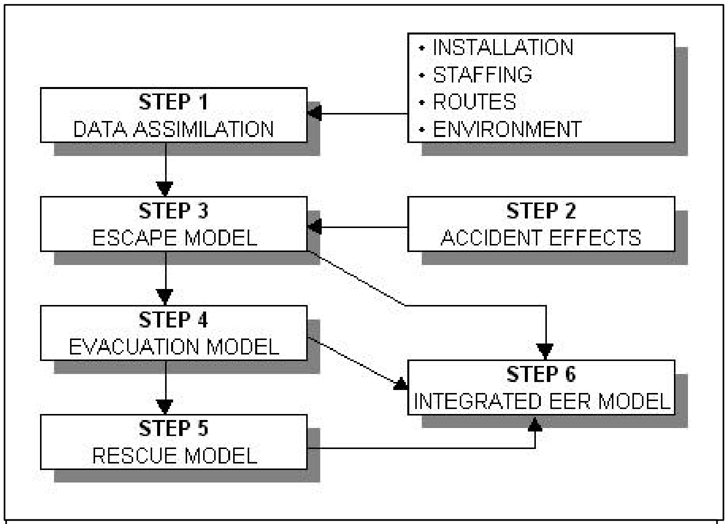

Figure 1: EER Model Schematic

There are two principal approaches to the assessment of the reliability of a complex process such as marine EER; simulation and risk analysis. Risk analysis is effective for the definition of failures or faults, while simulation is effective for modeling time sequences of different operations in order to provide an understanding of their interaction. An optimal combination of the two has been applied in the approach described herein (Bercha, 2004b; Bercha et al., 1999).

The architecture of the software generally follows the EER modeling structure described in Figure 1 and depicted schematically in Figure 2. This figure is also the opening screen of the model in its current form. The principal modules are aligned in vertical layers, and include global, escape, evacuation, rescue, and integrated modules. These main modules each have layers of Inputs, Parameters, Analysis, and Outputs.

Inputs are user-defined quantities which characterize each unique combination of characteristics including installation geometry, weather patterns, available evacuation modes, available rescue modes, and number of people and level of emergency, to name a few. Parameters are quantities which characterize the risk and performance of a given EER system under (input) specified conditions. Examples of parameters in the human factors (HF) area include the speed with which personnel move along different portions of escape routes such as walkways, stairs, ladders, and the error rate when a decision has to be made (Bercha et al., 2003). Mechanical failure parameters, on the other hand, pertain to availability and failure of components or systems on demand. Because human performance is often ignored in marine system reliability evaluation, a section below is dedicated to this subject. The parameters are the most important determinants of results for a given simulation; they have been judiciously selected from optimal sources; where available parameters were found to be statistically inadequate, experiments or research was conducted to evaluate them. Next, the analysis stratum applies algorithms to characterize the risk and performance time of each step and their synergistic effect. Finally, outputs present these results as tables and graphs for each step and their integrated results for a specified set of circumstances.

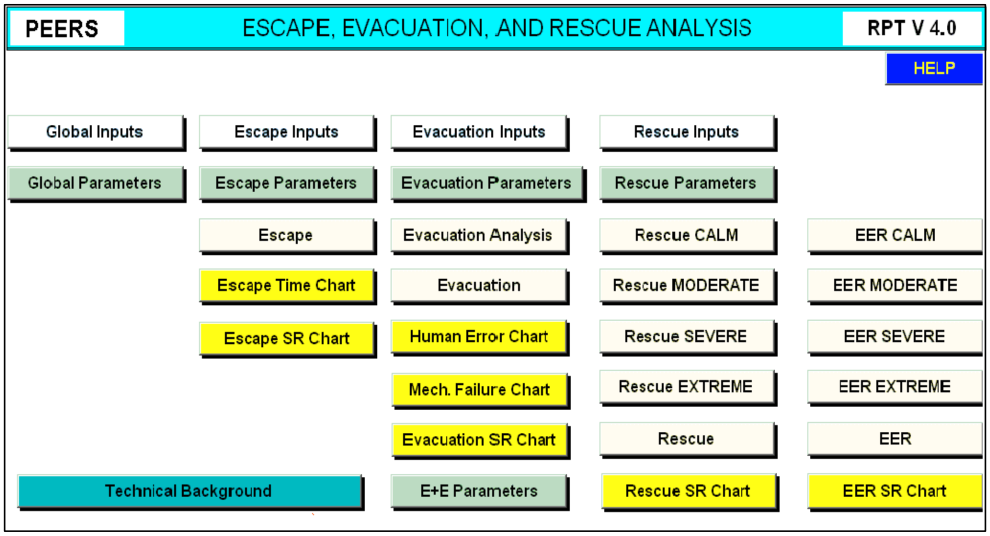

Figure 2: Model Architecture

Specific definitions of key concepts used in this EER assessment are as follows:

- Availability - The probability that a system is capable of commencing performance when required.
- Reliability - The probability that a process, task, or activity will be successfully completed (no casualties) at any and all required stages (in a system operation when the system is available) within a required time limit (if a time limit exists).
- Success - The achievement of a process or operation without incurring one or more casualties. Success considers both availability and reliability.

HUMAN PERFORMANCE ANALYSIS

Human reliability analysis was extensively developed in the late 1950s, 1960s, and 1970s under the auspices of the U.S. Nuclear Regulatory Commission, by a variety of investigators including Swain (1963), Swain and Guttman (1983), and others (Rasmussen, 1982; Rasmussen & Pedersen, 1984). In these works, human reliability has been defined as the probability that a person correctly performs some system required activity in a required time period (if time is a limiting factor), and performs no extraneous activity that can degrade the system or the process.

Human performance is defined as the way in which a human being carries out or attempts to carry out a given task. This definition applies for the type of macro modeling of processes, tasks, and activities applicable to EER analysis. Human performance, then, for the purposes of reliability analysis as described above, has two primary components; namely, reliability or lack of mistakes with which the task is carried out, and second, the time over which the task is carried out.

One of the most influential factors influencing human performance reliability is stress. Montagne, a French essayist in the late 1500s noted “men under stress are fools, and fool themselves”. This quotation reflects a commonly held view that stress is undesirable. In fact, it has been shown that the relationship between human performance and stress is non-linear – too little stress and too much stress both lead to less than optimum or deficient performance. The classical stress curve in Figure 3 (NUREG-75 WASH-1400, 1975) indicates that performance follows a curvilinear relationship with stress, from very low to extremely high.

The effects of the first three levels of stress can be approximated by applying modifying factors to human error probability (HEP) in the EER model. The fourth level, threat stress, is qualitatively different from the other three levels – the effects of this level of stress will outweigh other performance shaping factors (HSE, 1997). A summary set of guidelines for estimating HEPs for various types of tasks as a function of stress level is presented in Table 1. The change in HEP effects with time elapsed following a high stress situation is also quantifiable (Rasmussen et al., 1984), but is not explicitly needed here.

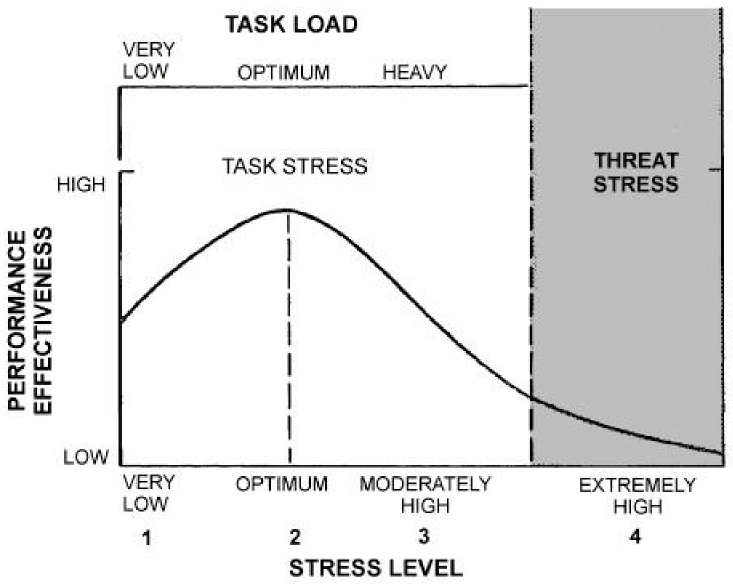

Figure 3: Hypothetical Relationship Between Performance and Stress with Task Stress and Threat Stress Division

ARCTIC EFFECTS ON HUMAN PERFORMANCE

In the context of the previous section, the stresses imposed by an Arctic environment can be considered as stressors, with their severity varying in proportion to the threat level of the EER and the severity of the environmental effects. Table 2 summarizes unique aspects of the Arctic which create stressors on human performance.

In general, these stressors can be classified in accordance with the stress levels indicated in Table 1. In a moderate set of Arctic conditions, the stress levels will be largely dominated by the operational and accident conditions, however, as the severity of the environment increases to an extreme condition such as an Arctic storm, the stress level can be considered extremely high, with the associated factors for modifying human error probability ranging up to a level of two orders of magnitude or 100.

The fact that cold alone does not greatly impair human performance was confirmed by low stress cold weather escape and evacuation performance experiments conducted by the authors (Bercha et al, 2001). There was no discernable difference in performance; in fact, the performance was slightly better under the colder conditions, perhaps because stress levels were slightly elevated from low to optimum as discussed above.

In the rescue component, however, which consists of a survival and a transfer sub-component, the cold temperatures associated with an Arctic environment will greatly decrease survival times if the evacuees are not properly protected and provisioned.

Table 1: Modifications of HEPs for the Effects of Stress on Skilled Personnel[1]

Item	**Stress Level**	**Factors for Modifying HEPs**		
		Low	**Exp.**	**High**
1	▪ Very Low (Very Low Task Load) ▪ Optimum (Optimum Task Load)	1	2	4
2	▪ Step-by-Step[2]	1	1	2
3	▪ Dynamic[3] ▪ Moderately High (Heavy Task Load)	1	1	2
4	▪ Step-by-Step	1	2	3
5	▪ Dynamic ▪ Extremely High (Threat Stress)	3	5-10	100
6	▪ Step-by-Step	2	5	20

[1] A skilled person is one with 6 months or more experience in the tasks being assessed. The “High” values can be used for novices as a first approximation.

[2] Step-by-step tasks are routine, procedurally guided tasks, such as carrying out written calibration procedures.

[3] Dynamic tasks require a higher degree of man-machine interaction, such as decision-making, keeping track of several functions, controlling several functions, or any combination of these.

Table 2: Arctic Effects on Human Performance

Stressor	**Details**
Cold Temperature	▪ Breathing difficulty
	▪ Muscular stiffness
	▪ Frost bite
	▪ Lowered metabolism
	▪ Hypothermia
	▪ Bulky clothing
	▪ Stiffness of suits impairing movement
Ice Adfreeze	▪ Incapacitates mechanisms
	▪ Slippery surfaces
	▪ Adds weight/mass
Combined Weather Effects	▪ Wind, snow, waves-impair HP
Marine Ice	▪ Precludes rapid descent to sea level
	▪ Can fracture if walked on
Low Visibility	▪ Ice fog, lack of solar radiation
	▪ Frosting on windows, visors, glasses
Threat Stress	▪ Fear of unknown
	▪ Disorientation

ARCTIC EFFECTS ON MECHANICAL PERFORMANCE

Current EER systems function in open water with varying reliability depending on the severity of weather conditions. Factors which need to be incorporated in Arctic EER systems, specifically for Arctic evacuation, are summarized in Table 3.

Table 3: Arctic Evacuation Problems

▪ Very cold. Adfreezing snow/ice obstructing mechanisms and causing slippage.
▪ No free fall or fast descent system due to ice.
▪ Ice conditions variable – dynamics and ice fraction can change quickly.
▪ Ice pressure, ride-up, adfreeze, pileup.
▪ Ice movement direction unpredictable.
▪ Visibility bad often – fog/Arctic winter.
▪ Damage to capsule greatly decreases survival.
▪ Thermoplastic behaviour of materials usually adversely affected in cold.
▪ Inflated components lose pressure as gas contracts in cold.
▪ Arctic system must also work for open water.

Escape on Polar Installations

The process of escape on installations under polar winter conditions, is not significantly different from that on installations in temperate frontier regions. Its optimization requires no new technologies, rather only cold weather provisions such as non-slip surfaces, heat traced walkways or ladders, or wind and snow barriers.

Evacuation from Polar Installations

The conventional evacuation process needs to be significantly altered to ensure safe evacuation of ships or installations in ice as described by Bercha (2004, 2003b, 2000). For lifeboats, alterations are needed both in the launch method and in the craft configuration while still maintaining the requisite IMO open water capability. Other methods of evacuation such as chutes, gondolas, inflatable carpets, also need significant modifications to adapt to polar conditions. A launch mechanism that can accommodate both the installation geometry and all expected ice conditions, including pile-ups, is needed.

Rescue After Evacuation from Polar Installations

Rescue consists of the survival of the evacuees and their transfer to a safe haven. A lifeboat hull needs to maintain integrity in pressured broken ice. On the ice, the vessel needs to maintain upright stability and to propel itself on the ice surface away from the installation, which could be on fire or about to explode. A simple adaptation is the provision of sled runners together with a winching mechanism, powered by either the lifeboat engine or a battery operated winch, so that the boat could winch itself to a pylon or anchor which would be deployed by appropriately qualified crew (Bercha, 2003).

RELIABILITY ASSESSMENT RESULTS FOR ARCTIC EER

The EER performance assessment process described earlier was applied to the evaluation of human and mechanical performance and its integrated effect in three representative EER scenarios as follows:

- Arctic EER using current technology.
- Arctic EER using enhanced technology.

- Non-Arctic EER using current technology.

Due to the complexity of the model, only sample and bottom line results are shown herein. A detailed discussion of the modeling steps and results is given in Bercha (2004b).

Table 4 gives a summary of the results. The resultant quantities are the human failure casualty probability (HF), the mechanical failure casualty probability (MF), and the resultant success rate (SR) in percentages. For evacuation they are shown for each of the four environmental severity conditions under weighted average as well for the weighted average (WA) for the total EER process consisting of the three components. The significance of the results is summarized in the conclusions.

Table 4: Summary of Human Factors Contributions to Arctic Evacuation and EER Reliability (All numbers are %)

		Evacuation					EER
		Calm	Moderate	Severe	Extreme	Evac. WA	EER WA
Non-Arctic	HF	1	2	36	90	7	
	MF	1	1	20	90	4	
	SR	99	96	43	10	89	70
Arctic Current	HF	1	4	54	90	11	
	MF	27	81	89	90	62	
	SR	71	14	9	10	52	28
Arctic Enhanced	HF	1	4	52	90	10	
	MF	1	1	20	90	4	
	SR	98	95	27	10	87	66

CONCLUSIONS

The following conclusions can be summarized from the work conducted:

- Assessment of polar EER system reliability can currently be carried out with available analytical techniques described in this paper.
- Although human performance plays a factor in the success of Arctic EER, its contribution is overshadowed by the shortcomings of available technological and mechanical systems to support the EER.
- Current open water technology applied to Arctic EER has an unacceptably high failure rate (72%). The mechanical failure rate of current technology in Arctic applications far outweighs the effects of human performance failure, by a factor of 5 to 1 (62 to 11).
- If advanced technologies are developed and implemented for Arctic EER, EER success rates (66) can be expected to be very similar to those of open water EER success rates (70).
- In both enhanced technology Arctic EER and current technology non-Arctic EER, human factors play a major role in success, out weighing the importance of mechanical performance – a factor of roughly 2 to 1.
- Because human performance can be enhanced through appropriate training, such training is recommended for all EER, whether based on Arctic-enhanced or current non-Arctic technology.

- Although Arctic-enhanced technologies can provide EER success rates comparable to those expected for open water applications, the conclusions above are based on speculative technologies that have not yet been developed and certainly can not be said to be proven.
- Current open water EER procedures and technologies would yield unacceptably low EER success rates (28) regardless of the level of human performance.

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