Human Performance in Arctic Offshore Escape, Evacuation, and Rescue

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ABSTRACT

As part of a comprehensive escape, evacuation, and rescue (EER) research program sponsored by the Transportation Development Centre of Transport Canada, the co-authors have investigated human performance under extreme conditions involving physical and mental stress. Part of the work focused on personnel performance in emergency evacuation situations causing extreme mental stress from offshore accident conditions, with Arctic environmental conditions also adding extreme physical stress. Because only limited and anecdotal data on human performance under such extreme conditions are available, and dedicated experiments would clearly be unacceptable, analysis of human performance under life-threatening conditions has been approached through the development of a computer model based on data from the literature giving unit error rates and times of performance, and on discussions with experts. The paper presents the background, methodology, computer program description, and gives examples of several different Arctic EER scenarios analysed and selected comparative non-Arctic scenario results.

KEY WORDS: Escape; evacuation; rescue; EER, Arctic; offshore; human performance.

INTRODUCTION

Successful marine emergency escape, evacuation, and rescue (EER) is achieved through an effective and efficient interaction of the evacuees' human performance and the mechanical performance of the physical EER system. Whether the emergency site is in Arctic or temperate regions, moderate or extreme environment, in the form of a vessel or a gravity based structure (GBS), the accident threat is a fire or explosion, or a structural or buoyancy failure, the EER success is always predicated on these two elements – the human and mechanical performances. Without a fit for function physical EER system, human performance becomes an act of brute survival – running, jumping, swimming, and fighting hypothermia. So, the subject here is not on human performance alone, but rather on the modeling of the interaction between humans and EER physical systems.

In the Arctic, just as for the non-Arctic regions, this applies equally; since EER success depends on the adequacy of the interaction between machines and humans. When we say "machines" or "mechanical" in this paper, the term is used in its broad context to include all non-human components including machinery, structures, electrical and electronic systems, communications, and software. But if the success of EER in the Arctic depends on the adequacy of the interaction between machines and humans, there is a problem. This problem is that there are no approved operational evacuation systems for ice covered waters. Although the author has published extensively on the technological approaches to Arctic EER systems (Bercha, 2002, 2001, 1995; Bercha et al, 1999, 2001, 2000a, 2000b; Cremers et al, 2001), no known operational systems have been identified to date. Usually, technology moves ahead of human factors; ironically, here, the opposite is true. Although some work has been published on Arctic human performance (Bercha et al, 2000b; Canadian Marine Drilling, 1982; Cremers et al, 2001), very little beyond what is cited above, has been published on the technological side.

If we were to restrict our discussion here to current approved EER technology used in the Arctic, this paper would be very short and simple; it would show that regardless of human performance, Arctic EER success rates can be expected to be very low, close to 50%. Thus, the authors will also allow speculation, and select some of the EER systems conceptualized in the above-cited references, with fit-for-purpose design giving a reasonable probability of EER success in the Arctic emergency context. Accordingly, in the balance of this paper, following a brief discussion on the fundamentals of human and mechanical performance concepts and EER modeling, results of applying these techniques to three scenarios will be presented. These will be ones in which human performance is based on interaction with currently approved technology, one in which it is based on the interaction with enhanced EER technology in the Arctic, and the third based on current technology in the non-Arctic setting.

HUMAN PERFORMANCE FUNDAMENTALS

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; Rasmussen et al, 1988, 1994).

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 the RPT. Human performance, then, for the purposes of reliability analysis, 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.

A *task* can be an individual action, an activity consisting of several actions, or a process such as launching a lifeboat, consisting of a series of activities.

Human error is defined as any member of a set of human actions that exceeds some limit of acceptability. *Human error probability* (HEP) is the probability that an error will occur when a given task is performed. Human error probability should be considered synonymous with human failure probability or human task failure probability.

A *stressor* is any external or internal force that has an impact on human performance.

Human reliability analysis (HRA) is a method by which human reliability is estimated in quantitative terms. In carrying out an HRA, it is necessary to identify those human actions that have an effect on process reliability or availability. The most common application of HRA is the evaluation of human performance required within a system or process concept. Methods developed by Swain and Guttman (1983), and other investigators (Rasmussen, 1985; Rasmussen et al, 1988) for solving practical human reliability problems is known as the Technique for Human Error Rate Prediction (THERP). It is this technique that has been substantially adopted as a basis for the current model for the more explicit inclusion of human factors effects.

The EER model (Bercha & Cerovšek, 1997; Bercha et al, 1999; Bercha Engineering, 2001) is essentially a probabilistic risk assessment and time simulation model. A model of a system, generally speaking, is a mathematical abstraction that symbolically reproduces or simulates the way in which the system functions operationally. In modeling human performance as part of a model, it is necessary to consider those factors that have the most effect on performance. Many factors affect human performance in a complex human-mechanism system, such as the EER process. Some of these Performance-Shaping Factors (PSS) are external to the person and some are internal. The external PSS include the entire work environment, including weather, noise, geometry of installation, as well as the equipment design and the written procedures or oral instructions. The internal PSS represent the individual characteristics of the person, his skills, motivations, and expectations that influence his performance. Psychological and physiological stresses result from a work environment in which the demands placed on the operator by the system or process do not conform to his capabilities and limitations.

One of the most influential factors 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 (Swain & Guttman, 1983; Rasmussen et al, 1988, 1994) 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. Some in-between level of stress is necessary to provide sufficient arousal to perform reliably. It is the relationship between stress of both or either psychological or physiological nature and human performance as described below, that is the primary focus of the current sub-project.

The classical stress curve in Figure 1 (NUREG-75 WASH-1400, 1975) indicates that performance follows a curvilinear relationship with stress, from very low to extremely high. For HRA, it is adequate to represent the entire continuum of stress by only four levels. The levels we have used throughout the Handbook are as follows:

- Very Low - Insufficient arousal to keep alert.
- Optimum - The facilitative level.
- Moderately High - Slightly to moderately disruptive.
- Extremely High - Very disruptive.

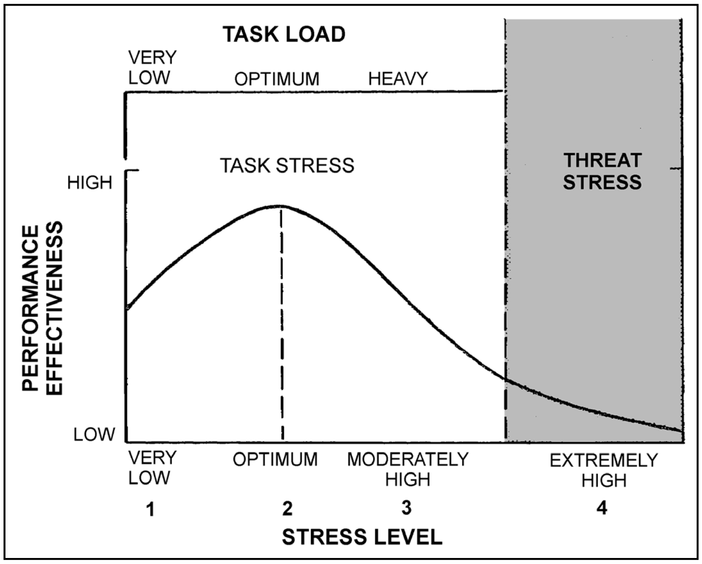

Figure 1
Hypothetical Relationship Between Performance and Stress with Task Stress and Threat Stress Division

For HRA purposes, we consider the moderately high level of stress to be moderately (rather than slightly) disruptive. We use the term *high stress* to include both moderately high and extremely high levels of stress.

In this work, we have used four levels of stress, but we designate them differently for explanatory purposes. The first three levels are attributed to the *task load*, and the fourth level is attributed to feelings of threat. The four levels are as follows:

1. Very Low Task Load - Insufficient *arousal* to keep alert.
2. Optimum Task Load - The facilitative level.
3. Heavy Task Load - Approaches or exceeds the human's normal capacity, moderately disruptive.
4. Threat Stress - Implies emotional reactions, very disruptive.

The effects of the first three levels of stress can be approximated by applying modifying factors to the HEPs in the RPT. The fourth level of stress is qualitatively different from the other three levels – the effects of this level of stress will outweigh other *performance shaping factors* (PSFs). For this reason, a different set of HEPs is assigned to the threat stress situation. A summary set of guidelines for estimating HEPs for various types of tasks as a function of stress level is presented in Table 1.

Table 1. Modifications of estimated 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

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[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. These requirements are the basis of the distinction between step-by-step tasks and dynamic tasks, which are often involved in responding to an abnormal event.

Figure 2 shows estimates of HEP as a function of time after the onset of the accident.

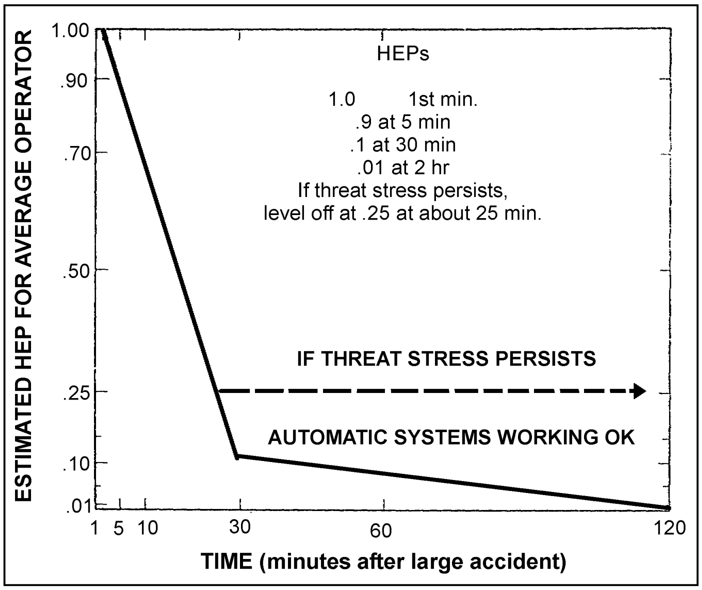


Figure 2
Estimated Human Performance After a Large Accident

The rationale for the curve was explained as follows (NUREG-75/014 WASH-1400, 1975):

> "Following an accident, human reliability would be low, not only because of the stress involved, but also because of a probable incredulity response. Among the operating personnel the probability of occurrence of a large accident is believed to be so low that, for some moments, a potential response would likely be to disbelieve indications. Under such conditions it is estimated that no action at all might be taken for at least one minute and that if any action is taken it would likely be inappropriate.
>
> With regard to the performance curve, in the study the general error (probability) was assessed to be .9 five minutes after a large accident, to .1 after thirty minutes, and to .01 after several hours. It is estimated that by seven days after a large accident there would be a complete recovery to a normal, steady-state condition and that normal error (probabilities) for individual behaviour would apply."

The solid 1ine in Figure 2 indicates the estimated HEPs that apply if the personnel are trained to mitigate the effects of the accident. Otherwise, threat stress is assumed, as shown by the dashed line, and the error probability will not decrease below the value of .25 as long as the threat stress conditions persist. The wide uncertainty bounds around the .25 estimate (.05 to 1.0) allow for some individuals to perform well and for others "to be a part of the problem."

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 themselves. Table 2 summarizes the unique aspects of the Arctic which create stressors on human performance.

Table 2. Arctic human performance stressors

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

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 human performance experiments conducted by the authors (Bercha et al, 2001). Here, groups of subjects conducted simple EER procedures, such as walking along external and internal walkways, up and down stairways, up and down ladders, through hatches, and into survival craft under moderately warm and moderately cold conditions. There was no discernable difference in their 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. Thus, the primary impact of the Arctic effects on human performance in escape and evacuation relate to psychological stress levels and not physical stressors.

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.

EER MODELING

The principal steps of EER modeling are illustrated in the block diagram in Figure 3. 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 Safe Refuge (TSR) or muster point. The evacuation process (Step 4) entails movement from the TSR 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 model, which takes into consideration the environmental conditions, available rescue modes such as helicopters, standby vessels, other ship traffic, or nearby land or harbour locations. In the final step (Step 6), the results of the individual component models are integrated to give an overall EER reliability of success probability rating for the emergency systems.

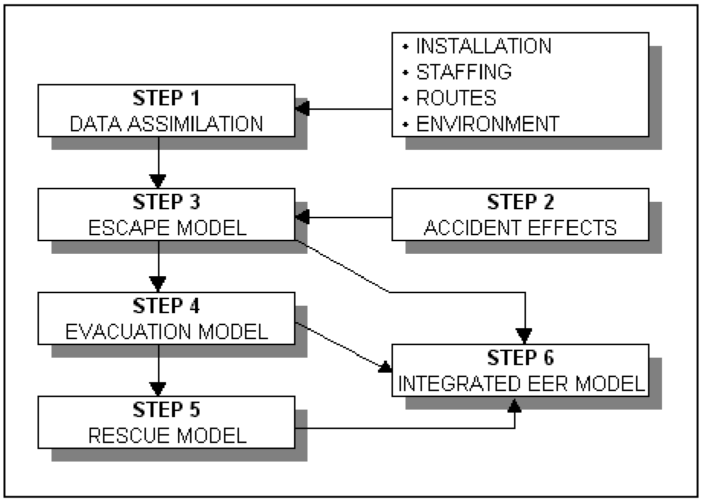


Figure 3
EER Model Schematic

There are two principal approaches to the assessment of the reliability of a complex process such as marine EER. These two approaches are simulation and risk analysis. In system simulation, a model of the continuous operation of different alternative operational modes of a system is utilized. Each operation, whether deleterious or not, is included in a simulation model. In risk analysis, on the other hand, only the errors or faults of a system are analyzed, yielding a casualty probability or risk assessment. In order to properly understand the reliability of the operation of a system, it is desirable to combine both risk assessment and simulation modeling to obtain a complete picture of the system. 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. Thus, risk analysis, which does not simulate the continuous operation of the system, but rather is restricted to the analysis of errors or faults, is applied for the latter function, the modeling of system failures. An optimal combination of the two has been applied as a basis for the development of the model described herein (Bercha Engineering, 2001; Bercha et al, 1999), and called the Risk and Performance Tool (RPT).

The architecture of the RPT (Bercha Engineering, 2001; Bercha et al, 1999) generally follows the EER modeling structure described in Figure 3 and depicted schematically in Figure 4. This figure is also the opening screen of the RPT in its current form. The principal modules are aligned in vertical layers, and include global, escape, evacuation, rescue, and integrated modules. The main modules, escape, evacuation, and rescue, each have the following layers:

- Inputs
- Parameters
- Analysis
- Outputs

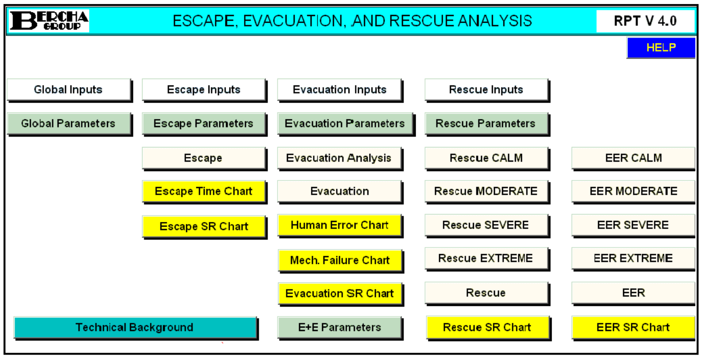


Figure 4
System Architecture

Inputs are user-defined quantities which characterize each unique combination of vessel platform 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 effect on this rate of movement of different numbers of individuals in a group, the level of emergency, and impediments such as smoke, debris, or cold weather and icing. The parameters are the most important determinants of results for a given situation; they have been judiciously selected from optimal sources; where available parameters were found to be statistically inadequate, experiments ore research were conducted to evaluate them. 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, distributions, and histograms for each step and their integrated results for a specified set of circumstances. In the analyses that follow for Arctic EER scenarios, some of the RPT outputs relating to human performance will be used to display the results.

CURRENT ARCTIC EER SYSTEMS

Current EER systems function in open water with varying reliability depending on the severity of weather conditions. Factors which would need to be incorporated in Arctic EER systems, specifically for Arctic evacuation, are summarized in Table 3. Because of feasibility considerations, Arctic systems must also qualify for open water operation; this eliminates specialized amphibious vehicle systems. A rudimentary adaptation of procedures for Arctic problems was attempted in the Tarsuit Island evacuation plan (Canadian Marine Drilling, 1982). Essentially, very rudimentary provisions as follows were made for the escape:

> "If the emergency is a fire in the accommodation, personnel in their rooms may be required to exit through the window and down the exterior ladder. Note that a chair is supplied in each room and is to be used to break the window. The chair can then be used to climb out of the window."

In a life threatening emergency, or even under mild stress, breaking a window and climbing through it can be hazardous. It is not a normally repeatable procedure for training purposes. Escape, thus, is likely to be a very low success probability procedure. Similarly, for the evacuation:

> "If aircraft or rescue vessels have not reached the Island, evacuation nets which are placed on the north, the west, the south and the east sides of the Island will be used to climb down the side of the caissons.
>
> Six (6) twenty-five man rafts will be supplied on the Island and will be used in an open-water, or mixed ice and open water evacuation. If there is sufficient ice cover the evacuation will be done over the ice on foot.
>
> Basic shelter and sustenance would be supplied in emergency packs to maintain the Island personnel on the ice or in the rafts for several days."

Here consideration to freeze-up of nets, possible dynamic pack ice (with open water) below, and the process of scrambling down the net (if it unfurls), is lacking. The above simply does not provide a satisfactory evacuation plan—again a low success probability.

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.
▪ Arctic system must also work for open water.

ENHANCED ARCTIC EER SYSTEMS

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. The escape process, by definition, is restricted to activities on the installation. Escape along outdoor walkways, stairways, and ladders may be hampered by accumulating snow, adfreezing ice, and low visibility and strong winds, but require 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. 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, but the discussion here will be restricted to lifeboats, the most common form of evacuation craft. The launch must safely transfer the loaded lifeboat from the installation to the ice surface or into the ice lead. An indoor, heated stowage location is preferable to ensure that all mechanisms are not impaired by ice or snow buildup. The orientation and location with respect to prevailing wind and ice motion must also be considered. One prevailing lee and one upwind location, each with 100% capacity, is favoured. A launch mechanism that can accommodate both the installation geometry and all expected ice conditions, including pile-ups, is needed. Figure 5 shows different conceptual designs intended to effect safe and reliable evacuation utilizing a TEMPSC or lifeboat. As can be seen, the concepts have been designed around a typical GBS with a sloped ice wall, requiring the launch mechanism to deposit the craft well beyond the toe of the ice wall or pile-up at the ice or water surface.

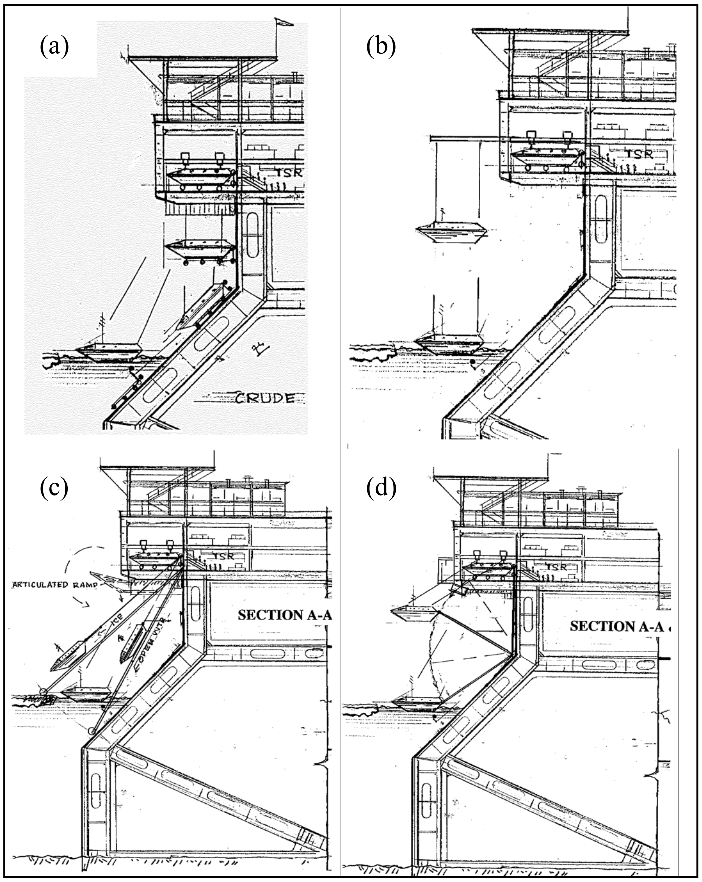


Figure 5
Conceptual Designs: (a) Portal, (b) Telescoping Boom, (c) Articulating Ramp, (d) Modified Boom

All of the concepts employ an indoor-stowed lifeboat, with various launching mechanisms. The relative simplicity, stowage, and craft and launch mechanism shown in Figure 5(b) make this an optimal candidate for more detailed engineering, which is ongoing at this time. Principal reasons for this choice include the simplicity and potential gravity activation of the telescoping sloping boom mechanism, indoor stowage of the entire launch mechanism and craft, and the telescoping boom capable of extending beyond a possible pile-up at the ice-structure interface zone.

Rescue After Evacuation from Polar Installations

The rescue component of EER, as defined above, consists of the survival of the evacuees and their safe transfer to a safe haven. First, consider the craft in pressured broken ice. The Norwegian explorer, Fridtjof Nansen, with the help of his British Naval Architect, Colin Archer, solved this problem in 1890 with the hull design of his vessel, the *Fram*. The efficacy of the design was borne out by the fact that the *Fram* survived pressured Arctic ice in the winters of 1893-95, as well as several subsequent expeditions in later years. Nansen's principle was that "the ship should be pushed upwards by the expanding ice as it froze (or pressured) by giving the hull very rounded lines… flaring out over the ice in the main ice contact belt" (Fram, 2003). An adaptation of the basic lifeboat using the Fram principle is shown in Figure 6(a). Thus, having a slope-sided lifeboat hull would greatly assist in its survival in pressured broken ice. For the on-ice case, the main problem is to maintain upright stability of the vessel, and to permit it to propel itself on the ice surface away from the installation, which could be on fire or about to explode. The simplest 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. Such a concept is illustrated in Figure 6(b). In this case, the primary objective is the clearing away from the potential hazardous installation to a stable location, where the occupants can await a rescue craft. Clearly, there is no limit to the possible on-ice locomotion designs, ranging from the amphibious *ARKTOS*, to the confirmed on- and off-ice reliable but high-energy consumptive air cushioned vehicle lifeboats.

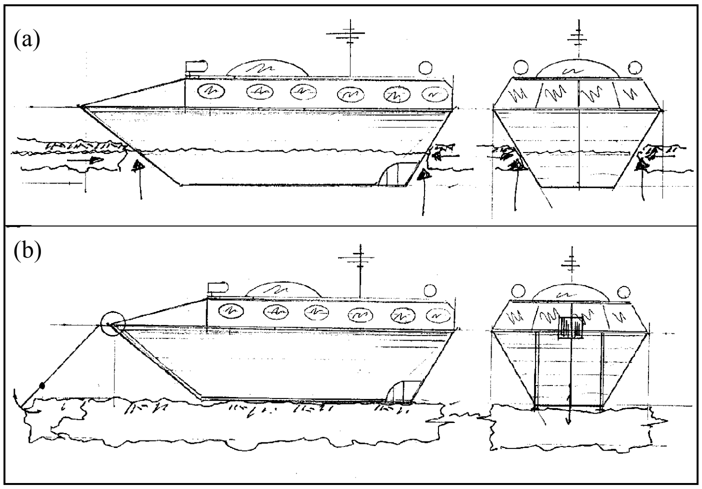


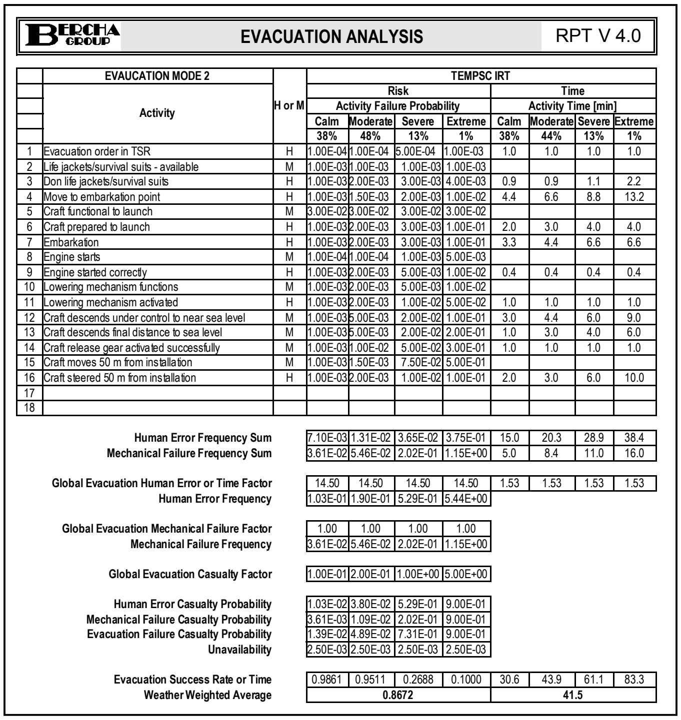
Figure 6
Conceptual Design: (a) Fram Principle IRT, (b) Anchor and Winch Sled

MODELING RESULTS FOR HP IN ARCTIC EER

The RPT described earlier was applied to the evaluation of human and mechanical performance in three 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. Figure 7 shows the evacuation analysis details for the ice-reinforced TEMPSC evacuation. As can be seen, on the left hand side of the results screen is a section on risk, while the right hand side gives the time simulation. Further, all of the activities are divided into those relating to human (H) performance and mechanical (M) performance. The figures given in each element of the matrix under risk are frequencies and probabilities. They are given for a series of characteristic environmental conditions which, for the Arctic case, are based on a combination of ice and weather severity. Time given is simply the activity time in minutes; when it does not exceed a preset limit it remains independent of the risk; when it exceeds a preset limit it begins to exacerbate the failure probability. In the lower end of the table are given a series of results pertaining to various human and mechanical performance measures. The bottom line is the casualty probability. As indicated earlier, the casualty probability is the probability of having one or more casualties. Casualties are serious injuries or fatalities. Success is its inverse, the probability of having no casualties. The weather weighted average is essentially the sum of the probabilities of each weather or ice condition multiplied by the associated success rate or time.



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	EVAUCATION MODE 2		TEMPSC IRT							
	Activity	H or M	Risk				Time			
			Activity Failure Probability				Activity Time [min]			
			Calm	Moderate	Severe	Extreme	Calm	Moderate	Severe	Extreme
			38%	48%	13%	1%	38%	44%	13%	1%
1	Evacuation order in TSR	H	1.00E-04	1.00E-04	5.00E-04	1.00E-03	1.0	1.0	1.0	1.0
2	Life jackets/survival suits - available	M	1.00E-03	1.00E-03	1.00E-03	1.00E-03				
3	Don life jackets/survival suits	H	1.00E-03	2.00E-03	3.00E-03	4.00E-03	0.9	0.9	1.1	2.2
4	Move to embarkation point	H	1.00E-03	1.50E-03	2.00E-03	1.00E-02	4.4	6.6	8.8	13.2
5	Craft functional to launch	M	3.00E-02	3.00E-02	3.00E-02	3.00E-02				
6	Craft prepared to launch	H	1.00E-03	2.00E-03	3.00E-03	1.00E-01	2.0	3.0	4.0	4.0
7	Embarkation	H	1.00E-03	2.00E-03	3.00E-03	1.00E-01	3.3	4.4	6.6	6.6
8	Engine starts	M	1.00E-04	1.00E-04	1.00E-03	5.00E-03				
9	Engine started correctly	H	1.00E-03	2.00E-03	5.00E-03	1.00E-02	0.4	0.4	0.4	0.4
10	Lowering mechanism functions	M	1.00E-03	2.00E-03	5.00E-03	1.00E-02				
11	Lowering mechanism activated	H	1.00E-03	2.00E-03	1.00E-02	5.00E-02	1.0	1.0	1.0	1.0
12	Craft descends under control to near sea level	M	1.00E-03	5.00E-03	2.00E-02	1.00E-01	3.0	4.4	6.0	9.0
13	Craft descends final distance to sea level	M	1.00E-03	5.00E-03	2.00E-02	2.00E-01	1.0	3.0	4.0	6.0
14	Craft release gear activated successfully	M	1.00E-03	1.00E-02	5.00E-02	3.00E-01	1.0	1.0	1.0	1.0
15	Craft moves 50 m from installation	M	1.00E-03	1.50E-03	7.50E-02	5.00E-01				
16	Craft steered 50 m from installation	H	1.00E-03	2.00E-03	1.00E-02	1.00E-01	2.0	3.0	6.0	10.0
17										
18										
	Human Error Frequency Sum		7.10E-03	1.31E-02	3.65E-02	3.75E-01	15.0	20.3	28.9	38.4
	Mechanical Failure Frequency Sum		3.61E-02	5.46E-02	2.02E-01	1.15E+00	5.0	8.4	11.0	16.0
	Global Evacuation Human Error or Time Factor		14.50	14.50	14.50	14.50	1.53	1.53	1.53	1.53
	Human Error Frequency		1.03E-01	1.90E-01	5.29E-01	5.44E+00				
	Global Evacuation Mechanical Failure Factor		1.00	1.00	1.00	1.00				
	Mechanical Failure Frequency		3.61E-02	5.46E-02	2.02E-01	1.15E+00				
	Global Evacuation Casualty Factor		1.00E-01	2.00E-01	1.00E+00	5.00E+00				
	Human Error Casualty Probability		1.03E-02	3.80E-02	5.29E-01	9.00E-01				
	Mechanical Failure Casualty Probability		3.61E-03	1.09E-02	2.02E-01	9.00E-01				
	Evacuation Failure Casualty Probability		1.39E-02	4.89E-02	7.31E-01	9.00E-01				
	Unavailability		2.50E-03	2.50E-03	2.50E-03	2.50E-03				
	Evacuation Success Rate or Time		0.9861	0.9511	0.2688	0.1000	30.6	43.9	61.1	83.3
	Weather Weighted Average		**0.8672**				**41.5**			

Figure 7
Arctic Enhanced Evacuation Analysis

Based on this type of calculation, Table 4 gives a summary of the application of the RPT to the three scenarios considered. Figures 8, 9, and 10 show histograms of the key resultant quantities. These resultant quantities are the human failure casualty probability (HF), the mechanical failure casualty probability (MF), and the success rate (SR). For evacuation they are shown for each of the four weather or ice conditions under weighted average as well for the weighted average (WA) for the total EER process consisting of the three components.

For the current technology scenario under Arctic conditions, as can be seen from Table 4 opposite "Arctic Current" and Figure 8, evacuation and EER weighted averages, respectively, are low at 52% and 28%. However, most of this reduction in success rate is attributable to mechanical failure rather than human failure. It can be seen that for the evacuation, 62% of the failure is attributable to mechanical effects, while only 11% is attributable to human performance. In fact, in comparing the current Arctic human failures with the enhanced Arctic scenario human failures, they are very similar. What differentiates the Arctic enhanced success rates at a relatively high level of 87% and 66% for evacuation and EER, respectively, as shown in Table 4 and Figure 9, is the high level of mechanical performance achieved. The weighted average of the mechanical failure rate in evacuation is only 4%, incidentally, the same as for the non-Arctic mechanical failure rate. Figure 10, finally, shows the non-Arctic scenario analysis results, showing somewhat higher success rates than the Arctic-enhanced, but a similar trend. Here, as in the Arctic-enhanced, the human failure rate contributes roughly twice as much to the evacuation failure as does mechanical failure rate. For the current technology Arctic scenario, the very opposite is the case, with mechanical failure contributing roughly five times as much to the evacuation failure as does human failure.

Table 4. Summary of human factors contributions to Arctic evacuation and EER

		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

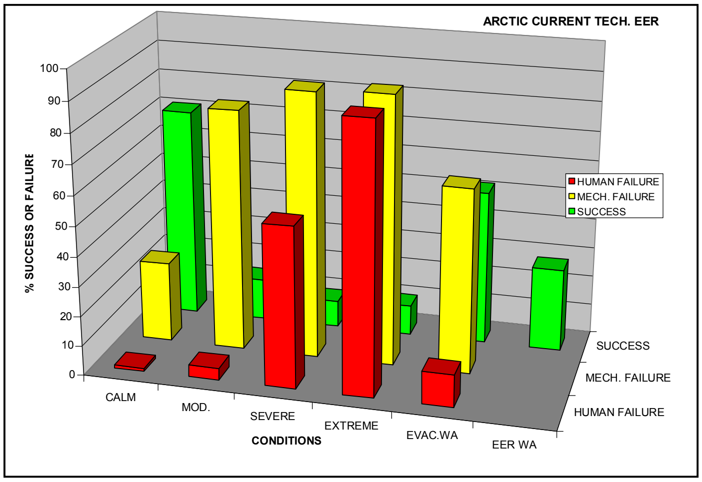

Figure 8
Arctic Current Technology EER Histogram

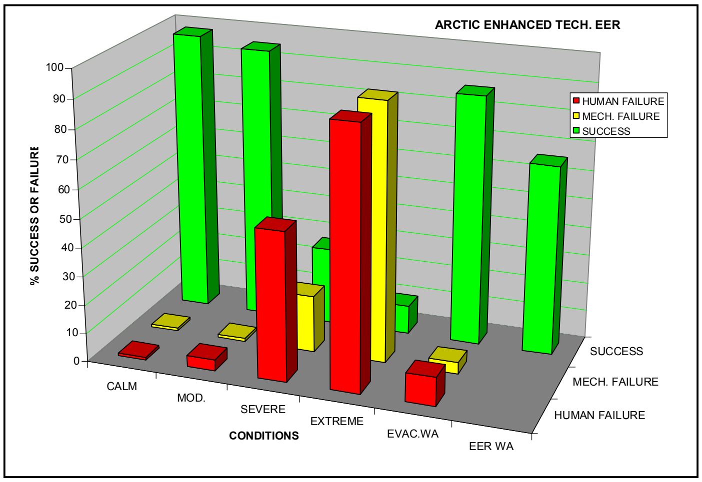

Figure 9
Arctic Enhanced Technology EER Histogram

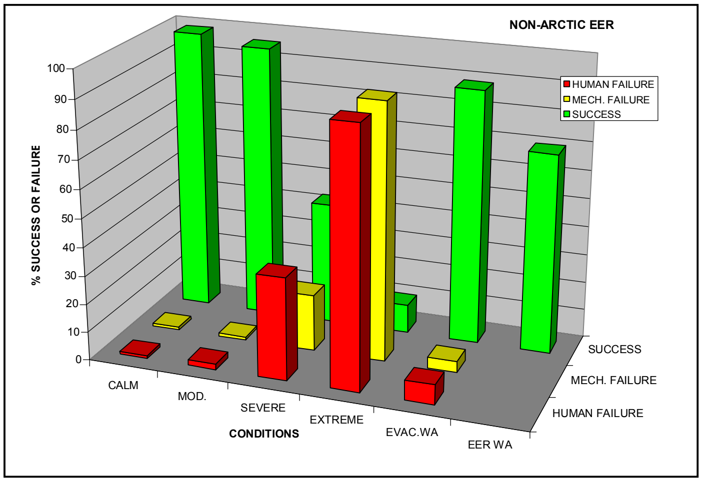

Figure 10
Non-Arctic EER Histogram

CONCLUSIONS

The following conclusions can be summarized from the work conducted:

- 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 failure rate of current technology in Arctic applications far outweighs the effects of human performance failure, by a factor of 5 to 1.
- If advanced technologies are developed and implemented for Arctic EER, EER success rates can be expected to be very similar to those of open water EER success rates.
- 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 this paper shows that it is likely that 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.

What is clear is that current open water EER procedures and technologies would yield unacceptably low EER success rates regardless of the level of human performance. If appropriate Arctic EER technologies are developed and become operational then human factors and associated levels of preparation and training will play a major role in enhancing Arctic EER success.

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