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Assessment of the Reliability of Marine Installation Escape, Evacuation, and Rescue Systems and Procedures

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ABSTRACT

This paper describes analyses developed for the assessment of reliability and performance characteristics of different escape, evacuation, and rescue (EER) components and their integrated performance as an EER system for different offshore installations and operating conditions. In the analyses presented herein, a computerized probabilistic EER simulator (PEERS) in its fourth version called the Risk and Performance Tool (RPT), uses an optimal combination of risk analysis and simulation. Essentially, the RPT simultaneously models the evolution of risks and times of performance for each of the activities, operations, and components, comprising an EER process under given operational, environmental, and accident conditions. In this paper, following a detailed description of the methodology utilized in the development of the RPT including the basis for input data, algorithms, and results, several typical offshore EER configurations for different conditions are analyzed and representative results are presented.

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

INTRODUCTION

Reliable escape, evacuation, and rescue (EER) could have averted or reduced the catastrophic casualty consequences of marine disasters such as the Alexander Kielland, Ocean Ranger, and the Piper Alpha. This statement automatically gives rise to two questions. What is reliable? How much could reliable EER have helped? The initiating events for the above disasters were neither unexpected nor unpredictable, although they were serious. The Piper Alpha marine disaster (Health & Safety Executive, 1997; SINTEF, 1983) was initiated by a relatively small maintenance-related gas leak, which rapidly escalated to encompass the entire installation; emergency procedures are well established for maintenance activities. In the case of the Ocean Ranger (Bercha, 1984), a severe storm caused the unexpected loss of ballast system control, which escalated to a loss of stability and relatively rapid catastrophic sinking. However, the design limits of the structure were not exceeded in the environmental conditions that initiated the disaster.

So how could one have predicted what applicable and successful EER process could have been in place for these cases? Undoubtedly, these installations had well established emergency response plans and conducted drills, including unannounced (surprise) escape and evacuation drills, on a regular basis. Unfortunately, no matter how realistic drills under non-emergency conditions are, they fail to simulate a real accident situation. Behaviour of personnel in an emergency, together with the stochastic nature of some of the parameters – including the accident damage, environment, and personnel response that significantly affect the escape, evacuation, and rescue process – cannot be simulated in drills. Mathematical modelling, however, is able to incorporate any accident and personnel responses, bounded only by our engineering and operational imaginations. No event is too small, too large, or too complex to be simulated, provided the basic steps are set out in a rational and logical manner and strict discipline using accepted simulation techniques and empirical bases is adhered to.

It should be noted that the scope of the analysis described here is limited to the reliability assessment of specified EER systems. It is not meant to replace the hazard identification (HAZID) and quantitative risk assessment (QRA) components of a Safety Case, which are essential to the design and operation of an optimal installation safety system including the EER system. Thus, no attempt is made here to assess the overall safety of the installation, its vulnerability to major accident scenarios, or safety assessments other than those directly associated with EER. However, the RPT can be used in a complementary manner to the Safety Case process, to assess reliability of EER systems for different major accident scenarios, with resultant recommendations on the optimization of EER components to minimize residual risks.

In the balance of this paper, following this general introduction, the basic steps of EER modelling are set out, followed by descriptions and representative results of EER analyses for open and ice covered waters

GENERAL DESCRIPTION OF EER RISK AND RELIABILITY 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 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, which consists of survival until a rescue platform is available and subsequent transfer of evacuees to that rescue platform. It 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.

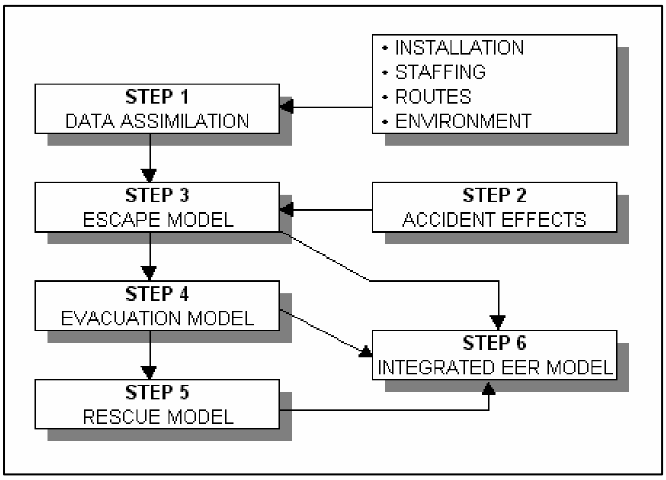

Fig. 1 EER Model Schematic

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 1 and depicted schematically in Figure 2. 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

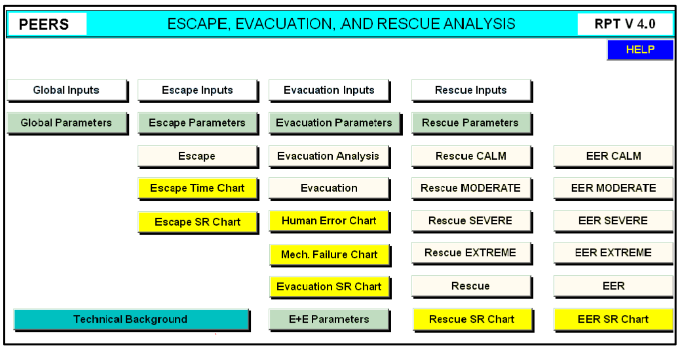

Fig. 2 System Architecture

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 effect on this rate of movement of different numbers of individuals in a group, the level of emergency, and impediments such as bottlenecks, smoke, debris, or cold weather and icing (Bercha et al., 2003). 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 were 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.

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). Reliability is independent of availability; reliability assessment is carried out on the assumption that the system is available.
- Success - The achievement of a process or operation without incurring one or more casualties. Success considers both availability and reliability.

DETAILS OF EER MODELING

Escape Modeling

A simple three-dimensional drawing or electronic representation of the escape routes is initially used to provide an understanding of their spatial distribution as illustrated in Figure 3. Characteristic escape parameters are then used to assess the unit rates of progress, which may be expected for different numbers of personnel along escape routes. Escape route configurations must be considered in conjunction with accident zones of impact, which may be superimposed on escape routes. Routes must be selected to avoid accident effects such as structural blockage, fire, toxic gas, or smoke.

Clearly, personnel not immediately affected by the accident would avoid escape routes within the hazard zone, and may be restricted to alternate routes, interconnected vertically as shown in the isometric view in Figure 3. Logical application of the unit parameters to an appropriate configuration of escape routes considering the initial locations of personnel throughout the installation can then be used as a basis for computation of expected times and arrival success to the TSR, as summarized by histograms for each of five routes shown in Figure 4.

Finally, the consideration is given to EER capacity and integrity. The time limit parameter for escape and TSR residence is used to evaluate risk and performance for specified major accident conditions and TSR capacity and integrity levels.

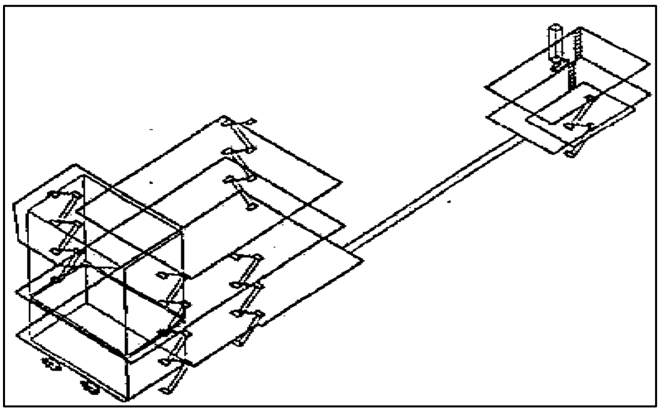

Fig. 3 Platform Complex Isometric View

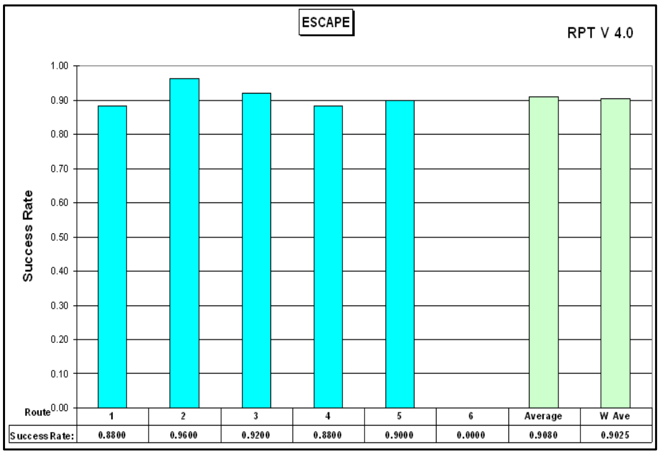

Fig. 4 Escape Success Histogram

Evacuation Modeling

Inputs for the evacuation model include the specification of each evacuation mode and its probability (%) of utilization in any given scenario. Because a detailed availability analysis is conducted, the number of units installed, the number of units needed to evacuate all persons on board (POB) and one unit's availability expressed as a percentage of installation service time are required inputs. Figure 5 shows Evacuation Inputs screen. Only three evacuation modes are shown for brevity here; the RPT has a full range of primary, secondary, and tertiary evacuation modes in its inventory

PEERS	EVACUATION ANALYSIS							RPT V 4.0
N	EVACUATION MODE	# Units Installed	# Units Required	Availability per Unit - %	Calm	Moderate	Severe	Extreme
					% OF TIME			
1	Helicopter	1	1	90	50%	40%	20%	1%
2	TEMPSC (Twin Davit)	2	1	95	38%	45%	62%	75%
6	Skyscape	1	1	95	12%	15%	18%	24%
	TOTAL				100%	100%	100%	100%

Fig. 5 Evacuation Input Screen

In the evacuation analysis, a clear distinction is necessary between mechanical failures and human performance failures in order to facilitate evacuation system evaluation and improvement. Mechanical failure, as defined in the PBS (Bercha et al., 2003), is used in the broad sense to include all non-human performance, including machinery, structures, electronics, electrical circuits, communication systems, and other non-human systems failures. Figure 6 shows the evacuation parameter screen for a typical evacuation mode, Evacuation Mode #2, the twin-davit TEMPSC. As can be seen, activities are subdivided into those that are predominantly governed by human performance (H) and those that are predominantly governed by mechanical performance (M). The numbers entered in this activity matrix represent the factors by which the base value of human error probability, mechanical failure probability, or activity time must be multiplied in order to generate the value of the associated probability or time. The source of the risk values are human performance data such as those published by the US Nuclear Regulatory Commission (NUREG-75/014, 1975) and various ergonomic studies (Rasmussen & Petersen, 1984; Rasmussen et al., 1988; Swain & Guttman, 1983). Application of these human performance parameters to the EER systems are discussed by Bercha in a previous ISOPE paper (Bercha et al., 2003). The mechanical (M) risk values are based on public and proprietary mechanical performance data bases. The time values are based on drill or test measurements taken by the authors (Bercha et al., 2001) as well as those obtained by various operators. The baseline data (taken under controlled safe conditions) were then analytically modified on the basis of human performance studies to account for the effects of operational, accident, and environmental conditions (Bercha et al, 2003).

PEERS	EVACUATION PARAMETERS										RPT V 4.0
EVACUATION MODE 2			TEMPSC (Twin Davit)								
	Availability	H or M	Risk				CF*	Time			
	0.9975		Activity Weather Failure Factor					Activity Weather Time Factor			
	Activity		Calm	Moderate	Severe	Extreme		Calm	Moderate	Severe	Extreme
1	Evacuation order in TSR	H	0.1	0.1	0.5	1.0	1.0	0.5	0.5	0.5	0.5
2	Life jackets/survival suits - available	M	1.0	1.0	1.0	1.0	1.1				
3	Don life jackets/survival suits	H	1.0	2.0	3.0	4.0	1.1	0.4	0.4	0.5	1.0
4	Move to embarkation point	H	1.0	1.5	2.0	10.0	1.1	2.0	3.0	4.0	6.0
5	Craft functional to launch	M	30.0	30.0	30.0	30.0	1.0				
6	Craft prepared to launch	H	1.0	2.0	3.0	100.0	1.0	1.0	1.5	2.0	2.0
7	Embarkation	H	1.0	2.0	3.0	100.0	1.1	1.5	2.0	3.0	3.0
8	Engine starts	M	0.1	0.1	1.0	5.0	1.0				
9	Engine started correctly	H	1.0	2.0	5.0	10.0	1.0	0.2	0.2	0.2	0.2
10	Lowering mechanism functions	M	1.0	2.0	5.0	10.0	1.0				
11	Lowering mechanism activated	H	1.0	2.0	10.0	50.0	1.0	0.5	0.5	0.5	0.5
12	Craft descends under control to near sea level	M	1.0	5.0	20.0	100.0	1.0	1.5	2.2	3.0	4.5
13	Craft descends final distance to sea level	M	1.0	5.0	20.0	200.0	1.0	0.5	1.5	2.0	3.0
14	Craft release gear activated successfully	M	1.0	10.0	50.0	300.0	1.0	0.5	0.5	0.5	0.5
15	Craft moves 50 m from installation	M	1.0	1.5	75.0	500.0	1.0				
16	Craft steered 50 m from installation	H	1.0	1.5	10.0	100.0	1.0	1.0	1.5	3.0	5.0

*CF = Congestion Factor

Base Human Error Probability	Base Activity Time (min)
1.00E-03	2.0
Base Mechanical Failure Probability	Lowest Credible Success Rate
1.00E-03	0.10

Fig. 6 Typical Evacuation Parameters

An advantage of this fundamental approach to activity performance and risk analysis is its applicability to virtually any new technology or new set of conditions (such as Arctic ice).

Next, the evacuation analysis is carried out. The main steps are generally described in Table 1. The results of the analysis for the example evacuation mode, the twin-davit TEMPSC, are given in Figure 7. Only activities 1 and 16 are shown; but totaled results for all of the 16 elements listed in Figure 6 are given. As can be seen, the baseline values of the probabilities and times for each activity are given in the top portion (matrix) of the display. The bottom portion gives the main steps of the computation of the risk and total time component. In the time simulation side (the right side of the display) only times that are additive are given. Thus, where both the mechanical and the human activity component for the specified activity overlap, such as the craft moving 50 m from the installation, only one of the times is given, while the other coincident activity time is given as zero.

The final results are also presented in histogram form. Dedicated histograms give the human error contribution to casualty probability, the mechanical failure contribution to casualty probability, and the combined success rate resulting from human and mechanical performance contributions (Figure 8). For study of uncertainties, the base inputs are entered as distributions, and the results are probability densities and time distributions (as illustrated in the case study later).

Table 1 Evacuation Analysis

EVACUATION ANALYSIS	DESCRIPTION
Calculated Activity Failure Probability	Activity Weather Failure Factor X (Base Human Error Probability **OR** Base Mechanical Failure Probability) For Global Version Reliability all failures in the mode due to Availability =0 For Global Success Version Availability is in the calculation.
Human Error Probability Sum	
Mechanical Failure Probability Sum	
Time Sum (M and H)	
Human Error Frequency	Human Error Probability Sum X Global Evacuation Human Error or Time Factor
Mechanical Failure Frequency	Mechanical Failure Probability Sum X Global Evacuation Mechanical Failure Factor
Human Error Fatality Probability	Human Error Frequency X Global Evacuation Fatality Factor
Mechanical Failure Fatality Probability	Mechanical Failure Frequency X Global Evacuation Fatality Factor
Task Failure Fatality Probability	Mechanical + Human Max. 1.0
Task Success Rate	1-Task Failure Fatality Probability
Task Success Time	Time Sum X Global Evacuation Time Factor
Weather Weighted Average	% of weather from Global Inputs

Rescue Modeling

The rescue process is generally subdivided into the survival and the transfer components. Human and mechanical performances are integrated here, although new data to assess these is expected. The large body of anecdotal information, together with expert opinion, has been used to provide the integrated probable survival times and inter-modal transfer success probabilities summarized in Table 2. Only two rescue modes are shown here – again the RPT rescue mode inventory covers six different rescue modes. The survival and transfer success probabilities are then used in the inter-modal event tree for the designated evacuation and rescue modes to evaluate rescue success probability. Figure 9 shows a typical rescue and integrated EER event tree from the RPT for severe weather, this time for three evacuation modes and five rescue modes.

PEERS — EVACUATION ANALYSIS — RPT V 4.0

	EVAUCATION MODE 2	H or M	TEMPSC IRT							
			Risk				Time			
			Activity Failure Probability				Activity Time [min]			
	Activity		Calm 38%	Moderate 48%	Severe 13%	Extreme 1%	Calm 38%	Moderat 44%	Severe 13%	Extreme 1%
1	Evacuation order in TSR	H	1.00E-04	1.00E-04	5.00E-04	1.00E-03	10	1.0	1.0	1.0
16	Craft steered 50 m from installation	H	1.00E-03	1.50E-03	1.00E-02	1.00E-01	20	3.0	6.0	10.0
	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	50	8.4	11.0	16.0
	Global Evacuation Human Error or Time Factor		10.00	10.00	10.00	10.00	1.32	1.32	1.32	1.32
	Human Error Frequency		4.10E-02	1.31E-01	3.65E-01	3.75E+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		7.10E-03	2.62E-02	3.65E-01	9.00E-01				
	Mechanical Failure Casualty Probability		3.61E-03	1.09E-02	2.02E-01	9.00E-01				
	Evacuation Failure Casualty Probability		1.07E-02	3.71E-02	5.67E-01	9.00E-01				
	Unavailability		2.50E-03	2.50E-03	2.50E-03	2.50E-03				
	Evacuation Success Rate or Time		0.9893	0.9629	0.4330	0.1000	26.4	37.9	52.7	71.8
	Weather Weighted Average		**0.8929**				**35.8**			

Fig. 7 Evacuation Analysis Results – Twin-Davit TEMPSC

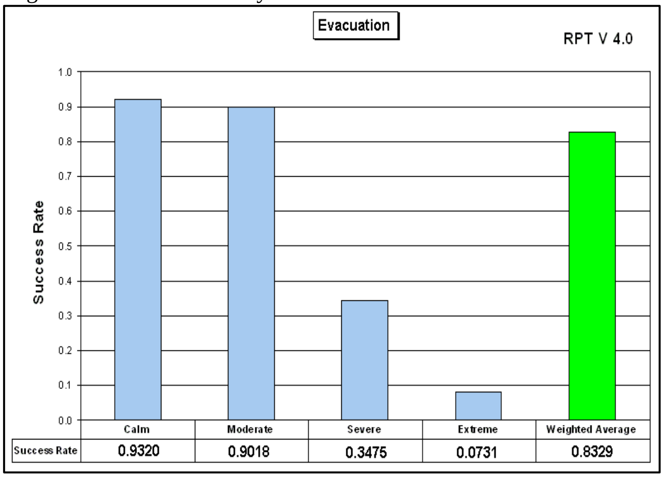

Fig. 8 Evacuation Success Histogram

Table 2 Rescue Survival Times and Inter-Modal Transfer Success Rates

	Rescue Mode	Any Rescue Mode				SAR Helicopter				Standby Vessel			
	Weather	C	M	S	E	C	M	S	E	C	M	S	E
	Evacuation mode	Survival Time [h]				Transfer Success Rate							
1	Helicopter	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2	TEMPSC (Twin Davit)	72	72	72	36	0.990	0.800	0.250	0.000	0.990	0.900	0.400	0.050
3	TEMPSC (Single Point)	72	72	48	36	0.990	0.800	0.250	0.000	0.990	0.900	0.400	0.050
4	TEMPSC (Freefall)	72	72	72	48	0.990	0.800	0.250	0.000	0.990	0.900	0.400	0.050
5	TEMPSC (PROD)	72	72	72	48	0.990	0.800	0.250	0.000	0.990	0.900	0.400	0.050
6	Skyscape	72	48	36	4	0.990	0.700	0.100	0.000	0.990	0.800	0.300	0.050
7	Seascape	72	72	72	72	0.990	0.800	0.250	0.000	0.990	0.900	0.400	0.050
8	Gemevac	n/a	n/a	n/a	n/a	0.000	0.000	0.000	0.000	0.980	0.900	0.200	0.000
9	Telescape	72	48	36	4	0.990	0.700	0.100	0.000	0.990	0.800	0.300	0.050

Integrated EER Assessment

The integrated EER results show the total performance of the EER system, including both human and mechanical performance in each main component of EER. Due to the intricate interactions between human performance and mechanical systems throughout each of the modules, it is unlikely that the component of human performance in the overall EER process would provide useful information. Figure 9 shows the integrated EER event tree for moderate weather. Figure 10, the overall EER success rate histogram, shows the total EER system performance under each of the four distinct weather conditions together with their weather weighted average for the location under consideration. The weather weighted average is a function of a specific geographic location (as it depends on the relative proportion of each weather class); the individual weather class results are independent of geographic location.

PEERS		INTEGRATED EER ANALYSIS										RPT V 4.0	
ESCAPE	EVACUATION						RESCUE						Relative Success Rate
Success Rate		MODE	% of Time	Success Rate	EER Time Success Factor	Survival Time [h]		MODE	Time to Availability [h]	Survival Time Factor	% of Time	Success Rate	
0.9080	1	Helicopter	40%	0.8775	1.0	n/a						1.0000	0.3187
	2	TEMPSC (Twin Davit)	45%	0.9604	1.0	72	1	SAR Helicopter	12	1.0	45%	0.8000	0.3237
							2	Standby Vessel	12	1.0	35%	0.9000	
							3	Passing Vessel	24	1.0	10%	0.8000	
							4	Land	6	1.0	5%	0.6000	
							5	Return to Installation	1	1.0	5%	0.8000	
	6	Skyscape	15%	0.7910	1.0	48	1	SAR Helicopter	12	1.0	45%	0.7000	0.0776
							2	Standby Vessel	12	1.0	35%	0.8000	
							3	Passing Vessel	24	1.0	10%	0.7000	
							4	Land	6	1.0	5%	0.5000	
							5	Return to Installation	1	1.0	5%	0.6000	
												Success Rate for MODERATE Weather	**0.7200**

Fig. 9 Rescue and Integrated EER Event Tree – Moderate Weather

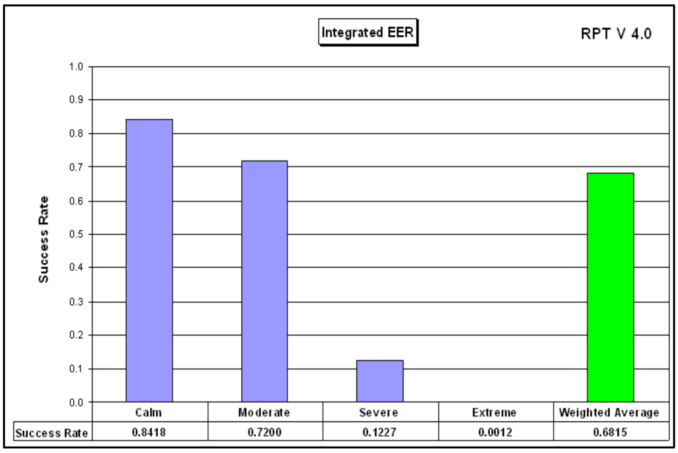

Fig. 10 Integrated EER Success Rate Histogram

MODEL VALIDATIONS

Table 3 summarizes the results of ten illustrative performance validation runs of the RPT. All RPT runs were run in the Monte Carlo mode so that time variance (DATA CDF %) could be directly obtained from the cumulative distribution (CDF) generated.

The variance is the key validation parameter; high variance suggests bad correlation, while low variance suggests good correlation. The variance ranges from 11% to 26%, with a numerical average of 17%. Any value below 20% shows excellent correlation (NSFI, 1985); thus, the average performance of the RPT for this restricted set of validations can be considered very good. The validations are restricted because, except for the two rescue data sets and the Jack-up data, all data sets were for the relatively deterministic escape component. Variance for modeling of the escape component should be quite low, as is the case here. It is, however, encouraging that the variance for the two rescue scenarios, in which the RPT was run in a custom mode, is also relatively low at 22%, while the evacuation scenarios show excellent agreement at 19%.

Table 3 Model Result Validation Summary

No.	EER COMPONENT	DESCRIPTION OF DATA		DATA TIME (min.)	RPT TIME (min.)	DATA CDF %	VARIANCE %
1	Escape	Installation muster to TSR		10.5	11.2	38	12
2				14.0	13.3	70	20
3	Escape	Service company muster & fire drills		15.0	14.2	65	15
4				10.0	11.2	39	11
5	Escape	Installation drills	Fire	29	34	36	14
6			Abandon	13	14.5	33	17
7			Abandon	09	14.5	33	17
8	Evacuation	Jack up evacuations	Evacuation (6 drills avg.)	16.5	19.0	69	19
9	Rescue	Service co. MOB rescue	Dacon scoop	38	34	68	18
10			FRC	06	08	24	26
Average Variance:							***17***

CASE STUDIES

A series of EER configurations was analyzed for a typical East Coast installation, with location weather classes distributed annually as shown in Table 4. The ice environment EER performance was assessed using the Arctic PEERS model, APEERS. The preferred evacuation systems and emergency response plans were used as the base case. The other cases consisted of selected variations in the evacuation system configuration, including cases 1.2 to 1.11 as shown in Table 4. As can be seen, the base case consists of a twin-davit (2D) TEMPSC and a Skyscape (with the Skyscape on the drilling platform separated from the main residence and process platform by a bridge as shown earlier in Figure 3). Next, a variety of evacuation system combinations were considered as shown for cases 1.2 to 1.5 inclusive. For the rescue case studies, two primary combinations were considered; namely, one with a Search and Rescue (SAR) helicopter was always available as required, and one where no SAR helicopter was available. Next, for the abandonment time limit, essentially a function of the accident condition (e.g., installation sinking), a relatively short time limit of 30 minutes and a more generous one of 60 minutes for abandonment (escape plus evacuation) were considered. Finally, two ice conditions were considered; namely, an ice pack with 6/10 concentration, which permits navigation of vessels such as TEMPSCs, but also allows variation among the first three weather conditions. It is unlikely that extreme or hurricane weather could occur when there is an ice pack covering 60% of the ocean. For the solid ice sheet, only the calm weather condition was considered. Here, the solid ice sheet was considered without ice deformation or rubble to simplify the studies.

The RPT was used both in the expected or point value mode, where only the mean values of all the input variables and parameters are used, and in the Monte Carlo mode, where distributed values of the key parameters were entered. Table 4 gives a summary of the point value results, as well as results relative to the base case (Case 1.1). The two right hand columns give the increment and its positive or negative percentage change relative to the base case success rates. On inspection it can be seen immediately that the highest open water increment occurs for Case 1.8 which imposes the restriction of a 30-minute abandonment time limit, which results in a major 30% reduction in EER success probability relative to the base case. Next most important is the 6/10 concentration of broken ice, which would likely result in the destruction of a TEMPSC that is not ice reinforced (as is the case here) for any but the calm weather conditions. A TEMPSC attempting to navigate in the leads of a 6/10 ice pack with moderate weather and the concomitant wind is likely to be destroyed by converging floes. On the other hand for the solid ice case, the success rate s quite high, in fact, 14% higher than the base case due to the stability of the ice cover and lack of any inclement sea state. It should be noted that the ice condition studies were predicated on ice being present year-around to emphasize the relative effect of the two ice condition extremes at the expense of simulating a realistic mix of ice and open water states as would be expected for any of the current ice populated operational arenas. Significant reductions in EER success probability are also evident for Case 1.4, where the TEMPSCs are replaced by a helicopter with the normal weather restrictions, and Case 1.5 where there are no helicopters available.

Table 4 Case Study Result Summary

Sensitivity	Case	Description	Type	Weather: Calm .38	Weather: Moderate 048	Weather: Severe .13	Weather: Extreme .01	Weighted Average	Base Increment: Value	Base Increment: %
Base	1.1	2 D. TEMPSC + SKYSCAPE	Evac.	0.9999	0.9949	0.9266	0.1600	0.9796	0.0000	0.00
			EER	0.9924	0.8678	0.3862	0.0049	0.8439	0.0000	0.00
Evacuation	1.2	2 D. TEMPSC + 1 D. TEMPSC	Evac.	0.9999	0.9952	0.9327	0.1600	0.9805	0.0009	0.09
			EER	0.9925	0.8829	0.3976	0.0049	0.8526	0.0087	1.02
	1.3	PROD + SKYSCAPE	Evac.	0.9999	0.9949	0.9266	0.1600	0.9796	0.0000	0.00
			EER	0.9924	0.8678	0.3862	0.0049	0.8439	0.0000	0.00
	1.4	HELICOPTER + SKYSCAPE	Evac.	0.9998	0.9938	0.9056	0.1600	0.9763	-0.0033	-0.34
			EER	0.9922	0.8047	0.2613	0.0047	0.7973	-0.0466	-5.84
	1.5	NO HELICOPTER - 2 D. TEMPSC + SKYSCAPE	Evac.	0.9998	0.9923	0.9104	0.1600	0.9762	-0.0034	-0.35
			EER	0.9874	0.7750	0.2508	0.0049	0.7801	-0.0638	-8.18
Rescue	1.6	SAR HELICOPTER MAX AVAILABLE	Evac.	0.9999	0.9949	0.9266	0.1600	0.9796	0.0000	0.00
			EER	0.9924	0.8470	0.3457	0.0029	0.8287	-0.0152	-1.83
	1.7	NO SAR HELICOPTER	Evac.	0.9999	0.9949	0.9266	0.1600	0.9796	0.0000	0.00
			EER	0.9924	0.8945	0.3963	0.0051	0.8581	0.0142	1.65
Abandonment Time	1.8	30-MINUTE ABANDONMENT TIME LIMIT	Evac.	0.9999	0.9949	0.9266	0.1600	0.9796	0.0000	0.00
			EER	0.8443	0.6075	0.2703	0.0034	0.6476	-0.1963	-30.31
	1.9	60-MINUTE ABANDONMENT TIME LIMIT	Evac.	0.9999	0.9949	0.9266	0.1600	0.9796	0.0000	0.00
			EER	0.9924	0.8678	0.3862	0.0034	0.8439	0.0000	0.00
Ice	1.10	ICE PACK 6/10 CONCENTRATION	Evac.	0.9216	0.8931	0.8210	-	0.8974	0.0822	-8.3
			EER	0.6001	0.3211	0.2501	-	0.4171	-0.4268	-50.6
	1.11	SOLID ICE SHEET – NO RUBBLE	Evac.	0.9950	-	-	-	0.9950	0.0154	1.5
			EER	0.9821	-	-	-	0.9821	0.1383	13.82

In general, open water evacuation success is quite high for calm and moderate weather, but begins to decay for severe weather and drops dramatically for extreme weather. Nevertheless, the weighted evacuation success rate for the chosen location is relatively high, at approximately 98%. When the rescue component is integrated into it, a much greater weather sensitivity is manifested for both moderate and severe weather with the extreme weather likelihood of success being less than 1 percent. The weighted average also drops significantly below 98%to 84% when considering the total escape, evacuation, and rescue process. This does point out that even though evacuation success may be high, rescue can still considerably detract from the EER success rate, particularly when considering the more severe and extreme weather conditions.

Monte Carlo results for the base case average outputs are shown in Figures 11 and 12. Figure 11 shows the weather-weighted average for the evacuation success rate, which as expected from Table 4, has an expected value of approximately 98%, with only ±1% spread for 95% confidence limits. Next, Figure 12 shows the distribution for the integrated EER success rate, showing a mean value as shown in Table 4 of approximately 84.5% with upper and lower 95% confidence intervals – roughly 14% of mean value. Both the point values and the Monte Carlo values show the importance of considering the entire EER system as a whole; that is, evacuation success rates averaged over all weather classes may be relatively high, while the integrated success rate, which is quite sensitive to the severe and extreme weather classes, can be significantly lower with a much greater spread in confidence limits.

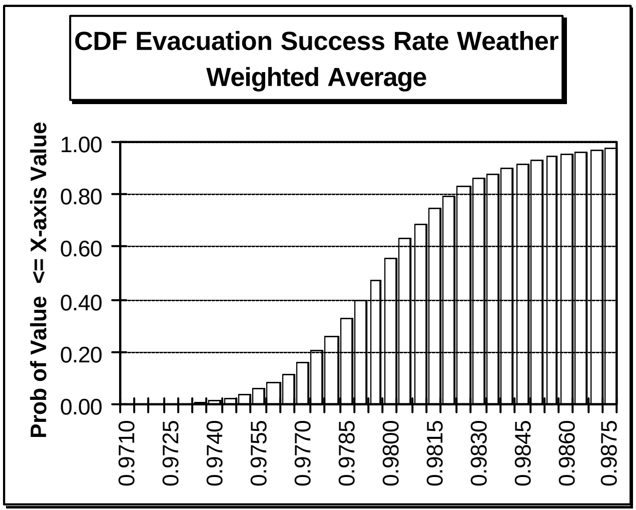

Fig. 11 Monte Carlo Base Case – Evacuation Success Rate CDF – Weather-Weighted Average

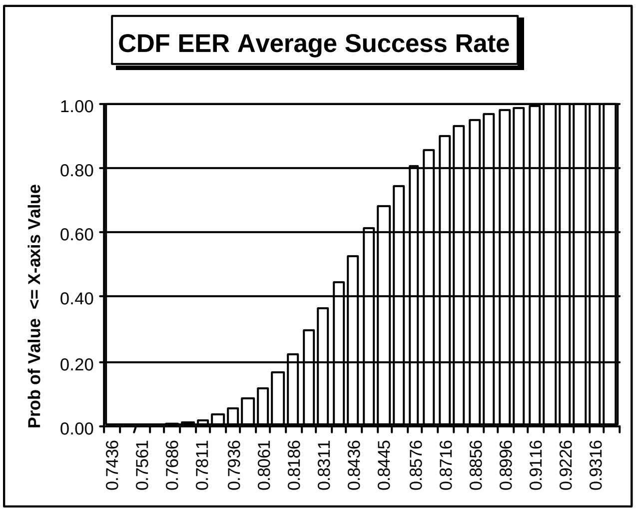

Fig. 12 Monte Carlo Base Case – EER Average Success Rate CDF

CONCLUSIONS

A numerical probabilistic model of EER reliability and performance providing information useful for the assessment and improvement of EER systems and procedures was described. Capabilities of the model include the following:

- Assessment of adequacy of each escape route under accident and operational condition.
- Assessment of adequacy of specified installation systems and procedures for each accident scenario.
- Evaluation of probable contributions of human and mechanical

performance for each evacuation activity so that emphasis can be placed on the most probable cause of failures in effecting improvements.

- Sensitivity of risk and performance to changes in EER configurations, geographic location, accident scenario, and installation engineering and operational parameters.
- Ability to study the effect of uncertainties and estimate confidence intervals for a given set of conditions.
- Absolute and relative contributions to EER reliability of each activity, component, and operational or environmental factor.
- Development of an overall probabilistic index reflecting the adequacy of the total EER system for a given location, installation and environment, and operational and accident scenarios.
- Investigation of uncertainties through either mean value sensitivities or probability density distributions for success rates.
- Extension of the model to assess new technologies or EER operations under unprecedented conditions.

Specific conclusions obtained from application of the modeling technique to different case studies may be summarized as follows:

- Escape component of the EER process is generally the most reliable; however, the escape model described in this paper does not include direct casualties resulting from the accident, which would generally be evaluated in a safety case QRA.
- The evacuation reliability and performance is highly sensitive to the type of configuration of evacuation systems, time limit for escape and evacuation (which could be imposed in the instance of a rapidly deteriorating accident situation), environmental parameters, and availability of evacuation systems.

Specific results on evacuation analysis may be summarized as follows:

- If a time limit in the order of 30 minutes is imposed on abandonment (escape plus evacuation), a significant reduction in the probable reliability of the EER process is effected.
- Evacuation success is quite high for open water calm and moderate weather but begins to decay for severe weather and declines dramatically for extreme (hurricane) weather.
- For most locations, the weighted evacuation success rate is relatively high, in the upper ninety percentages.
- Broken and solid ice conditions give dramatically different evacuation results. For broken ice, the use of current lifeboat technology (that is not ice resistant) yields low evacuation success probabilities. On the other hand, for solid ice, evacuation success is quite high.

The following specific conclusions can be reached regarding integrated EER:

- Although the weighted average evacuation success rate is relatively high, when the rescue component is integrated into it, the integrated EER average rate drops significantly, in the order of 15%. Even though evacuation success may be high, rescue can considerably detract from the overall EER success rate.
- Overall EER success for broken ice is dramatically reduced due to the unavailability of adequate EER technology to resist ice forces.
- Solid ice sheet evacuation and EER is relatively high due to the stable platform likely to be offered by solid ice, even for installations only equipped with open water equipment.

The Monte Carlo results show a variability in the predicted success rates.

- The evacuation success rate shows a spread of approximately 2% of the mean value between the 95% upper and lower confidence interval.
- The integrated EER average success rate shows a considerably greater spread, roughly 24% of mean between the upper and lower 95% confidence interval.

The following recommendations can be drawn from the work:

- Due to the availability of good input data, the escape model has been found to be quite accurate for drill and precautionary evacuation situations. The addition of accident effects, such as blast damage, smoke, and toxic gas, would result in additional uncertainties in the escape model and should be incorporated in the future.
- Evacuation modeling for open water conditions is adequate for drills and precautionary evacuations, but requires further analysis to incorporate accident effects.
- In the case of ice cover – either partial or complete – adequate operational technologies need to be identified and included in the model. One such technology, which will be included in future versions of the model, is the ARKTOS system.
- Currently no suitable fully documented data for the transfer component of the rescue process exist, resulting in significant uncertainties in rescue modeling.

Additional work, including full-scale exercises and studies on the impact of training should be conducted to alleviate these uncertainties.

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