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Finite Discrete Markov Model of Ship Safety

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ABSTRACT: The ship safety modeling is the process used to convert information from many sources about the ship as an antropotechnical system into a form so that it can be analyzed effectively. The first step is to fix the system (ship, human, environment) boundaries to clearly identify the scope of the analysis. The ship can be generally defined by conceptual sketches, schematics drawings or flow diagrams to establish the element hierarchy which evolves from the physical and functional relationships. The man could be generally defined by the operational procedures. The environment could be generally defined by the mission place and time of the year. The information is needed considering that the accidents are caused by factors associated with ship (failure, design defect), man (human error, workload), and environment. Safety is a system property that we intuitively relate to a system's design, accident rates and risk. This work proposes finite discrete Markov model as an example of systematic approach to the analysis of ship safety.

1 INTRODUCTION

The safety of the ship system could be considered as a series of barriers or against the potential for failure. These barriers may include hardware, software, and the human element and the presence of one or more of the barriers will prevent accidents from happening. But it happens that the safety barriers are penetrated and an accident occurs.

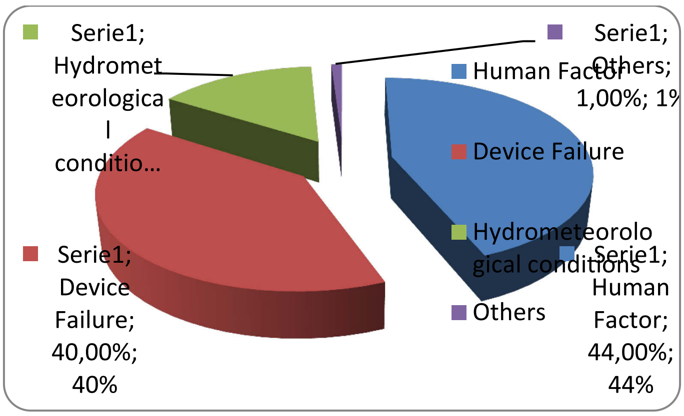

Figure 22. Ships accident statistic, *American Bureau of Shipping, 2004*

Very often when an incident has occurred, once tends to interpret the past, prior to the event, only in terms of its bearing on that event which means that the total contemporaneous context is missing. So once concentrate only on "significant" event's chains.

2 THE SYSTEM

2.1 *The ship system*

The ship safety model should cover the ship geographically and all the installed systems including propulsion and electric power production, energy production, emergency power, bridge systems, safety systems, human factor and passenger related systems.

The necessary methodology consists of following stages, (Soares, Teixeira, 2001):

1 Generic Ship Model
2 Topographical Safety Block Diagram
3 Ship Safety Model

Generic Ship Model describes how all the ship functions, subsystems and systems, influence the ship safety. Importance of each component should be clearly defined. Generic Ship Model could be further utilized as a basis for comprehensive Ship Safety model.

Specific criteria should be developed to enable efficient estimation of the crew influence on the ship safe factor.

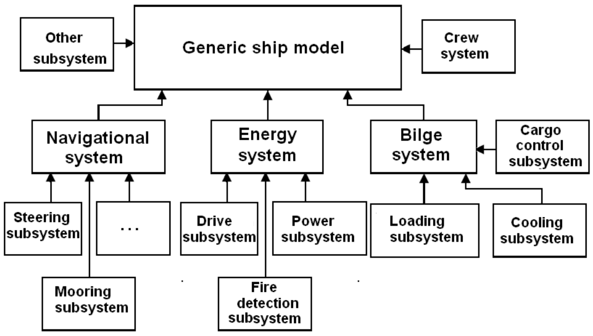

Figure 23. Generic model of some ship's subsystems and systems

2.2 *Navigational system*

Since half on twenty century rules concerning vessel technical condition, crew knowledge and operational action proving vessel safety are have been defined by International Maritime Organization. The measure of vessel safety is a risk defined as a function of threats and consequences relating to theoretical and actual risk, (Soliwoda 2008).

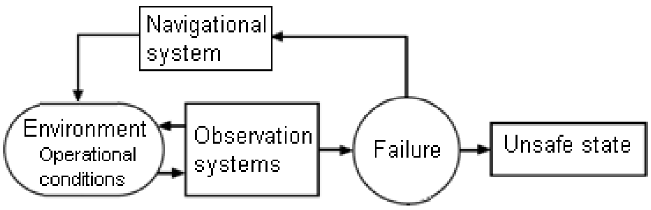

Figure 24. Vessel reliability conditions according to navigational system and navigational situation.

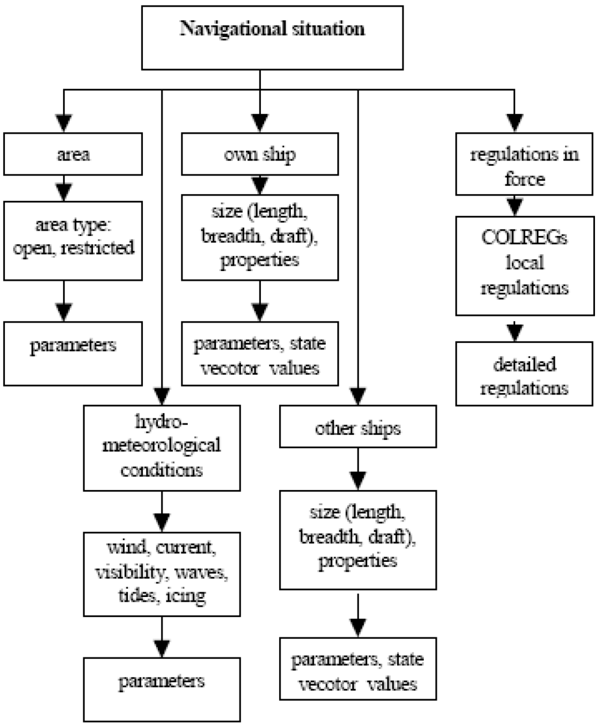

Figure 25. Model of ship encounter situations (Pietrzykowski 2007)

2.3 *Human error*

Human reliability is one of main factors which influence safety at maritime transport. Generally we can select the sources of human error into intended and unintended.

Unintended errors can be classified as :

1 Errors of Omission

– Involve failure to do something.

2 Errors of Commission

– Involve performing an act incorrectly.

3 Sequence Error

– Involve performs some step in a task or tasks out of sequence.

4 Timing Error

– Involve fails to perform an action within an allotted time or performing too fast or to slow.

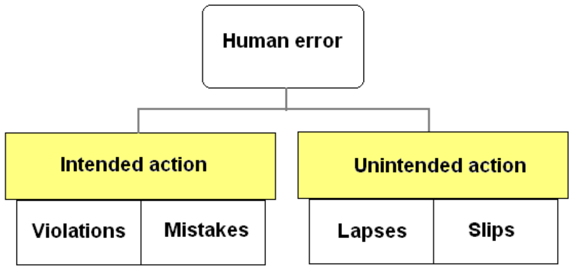

Figure 26. Sources of human error

Table 1. Human errors sources statistic, ABS REVIEW AND ANALYSIS OF ACCIDENT DATABASES: 1991 – 2002

Sources	%
Situation assessment and awareness	15,2
Task omission	10,4
Management	10,1
Knowledge, skills, and abilities	7,3
Mechanical / material failure	6,6
Weather	6,6
Complacency	5,6
Risk tolerance	4,8
Business management	4,8
Navigation vigilance	4,6
Lookout failures	4,3
Maintenance related human error	4,1
Fatigue	3,5
Unknown cause	3,3
Procedures	2,8
Manning	2,0
Commission	1,5
Uncharted hazard to navigation	1,3
Substance abuse	1,3

Factors Contributing to Accidents, (Clemens 2002)

– Management
– Physical Environment
– Equipment Design

- Work Itself
- Social/Psychological Environment
- Worker/Co-worker
- Unsafe Behavior/Chance (Risk)

Exposure to Hazardous Situation, (Lawton, Miller, Campbell 2005)

- Perception of Hazard
- Cognition of Hazard
- Decision to Avoid
- Ability to Avoid
- Safe Behavior

Probability of operator error (Clemens 2002)

$$Q\left(\frac{t}{T_m}\right) = \exp\left\{-\left(\frac{t - a_1 \cdot T_m}{a_2 \cdot T_m}\right)^{a_3}\right\} \qquad (1)$$

where:

- a_1, a_2, a_3 are parameters connected with factors such as skills, knowledge, regulations;
- T_m is an average time for analyzed operation;
- t is time which operator has for this operation.

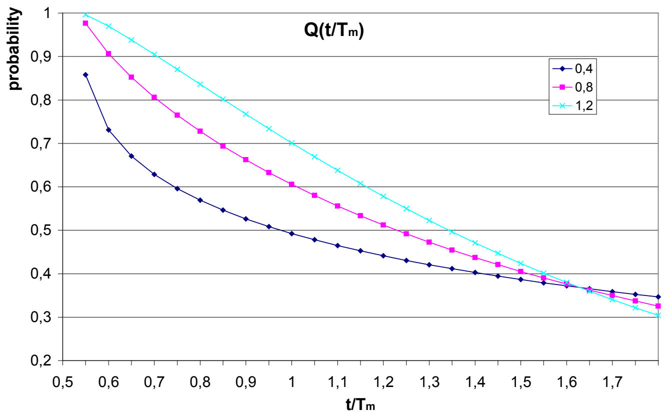

Figure 27. Probability of operator error for different skills and knowledge parameters, (Smolarek & Soliwoda, 2008)

Also the Human Cognitive Safety Model (HCSR) can be used as a method for computing factor of human's safety degree for the whole safety degree of HMESE, (Wang Wuhong, at al 1997). If the uncertainties of human's conduct operation are taken into consideration, the error probability of human cognitive activities can be re-written as (Wang Wuhong, at al 1997):

$$P_h(t) = \begin{cases} \exp\left\{-\left(\dfrac{\exp\left[\ln\left(t/\widehat{T}_{1/2}\right) - \sigma_u \Phi^{-1}(x)\right] - C_{\gamma_j}}{C_{\eta_j}}\right)^{\beta_j}\right\} & \text{when } t \ge C_{\gamma_j} \widehat{T}_{1/2} \exp\left[\sigma_u \Phi^{-1}(x)\right] \\ 1.0 & \text{when } t < C_{\gamma_j} \widehat{T}_{1/2} \exp\left[\sigma_u \Phi^{-1}(x)\right] \end{cases} \qquad (2)$$

$$x = P_{h\gamma}\left\{P_h \le P_h^{'}(t)\right\} \qquad (3)$$

where:

- $\widehat{T}_{1/2}$ — the most suitable estimated median of time required to complete the behavior;
- σ_u — logarithmic standard deviation of response time about operator;
- $\Phi^{-1}(x)$ — reverse standard normal accumulation distribution function;
- x — ratio between defined probability and non-response.

3 SAFETY MODEL

Ship is the human-machine system in which the functions of a human operator (or a group of operators - crew) and a machine are integrated. In safe analysis it is necessary to emphases the view of such a system as a single entity that interacts with external environment so it's obvious to take into consideration, (Gucma, 2005). From the three aspects of "human", "machine", "environment", in this paper qualitatively analyses the influence of two aspects, human and machine on safety of Human-Machine-Environment System in the ship transportation process. The safety degree of a ship is the function of the three sub-systems about human, machine and environment and can be regarded as the functional system according to human error and technical failure. The human error and technical failure are express interaction human-environment and ship-environment, (Smolarek, 2008):.

The graph of ship system safety states changes is presented at figure 8. We take into consideration the ship safety model which is discreet in state and time domain.

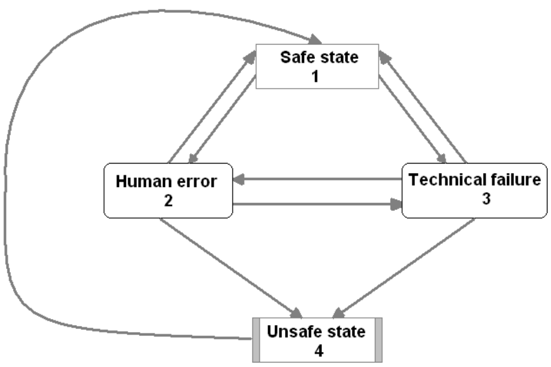

Figure 28. Graf of system state changes.

Where state 2 is partially unsafe state according to human error and state 3 is partially unsafe state according to technical failure of the ship or its any subsystem.

Corresponding transition matrix of one-step transition probabilities

$$P = \begin{bmatrix} 0 & p_{12} & p_{13} & 0 \\ p_{21} & 0 & p_{23} & p_{24} \\ p_{31} & p_{32} & 0 & p_{34} \\ p_{41} & 0 & 0 & p_{44} \end{bmatrix} \qquad (4)$$

According to matrix (4) we have

$$\begin{aligned} p_{12} + p_{13} &= 1 \\ p_{21} + p_{23} + p_{24} &= 1 \\ p_{31} + p_{32} + p_{34} &= 1 \\ p_{41} + p_{44} &= 1 \end{aligned} \tag{5}$$

Using the total probability and memoryless property of Markov chains we obtain the Chapman Kolmogorov equations

$$p_{ij}(k,k+n) = \sum_{r} p_{ir}(k,k+m) \cdot p_{rk}(k+m,k+n)$$
$$i, j \in \{1,2,3,4\}, 0 \le m \le n. \tag{6}$$

If it is an irreducible non periodic Markov chain consisting of *positive recurrent* states then a unique stationary state probability vector $\boldsymbol{\pi}$ exists

$$\pi = \cdot \begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \end{bmatrix} \tag{7}$$

where:

– π_k - is a steady state probability, k = 1,2,3,4;

and the matrix equation for vector $\boldsymbol{\pi}$ is given by

$$\begin{bmatrix} -1 & p_{21} & p_{31} & p_{41} \\ p_{12} & -1 & p_{32} & 0 \\ p_{13} & p_{23} & -1 & 0 \\ 1 & 1 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \tag{8}$$

where:

– p_{jk} - is a transition probability from state j to state k, j,k=1,2,3,4.

If the condition

$$\det \begin{bmatrix} -1 & p_{21} & p_{31} & p_{41} \\ p_{12} & -1 & p_{32} & 0 \\ p_{13} & p_{23} & -1 & 0 \\ 1 & 1 & 1 & 1 \end{bmatrix} \cdot \neq 0 \tag{9}$$

is satisfied, then the solution is given by

$$\pi_1 = \frac{(p_{23}p_{32} - 1)}{(1+p_{41})(p_{23}p_{32} - 1) + (p_{13}p_{32} + p_{12})(p_{21} - p_{41}) + (p_{12}p_{23} + p_{13})(p_{31} - p_{41})}$$
$$\pi_2 = \frac{-p_{12} - p_{13}p_{32}}{(1+p_{41})(p_{23}p_{32} - 1) + (p_{13}p_{32} + p_{12})(p_{21} - p_{41}) + (p_{12}p_{23} + p_{13})(p_{31} - p_{41})}$$
$$\pi_3 = \frac{-p_{13} - p_{12}p_{23}}{(1+p_{41})(p_{23}p_{32} - 1) + (p_{13}p_{32} + p_{12})(p_{21} - p_{41}) + (p_{12}p_{23} + p_{13})(p_{31} - p_{41})}$$
$$\pi_4 = \frac{p_{21}p_{32}p_{13} + p_{12}p_{23}p_{31} + p_{31}p_{13} + p_{23}p_{32} + p_{21}p_{12} - 1}{(1+p_{41})(p_{23}p_{32} - 1) + (p_{13}p_{32} + p_{12})(p_{21} - p_{41}) + (p_{12}p_{23} + p_{13})(p_{31} - p_{41})}$$

If transition probabilities are equal to p, then

$$\pi_1 = \frac{1}{1+p}; \quad \pi_2 = \frac{p}{1-p^2}; \quad \pi_3 = \frac{p}{1-p^2}; \quad \pi_4^0 = 1 - \frac{p}{1-p} \tag{10}$$

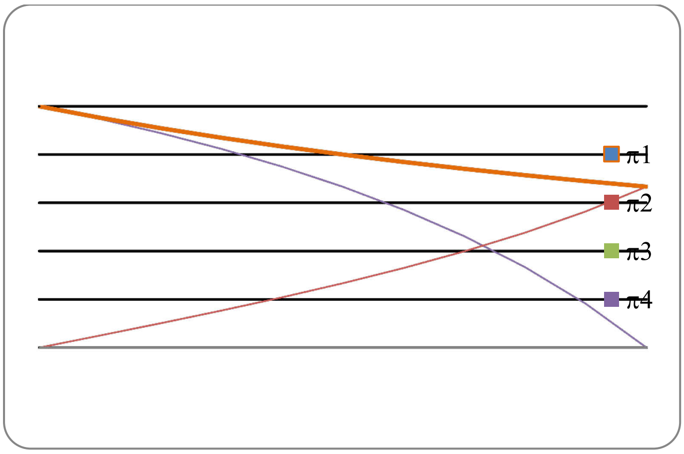

Figure 29 Graf of tendency of stationary state changes for increasing p

4 CONCLUSIONS

Vessel safety assessment carried out upon IMO standards allows theoretical estimating of safety without actual vessel conditions details and condition of crew. For more sophisticated cognitive modeling is necessary to model numerous failure modes or represent complex interdependencies between human error sources, ship route, ship technical and exploitations parameters. An alternative to representing the seaman as an element of a ship system is to represent him as a subsystem in and of itself. It means that the seaman should be modeled autonomously.

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