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# Construction of the Ship's Technical Failure Model to Assess its Navigational Safety

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ABSTRACT: The ship technical failures contribution in overall number of navigational accidents are significantly smaller than those caused by human factor but in safety analysis they cannot be neglected. The paper presents methodology of modeling the technical failures of ships with respect of most important ship systems such as main engine, power generators and steering gear. The repair time is also taken into account. The data for simulation was obtained from analysis of ships statistical data of polish owners. The model could be used mostly in assessment with projecting phase of ship appliances, simulating owner's economical analysis or generating random events in marine simulators.

## 1 INTRODUCTION

Construction of ships can be designed using the probabilistic methods of reliability analysis. In virtue of its complicate level the ship technical appliances such as engines, auxiliaries or other in the engine-room are sensitive to environmental and human factor influence. The interrelation between events causing failures can be examined by application of computer simulation method and reliability analysis.

Assuming the definition of reliability as feature of device which allows of functioning without failure in specific conditions and given time, we determine its numerical and functional measures, which usually are:

- expected value of working time until failure $\overline{T_u}$,
- reliability function *R(t),*
- failure rate function *λ(t).*

These are measures of probabilistic nature, because based on the assessment of probability for occurrence of an event of failure preventing from functioning, what is meant by providing function intended for the technical device [1].

## 2 SIMULATION MODEL'S RESEARCH POPULATION

Simulation model of ship failures to assess its safety is an mathematical algorithm estimating, what is the probability of damage occurrence or ship failure, having the influence navigational safety. The calculations are based on statistical distributions properties, which reflect (on the level of suitable confidence degree) the course of ships' elements damages in reality.

Rate of ship damages depends on many factors, among others:

- the age of the unit,
- the type of the ship,
- tonnage,
- type of navigation,
- navigation basin,
- others.

Obtaining such detailed data to compile a numerous and reliable research population is very problematic, or even unavailable. Population on which the model is based, is Polska Żegluga Morska fleet and data from annual reports from ship repair yards and producers of engineering ship devices.

Statistical data (table 2) on ship damages cover the 6 year-time period (1999-2005) and concern all the company's ships. Currently PŻM owns in total 77 ships, with total deadweight 2,1 mln dwt. These are bulk carriers in groups: coaster (4 400 dwt), numerous group of handy-size and panamaxes (73 500 dwt). Except bulk carriers PŻM owns 4 sulfur cariers and ferries m/f Polonia and m/f Gryf managed by Unity Line Szczecin.

Process of given system damage probability estimation, finds its reflection in properties of exponential distribution.

## 3 MODEL'S INPUT DATA

Input data and random variable of the damage and ship's failure model, have been prepared basing on the statistical samples of PŻM fleet, Ship Repair Yard and publications connected with the life-span and use of ships' systems.

Input variable is the amount of annual utilization periods of the ship. By annual utilization period we understand an average number of running days of the ship's systems per year (tab. 1). It fluctuates around 208 for ships with deadweight 1000-100000 DWT (90% of PŻM fleet, being the research population). Research population is the data with average number of damages and failure of ships, during the utilization period and average or limited repair times (tab. 2).

Table 1. Annual average utilization time of ship. Source: [3]

| DWT | Engine working time | Annual exploitation time of the ship | Number of calls to port | Number of days in the port | Engine working time | Engine non working time (in port) | Number of days at sea | Time of demurrage | Max days at sea (~5 days of demurrage) |
|---|---|---|---|---|---|---|---|---|---|
| [tons] | [h] | [day] | - | [day] | [day] | [day] | [day] | [day] | [day] |
| | *A* | *B* | *C* | *D=C x 1,5* | *E=A/ 24* | *F=B - (A/24)* | *G=B - D* | *H=360 - B* | *I=360 - D* |
| < 5,000 | 4000 | 240 | 100 | 150 | 167 | 73 | 90 | 120 | 210 |
| 5,000 – 100,000 | 5000 | 270 | 60 | 90 | 208 | 62 | 180 | 90 | 270 |
| > 100,000 | 6000 | 300 | 35 | 53 | 250 | 50 | 247 | 60 | 307 |
| Average of world fleet | 5840 | 300 | 70 | 105 | 243 | 57 | 210 | 60 | 255 |

Table 2. Number of PŻM fleet damages/failures. Based on PŻM data

| Damage/failure | Annual number of damages/failures | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
| Damage of machinery appliances : | [%] of overall PŻM ships | | | | | | |
| - main engine | 10.1 | 2.2 | 18.5 | 23.0 | 17.1 | 21.3 | 5.3 |
| - auxiliares | 7.9 | 6.6 | 7.4 | 10.8 | 9.2 | 8.0 | 6.7 |
| - other appliances [1)] | 1.1 | 0.0 | 2.5 | 5.4 | 5.3 | 4.0 | 2.7 |
| Damage of steering: | [%] of overall PŻM ships | | | | | | |
| - rudder | 2.2 | 2.2 | 1.2 | 4.1 | 1.3 | 1.3 | 4.0 |
| - installation of main shaft and propeller | 6.7 | 5.5 | 7.4 | 5.4 | 3.9 | 5.3 | 2.7 |

By damage we understand the faultiness state of the system, which is eliminated just and only by the ship crew. By the failure of the ship, we mean the faultiness state which occur during the utilization of the ship, which can not be eliminated by the means of ship's crew, what results in necessity of repair in shipyard or by service (tab. 3).

It has been accepted that every failure is preceded by the inspection (minimum 30 minutes) of unsuccessful trial to repair the damage.

Table 3. Number of events on one unit in the 1-year-period of utilization time and approximated times of repair. Based on PŻM and "Gryfia" Repair Yard data

| Damage/failure | Average number of failures | Time of repair | | Average number of damages | Time of repair | |
|---|---|---|---|---|---|---|
| | [failures/per utiliz. period] | min [h] | max [h] | [damages/ per utiliz. period] | min [h] | max [h] |
| Damage of machinery appliances : | | | | | | |
| - main engine | 0.139 | 168 | 2160 | 12.83 | 0.5 | 72 |
| - auxiliares | 0.081 | 60 | 336 | 5.3 | | 84 |
| - other machinery appliances * | 0.030 | 4 | 250 | 4.24 | | 110 |
| Damage of steering: | | | | | | |
| - ruder or steering instalation | 0.023 | 264 | 496 | 1.1 | 0.5 | 69 |
| - installation of main shaft and propeller | 0.053 | 24 | 1465 | - | - | - |

* – for remaining devices we account among others: boilers, steam devices, cooling installation, fuel installation and other secondary systems, excluding the main engine and auxiliary engines. For damages we account also damages caused by fires.

Model does not take into consideration ageing processes and renewal of particular systems' elements, due to the lack of access to this type of data.

## 4 THE FAULT-TREE MODEL'S ALGORITHM

Simulation model in the form of statistical fault-tree simulates the probabilities of systems' damages and ships failures (fig. 1) in chosen amount of annual periods of use. The above model has been worked out basing on the random variable of $X = t$ exponential distribution simulation, describing the course of probabilities for occurrence of an event, after time *t*, described with the dependency:

$$F(x) = 1 - \exp(-\lambda x) \quad (1)$$

$$x = t = \frac{1}{\lambda} \ln \frac{1}{1 - Rn} \quad (2)$$

where: $Rn$ = random variable of the uniform distribution, containing in the range $Rn \in [0,1]$; $\lambda$ = number of failures for one ship in 1-year period of utilization (~208 days).

Simulation of damage of failure occurrence proceeds according to the dependency:

$$P_D(t) > P_{LD}(t) \quad (3)$$

where: $P_D(t)$ = probability of damage occurs;
$P_{LD}(t)$ = probability obtained from the random variable of uniform distribution $Rn \in [0,1]$.

We assume that every failure is preceded by the damage, which is impossible to remove in the scope of abilities of ship crew members. Time needed to remove the damage is simulated on the basis of random variable of uniform distribution, assuming, that it has a random character (according to the ship repair yard employees) and that the minimal time of repair equals to 30 minutes.

Simulation of the failure occurrence proceeds according to the dependency:

$$P_F(t) > P_{LF}(t) \quad (4)$$

where: $P_F(t)$ = probability of failure occurs;
$P_{LF}(t)$ = probability obtained from the random variable of uniform distribution $Rn \in [0,1]$

Results of computer simulation of the statistical event-tree using the Monte Carlo method, are obtained on the basis of dependency:

$$P_D(t) = P_{D1}(t) P_{D2}(t) \ldots P_{Dn}(t) \quad (5)$$

$$P_F(t) = P_{F1}(t) P_{F2}(t) \ldots P_{Fn}(t) \quad (6)$$

where: $P_n(t)$ = probability of last damage or failure that occurred in simulation and:

$$t_D = t_{D1} + t_{D2} + \ldots + t_{Dn} \quad (7)$$

$$t_F = t_{F1} + t_{F2} + \ldots + t_{Fn} \quad (8)$$

where: $t_n$ = time needed to repair the damage or failure.

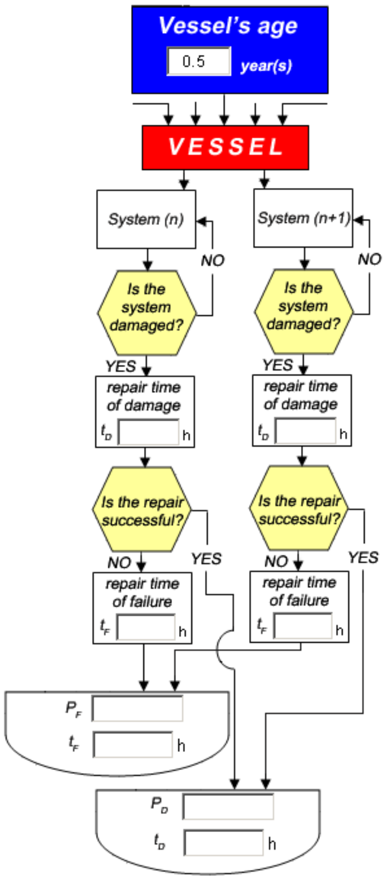
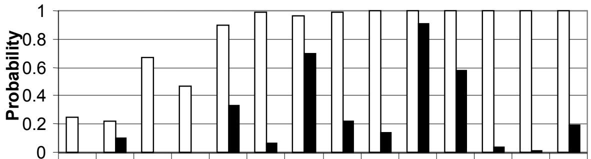



Fig. 1. Algorithm of the fault-tree model

## 5 RESULTS OF SIMULATION

From the results of simulation and from the analysis of gathered data it comes out, that together with the increase in number of ship utilization periods, susceptibility for given system failure increases as well. It is due to the fact, that every ship device is subjected to the process of wearing out, intensity of which depends on utilization factors like, among others, the professionalism of the crew, accuracy of design and workmanship, the environmental conditions in which it works.

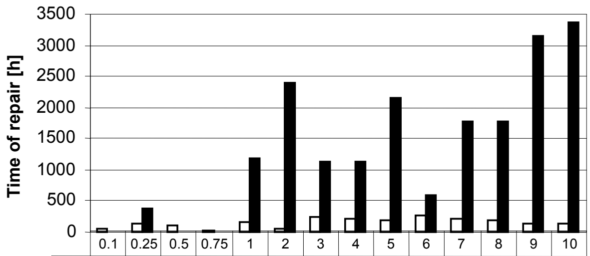
From the performed simulations, basing on the experts' knowledge and the research materials, it results that the process of ships systems damages in its great measure has the random character. It is impossible to explicitly state and translate into tabular manner, the ratio of number of specific types of damages occurrence to the beforehand assumed age of the unit. It happens that the relatively new ships suffer from damages, which have never occurred in old and utilized units.




| | 0.1 | 0.25 | 0.5 | 0.75 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_D(t)$ | 0.25 | 0.22 | 0.67 | 0.47 | 0.9 | 0.99 | 0.96 | 0.99 | 1 | 1 | 1 | 1 | 1 | 1 |
| $P_F(t)$ | 0 | 0.1 | 0 | 0 | 0.33 | 0.06 | 0.7 | 0.22 | 0.14 | 0.91 | 0.58 | 0.04 | 0.01 | 0.19 |

Annual utilization period

Fig. 2. Example results of safety model simulation for ship – probability of damages or ship systems failure occurrence for the number of utilization periods from 0.1 to 10




| | 0.1 | 0.25 | 0.5 | 0.75 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| □ $t_D$ | 61.9 | 129 | 108 | 36.8 | 160 | 64.9 | 241 | 224 | 184 | 277 | 205 | 184 | 147 | 139 |
| ■ $t_F$ | 0 | 369 | 0 | 0 | 1188 | 2396 | 1118 | 1142 | 2158 | 589 | 1790 | 1766 | 3145 | 3375 |

Annual utilization period

Fig. 3. Example results of safety model simulation for ship – time of repair of damages or ship systems failures for the number of utilization periods from 0.1 to 10

Similar distribution has the characteristic of probability density for damage occurrence in relation to characteristic of failure occurrence. Intensity of both events is a random process and depends on numerous factors (quality of service, physical and chemical phenomena), which one can not, in any way, consider in this type of model.

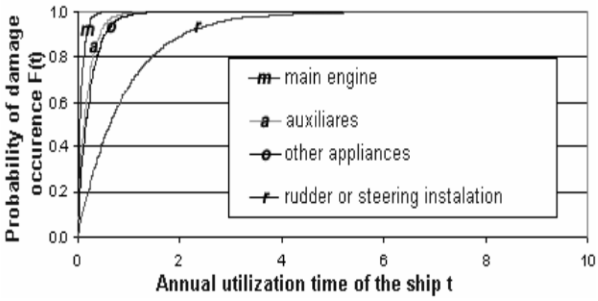



Fig. 4. Probability of system damage occurrence after the time t for the number of utilization periods from 1 to 10

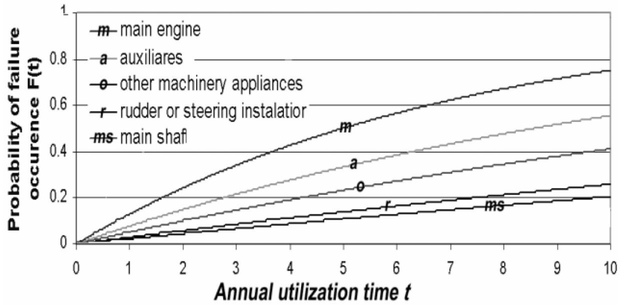



Fig. 5. Probability of system failure occurrence after time t for the number of utilization periods from 1 to 10

## 6 CONCLUSION

Using the properties of exponential distribution, statistical event-tree method and Monte Carlo method, as well as considering abovementioned real statistical data, I have created the analytical model simulating the probability of damage or failure on the ship in the assumed time. It determines the chance of event occurrence after chosen amount of 1-year utilization periods. Using the properties of exponential distribution and the mentioned Monte Carlo method, it was possible to simulate the times, which are required to bring the state of system efficiency back, for the systems which were the subject of failure in the mentioned model of probabilities intensity.

Calculations and simulation analysis which were carried out, create the picture of event probability rate on the specific units. Such simulations allow to state, how does the damage and failure distribution develop, for the given type of ship (in the model, data concerning bulk carriers of tonnage from 10 to 100 thousand DWT was used) and on this basis conclude which systems on the ship requires close attention in the aspect of increasing the safety and reliability of service. Moreover they can be also used by different types of institutions responsible for navigation safety, procedure planning, planning of recommendations and orders applied to utilization and design of solutions for the marine industry.

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