Polish J. of Environ. Stud. Vol. 18, No. 2A (2009), 39-44

Assessment of Reliability and Availability of Fishing Vessels Power, Propulsion and Technological Plants Based on Fault Tree Analysis

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Abstract

In the paper there has been presented the methodology of estimating reliability and availability of fishing vessels power, propulsion and technological systems (*SENiT*) with the use of fault tree as a a graphical representation of the reliability structure of the system. *SENiT* have been presented as systems with variable functional and reliability structures. Basic fishing vessels *SENiT* operational states with regard to the reliability structure changes of the system have been characterized. A description of reliability structure change of the system using the external events vector has been suggested. The methodology of estimating reliability of complex technical systems has been presented. The models of reliability structure of *SENiT* have been shown as fault trees. An exemplary report based on the fault tree analysis and description of the system configuration with the use of external events vector have been enclosed.

Keywords: fishing vessel, technological plant, power plant, reliability and availability estimation, fault tree analysis

Introduction

Fishing vessels power, propulsion and technological systems (*SENiT*) are multi-state complex technical systems with variable functional and reliability structures. Since it is possible to apply more and more modern power systems, which is related to the fishing fleet development, the assessment of fishing vessel power propulsion (providing the vessel with propulsion and auxiliary mechanisms) and technical (fishing, processing and fish storage) systems reliability especially in reference to the cost of investment and operation of various construction solutions of *SENiT* systems turns out to be a fundamental issue.

The paper deals with selected aspects of fishing vessels *SENiT* reliability assessment, which is the result of The Branch Project "Fishing and fish processing 2004-2006" as a part of innovative and other various actions entitled "Methodology of reliability and operational availability of fishing vessels power systems' The subject has been worked out by the author in cooperation with Professor Zbigniew Matuszak and the detailed research results have been enclosed in [9]. The paper presents only the issues the author has worked on by himself. Comprising the application of fault tree analysis to the *SENiT* reliability assessment as well as the method development due to which modeling changes of operational state by means of external events vector turns out to be possible.

The systems analysis making use of *FTA* (*Fault Tree Analysis*) is based on detailed and deductive evaluation of the analyzed technical system's working principles.

The most essential part of the method is graphic representation of logical relations between specified components fault states (down-states) of the technical system in question, the equipment and software working errors, human (operator's) errors and external events; e.g., showing the interactions between various systems and external environment

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whose combination may lead to the analyzed defined state of the whole system, that is the occurrence of *top event*.

The method of fault tree analysis was successively developed during the last decades which is to be attributed to a big group of scientists and engineers. In 1941 H. W. Heinrich [14] came up with the methodology which became the foundation of the fault tree analysis; he illustrated a linear sequence of selected factors leading to an accident (domino theory). For the first time in 1961 H. A. Watson from Bell Labs made use of the *FTA* method in cooperation with the US Air Forces when he carried out the safety analysis of the structure controlling the launch of Minuteman rocket missile [21]. In nineteen sixties appeared first publications concerning *FTA* method. Their authors were H. Watson [21], A. Maerns [16] (basic methodology), D. Haasl [13] (development of the fault tree construction method). In the following years due to R. Schroeder (*BACSIM, AFTD*), W. Vesely (*KITT, PREPP*), D. Worrel (*SETS*), R. Willie (*FTAP*) and others [8, 15, 18] many computer programs supporting the qualitative and quantitative *FTA* analyses were created. Since the very beginning various aspects of the method have been developed like e.g., fault tree automatic synthesis by J. Fussell; events importance analysis by H. Lambert, W. Vesely, J. (kinetic tree theory, *MOCUS* algorithm), P. Pande (*MICSUP* algorithm) and others [8].

There can be noticed some development trends of the method which appoint it to specific applications. Until now *FTA* analysis as a very effective tool is widely used in power, automobile, railway and chemical industry. Description of the method's adaptation, its accuracy improvement and enlarging its application range have been the topic of numerous publications both domestic and worldwide [3, 10, 19, 22].

However, among the publications dealing with assessment of reliability of marine power plant systems the attempts of discussing the subject of analytical methods application in reference to the marine power plants of sea-going vessels have occurred rarely and presented the aspect generally. In literature fault tree analysis as a tool applied to various calculation methods of marine machinery reliability measures has been sporadically presented [1, 4-7, 17], whereas the form of its application together with external events vector describing the system configuration at a given operational state, according to the author of the paper's knowledge, has been presented for the first time in this paper.

Fishing Vessels *SENiT* Systems

For the needs of the fishing vessels *SENiT* reliability an availability analysis there have been modeled structures of the systems based on the model of a general system. In the analyzed case as the example, the system has not got any stand-by components. In the real systems reliability analysis it is necessary to take into account more complex structures (treshhold, series-parallel, parallel-series etc.). In the analyzed here case for full functionality of the vessel, it is necessary up state of all components of the system (series reliability structure). The system components and the exemplary data concerning failure intensity (failure rate) and availability of the system components have been illustrated in Table 1 (exponential distribution of components time to failure). The data on components failure have been assumed on the basis of [11]. In case of real systems analysis, there is necessary assumption of the other - better fit to the real working conditions of the components – probability distributions of components time to failure and their parameters based on the operational research of the system.

Basic operational states of a fishing vessel *SENiT* are:

1. Sea voyage, when a vessel moves/proceeds between fisheries or/and ports, all system components except trawl and net winches work. In such situation there can be the case of the working *ME* propelling via the gear the uncoupled propeller shaft, fixed propeller or controllable pitch propeller equipped with a Kort's nozzle, an engaged *AC* shaft generator, installed but disengaged shaft pumps and winches and electrical winches uninstalled or switched off.
2. Casting and hauling in the nets, when all the system components except net winches work. At this state there is a possibility of the case of the working *ME* propelling via the gear the uncoupled propeller shaft, fixed propeller or controllable pitch propeller equipped with a Kort's nozzle, an engaged *AC* shaft generator, installed and engaged shaft pumps and shaft winches and uninstalled electrical winches.
3. Trawling operation, when all components work. There may occur the case of the working *ME* propelling via the gear the uncoupled propeller shaft, fixed propeller or controllable pitch propeller equipped with a Kort's nozzle, an engaged *AC* shaft generator, installed and engaged shaft pumps, installed and engaged trawl winch and installed but disengaged shaft net winch and uninstalled or disengaged electrical winches.
4. Fishing when drifting or laying in the port, when all power generators work whereas winches and the main propulsion unit do not. In this situation there may occur the case of the working *ME* propelling via the gear the *AC* shaft generator with the disengaged propeller shaft being in exactly the same state, fixed propeller without the Kort's nozzle, installed in the system and engaged shaft pumps, installed and disengaged shaft winches and uninstalled or switched off electrical winches.

The particular system elements can be switched on and off work depending upon the vessel's operational state. Apart from that not all components need to appear in the considered fishing vessels which is connected with a specific technological solution applied during the vessel's construction. The worked out models presented in the further part of the paper allow for reliability and availability analysis of the systems in various structure combinations of the components and for different operational states. The models have been worked out by the author of the paper.

Marine power systems including fishing vessels are known for their functionality and reliability structure variable in time which is due to changes of a vessel's operational state [2].

Table 1. Values of fishing vessel SENiT availability and failure intensity of components.

Symbol	Componnent description	Availability a [-]	Failure intensity λ [10^{-6} h^{-1}]
1	The main engine with auxiliary operating installations (*ME*)	0,995907	575
2	The main engine exhaust manifold	0,999586	82
3	Air supercharging system (air filter, air cooler, turbocharger)	0,998221	418
4	Clutch of the main engine intermediate shaft	0,999997	3,3
5	Gear box	0,999773	42,9
6	Shaft line (intermediate and propeller shafts, bearings and the stern tube sealing)	0,999983	29,1
7	Fixed or controllable pitch propeller	0,999997	3,3
8	The propeller Kort's nozzle	0,999999	0,2
9	Alternating current shaft generator	0,999972	4,4
10	Direct current shaft generator	0,999972	4,4
11	Pump No 1 driven by the main engine propulsion gear	0,999181	176,9
12	Pump No 2 driven by the main engine propulsion gear	0,999181	176,9
13	Hydraulic propulsion system (pump-motor) of the trawl winch driven by the main engine propulsion gear	0,999851	88,2
14	The trawl winch gear driven by the system 13	0,999773	42,9
15	The trawl winch pulley driven by the system 13	0,999993	11,1
16	Hydraulic propulsion system (pump-motor) of the net winch driven by the main engine propulsion gear	0,999851	88,2
17	The net winch gear driven by means of system 16	0,999773	42,9
18	The net winch pulley driven by system16	0,999993	11,1
13a	Electromotor of the trawl winch	0,999181	176,9
14a	The trawl winch gear driven by the system 13a	0,999773	42,9
15a	The trawl winch pulley driven by the system 13a	0,999993	11,1
16a	Electromotor of the net winch	0,999181	174,9
17a	The net winch gear driven by means of system 16a	0,999773	42,9
18a	The net winch pulley driven by system16a	0,999993	11,1
19	The sea water pump for power and technological systems operation	0,998787	297,5
SAC	Clutch of the alternating current generator shaft	0,999773	42,9
SDC	Clutch of the direct current generator shaft	0,999773	42,9
SP1	Clutch of pump No. 1	0,999773	42,9
SP2	Clutch of pump No. 2	0,999773	42,9
SW1	Clutch of hydraulic pump of winch 15 propulsion system	0,999773	42,9
SW2	Clutch of hydraulic pump of winch 18 propulsion system	0,999773	42,9
SH1	Clutch of hydraulic pump of winch 15 propulsion system	0,999773	42,9
SH2	Clutch of the hydraulic engine of the winch 18 propulsion system	0,999773	42,9
SWL	Clutch of the propulsion shaft	0,999773	42,9
x	Diesel generating set	0,999339	181,7
y	Other electrical consumers.	0,991335	1951,9

At different states the systems are featured by switching on or off work specific components due to the vessels capability of various tasks realization. Due to the work structure and specificity all components form series reliability structure with variable number of system components which depends upon a specific *SENiT* technological solution and the vessel's operational state.

Methodology of *SENiT* Reliability Measures Assessment

As a part of the project [9] the methodology of estimating reliability of the system with constant and variable work structure for the most frequently occurring simplest and basic types of failure has been presented. The detailed

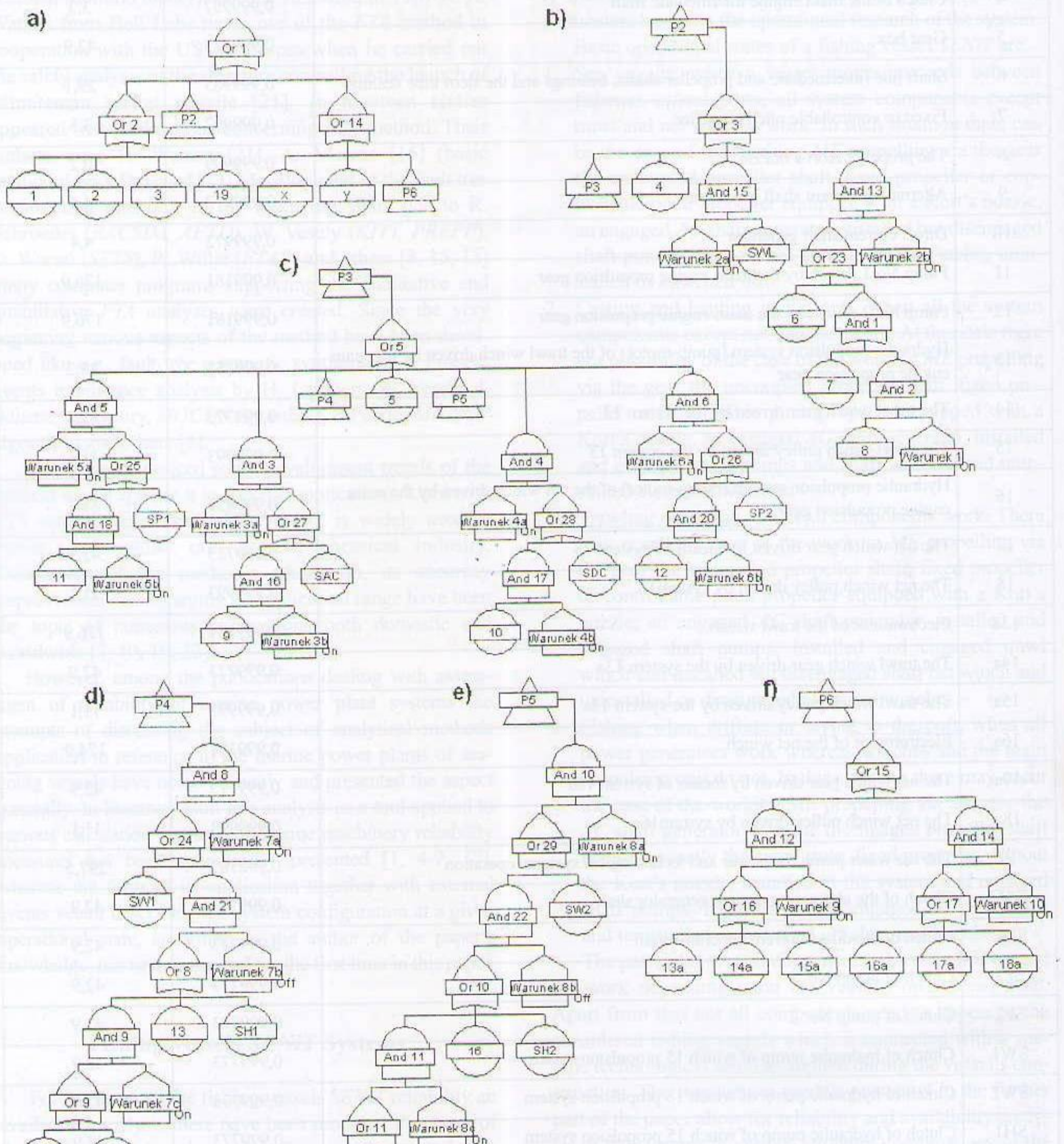

Fig. 1. Fault tree of a fishing vessel SENiT: a) the main tree; b) sub-tree of shaft line; c) sub-tree of a gear box block; d) sub-tree of a trawl winch driven by the main engine; e) sub-tree of a net winch driven by the main engine; f) sub-tree of electrically driven trawl and net winches down-state.

analysis comprised application of the methodology to estimating reliability of the system with constant and variable system reliability structure for the selected special basic cases of reliability structures.

In the part of project [9] concerning selected methods of marine power plants systems including fishing vessels' reliability and availability as a part of the project reported the following methods nave been characterized: overview of systems state, table of logic algebra function (*FAL*), minimal path-sets and cut sets; block reliability diagrams, method of complex decomposition, method of Markov chains (processes), method of modeling statistical events and random processes and fault tree analysis. Apart from that, examples including precise calculations due to the application of the methods of: decomposition, down-state minimal cut sets and fault tree analysis have been enclosed. Moreover, the paper deals with an example of an analysis to which fault tree analysis and external events vector describing the system configuration have been applied, which was the author's individual contribution to the project.

All reliability analysis methods consist of a considerable number of common stages such as [3, 8, 12, 18-20]:

1. Specifying initial assumptions comprising the system boundaries, outlining its components at a certain assumed level of decomposition.
2. Carrying out statistical research on the basis of real objects, analysis of random tests membership with failures up to one general population in case of using various tests data, analysis of empirical distribution adjustment to the commonly known theoretical distributions and calculation the distributions parameters.
3. Completing the information with data from the recognized reliability databases in case of missing or incomplete information about reliability of system components.
4. Assessment of system components reliability measures.
5. Construction of system reliability structure model.
6. Application of selected specified analysis methods (e.g., fault tree analysis) to estimate reliability system measures.
7. Drawing conclusions based on the obtained results of quantitative and qualitative analysis.
8. Additional analyses based on the obtained results such as the importance and sensitivity analysis of system components and uncertainty analysis of the obtained results.

As a matter of fact each of the outlined stages appears to be complex and consists of a number of actions which depending upon the system complexity turn out to be more or less time consuming but require accurate and precise specifying of assumptions and requirements.

Fault tree analysis of *SENiT* may be carried out on three levels:

- operational level indicating the power plant operational conditions in which the failure occurred (sea voyage, maneuvering, work with dynamic positioning, laying in the port, laying in the shipyard, sea-trials etc.),
- system level pointing out which subsystems of the marine transport system (vessel, operating personnel, influence of the environment) could have been the cause of the failure;
- causal level pointing out which events could have been the cause of the system failure.

As the events, all changes in the structure and working of components constituting a physical part of the system, system operator's errors and the influence of external factors have been taken. Events can occur due to system components failure, not properly done the maintenance and handling of the system as well as due to influence of environment.

Case Study

From the general point of view the presented system corresponds to a series reliability structure whose proper parts may be switched on or off the structure depending upon the technological solution applied to a vessel and her operational state (engagement and disengagement as well as switching on and off system components).

The system reliability structure has been modeled by means of the fault tree shown in Fig. 1a. Since the model was developed for sub-trees equivalent to the subsystems of *SENiT* transfer symbols have been used. Individual subtrees of the main fault tree have been shown in Fig. 1b-1f.

Components participating in a vessel's *SENiT* work at a certain operational state are connected in a series structure (down-state of any of the components shall cause limited functionality of a fishing vessel). Conditions permitting to switch on and off components not participating in the work process have been modeled by means of additional model in the form of external events vector. Detailed meaning of the vector components has been presented in [9].

For the considered operational states of specified configurations *SENiT* exemplary availability and reliability analyses of the work states have been carried out. Literature data shown in Table 1 have been taken as input values of measures describing primary events in fault trees. Calculations have been done with use of *CARA Fault-Tree 4.1*, academic version computer code.

In Fig. 2 an exemplary *SENiT* analysis during a sea voyage for the case of working *ME* propelling via the gear the uncoupled propeller shaft, fixed propeller without a Kort's nozzle, an engaged *AC* shaft generator, installed but disengaged shaft pumps and winches.

Conclusions

In the paper one of reliability assessment methods for *SENiT* analyzed as a part of the project [9] has been shown. Fault tree connected with external events vector for description of the system configuration allows for making calculations automatic which may appear useful for comparative evaluation of investment expenses concerning various technological solutions of a system.

Two other methods: decomposition and cut-sets analysis presented in [9] need a separate model for each configuration to be created, which has been eliminated for *SENiT* models in the form of fault trees due to the introduction of external events vector.

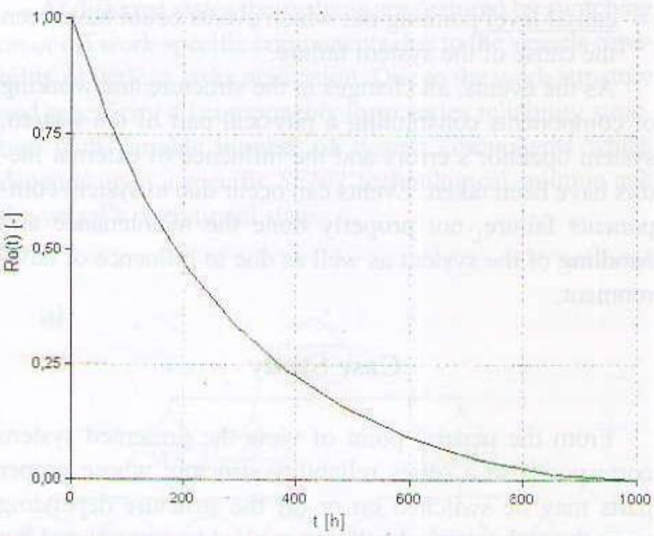

Fig. 2. Fragment of report of SENiT analysis for a sea voyage state.

Date: 08-02-21 Time: 19:39:01
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New fault tree
Calculation of Ro(t) - survival probability
Method: Numerical integration
All calculated results:
Results of numerical integration:

Expected # of failures in period:	1,12592
Expected # of failures/unit time:	0,00112592
MTTF = Mean time to first failure:	251,034

Apart from the methods mentioned in the project [9] there have been many other ways of modeling reliability structure of a system like for example block reliability diagrams, Markov models, event trees. Detailed presentation of each of the methods exceeds the range of the publication. The method's detailed description can be found in literature dealing with this subject. In the project only selected methods applicable to the analyzed *SENiT* as relatively simple and accurate providing easily modified models depending upon the system structure have been presented.

Acknowledgements

Work has been done under The Branch Project OR 16-61535-OR 1600006/06 "Fishing and fish processing 2004-2006" (Sektorowy Program Operacyjny "Rybołówstwo i przetwórstwo ryb 2004-2006").

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