ZBIGNIEW MATUSZAK, D.Sc.,M.E.
MARCIN KOŁODZIEJSKI, M.Sc.,M.E.
Maritime University, Szczecin
Institute of Ship Power Plant
Technical Exploitation

Importance assessment of ship power plant system components

SUMMARY

Different importance measures applicable to ship power plant system components are presented. Birnbaum's and Lambert's importance measures were applied to choose the most important components of one of the power plant systems onboard the KOPALNIA KLEOFAS.

The paper presented at XVI Ship Technology Scientific Session, Szczecin - Dziwnówek, 1994

INTRODUCTION

Ship power plant systems are composed of many elements. While analyzing reliability of such complex systems it is often necessary to determine which of the system's elements (components) is the most important in respect of the maximum value of a chosen reliability index, viz., e.g., which of the components influences most an expected value of system's correct operation time or whose reliability improvement or degradation impacts most such changes of the expected value of system's correct operation time. The problem is known as: that of the"weak link" searching for in a system, or that of searching for the most unreliable groups of elements in a system, or importance analysis.

From reliability point of view, component's importance in a system depends on the reliability value of the component and its position in system's reliability structure. The more a component resembles the self-contained one which is serially included into system's structure, „the more important" it is.

The degree of component's importance can be assessed by using the so called measures of component's importance; each of them is based on a slightly different approach. Choice of the measure relevant to a given practical problem depends on the component importance criterion applied to solving the problem .

In this paper an attempt is presented to assess the applicability of different component's importance measures on the basis of an analysis of the piston oil circulating lubrication and cooling system of 662-VT2BF (Burmeister & Wain) main engine installed onboard the KOPALNIA KLEOFAS bulk carrier owned by the Polish Steamship Company (PŻM). „Weak links" of the system were also identified on the basis of some selected importance measures.

The presented component's importance analysis is that of a system composed of the unreparable elements, because it is known [6] that under some conditions the reparable elements can be considered as unreparable ones while carrying out reliability analysis.

CHARACTERISTICS OF SOME IMPORTANCE MEASURES OF SYSTEM'S COMPONENTS

In 1969 Birnbaum [3] proposed an importance measure of the component n_i at the time instant, t, in the following form:

$$I_B^{(i)}(t)=h[1_i,R(t)]-h[0_i,R(t)] \tag{1}$$

where:

h - system's serviceability (reliability) function with the component's reliability functions, $R_i(t)$, as its arguments, thus:

$$R(t)=h[R(t)]=h[R_1(t),R_2(t),\dots R_n(t)]$$

The expression (1) determines reliability decrement of a system (e.g. a ship installation) caused by a failure of the component n_i because $h[1_i,R(t)]$ determines system's reliability when the component is serviceable (at t time instant), but $h[0_i,R(t)]$ system's reliability when the component is unserviceable.

Birnbaum's measure can also be understood as the probability of failure occurence of the system component n_i at t time instant which causes the system to fail, i.e. that at that time the system is in a critical state due to the component n_i. Therefore Birnbaum's measure can be defined as follows:

$$I_B^{(i)}=\frac{\partial h(R)}{\partial R_i}\Big|R_j=R_j(t) \tag{2}$$

The importance measure does not depend on the reliability of the component n_i , but only on system's reliability structure, on time and reliability of the rest of components.

Another importance measure, independent of time, is Barlow-Proschan's measure [1]:

$$I_{B-P}^{(i)} = \int_0^\infty f_i(t) I_B^{(i)}(t)dt \tag{3}$$

where:

$f_i(t) = F_i'(t)$ - the failure probability density of n_i component

$F_i(t)$ - the failure cumulative probability distribution of the component.

The Barlow-Proschan's measure is equal to the probability of the system's failure to be caused by the failure of n_i component. It is sometimes considered to be the „averaged Birnbaum's measure" in respect to $F_i(t)$. If (3) is integrated within the range $[0,t]$, such measure expresses the probability that a system fails before t time instant and it is caused by the failure of n_i component.

A decrement of system's correct operation residual time, caused by the failure of a given component, may also serve as a component's importance measure [7,8]. If system's components fail independently from each other, the measure is called „Natvig's measure" and takes the following form:

$$I_N^{(i)} = k_N \int_0^\infty R_i(t)\left[-\ln R_i(t)\right] I_B^{(i)}(t)dt \tag{4}$$

where:

k_N - the factor assuring summation of the measure to 1.

Another importance measure, independent of time, is Bergman's measure [2,9]:

$$I_{Be}^{(i)} = k_{Be} \int_0^\infty t f_i(t) I_B^{(i)}(t)dt \tag{5}$$

Applicability of all three presented measures is similar.

Lambert's measure [5] of component's importance for a system is based on the so called „critical component" notion. The measure takes into account that for the critical component n_i:

- the system fulfils its functions when the component is serviceable
- the system does not fulfil its functions (fails) when the component fails.

All components are obviously critical in a system of the serial structure, but in the case of other structures a component becomes critical when the components, remained in the unserviceability cuts which a given component belongs to, fail.

Lambert's measure is of the following form:

$$I_L^{(i)} = \frac{\left\{h\left[1_i, R(t)\right] - h\left[0_i, R(t)\right]\right\} F_i(t)}{1 - h\left[R(t)\right]} \tag{6}$$

The numerator of (6) expresses the probability of that a system to be , at the time instant t, in such a state that the component n_i is critical and fails before the time instant t.

Two measures only, the Birnbaum's and Lambert's ones, out of those above reviewed, can be practically used in the case of the system examined by these authors.

The remaining ones can be used in the case if a functional dependence of system's reliability(or its cumulative distribution) on the operation time of all components of the system were found. In the investigated case it was not available because the magnitudes were determined empirically (constant values, independent of time) on the basis of ship's power plant observation for seven months.

DESCRIPTION OF THE INVESTIGATED SYSTEM

In the main engine circulating lubrication system (Fig. 1) the following components were taken into account:

3,4 - screw circulation pumps, 6,7 - coolers (of shell-and-tube type), 5 - mixing valve, 19 - compressed-air-cleaned oil filter, 20 - pressure tank, 23 - pressure tank overflow with an inspection eyehole (placed in the power plant control room [CMK] to control system's operation), 22 - main engine, 21 - spare oil tank, 1 - service oil tank, 2.1 - engine crankcase dump valve, 10,13 - oil processing heater, 11,14 - centrifugal separator, 17 and 18 - valves cutting out the inlet and oulet pipes connecting separators (one of the separators cleans the circulating oil for the main engine only, but the other - the lubricating oil for auxiliary engines ; they can substitute each other in emergency), 15 and 16 - connections of inlet and outlet pipes with the valve boxes which steer flow of circulating oil for auxiliary engines, 8 - valve box which steers inlet of the main engine circulating oil into separator: A - suction of the oil from stuffing-box leakage tank, B - suction the oil, remaining after cleaning oil filter, from contaminated oil tank , C - suction from the circulating oil tank, D - suction from the spare oil tank, E - suction from the main engine crankcase.

The tank 20 is located in the funnel casing at the height equal to the liquid head corresponding to the regular circulation pressure in the installation. Whenever the oil pressure in the installation drops the oil level in the tank drops as well. The tank overflow is placed in the upper part of the tank thus any oil level dropping can be observed in CMK. The pressure control is also installed in the overflow piping, which activates alarm signals in the case of oil pressure dropping below the allowable value. Two automatic switch keys of MORBEY type are installed in the overflow tank, which in the case of oil pressure dropping in the installation (and therefore also oil level lowering in the pressure tank) activate the second, stand-by pump.

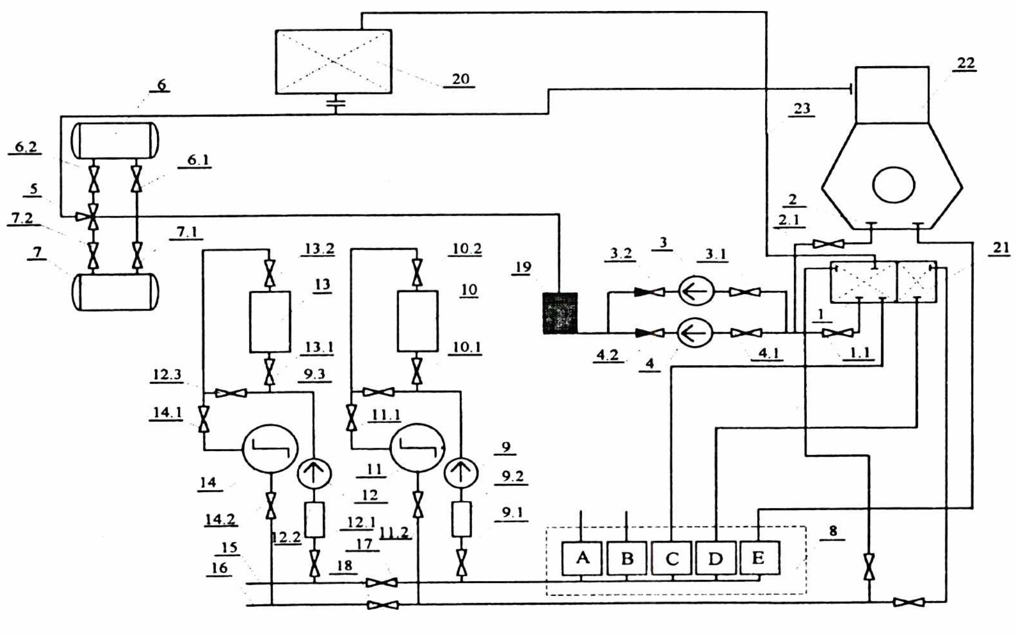

Fig. 1. Scheme of lubricating oil system (Description and denotations in the text)

Oil circulation in the system is forced by one of the two circulation pumps, 3,4 , which sucks oil from the circulation tank, 1, and sends it through a filter to the two coolers, 6,7, connected paralelly through the thermostatic valve, 5, which mixes both oil fluxes (that going through the cooler, viz. of a lower temperature, with that passing by the cooler, viz. of a higher temperature) with a changeable ratio to make possible keeping the oil temperature of 40,42 °C, specified by the engine maker, constant. The oil is then directed to the main engine where it is distributed to reach seperate cylinders. The oil flows through a pipe to the main bearing then through a hollow in the crankshaft to the crankshaft bearing then it finds its way to the crosshead bearings to flow down eventually to the crankcase and to the circulation tank. A separated oil flux is pressed through a hinge pipe to a piston rod and further through an internal duct in the rod to piston cooling space.

In the piston, the partition plates force the oil to flow along the possible longest way to cause the best heat exchange. Then the oil comes back through the piston rod and the control eyeholes to the circulation tank underneath the main engine. The circulating oil is cleaned in the centrifugal separating process. A centrifugal separator is used simultaneously to heat the oil preliminarily just before starting the engine. The following additional auxiliary tanks can be found in the circulating oil system: a stuffing-box leakage tank, after-filter-cleaning contaminated oil tank. The latter can be emptied to the circulation tank only when the residuals passed through a separator. Circulation tank oil fill-up from the spare oil tank can be performed by the oil separation system (or by the oil transporting system common for all the power plant systems). The separation system of the main engine circulating oil works continuously and stops only to clean centrifugal separators up. The to-be-cleaned oil is sucked by separator's pump from the circulation tank (or from the engine crankcase in emergency) and then is processed in the centrifugal separator. The cleaned oil is sent back to the circulation tank (or to the spare oil tank).

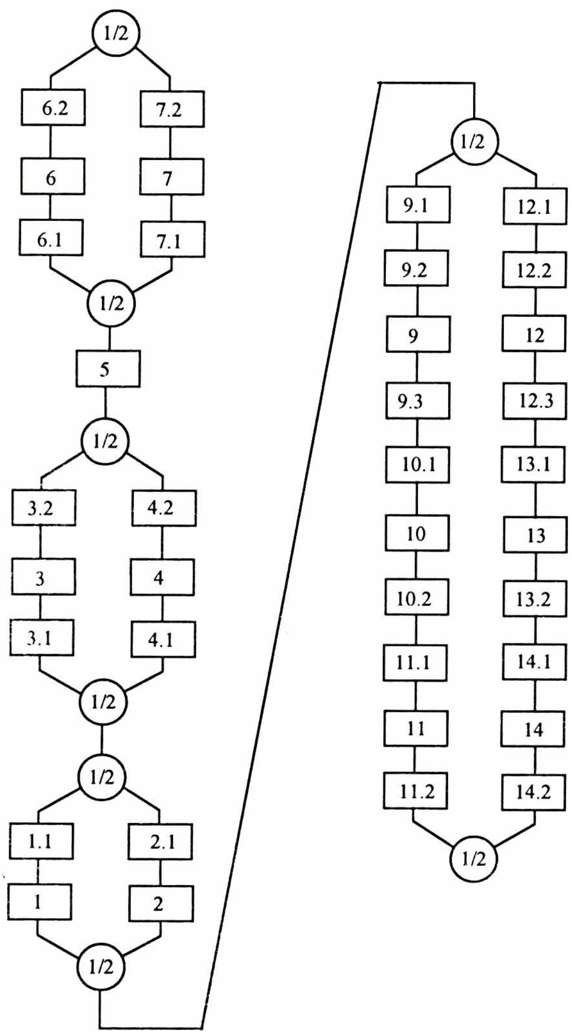

Fig. 2. A reliability structure of the oil circulating lubrication system (denotations in the text below)

In the oil circulating lubrication sub-system, the items of the following number symbols were distinguished to be the components of the reliability structure shown in Fig. 2:

6 - the oil cooler
6.2 - the inlet valve of the cooler 6
6.1 - the outlet valve of the cooler 6
7 - the oil cooler
7.2 - the inlet valve of the cooler 7
7.1 - the outlet valve of the cooler 7
20 - the oil circulation tank
3 - the oil circulation pump
3.1 - the suction-side valve of the pump 3
3.2 - the pressure-side valve of the pump 3
4 - the oil circulation pump
4.1 - the suction-side valve of the pump 4
4.2 - the pressure-side valve of the pump 4
1.1 - the outlet valve of the oil tank 1
2 - the engine crankcase
2.1 - the crankcase emergency-suction-off valve
8 - the oil flow control valve box of the main engine oil separating sub-system
9.1 - the valve in front of the centrifugal separator pump 9
9.2 - the oil filter in front of the centrifugal separator pump 9
9 - the centrifugal separator pump
9.3 - the valve behind the centrifugal separator pump 9
10.1 - the valve in front of the oil heater 10
10 - the oil heater
10.2 - the valve behind the oil heater 10
11.1 - the valve in front of the centrifugal separator 11
11 - the centrifugal separator
11.2 - the valve behind the centrifugal separator 11
12.1 - the valve in front of the centrifugal separator pump 12
12.2 - the oil filter in front of the centrifugal separator pump 12
12 - the centrifugal separator pump
12.3 - the valve behind the centrifugal separator pump 12
13.1 - the valve in front of the oil heater 13
13 - the oil heater
13.2 - the valve behind the oil heater 13
14.1 - the valve in front of the centrifugal separator 14
14 - the centrifugal separator
14.2 - the valve behind the centrifugal separator 14

The system constitutes a serial-parallel threshold structure.

SEARCHING FOR WEAK LINKS OF THE SYSTEM

The results of the searching with the application of Birnbaum's and Lambert's measures are given in both Tab. 1 and Fig. 3.

Tab. 1. Component importance measure values of the investigated system

Component symbol	Component number	$R_i(t)$	h $[1_i, R(t)]$	h $[0_i, R(t)]$	I - B(t)	$F_i(t)$	I - L(t)
A	19	0.920	0.853	0.000	0.853	0.080	0.464
B	6	0.980	0.853	0.820	0.033	0.020	0.004
C	6.1, 6.2	0.990	0.853	0.820	0.033	0.010	0.002
D	7	0.980	0.853	0.820	0.033	0.020	0.004
E	7.1, 7.2	0.990	0.853	0.820	0.033	0.010	0.002
F	3, 4	0.890	0.853	0.756	0.097	0.110	0.073
G	3.1,3.2,4.1,4.2	0.990	0.853	0.756	0.097	0.010	0.007
H	1	0.980	0.853	0.845	0.008	0.020	0.001
I	1.1	0.990	0.853	0.845	0.008	0.010	0.001
J	2	1.000	0.853	0.853	0.000	0.000	0.000
K	2.1	0.990	0.853	0.828	0.025	0.010	0.002
L	8	0.950	0.853	0.000	0.853	0.050	0.290
M	9	0.890	0.853	0.681	0.172	0.110	0.129
N	9.1	0.990	0.853	0.681	0.172	0.010	0.012
O	9.2	0.990	0.853	0.681	0.172	0.010	0.012
P	9.3	0.990	0.853	0.681	0.172	0.010	0.012
R	10.1	0.990	0.853	0.681	0.172	0.010	0.012
S	10	0.980	0.853	0.681	0.172	0.020	0.023
T	11	0.920	0.853	0.681	0.172	0.080	0.094
U	11.1, 11.2	0.990	0.853	0.681	0.172	0.010	0.012
V	12.1	0.990	0.853	0.681	0.172	0.010	0.012
X	12	0.890	0.853	0.681	0.172	0.110	0.129
Y	12.2	0.990	0.853	0.681	0.172	0.010	0.012
Z	12.3	0.990	0.853	0.681	0.172	0.010	0.012
A1	13.1, 13,2	0.990	0.853	0.681	0.172	0.010	0.012
B1	13	0.980	0.853	0.681	0.172	0.020	0.023
C1	14.1, 14.2	0.990	0.853	0.681	0.172	0.010	0.012
D1	14	0.920	0.853	0.681	0.172	0.080	0.094

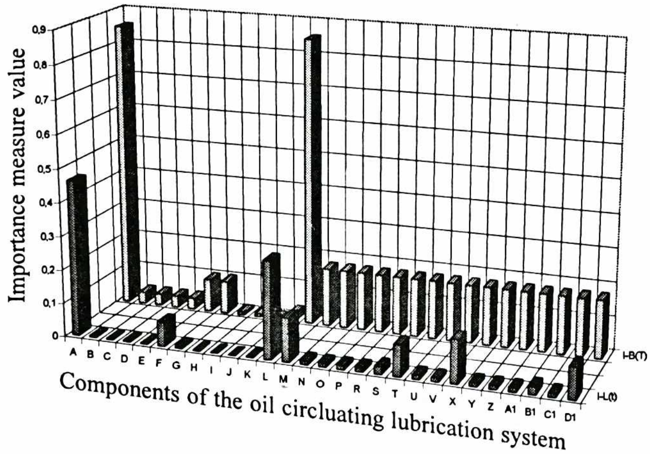

Fig. 3.Component importance measure values of the investigated system: I - B(t) - Birnbaum's , I - L(t) - Lambert's measure values (Capital letter symbols of the components are assigned to their number symbols in Tab. 1)

The following group of components of the system in question (Tab. 2) was disclosed as its weak links in result of the component importance assessment with the use of Birnbaum's measure:

Tab. 2. Weak links of the system according to Birnbaum's measure

Component		$I_B(t)$
A	- oil filter	0.853
L	- valve box	0.853
M	- separator pump	0.172
N	- in-front-of-sep.pump valve	0.172
O	- in-front-of-sep.pump filter	0.172
P	- behind-sep.pump valve	0.172
R	- heater inlet valve	0.172
S	- oil heater	0.172
T	- oil separator	0.172
U	- separator-in and -out valves	0.172
V	- in-front-of-sep.pump valve	0.172
X	- separator pump	0.172
Z	- behind-sep.pump valve	0.172
Y	- in-front-of sep.pump filter	0.172
A1	- heater-in and -out valves	0.172
B1	- oil heater	0.172
C1	- separator-in and -out valves	0.172
D1	- oil separator	0.172
F	- oil circ. pumps	0.097
G	- circ.pump-in and -out valves	0.097

The Birnbaum's measure indicated that the most important components of the system were those functioning in it as serial components, viz. the oil filter and valve box. The remaining selected weak-link components were the devices used in oil cleaning. The results are not adequate to the real state, as far as the oil circulating lubrication system is concerned, due to specific features of Birnbaum's measure which is mainly based on system's reliability structure. Most components of the system are placed in an almost identical way in such structure. All that indicates the importance assessment by using Birnbaum's measure to be rather imperfect.

A component importance analysis of the same system performed with the use of Lambert's approach revealed the following devices (Tab. 3) to be weak-link components of the system:

Tab. 3. Weak links of the system according to Lambert's measure

Component		$I_L(t)$
A	- oil filter	0.464
F	- oil circ. pumps	0.073
L	- valve box	0.290
M, X	- sep. pumps	0.129
T, D1	- oil separators	0.094

This assessment brought results quite different from those of the previous case. The following devices were selected the most important: the oil filter, valve box, separator pumps and separators as such. As far as the separators and their pumps are concerned they could be obviously weak links of the system, but the high value of Lambert's measure of the valve box makes think. This is due to its serial connection, location within system's structure as well as because of the assumed continuous oil cleaning mode while using the system. Its unserviceability would cause the oil separating sub-system to fail and, according to that assumption, the unserviceability of all the system in question. The high importance measure value of the oil filter is caused by its serial connection with the neighbouring components of the system and lack of any redundancy provided to it in the system.

CONCLUSIONS

It can be stated in result of the presented analysis that large differences appear of the weak links indicated when using Birnbaum's and Lambert's measures to the investigated system, as well as discrepancies between values of the measures applied to the same components. This is due to different philosophy behind the considered measures while applying them to the system and its components as well.

Birnbaum's measure can be defined as a measure typical of system's structure as it determines component importance on the basis of the way in which the component is located within the system and of component's redundancy level. It does not depend on the reliability of a given component but on system's reliability structure and the reliability of the remaining components exclusively. It determines the decrement of system's reliability, resulting from failure of a given component.

Lambert's measure is more universal in comparison with the previous one. It takes into account not only system's reliability structure and the location of a given component within it but also its reliability value.

It should be added that the application of the other component importance measures, discussed in this paper, to a system requires long-lasting observation and recording failures of the components of the system onboard ship in service.

BIBLIOGRAPHY

1. Barlow R.E., Proschan F.: „ Importance of system components and fault tree events ". Stochastic Processes and their Applications, vol. 3, 1975
2. Bergman B.: „ On reliability theory and its applications ". Scandinavian Journal of Statistics, vol.12, 1985
3. Birnbaum Z. W.: „ On the importance of different components in a multicomponent system ". [in]: Multivariate Analysis - 2, Ed. P.R. Krishnaiah, Academic Press, New York, 1969
4. Karpiński J., Korczak E.: „ Metody oceny niezawodności dwustanowych obiektów technicznych ". Omnitech press, 1990
5. Lambert H.E.: „ Measures of importance of events and cut sets in fault trees ". [in]: Reliability and Fault Tree Analysis, R.E. Barlow, J.B. Fussel, N.D. Singpurwalla, SIAM, Philadelphia, 1975
6. Matuszak Z.: „ Wybór metody do szacowania niezawodności instalacji siłowni okrętowych ". Materiały Konferencji EXPLO-SIL '92, Gdynia, 1992
7. Natvig B.: „A suggestion of a new measure of importance of system components ". Stochastic Processes and their Applications, vol. 9, 1979
8. Natvig B.: „ New light on measures of importance of system components ". Scandinavian Journal of Statistics, vol.12, 1985
9. Xie M.: „ Some contributions to reliability analysis ". Ph.D. dissertation, Department of Mechanical Engineering, Ling Ping University, 1987

Appraised by Jan Gronowicz, Prof.,D.Sc.,M.E.