CONCEPTION OF TAKING DECISIONS WITH REGARD TO RELIABILITY AND SAFETY OF COMBUSTION ENGINES

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Abstract

The paper presents one of the simplest decision-taking situations, which occur in time of operating different combustion engines. From the presented possibility of taking decisions, it results, that even in the case of a complex decision-taking situation, consideration of expected consequences makes it possible to assign very easily a proper single number, stating for an expected value of consequences, to each kind of decision. It also enables choosing such an operating decision for which the expected value of consequences is the greatest.

1. Introduction

Taking decisions, in time of operating combustion engines, takes always place in the stochastic decision-taking situation - thus, in conditions of uncertainty. That means, that the rules of the theory of probability and inductive (mathematical) statistics must be applied. Operating decisions are taken at the beginning (before starting) and in time of operating the combustion engines. That means, that these decisions are taken at least once on the base of the possessed primary information (received e.g. during testing the reliability of combustion engines and their particular systems) which can be named „a' priori" and then - on the base of information received in time of operating these combustion engines (e.g. because of using diagnostics, not only in technical aspect), which can be named „a'posteriori".
Decisions, which are taken at the beginning of the operation, are necessary to plan the process of using and operating the mentioned combustion engines. These decisions must consider statistic risk of which the estimation is the probability of taking a wrong decision, being the result of [2, 5]:

- impossibility of precise estimation of unknown parameters of random variables' distributions, which are the states of the process of operating combustion engines and their particular systems,
- lack of the possibility of elaborating the completely reliable or enough reliable information, which is necessary to take the right decision.

The first case generates random mistakes of which the estimation is , so called, the stochastic precision of inferring and the second one - random mistakes and such mistakes which can be considered as not random (systematic). Determination of the last kind of mistakes is the problem, that I suggest to call the problem of inference accuracy (or precision). One definition of the all mistakes is, as it's known, the problem of the statistic precision of inferring. However, in time of combustion engines operation, the reason of taking wrong or irrational decisions are difficulties in establishing a full diagnosis of sufficient reliability as for the technical state of mentioned engines and their systems and also a similar diagnosis referring to the expected outside conditions which can appear during operation [2, 3, 4].

In the presented above decision situation, taking a rational decision is possible in case of employing the statistic theory of decision thus, also - the expected value of consequences as the criterion of taking such decision [1, 2, 5].

2. Formulation of the problem

During operation of every combustion engine, the following situations can appear to be different from the normal one (s_0^*): complicated (s_1^*), dangerous (s_2^*), emergency (s_3^*) and catastrophic (s_4^*) [2, 5]. The situations s_j^*(j = 0, 1,..., 4) are disjoint subsets that make the set S^*. The situations $s_j^* \in S^*$(j =0, 1,...., 4) are, in this case, of the following exemplary interpretation [2, 9]:

- s_0^* - normal situation, so such situation, when the engine's user performs routine works which is used to do,
- s_1^* - complicated situation, so such situation that becomes when some events proceed which make realization of a task difficult,
- s_2^* - dangerous situation, so such situation that becomes when some events proceed which make realization of a task impossible,
- s_3^* - emergency situation, so such situation that becomes when some events proceed which threat the safety of the engine's user,
- s_4^* - catastrophic situation, so such situation that becomes when there is no chance to avoid loosing a life of the engine's user.

These all situations make the set:

$$S^* = \{s_0^*, s_1^*, s_2^*, s_3^*\}. \tag{1}$$

Occurring one of the mentioned situations during the combustion engine operation depends mainly on the technical state of the engine. It can be accepted that, in this case, the set of combustion engine's technical states is of essential meaning

$$S = \{s_1, s_2, s_3, s_4\} \tag{2}$$

and its interpretation is as follows [7, 8]:

- s_1 – state of full ability (total ability), so such technical state of a combustion engine when the engine may be operated at full load range for which was destined in the phase of designing and producing,
- s_2 – state of partial ability (not full, not total ability), so such technical state of a combustion engine which enables realization of all tasks (just like the state s_1) but at lower values of operating factors (for instance, at lower usable efficiency, so at higher fuel consumption),
- s_3 – state of task disability, so such technical state of a combustion engine which enables realization of some tasks (for instance such state which makes impossible operation of engine on the characteristic of external rated power),

- s_4 – state of full disability (total disability), so such technical state of a combustion engine which makes impossible realization of any task from the set of tasks, for which this engine was destined in the phase of designing and producing (for instance, such state of engine which is the reason of shut down of one of its cylinders).

In case of getting worse the technical state of engine, when the state changes from the state s_1 to s_2, next to the state s_3 and finally – to s_4, during the operation time the situations s_1^*, s_2^*, s_3^* and even s_4^* can occur in turn.

Having the information about the technical state of the engine, outside conditions of the engine's work and predispositions of the user, a rational decision can be taken by employing the statistic theory of decision, from among the following three exemplary possibilities:

- decision d_1 - to start performing the given task,
- decision d_2 - first of all, to carry out proper (according to the made diagnosis) preventive service of the engine's particular systems, in order to renovate their properties which are necessary to perform the task, and next to start realization of the task in the date established by customer,
- decision d_3 - to delay performance of the task until all reasons which could threat the safety of the user are eliminated.

3. Solution of the problem

Taking one of the mentioned decisions $d_k(k = 1, 2, 3)$ belonging to the set:

$$D = \{d_1, d_2, d_3\} \ . \tag{3}$$

with regard to the sets: four - elements set of the states S and five - elements set of the situations S^*, causes determined consequences $c(d_k\, s_i, s_j^*) = c_m \in C(m = 1, 2, ..., 60)$, which should be estimated before taking a decision. These consequences depend, of course, on the mentioned states $s_i(i = 1, 2, 3, 4)$ and situations $s_j^*(j = 0, 1, 2, 3, 4)$. They can be monetary values (costs or profits) or other important for a combustion engine's user benefits or looses.

Choice of the best decision from the mentioned decisions, in conditions resulting from the possibility of occurring (with determined probability, of course) states $s_i(i = 1,..,4)$ and situations $s_j^*(j = 0,1,...,4)$, needs taking into account the following decision criterions:

- expected values $E\ (c/d_k,\ s_i)$ of consequences $c(d,\ s_i,\ s_j^*)$, thus expected values of consequences at the assumption that the decision d_k was taken during the state s_i of the engine,
- expected values $E(c/d_k)$, referring to each of decisions d_k as the values being the product of expected values $E(c/d_k,\ s_i)$ and probabilities $P(s_i)$ - so probabilities of occurring particular states $s_i(i = 1, 2, 3, 4)$.

The mentioned expected values can be determined from the following dependences [1, 3, 5]:

$$E(c|d_k) = \sum_{i=1}^{4} E(c|d_k, s_i)P(s_i); \quad k = 1,\ 2,\ 3\ , \tag{4}$$

where:

$$\left.\begin{aligned}
&E(c|\, d_1, s_1) = P(s_0^*|\, d_1, s_1)c(d_1, s_0^*, s_1) + P(s_1^*|\, d_1, s_1)c(d_1, s_1^*, s_1) + \\
&\quad + P(s_2^*|\, d_1, s_1)c(d_1, s_2^*, s_1) + P(s_3^*|\, d_1, s_1)c(d_1, s_3^*, s_1) + \\
&\quad + P(s_4^*|\, d_1, s_1)c(d_1, s_4, s_1) \\
&E(c|\, d_1, s_2) = P(s_0^*|\, d_1, s_2)c(d_1, s_0^*, s_2) + P(s_1^*|\, d_1, s_2)c(d_1, s_1^*, s_2) + \\
&\quad + P(s_2^*|\, d_1, s_2)c(d_1, s_2^*, s_2) + P(s_3^*|\, d_1, s_2)c(d_1, s_3^*, s_2) + \\
&\quad + P(s_4^*|\, d_1, s_2)c(d_1, s_4, s_2) \\
&\cdot \quad \cdot \quad \cdot \quad \cdot \\
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&\cdot \quad \cdot \quad \cdot \quad \cdot \\
&E(c|\, d_2, s_2) = P(s_0^*|\, d_2, s_2)c(d_2, s_0^*, s_2) + P(s_1^*|\, d_2, s_2)c(d_2, s_1^*, s_2) + \\
&\quad + P(s_2^*|\, d_2, s_2)c(d_2, s_2^*, s_2) + P(s_3^*|\, d_2, s_2)c(d_2, s_3^*, s_2) + \\
&\quad + P(s_4^*|\, d_2, s_2)c(d_2, s_4^*, s_2) \\
&\cdot \quad \cdot \quad \cdot \quad \cdot \\
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&\cdot \quad \cdot \quad \cdot \quad \cdot \\
&E(c|\, d_3, s_3) = P(s_0^*|\, d_3, s_3)c(d_3, s_0^*, s_3) + P(s_1^*|\, d_3, s_3)c(d_3, s_1^*, s_3) + \\
&\quad + P(s_2^*|\, d_3, s_3)c(d_3, s_2^*, s_3) + P(s_3^*|\, d_3, s_3)c(d_3, s_3^*, s_3) + \\
&\quad + P(s_4^*|\, d_3, s_3)c(d_3, s_4^*, s_3) \\
&E(c|\, d_3, s_4) = P(s_0^*|\, d_3, s_4)c(d_3, s_0^*, s_4) + P(s_1^*|\, d_3, s_4)c(d_3, s_1^*, s_4) + \\
&\quad + P(s_2^*|\, d_3, s_4)c(d_3, s_2^*, s_4) + P(s_3^*|\, d_3, s_4)c(d_3, s_3^*, s_4) + \\
&\quad + P(s_4^*|\, d_3, s_4)c(d_3, s_4^*, s_4)
\end{aligned}\right\} . \tag{5}$$

Estimation of the expected values $E(c|\, d_k, s_i)$ for $k = 1, 2, 3$ and $i = 1, 2, 3, 4$ and then $E(c|\, d_\mathrm{k})$ makes it possible to employ the following decision logic: *from among decisions d_k(k = 1,2,3) it should be chosen this one which the biggest value $E(c|\, d_k)$ has been assigned to.*

Employment of this logic is reasonable because in the Bayes' statistic theory of decisions, it has been proved that the expected value of consequences (benefits or looses) can be the criterion of choice of the most beneficial decision from among the all which are possible to be taken, according to the earlier formulated principle, if the values of consequences (results, effects) of taking these particular decisions [1, 5, 6] have been properly determined.

The presented possibility of taking operating decisions refers to the situations when a decision-taker (a person who takes decisions) possess the a'priori information about technical state of combustion engines, received e.g. from the tests of reliability of the engines, being indispensable to perform a task (to reach the aim) and expressed in the form of the probability $P(s)$. In case of obtaining some more information about the technical state of the combustion engine, the a' posteriori probability $P^*(s_i)$ of occurring the state s of the engine should be taken into account in the formula (4). The probability can be determined from the following formula [4]:

$$P^*(s_i) = P(s_i|k_i) = \frac{P(s_i)P(k_i|s_i)}{\sum_{r=1}^{4} P(s_r)P(k_r|s_r)}, \tag{6}$$

where:

k_i - vector of values of diagnostic parameters observed in time of testing the technical state s_i (i = 1, 2, 3, 4) of engine.

The formula (6) is a measure of the justness of a diagnosis, so it is right at the assumption that the diagnosing system (DGS) of a tested ship's system (being the DNS - diagnosed system) is in the state of the full ability [3, 4].

4. Final conclusions

Nowadays, the calculus of probability and the inductive (mathematical) statistics in the version presented in Bayes' statistic theory of decisions [1, 3, 5] are more and more common in user for the process of taking decisions. This theory enables possible creating mathematical models for taking decisions in conditions of uncertainty. It explains how to make a choice of a decision from the set of the possible-to-be-taken decisions, when among others, the state of the system which is indispensable to reach the aim, cannot be precisely determined. The theory has been widely applied for commercial undertakings (where one can relatively quickly and easily check the rightness of the taken decision), but it has also been very helpful in the civil and water engineering, especially while building roads and bridges, drainage pipes (ditches), breakwaters, high-wind (hurricane) dams, etc. This theory, as it results from considerations presented in this paper, can be used for operation activity, as well, in the scope of taking decisions in a stochastic decision situation, when consequences of taken particular decisions are very important.

The possibility of employing the Bayes' statistic theory of decisions in the operation activity follows from two reasons. The first reason is that the probabilistic conception of value has been taken into account in this theory. The second one is that the ground for elaborating this theory has been the notice that it's impossible to separate subjective elements of decision analysis from its subjective factors, and this is just the cause of taking decisions of which realization doesn't warrant reaching the wanted result (effect of action) with total certainty. That is because the process of deciding takes place in conditions of uncertainty created by:

– random factors that influence realization of processes, the process of operation of technical systems, as well,

– limited (sometimes, very much) scope of information, especially about the technical state of systems.

In the Bayes' approach to the problem of taking decisions in conditions of uncertainty, so in conditions of a statistic risk , it's admitted that [1, 2, 5]:

- consequences (results) of taken decisions depend on the scale of recognizing random important (affecting results of these decisions) factors, which in this case, are called the state of nature and the state can be e.x. the technical state of a system (e.g. piston or turbine engine, etc),
- getting additional (new) information about the state of nature not always enables expected conclusions to be absolutely (or sufficiently) worth of trusting,
- getting additional information about the current operating state (in case of occurring doubts if that information, we have, is sufficient to take a decision or is enough reliable) is not always economically reasonable and that's why there is not such information,
- it can be assumed that inaccuracy of description of the real state of operation, so uncertainty of the value of this state's properties, can be determined (expressed) with the help of the probability , what causes that a decision- taker (a person who takes decisions) has a possibility of establishing the risk of the decision and making the decision analysis, thanks to which is able to take the optimum operating decision, taking expected values $E(c \mid d)$ of consequences (c) as the criterion of optimization , at the assumption that the decision (d) has been taken.

Taking an operating decision consists in choosing the optimum decision belonging to the set of possible-to-be-taken decisions, so such a decision that is assigned with the biggest expected value of consequences to.

In order to estimate expected values $E(c|\, d_k)$ being necessary for taking one of possible decisions $d_k(k = 1, 2, 3)$, it is indispensable to know probabilities: $P(s_j^*)(j = 0, 1, ... , 4)$ and $P(s_i)(i = 1, 2, 3, 4)$.

The formulas needed for estimation of these probabilities have been derived in the papers [2, 6].

References

[1] Benjamin J. R., Cornell C. A., *Rachunek prawdopodobieństwa, statystyka matematyczna i teoria decyzji dla inżynierów*. WNT, Warszawa 1977. Original publication: Jack R. Benjamin., C. Allin Cornell., *Probability, Statistics, and Decision for Civil Engineers*. Copyright 1970 by McGraw-Hill, Inc.

[2] Girtler J., Kuszmider s., Plewiński L., *Wybrane zagadnienia eksploatacji statków morskich w aspekcie bezpieczeństwa żeglugi*. Monografia. WSM, Szczecin 2003.

[3] Girtler J., *Diagnostyka jako warunek sterowania eksploatacją okrętowych silników spalinowych*. Monografia. Studia Nr 28. WSM, Szczecin 1997.

[4] Girtler J., *Zastosowanie wiarygodności diagnozy do podejmowania decyzji w procesie eksploatacji urządzeń*. Materiały V Krajowej Konferencji DIAG'2003 NT. Diagnostyka techniczna urządzeń i systemów. WE WAT, Warszawa-Ustroń 2003, s.100-109.

[5] Girtler J., *Suggestion of interpretation of action and the rule of taking decisions with regard to safety of ship traffic.* Exploitation Problems of Machines. Polish Academy of Sciences, Mechanical Engineering Committee. Quarterly, Vol. 35, issue 2(122), Warsaw 2000, pp.177-191.

[6] Girtler J., *Availability of sea transport means*. Archives of Transport. Polish Academy of Sciences, Committee of Transport. Quarterly, Vol. 9, issue 3-4, Warsaw 1997, pp.67-75.

[7] Girtler J., *Operational of diesel engine as the index of their reliability and safety*. Journal of KONES. International Combustion Engine. Vol. 10, No 1-2, Warsaw 2003, pp.17-24.

[8] Girtler J., Semi-Markov model of diesel engine' operating process. The Archives of Automotive Engineering, Vol. 7, No 3, pp.165-196 (2004).

[9] Jaźwiński J., Borgoń J., Niezawodność eksploatacyjna i bezpieczeństwo lotów. WKiŁ, Warszawa 1989.