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PROBABILISTIC METHOD OF ACCEPTANCE CONTROL OF THE FIFTH-LEVEL AUTOMATIC DRIVING SYSTEM UNDER NONHOMOGENEOUS OPERATING CONDITIONS

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***Abstract*—*The problem of acceptance control of a fifth-level automatic driving system is investigated when using nonhomogeneous samples and allowing one failure in the total sample. It is shown that by using different operating and test conditions, subdivided into normal and complex conditions, the required test volume of testing at one failure accepting in the overall nonhomogeneous sample can be determined based on the Bernoulli's binomial test (that was introduced to the test under similar conditions, when using a nonhomogeneous sample). There is no need to determine the probability of condition occurrences, values of the partial success probabilities; and their hypotheses are not tested. The paper proves that the Bernoulli's binomial test scheme use allows minimizing the required total volume of testing under nonhomogeneous operating conditions, providing the required level of reliability about the decisions made.*

Index Terms—Acceptance control; nonhomogeneous samples; autopilot system of the fifth-level car; minimization of test volumes.

I. INTRODUCTION

Probabilistic methods of quality control of the fifth-level piloting system of the car should confirm the hypothesis about the required level of operation success (accuracy) is achieved, with a high level of confidence in decision.

The success (accuracy) of a car self-driving operation is thought to be falling of all movement, location, visualization and identification parameters (dimensions, distance to objects, direction, speed, etc.) of a car piloting system into the space and time limits in real time (Fig. 1).

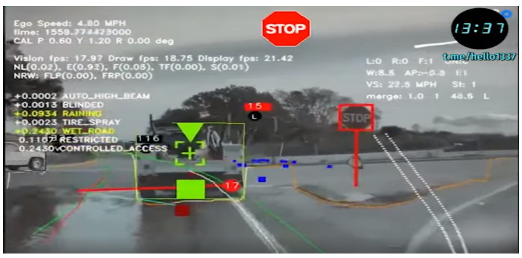

Fig. 1. Demonstrative visualization of data taken into account by the autopilot of "Tesla" cars

II. PROBLEM STATEMENT

Certification tests of an electric vehicle must be natural, i.e. they must be carried out under expected operating conditions (EOC). In such conditions the sample obtained from the test results is fundamentally nonhomogeneous in reference to the operating conditions.

Probabilistic acceptance control methods support testing hypothesis of the type $P \geq P_R$ with an acceptable failure risk. Here P is the success probability, compliance with the specified requirements and P_R is the required probability value. Let's denote β is the consumer's risk, i.e. the error probability in $P \geq P_R$ hypothesis accepting. The binomial Bernoulli's testing scheme (BSI) [1], [3] supports determining the minimum required volumes N_K for hypothesis under test accepting with a risk β_K, where $k = 0,1,2,..$ is the acceptance value of failures in N_K tests, in function of the required P_R. But the BSI has a significant disadvantage. For example, when checking the compliance of highly responsible systems, the required success probability $P_R = 0.95$ is assigned and the acceptable risk of erroneous acceptance of the hypothesis $P \geq P_R$ is equal to $\beta = 0.1$ (also more strict requirements can be imposed). According to the BSI, for $P_R = 0.95$, $\beta = 0.1$ the minimum required volumes of N_K are $N_0 = 45$, $N_1 = 77$ and $N_2 = 135$. As the P_R, k values increase or the β risk value decreases, the required minimum sample volumes increase, naturally.

It is based on the assumption of a constant failure probability $q = 1 - P$ in each test. This assumption is practically not met. Indeed, q = const. cannot be considered when testing the autopilot under various weather conditions, the maneuvering modes are also different: parking, starting off, braking or driving

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straight. Therefore, to accept the hypothesis $P \geq P_R$ with the acceptable risk β_K, it is necessary to take into account the fact that the samples under test are nonhomogeneous. The well-known Poisson test scheme [3] allows determining the probability of appearance of k number of failures when using nonhomogeneous samples. However, in this scheme, it is necessary to set specific values of partial probabilities P_i. The assignment of these values is problematic. Thence, the Poisson scheme is not usually used in practice.

The following problems exist: classification of different n operating and test conditions; determination of their appearances $S_i, i=\overline{1,n}$; assignment of the required success probabilities $P_{R,i}$; the particular hypothesis testing $P_i \geq P_{R,i}$; interpretation of the results obtained, for example, different risks β of accepting hypotheses for partial probabilities P_i, etc. Perhaps the main problem is to solve the problem of providing significantly large test volumes, cost and test time.

The paper suggests a partial and possible solution to these problems under the following assumptions and restrictions:

1) No more than one failure is allowed in the total nonhomogeneous sample.

2) A proportional nonhomogeneous sample is used when the volumes of its layers as follows: $N_i^* = S_i N^*$, where N^* is the total volume.

3) The layer's number is $n = 2$, i.e. all operating and test conditions can be considered normal or complex.

4) The appearance of these conditions S_1, S_2 are assumed to be the same or assigned unequal in some cases.

5) The required partial probability values $P_{R,i}$ are not assigned and hypotheses of the type $P_i \geq P_{R,i}$ are not tested.

To solve this problem, we use and develop the results of our previous works [6] – [8].

First of all, we replace the requirements $P_i \geq P_{R,i}$ (the values $P_{T,i}$ are unknown in principle) with a single requirement: $P_T \geq P_R$, where P_T is the total probability. We are considering the possibility of expanding the limits of BSI's applicability for determining the required operating conditions of systems and serial products.

For this purpose, we check the ratio analysis for the probability of appearance of no more than one failure in a homogeneous sample and in a total, two-layer, nonhomogeneous and proportional sample.

We don't assign a specific probability values P_1, P_2, but we suppose $P_T = S_1 P_1 + S_2 P_2$, where the values S_1 and S_2 are set.

III. Comparative Analysis of Expressions for the Probability of Appearance of No More than One Failure in a Homogeneous and Two-layer Nonhomogeneous Samples

The probability theory implies that the probability of no more than one failure in a homogeneous sample of volume N_1 with the probability of success P_R is follows:

$$\beta_1 = \beta_0 + B_1, \tag{1}$$

where

$$\beta_0 = P_R^{N_1}, \; B_1 = N_1 P_R^{N_1 - 1} q_R. \tag{2}$$

For a two-layer nonhomogeneous sample of volume N_1^* this probability is equal to:

$$\beta_1^* = \beta_0^* + B_1^*, \tag{3}$$

where

$$\begin{aligned} &\beta_0^* = P_1^{N_{1,1}^*} P_2^{N_{1,2}^*}, \\ &B_1^* = N_{1,1}^* P_1^{N_{1,1}^* - 1} q_1 P_2^{N_{1,2}^*} + N_{1,2}^* P_2^{N_{1,2}^* - 1} q_2 P_1^{N_{1,1}^*}. \end{aligned} \tag{4}$$

Here, in equations (1) and (2) $\beta_0, \beta_0^*; B_1, B_1^*, \beta_1, \beta_1^*$ are the probabilities, respectively: for absence of failures, for exactly one failure and for no more than one failure. The superscript "*" corresponds to a nonhomogeneous sample.

The values of P_1, P_2 in (4) may be unknown. Let's consider the case when the values of S_1, S_2 are a priori unknown. Then it should to take $S_1 = S_2 =$ $= 0.5$, $N_{1,1}^* = N_{1,2}^* = 0.5 N_1^*$. We consider $N_1^* = N_1$. Let's denote $N_1 = 2m$, $N_{1,1}^* = N_{1,2}^* = m$. We consider $P_T = P_R$, denote $P_T = P$, $q_T = q_R = q$. Then we write using equations (2) and (4):

$$B_1 = 2mP^{2m-1} q = 2mP^{2m} V^{-1}, \tag{5}$$

$$\begin{aligned} B_1^* &= mP_1^{m-1} q_1 P_2^m + mP_2^{m-1} q_2 P_1^m \\ &= m\left(P_1 P_2\right)^m V_1^{-1} + m\left(P_1 P_2\right)^m V_2^{-1}, \end{aligned} \tag{6}$$

where $V_1 = \dfrac{P_1}{q_1}$, $V_2 = \dfrac{P_2}{q_2}$, $V = \dfrac{P}{q}$.

Since in this case we can accept:

$$P_1 = P(1+\delta),\ P_2 = P(1-\delta),$$
$$P_1P_2 = P^2(1-x),\ x = \delta^2,$$
$$q_1 = q - P\delta,\ q_2 = q + P\delta,$$

then (6) can be rewritten in the form:

$$B_1^* = mP^{2m}\left(1-x\right)^m\left(V_1^{-1}+V_2^{-1}\right). \qquad (7)$$

It was previously proved [7], [9], that $\beta_0^* \le \beta_0$ for any values $N^* = N$, for any value of n layers of a nonhomogeneous sample for any values of S_i. Then to meet the inequality $\beta_1^* \le \beta_1$ in the case considered here it is sufficient and necessary to find the conditions under which the inequality $B_1^* \le B_1$ is met. For this purpose we consider a ratio $\varphi = B_1^* / B_1$, using equations (5) and (7), obtaining:

$$\varphi_1 = 0.5\left(1-x\right)^m \frac{\left(V_1^{-1}+V_2^{-1}\right)}{V^{-1}} = \left(1-x\right)^{m-1}\left(1+Vx\right). \qquad (8)$$

(In deriving the above equation (8) the relation $\frac{\left(V_1^{-1}+V_2^{-1}\right)}{V^{-1}} = \frac{2\left(1+Vx\right)}{1-x}$ is used).

According to the equation (8) we have: $\varphi_1 = 1$ if $x = 0$ and $\varphi_1 \le 1$, if $\varphi^{(1)}(x) \le 0$.

Consider the derivative of equation (8):

$$\varphi_1^{(1)}(x) = -\left(m-1\right)\left(1-x\right)^{m-2}\left(1+Vx\right) + V\left(1-x\right)^{m-1} \qquad (9)$$

$\varphi_1^{(1)}(x) \le 0$, if, according to the equation (9), the condition is met:

$$\left(m-1\right) \ge \frac{V\left(1-x\right)}{1+Vx}. \qquad (10)$$

We strengthen the inequality (10), by neglecting the value of Vx in the denominator (10), and then the value of x in the nominator's parenthesis (10). (Indeed, for $P = P_R = P_T = 0.95$ we have $V = 19$, $x_{\max} < 0.00277$, $Vx_{\max} \le 0.0526$, that is $x_{\max} << 1$, $Vx_{\max} << 1$).

Then we obtain from the inequality (10) a strengthened inequality of the type

$$m \ge 1 + V = q^{-1},\ 2m \ge 2q^{-1}. \qquad (11)$$

When the inequality (11) is satisfied, we conclude that $B_1^* \le B_1$. Then $\beta_1^* \le \beta_1$ at

$$N_1^* = N_1 \ge 2q^{-1}. \qquad (12)$$

For example, if $P_R = 0.95$ from (12), we receive $N_1^* = N_1 \ge 40$. But according to the BSI $N_1 = 77$ is required to provide the risk $\beta_1 = 0.1$ (in case of a homogeneous sample). Thus, when choosing N_1^* = 78 the acceptable risk $\beta_1^* \le 0.1$ for accepting the hypothesis $P_T \ge 0.95$ is obviously provided if there is one failure in the total nonhomogeneous sample.

IV. Conclusions

When using different operating and test conditions subdivided into normal and complex ones, the required test volume with one failure allowed in the total nonhomogeneous sample can be determined based on the binomial Bernoulli's test scheme (which was introduced for tests under homogeneous conditions, using a homogeneous sample).

Using the binomial Bernoulli's test scheme allows minimizing the required total test volume even under nonhomogeneous operating conditions.

It is possible to solve probabilistic acceptance control problems when the number of layers of a nonhomogeneous sample is more than two, and also when the acceptance number of failures is more than one.

The results of the work can be used for acceptance control of the automatic driving system of the fifth level, under nonhomogeneous test conditions, with the required level of confidence in the decisions made.

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О. Ю. Красноусова. Імовірнісний метод приймального контролю системи автоматичного водіння автомобіля п'ятого рівня при неоднорідних умовах експлуатації

Розглянуто задачу приймального контролю системи автоматичного водіння автомобіля п'ятого рівня при використанні неоднорідних вибірок і при допуску однієї відмови в сумарній вибірці. Показано, що при використанні різних умов експлуатації та випробувань, що поділяються на нормальні і складні умови, необхідний обсяг випробувань при допуску однієї відмови в сумарній неоднорідній вибірці можна визначити, виходячи з біномінальної схеми випробувань Бернуллі (яка була введена для випробувань в однорідних умовах, при використанні однорідної вибірки). При цьому немає необхідності визначати ймовірність зустрічальності умов, значення парціальних ймовірностей успіху, не перевіряються їх роздільні гіпотези. В роботі показано, що використання біноміальної схеми випробувань Бернуллі дозволяє мінімізувати необхідний сумарний обсяг випробувань і при неоднорідних умовах експлуатації, забезпечуючи необхідний рівень надійності прийнятих рішень.

Ключові слова: приймальний контроль; неоднорідні вибірки; система автопілотування автомобіля п'ятого рівня; мінімізація обсягів випробувань.

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О. Ю. Красноусова. Вероятностный метод приемочного контроля системы автоматического вождения автомобиля пятого уровня при неоднородных условиях эксплуатации

Рассмотрена задача приемочного контроля системы автоматического вождения автомобиля пятого уровня при использовании неоднородных выборок и при допуске одного отказа в суммарной выборке. Показано, что при использовании разных условий эксплуатации и испытаний, подразделяемых на нормальные и сложные условия, требуемый объем испытаний при допуске одного отказа в суммарной неоднородной выборке можно определить, исходя из биноминальной схемы испытаний Бернулли (которая была введена для испытаний в однородных условиях, при использовании однородной выборки). При этом нет необходимости определять вероятности встречаемостей условий, значения парциальных вероятностей успеха, не проверяются их раздельные гипотезы. В работе показано, что использование биномиальной схемы испытаний Бернулли позволяет минимизировать требуемый суммарный объем испытаний и при неоднородных условиях эксплуатации, обеспечивая необходимый уровень надежности принимаемых решений.

Ключевые слова: приемочный контроль; неоднородные выборки; система автопилотирования автомобиля пятого уровня; минимизация объемов испытаний.

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