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Models Quality of Mechatronic Products

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Introduction

Complex mechatronics products (MP) are defined in technical documentation as an entire series of parameters, the values of which determine the level of product quality. Parameters can be differentiated according to their importance regarding the implementation of purpose functions. International standard ISO-2859-0 recommends to divide parameters into two – A, B – or three – A, B, C – classes (groups). Here A – most important or significant parameters, and B, C – secondary or less significant parameters. Such classification of parameters is convenient when analyzing problems of multi-parametric product quality control. When imitational modeling is applied, stochastic models of quality level are required for separate parameters, their groups and for entire product [2, 6].

In companies which utilize modern technologies databases of manufactured production and technological processes are constantly maintained and complemented. Data is often read and input automatically. By using computer networks and database control and analysis systems, information can be transmitted in real-time and can be used in decision making processes at each intermediate or final stage of manufacture. Thus there is a possibility to use information not only from the current but also from the previous stages of manufacture. That can increase the quality of MP.

Modern MP control system involves control of raw materials, components, transitional control of elements or nodes, technological process and final product. In this way MP control system plays an important role by influencing cost and the final result.

Continuous inter-operational quality control is commonly applied in manufacture process of MP products. Selective control peculiarities of such MP are analyzed in publications [1–4] on the grounds of color picture tube manufacture specifics. In this paper we will describe the performance of multistage continuous inter-operational control with the help of stochastic models, when MP classification errors of the first and second kind are present. Main attention is paid to the transformation of production defectivity level probability distributions, which in turn allows to estimate the efficiency of inter-operational control in the way of modeling, and to select the required number of control stages and their characteristics.

Models of control quality

Inter-operational control fragment is presented in Fig. 1, which involves two stages of continuous control K_1 and K_2 (in both stages MP are classified according to analogical decision rules) [1–4].

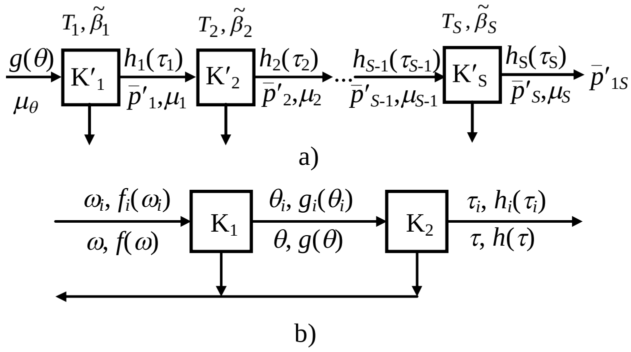

Fig. 1. Stochastic models of control quality: a – S stage; b – multi-parameter MP double level control

Analyzing double-level control schematics shown in Fig. 1, when MP is described as ℓ-dimensional parameter vector [1, 2], $i = 1 - \ell$.

Here $\omega_i, \theta_i, \tau_i$ – defective MP probabilities by i-th parameter before first level K_1, before and after second level K_2. These are accidental values with densities $f_i(\omega_i), g_i(\theta_i), h_i(\tau_i)$ and distribution functions $F_i(\omega_i)$, $G_i(\theta_i)$, $H_i(\tau_i)$. Respectively ω, θ, τ – analogical characteristics for product by all controlled ℓ parameters.

For further analysis good MP probabilities by i-th parameter are needed: $\xi_i = 1 - \omega_i$, $\eta_i = 1 - \theta_i$, $\zeta_i = 1 - \tau_i$ – accidental values with densities:

$$\ddot{\varphi}_i(\xi_i) = f_i(1 - \xi_i),\ \varphi_i(\eta_i) = g_i(1 - \eta_i),\\ \dot{\varphi}_i(\zeta_i) = 1 - h_i(1 - \zeta_i). \quad (1)$$

Distribution functions:

$$\ddot{\Phi}_i(\xi_i) = 1 - F_i(1 - \xi_i),\ \Phi_i(\eta_i) = 1 - G_i(1 - \eta_i),\\ \dot{\Phi}_i(\zeta_i) = 1 - H_i(1 - \zeta_i). \quad (2)$$

Accidental values: $\xi = 1-\omega,\ \eta = 1-\theta,\ \zeta = 1-\tau$ – are good MP probabilities by all ℓ parameters.

Analyzing situations, when all accidental values θ_i, also accidental values η_i densities $g_i(\theta_i), \varphi_i(\eta_i)$ are known and written in beta law: $\theta_i \sim \mathrm{Be}(a_i, b_i), \eta_i \sim \mathrm{Be}(b_i, a_i)$, here a_i, b_i – beta law forms parameters [1 – 4]. Then τ_i is directly transformed (T), o ω_i – reverse transformed (A) accidental value θ_i with transformation parameter $\tilde{\beta}_i$:

$$\dot{\beta}_i = \frac{\beta_i}{1-\alpha_i},\ \ \alpha_i + \beta_i < 1; \qquad (3)$$

where α_i=const, β_i=const – first and second kind errors probabilities [1] by i-th parameter, $i = 1-\ell$.

Densities $h_i(\tau_i)$ and $f_i(\omega_i)$ by analogy with [1, 2] models are:

$$\begin{cases} h_i(\tau_i) = \dfrac{B_i^{-1}\tau_i^{\alpha_i-1}(1-\tau_i)^{b_i-1}}{\tilde{\beta}_i^{\alpha_i}(1+c_i\tau_i)^{a_i+b_i}}, \\ f_i(\omega_i) = \dfrac{\tilde{\beta}_i^{\alpha_i}\omega_i^{a_i-1}(1-\omega_i)^{b_i-1}}{B_i(1-\tilde{\gamma}_i\omega_i)^{a_i+b_i}}, \end{cases} \qquad (4)$$

where $B_i = B(a_i, b_i) = \dfrac{\Gamma(a_i)\Gamma(b_i)}{\Gamma(a_i+b_i)}$ – beta function; $\Gamma(z)$ – gamma function; $\tilde{\gamma}_i = \dfrac{\gamma_i}{1-\alpha_i} = 1-\tilde{\beta}_i$, $\gamma_i = 1-\alpha_i-\beta_i$, $c_i = \tilde{\gamma}_i/\tilde{\beta}_i \equiv \gamma_i/\beta_i$, $\Gamma(1) = 0! = 1$.

We have only the approximation of density $g(\theta)$ [1–3] $g_\sigma(\theta)$:

$$g_\sigma(\theta) = B^{-1}(a^*, b^*)\theta^{a^*-1}(1-\theta)^{b^*-1}; \qquad (5)$$

where $a^* = \mu\left(\dfrac{\mu\bar{\mu}}{\sigma^2}-1\right)$, $b^* = \dfrac{\bar{\mu}}{\mu}a^*$, $B^{-1}(a^*, b^*) \equiv 1/B^*$.

The $h(\tau)$ approximation $h_\sigma(\tau)$ is applied [1, 2]:

$$h_\sigma(\tau) = \frac{\sigma^{-1}(a^*, b^*)\tau^{a^*-1}(1-\tau)^{b^*-1}}{\tilde{\beta}^{a^*}(1+c\tau)^{a^*+b^*}}, \qquad (6)$$

Solution equations of parameter $\tilde{\beta}$ are

$$\begin{aligned} &\frac{\tilde{\beta}}{B^*}\sum_{s=0}^{\infty}\tilde{\gamma}^s\int_0^1\theta^{s+a^*}(1-\theta)^{b^*-1}d\theta = \\ &= \tilde{\beta}\sum_{s=0}^{\infty}\tilde{\gamma}^s\prod_{r=0}^{s}\frac{a^*+r}{a^*+b^*+r} = \mu_\tau, \end{aligned} \qquad (7)$$

$$\begin{aligned} &\tilde{\beta}\sum_{s=0}^{\infty}\tilde{\gamma}^s\prod_{r=0}^{s}\frac{b^*+r}{a^*+b^*+r} = \bar{\mu}_\omega, \\ &B^* = B(a^*, b^*) = \frac{\Gamma(a^*)\Gamma(b^*)}{\Gamma(a^*+b^*)}. \end{aligned} \qquad (8)$$

For the transformation models are obtained by substituting $\tilde{\beta}$ for $1/\tilde{\beta}$.

When θ ~Be(a,b), $g(\theta)$ is known. We have $h_\Sigma(\tau) \equiv h_\sigma(\tau)$, and parameter $\tilde{\beta}$ under integer values of a and b is

$$\begin{aligned} &\frac{B^{-1}(a,b)}{c}\sum_{j=0}^{b-1}C_{b-1}^{j}(-1)^j\left[\frac{1}{\tilde{\gamma}^{a+j}}\ln\frac{1}{\tilde{\beta}} - \right. \\ &\left. - \sum_{k=0}^{a+j-1}\frac{1}{(a+j-k)\tilde{\gamma}^k}\right] = \mu_\tau. \end{aligned} \qquad (9)$$

Approximation $h_\Sigma(\tau)$ is written separately when a_i=1 and b_1=b_2≥1 (ℓ=2):

$$\begin{cases} \varphi(\eta) = -b_1^2\eta^{b_1-1}\ln\eta, \\ g(\theta) = -b_1^2(1-\theta)^{b_1-1}\ln(1-\theta), \\ h_\Sigma(\tau) = \dfrac{b_1^2(1-\tau)^{b_1-1}}{\tilde{\beta}(1+c\tau)^{b_1+1}}\ln\dfrac{1+c\tau}{1-\tau}, \end{cases} \qquad (10)$$

where $c = \dfrac{1}{\tilde{\beta}} - 1$.

Parameter $\tilde{\beta}$ comes as a solution of the following equations:

$$\tilde{\beta}b_1^2\sum_{j=0}^{b_1-1}C_{b_1-1}^{j}(-1)^j\sum_{s=0}^{\infty}\frac{\tilde{\gamma}^s}{j+s+2}\sum_{k=1}^{j+s+2}\frac{1}{k} = \mu_\tau \qquad (11)$$

or

$$\tilde{\beta}b_1^2\sum_{s=0}^{\infty}\frac{\tilde{\gamma}^s}{(s+b_1+1)} = \bar{\mu}_\omega. \qquad (12)$$

Additionally we will write expressions of the mean $\mathrm{E}\tilde{\beta}$ of parameter $\tilde{\beta}$ for both cases. Such relations are valid:

$$\mathrm{E}\tilde{\beta} = 1-\mathrm{E}\tilde{\gamma},\ \text{kai}\ \tilde{\beta} = 1-\tilde{\gamma}, \qquad (13)$$

$$\mathrm{E}\tilde{\gamma} = \int_0^1\tilde{\gamma}(\theta)g(\theta)d\theta = \int_0^1\tilde{\gamma}(\eta)\varphi(\eta)d\eta, \qquad (14)$$

$$\tilde{\gamma}(\theta) = \frac{1}{\theta}\left[\tilde{\gamma}_1\theta_1(1+\tilde{\gamma}_2\theta_2)+\tilde{\gamma}_2\theta_2\right]. \qquad (15)$$

The condition θ_1=θ_2 or $\eta_1 = \eta_2 = \sqrt{\eta}$ is applied and when θ_i=1–η_i, we have (i=1; 2)

$$\tilde{\gamma}(\eta) = (\tilde{\gamma}_1+\tilde{\gamma}_2)\frac{1-\sqrt{\eta}}{1-\eta} - \tilde{\gamma}_1\tilde{\gamma}_2\frac{1-2\sqrt{\eta}+\eta}{1-\eta}. \qquad (16)$$

Let‘s assume a_i=b_i=1 and from (14), (16) under density $\varphi(\eta)$=–lnη we have:

$$\begin{aligned} &\mathrm{E}\tilde{\gamma} = (\tilde{\gamma}_1+\tilde{\gamma}_2)\left(4-\frac{\pi^2}{3}\right) - \tilde{\gamma}_1\tilde{\gamma}_2\left(7-\frac{2\pi^2}{3}\right) \approx \\ &\approx 0.71(\tilde{\gamma}_1+\tilde{\gamma}_2) - 0.42\tilde{\gamma}_1\tilde{\gamma}_2, \end{aligned} \qquad (17)$$

$$E\tilde{\beta} = (\tilde{\beta}_1+\tilde{\beta}_2)\left(\frac{\pi^2}{3}-3\right)+\tilde{\beta}_1\tilde{\beta}_2\left(7-\frac{2\pi^2}{3}\right)\approx \approx 0.29(\tilde{\beta}_1+\tilde{\beta}_2)+0.42\tilde{\beta}_1\tilde{\beta}_2; \tag{18}$$

where π=3.141593.

If $a_i=1$, $b_1=2$, $b_2=1$, when $\varphi(\eta)=2(1-\eta)$ we have:

$$E\tilde{\gamma} = \frac{1}{3}\left[2(\tilde{\gamma}_1+\tilde{\gamma}_2)-\tilde{\gamma}_1\tilde{\gamma}_2\right], \tag{19}$$

$$E\tilde{\beta} = \frac{1}{3}\left(\tilde{\beta}_1+\tilde{\beta}_2+\tilde{\beta}_1\tilde{\beta}_2\right). \tag{20}$$

For inverse **A** transformation $\tilde{\beta}$ is substituted for $1/\tilde{\beta}$; then

$$E\left(\frac{1}{\tilde{\beta}}\right)\approx 0.29\left(\frac{1}{\tilde{\beta}_1}+\frac{1}{\tilde{\beta}_2}\right)+0.42\frac{1}{\tilde{\beta}_1\tilde{\beta}_2}, \tag{21}$$

$$E\left(\frac{1}{\tilde{\beta}}\right)\approx\frac{1}{3}\left(\frac{1}{\tilde{\beta}_1}+\frac{1}{\tilde{\beta}_2}+\frac{1}{\tilde{\beta}_1\tilde{\beta}_2}\right). \tag{22}$$

If ℓ=2, then transformation of **T** realization and **A** tarnsformation is: $\tilde{\beta}_1=1/4$; $\tilde{\beta}_2=1/3$; $\tilde{\gamma}_1=3/4$; $c_1=3$; $\mu_{\tau_1}=3\left(\frac{4}{3}\ln 4-1\right)=0.2828$; $a_i=b_i=1$; $\sigma^2_{\tau_1}=\frac{1}{9}\left(4-\frac{16}{9}\times \times\ln^2\frac{1}{4}\right)=0.06483$; $\sigma_{\tau_1}=0.2546$; $\bar{\mu}_{\tau_1}=0.7172$; $\tilde{\gamma}_2=2/3$; $c_2=2$; $\mu_{\tau_2}=2\left(\frac{3}{2}\ln 3-1\right)=0.3240$; $\bar{\mu}_{\tau_2}=0.6760$; $\sigma^2_{\tau_2}=\frac{1}{4}\left(3-\frac{9}{4}\ln^2\frac{1}{3}\right)=0.07109$; $\sigma_{\tau_2}=0.2666$ we will have such values: $\mu_{\omega_1}=0.7172$; $\sigma^2_{\omega_1}=0.06483\equiv\sigma^2_{\tau_1}$; $\mu_{\omega_2}=0.6760$; $\sigma^2_{\omega_2}=0.07109\equiv\sigma^2_{\tau 2}$; $h_1(\tau_1)=\frac{4}{(1+3\tau_1)^2}$; $h_2(\tau_2)=\frac{3}{(1+2\tau_2)^2}$; $f_1(\omega_1)=\frac{4}{(4-3\omega_1)^2}$; $f_2(\omega_2)=\frac{3}{(3-2\omega_2)^2}$; $\mu_{\omega_1}=\bar{\mu}_{\tau_1}$; $\mu_{\omega_2}=\bar{\mu}_{\tau_2}$; $h(\tau)=\frac{1}{3(1+\tau)^2}\left[\frac{3-\tau}{1+\tau}\ln\frac{(1+2\tau)(1+3\tau)}{1-\tau}-\frac{4}{1+3\tau}-\frac{3}{1+2\tau}+7\right]$; $f(\omega)=\frac{12}{(6\omega-5)^2}\left[\frac{7-6\omega}{6\omega-5}\ln\frac{(4-3\omega)(3-2\omega)}{12(1-\omega)}-\frac{1}{4-3\omega}-\frac{1}{3-2\omega}+\frac{7}{12}\right]$; $\mu_\tau=1-(1-\mu_{\tau_1})(1-\mu_{\tau_2})=0.6234$; $\mu_\omega=1-(1-\mu_{\omega_1})(1-\mu_{\omega_2})=0.9084$; $\sigma^2_\tau=\sigma^2_{\tau_1}\left(\bar{\mu}^2_{\tau_2}+\sigma^2_{\tau_2}\right)+ +\sigma^2_{\tau_2}\bar{\mu}^2_{\tau_1}=0.07080$; $\sigma_\tau=0.2661$; $\sigma^2_\omega=\sigma^2_{\omega_1}\left(\bar{\mu}^2_{\omega_2}+\sigma^2_{\omega_2}\right)+ +\sigma^2_{\omega_2}\bar{\mu}^2_{\omega_1}=0.01710$; $\sigma_\omega=0.1308$.

In the second case $g(\theta)=-\ln(1-\theta)$, then:

$$h_\Sigma(\tau)=\frac{1}{\tilde{\beta}(1+c\tau)^2}\ln\frac{1+c\tau}{1-\tau},\quad a_i=b_i=1,\quad i=1,2, \tag{23}$$

and equation solution:

$$\tilde{\beta}\sum_{s=0}^{\infty}\frac{\tilde{\gamma}^s}{s+2}\sum_{k=1}^{s+2}\frac{1}{k}=\mu_\tau . \tag{24}$$

When μ_τ=0.6234, we have: $\tilde{\beta}=0.2314$, $c=\frac{1}{\tilde{\beta}}-1=3.322$, then

$$h_\Sigma(\tau)=\frac{4.322}{(1+3.322\tau)^2}\ln\frac{1+3.322\tau}{1-\tau},\ \tilde{\beta}_1=1/4,\ \tilde{\beta}_2=1/3. \tag{25}$$

By applying beta density Be(a*, b*) parameters $a^*=\frac{15}{7}= =2.1429$ and $b^*=\frac{5}{7}=0.7143$, we have:

$$g_\sigma(\theta)=1.29\frac{\theta^{1.143}}{(1-\theta)^{0.286}}, \tag{26}$$

$$h_\sigma(\tau)=\frac{29.694\tau^{1.143}}{(1-\tau)^{0.286}(1+3.322\tau)^{2.857}},\ \tilde{\beta}_1=1/4\ \tilde{\beta}_2=1/3. \tag{27}$$

From (9) solution of $\tilde{\beta}$ is

$$\tilde{\beta}\sum_{s=0}^{\infty}\tilde{\gamma}^s\prod_{r=0}^{s}\frac{15+7r}{20+7r}=\mu_\tau . \tag{28}$$

For inverse transformation of **A** we have:

$$f_\Sigma(\omega)=\frac{\tilde{\beta}}{(1-\tilde{\gamma}\omega)^2}\ln\frac{1-\tilde{\gamma}\omega}{1-\omega},\quad a_i=b_i=1, \tag{29}$$

$$\tilde{\beta}\sum_{s=0}^{\infty}\frac{\tilde{\gamma}^s}{(s+2)^2}=\bar{\mu}_\omega . \tag{30}$$

Table 1. Density values: ℓ=2, $h(0)=f(0)=0$, $a_i=b_i=1$, $a^*=\frac{15}{7}$, $b^*=\frac{5}{7}$

Case No. 1., $\tilde{\beta}_1=1/4$, $\tilde{\beta}_2=1/3$; $h(1)=f(1)=\infty$										
τ, ω	0.01	0.05	0.1	0.2	0.4	0.6	0.8	0.9	0.95	0.99
$h(\tau)$	0.115	0.484	0.792	1.102	1.194	1.082	0.957	0.921	0.930	0.987
$h_\Sigma(\tau)$	0.173	0.651	0.955	1.143	1.081	0.971	0.939	1.001	1.106	1.424
$h_\sigma(\tau)$	0.115	0.633	0.970	1.173	1.077	0.939	0.896	0.975	1.126	1.708
$f(\omega)$	0.0008	0.0046	0.010	0.025	0.085	0.248	0.892	2.267	4.651	14.65
$f_\Sigma(\omega)$	0.0005	0.0027	0.006	0.016	0.062	0.218	0.973	2.696	5.402	13.34
$f_\sigma(\omega)$	0.0003	0.0018	0.005	0.014	0.058	0.217	0.999	2.724	5.298	12.76

When $\mu_\omega = 0.9084$ and $\overline{\mu}_\omega = 0.0916$, solution is $\widetilde{\beta} = 0.2175$, and

$$f_\Sigma(\omega) = \frac{0.2175}{(1-0.7825\omega)^2} \ln \frac{1-0.7825\omega}{1-\omega}, \qquad (31)$$

$$f_\sigma(\omega) = \frac{\widetilde{\beta}^{a^*} \omega^{a^*-1}(1-\omega^*)^{b^*-1}}{B(a^*, b^*)(1-\widetilde{\gamma}\omega)^{a^*+b^*}} = \\ = \frac{0.049\omega^{1.143}}{(1-\omega)^{0.286}(1-0.7825\omega)^{2.857}}. \qquad (32)$$

Furthermore under $\widetilde{\beta}_1 = 1/4$, $\widetilde{\beta}_2 = 1/3$ we calculate $\mathrm{E}\widetilde{\beta} = 0.2042$ for **T** transformation and $\mathrm{E}\widetilde{\beta}_\mathrm{A} = 0.1414$ for **A** transformation.

Values of densities $h(\tau)$, $h_\Sigma(\tau)$, $h_\sigma(\tau)$, $f(\omega)$, $f_\Sigma(\omega)$, $f_\sigma(\omega)$ are given in Table 1.

Conclusions

1. It is obvious that under small values of $\widetilde{\beta}_i$ ($\widetilde{\beta}_i \le 1/8$) the maximal value of approximated density $h_\sigma(\tau)$ for T transformation is $h_{M\sigma}=h_\sigma(\tau_{M\sigma})$ at the mode point $\tau=\tau_{M\sigma}$ is higher than the maximal value $h_M=h(\tau_M)$ of density $h(\tau)$ at the mode point $\tau=\tau_M$, since $\widetilde{\beta}$ =const is applied, even though real value of $\widetilde{\beta}$ varies from $\widetilde{\beta}(0) = 1/2(\widetilde{\beta}_1 + \widetilde{\beta}_2)$, τ=0, or $\widetilde{\beta}(1) = \widetilde{\beta}_1\widetilde{\beta}_2$, τ=1. To equalize maximums of both densities the higher $\widetilde{\beta}$ value $\widetilde{\beta}^* > \widetilde{\beta}$ should be used since the real $\widetilde{\beta}$ value increases under small τ values.
2. Obtained expressions let modelling of wanted situations in between operational-control schematics visually by defect level densities transformations (on computer display), giving densities parameters in desirable schematic place and choosing real separate parameters classification probabilities in addition with controlled parameters nomenclature.
3. Exact multi-parameter expressions of MP defect levels expressions are very complicated because of multinomial integration procedure. Offered modelling variants should serve as useful instrument for control system design.

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This publication is about continuous between-operational control main probabilities characteristics modelling techniques for multilevel MP, when separate independent parameters defect level probabilities distributions are set (known) in chosen control schematics place. Denied MP streams go back to production process for regeneration and classification rules, in different control levels, are similar. Made MP defect level probability density direct and reverse transformations models by separate parameter levels densities transformations. Offered to use approximated models instead of whole MP defect level probabilities density transformed models because of complicated process of integration and models get more simple expressions. Ill. 1, bibl. 4 (in English; abstracts in English, Russian and Lithuanian).

Д. Эйдукас, Р. Кальнюс. Модели контроля качества мехатронных изделий // Электроника и электротехника. – Каунас: Технология, 2009. – № 7(95). – С. 59–62.

Предложена методика моделирования основных вероятностных характеристик системы сплошного контроля мехатронных изделий, когда заданы (известны) вероятностные распределения уровней дефектности по отдельным независимым параметрам в нужной точке схемы контроля. Потоки забракованных изделий возвращаются в процесс производства для регенерации, а правила классификации изделий на отдельных ступенях контроля одинаковы при наличии существенных ошибок классификации по отдельным параметрам. Получены модели прямой трансформации плотностей вероятностей уровня дефектности всего изделия на основе моделей трансформации плотностей вероятностей уровня дефектности по отдельным параметрам. Представлены расчётные модели основных вероятностных числовых характеристик (математическое ожидание и дисперсия), когда отдельные параметры описываются бета распределением. Ил. 1, библ. 4 (на английском языке; рефераты на английском, русском и литовском яз.).

D. Eidukas, R. Kalnius. Mechatroninių gaminių kokybė, modeliai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 7(95). – P. 59–62.

Pateikta ištisinės tarpoperacinės kontrolės pagrindinių tikimybinių charakteristikų modeliavimo metodika daugiaparametriams MP, kai atskirų nepriklausomų parametrų defektingumo lygių tikimybių skirstiniai yra duoti (žinomi) pasirinktoje kontrolės schemos vietoje. Išbrokuotų MP srautai grąžinami į gamybos procesą regeneruoti, o klasifikavimo taisyklės atskirose kontrolės pakopose analogiškos, esant nepaneigtinoms MP klasifikavimo pirmos ir antros rūšies klaidoms. Sudaryti MP defektingumo lygio tikimybių tankio tiesioginės transformacijos modeliai pagal atskirų parametrų defektingumo lygių tankių transformacijas. Il. 1, bibl. 4 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).