Prediction model of the efficacy and the implementation time of transportation intelligent systems

A. L. Chupin¹, Zh. S. Chupina¹, N. N. Morozova¹, T. M. Vorotyntseva ¹ and E. V. Levinskay²

¹RUDN University, 117198, 6 Miklukho-Maklaya street, Moscow, Russia
²RANEPA, 119571, 82 Vernadsky Avenue, Moscow, Russia

E-mail: vSe.1@mail.ru, chupin_al@pfur.ru

Abstract. The article deals with a formalized model of the efficiency forecast based on the analysis of different models of the efficiency forecast and the implementation time of intelligent systems. This model is associated with mathematical counting of the future value of the process. This model is based on the representation of renewal and modernization in the form of a stochastic process. The mathematically-oriented understanding of this process is based on the sum of random variables, the result of which reflects the occurrence of events that lead to the failure of the implementation time of intelligent systems and the failures during modernization.

Keywords: IS, equipment upgrade, transport, timing, forecast, system.

1. Introduction

Nowadays, the Russian Federation is moving towards the entire development like all the states-members of the Council of Europe, but without the powerful development of information technology, the movement is problematic. However, currently, according to the Federal State Statistics Service, the dependence of technologies is more than 90%. This fact is associated with that the 21st century will mark the age of economic pharmacy, the introduction of information technologies into all spheres of life. The percentage of enterprises that develop and implement technological innovations does not exceed 10%. So, at present and in the foreseeable future, the most important task of the Russian economy is the development of information technologies, specifically in the transport infrastructure. The initial step to develop technologies is to modernise relevant industrial enterprises. In market conditions, the development is aimed at ensuring the ability to respond quickly to changes in the circumstances of the product markets. These changes are directly supported by equipment upgrades and technological process improvements. The changes are associated with the span time, the materials and the conditions which are typical for industrial enterprises of the labour resources deficit. So, an important element to justify the changes is the indicator of the efficiency of implementation and determination of the end of the process which will lead the enterprise to release of updating and modernization. The unpredictability of this process will be a characteristic feature. It will be manifested in disruptions in the delivery time of equipment, the modernization failures and the resulting changes in both time and cost parameters of the studied processes. The indicator of events, their number, leading to failures of terms, of course, is not known. In this regard, the formation and development of management decisions in the field of technology implementation of the industrial equipment, the determination of its cost and time parameters will have to be based on the prediction.
The effective tool to predict is mathematical models. In the types of mathematical models, the possibility to observe this forecast is provided by a stochastic model, and the result is the sum of random variables, the result of which reflects the occurrence of events that lead to the failure of the implementation of intelligent transport systems and failures of modernization of production processes. The model and its processes are based on theoretical approaches, which are substantiated by the authors B.V. Gnedenko and A.N. Kolmogorov in their work of "Limit distributions for the sums of independent random variables". Also, in this work and others, the models assuming the presence of limit distributions for the sums of independent random variables are considered. An important part of an accurate forecast to manage the modernization of an industrial enterprise proves the need to take into account the limitation of the random number of these destructive events. The study is aimed to develop a model that provides a forecast of the efficiency and timing of the development of intelligent systems.

2. The formalized prediction model

In general, the problem of the efficiency and timing prediction of intelligent transport systems development comprises follows. Regarding an enterprise whose interest is the development of information technology, the development of equipment and process modernization is the main goal of any production. During the process, some destructive events may occur, which lead to delays and failures of the modernization process. The result of each event is increasing the time to complete the whole upgrade process and the efficiency upgrading by a value of $G$ and by a value of $H$. From this formalization model, the values of $X$ and $Y$ are reasonable to consider as random variables. The task of this forecast is to determine the probability that the process of information technologies implementing (intelligent systems) and the production process modernization of the enterprise will be completed within the scheduled term (scheduled time $T$) and the probability that the effectiveness of the implementation will not exceed the set value $S$. The condition will be considered as $T$ and $S$ exceed the ideal time conditions $T_0$ ($T$ zero) and the effectiveness of the implementation $S_0$ necessary for the modernization of the enterprise. Thus, under the conditions of the problem, it is required to determine the probability

$$F_1(\alpha) = P (\alpha \leq T - T_0) \quad (1)$$
$$F_2(S) = P (\beta \leq S - S_0), \quad (2)$$

where $\alpha$ is a random variable equal to the sum of $n$ random variables $G$; $\beta$ is a random variable equal to the sum of $n$ random variables $H$.

Determining the probabilities (1) and (2) includes evaluating the distribution functions of random variables $n$, $G$, $H$. Usually, some enterprises have a limited amount of statistical information. Therefore, only the mathematical expectation $\mu$ of the time interval between the destructive events leading to an increase in the completion time of the modernization process of an industrial enterprise, as well as the mathematical expectations $\hat{G}$, $\hat{H}$ of the values $G$ and $H$ caused by these events of production functions. In such an information situation, based on the principle of maximum entropy (how much we do not know), the time interval between successive events and the values of $G$, $H$ should be assumed to be distributed over exponential distributions (exponential). The number of $n$ destructive events is distributed according to Poisson's law

$$P(r=n) = \frac{\mu^n}{n!} e^{-\mu}, \quad (3)$$

where $P(r=n)$ is the probability of that the number $r$ of destructive events that took place during the modernization of the enterprise process is equal to $n$;

$\mu$ is the parameter of the Poisson distribution.

The density function of the distribution of a random variable $G$ has the form:

$$f_1(g) = \lambda_1 e^{-\lambda_1 g}, \quad g \in \{0, 1\} \quad (4)$$

where $\lambda_1 = \frac{1}{6}$ is a parameter of exponential distribution of a random variable of $G$ increase of term of the introduction of intelligent systems owing to the approach of the next destructive event.
The density function of the distribution of a random variable $H$ has the form
\[ f_2(h) = \lambda_2 e^{-\lambda_1 h}, \quad h \in \{0, 1\} \quad (5) \]

where $\lambda_2 = \frac{1}{H}$ is the exponential distribution parameter of the random variable $Y$.

The efficiency of the process of modernization development of the enterprise due to the occurrence of the next destructive event.

Taking into account the relations, (3), (5), the random variables $\alpha$ and $\beta$ are the sums of the Poisson number of exponentially distributed random variables $G$ and $H$. The apparatus of characteristic functions comprises the following peculiarities.

For a random variable $\alpha$ the characteristic function has the form:
\[ \phi_{\alpha}(t) = \int_{-\infty}^{\infty} e^{it\alpha} dF_1(\alpha) \quad (6) \]

For a random variable $\beta$ the characteristic function has the form:
\[ \phi_{\beta}(t) = \int_{-\infty}^{\infty} e^{it\beta} dF_2(\beta) \quad (7) \]

In the relations (6), (7) $t$ is a real variable, $i$ – an imaginary unit.

Since the very purpose of using characteristic functions is predetermined by the fact that they have the properties of uniqueness and multiplicativity. The multiplicativity property is that the characteristic function of the sum of independent random variables is equal to the product of their characteristic functions. The uniqueness property determines that the characteristic function $\phi_z(t)$ some random variable $Z$ is absolutely intertwined (integrable) on the entire real axis, and the function $F(z)$ has a continuous derivative $f(z)$ (distribution density), then there are relations (inversion formula):
\[ f(z) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{itz} \phi_z(t) dt \quad (8) \]

The relation (8) indicates a one-to-one correspondence between the characteristic function of a random variable $Z$ and the density function of its distribution.

The characteristic function of the exponential distribution (4) has the form:
\[ \phi_1(t) = (1 - it\lambda_1^{-1})^{-1}. \quad (9) \]

Given (3), (6), the characteristic distribution function $\phi_\alpha(t)$ (1) is:
\[ \phi_\alpha(t) = \sum_{n=0}^{\infty} \frac{v^n e^{-v}}{n!} (1 - it\lambda_1^{-1})^{-n} \quad (10) \]

Using the inversion formula, we determine the density function of the random variable distribution $\alpha$:
\[ f(\alpha) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{itz} \phi_\alpha(t) dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{itz} \sum_{n=0}^{\infty} \frac{v^n e^{-v}}{n!} (1 - it\lambda_1^{-1})^{-n} dt \quad (11) \]

After replacing the summation and integration order in (11), we can obtain:
\[ f(\alpha) = \frac{1}{2\pi} \sum_{n=0}^{\infty} \frac{v^n e^{-v}}{n!} \int_{-\infty}^{\infty} e^{itz} (1 - it\lambda_1^{-1})^{-n} dt \quad (12) \]

From (12), using the integral from the table of integrals, sums, series and studies of authors I.S. Gradstein, I.M. Ryzhik, we obtain:
\[ f(\alpha) = \sum_{n=0}^{\infty} \frac{v^n e^{-v} \lambda_1(n)}{n! \lambda_1(n)} \quad (13) \]

where $\Gamma(n)$ is the gamma function.

From (13) it follows that the probability (1) that the process of implementation and development of intelligent systems will be completed in the scheduled time will be equal to:
\[ f_1(\alpha) = P(\alpha \leq T - T_0) = \sum_{n=0}^{\infty} \frac{v^n e^{-v}}{n!} \int_{0}^{T-T_0} \frac{(\lambda_1(n))^{n-1} e^{-\lambda_1 s}}{\lambda_1(n)} ds \quad (14) \]

The characteristic function of the exponential distribution (5) has the form:
\[ \phi_2(t) = (1 - it\lambda_2^{-1})^{-n} \quad (15) \]

Using the inversion formula, we can determine the density function of the distribution of a random variable $\beta$:
\[ f(\beta) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{itz} \phi_\beta(t) dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{itz} \sum_{n=0}^{\infty} \frac{v^n e^{-v}}{n!} (1 - it\lambda_2^{-1})^{-n} dt \quad (16) \]

\[ \text{where } \lambda_2 = \frac{1}{H} \text{ is the exponential distribution parameter of the random variable } Y. \]
Further, by performing transformations similar to (12), (13), we obtain the density function of the distribution of the random variable $\beta$ in the form:

$$f(\beta) = \sum_{n=0}^{\infty} \frac{\nu^n e^{-\nu} (\lambda_1 \beta)^n}{n!} \frac{1}{\lambda_1 \Gamma(n)}$$

(17).

It follows from (18) that the probability (2) that the efficiency of the implementation of intelligent systems will not exceed the set value $S$ and it is equal to:

$$f_2(\beta) = P(\beta \leq S - S_0) = \sum_{n=0}^{\infty} \frac{\nu^n e^{-\nu} \int_0^{S - S_0} (\lambda_2 a)^n a^{-1} e^{-\lambda_2 a} \lambda_2 \Gamma(n) \, da}{n!}$$

(18).

3. Conclusions

The main elements of managerial decisions in the model development which provides the prediction of the effectiveness and timing of the intelligent systems development are the assessment of the cost of implementing and developing intelligent systems [10], [11]. At the early stages to formulate these decisions, the determination of the cost and time parameters of the update and implementation of the modernization process should be based on forecasting. This prediction is carried out in conditions of limited statistical information. Well-known methods do not fully take into account the specifics of the studied processes, so they can lead to enormous errors in forecasting efficiency. The relations (14) and (18) obtained in the present work allow estimating more adequately the introduction and development of intelligent systems.

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