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Voronezh State University of Architecture and Civil Engineering
Ph. D. in Engineering, Prof. of Dept. of Construction Management
A. I. Polovinkina
D. Sc. in Engineering, Prof. of Dept. of Technology of Building Materials, Products and Structures
V. T. Pertsev
Russia, Voronezh, tel.: (473)271-40-36; e-mail: kpn55@rambler.ru

Institute Management Problems named after Trapeznikov
D. Sc. in Engineering, Prof. A. V. Schepkin
Russia, Moscow, tel.: (950)132-56-78

A. I. Polovinkina, V. T. Pertsev, A. V. Schepkin

SYSTEM OF PENALTIES IN THE SECURITY PROVISION OF BUILDING ENTERPRISES OF THE REGION

Problem statement. Systems of management decisions support are implemented on the regional scale. They include the economic models providing secure operation of complex technical systems and particularly hazardous industries. The most widely spread economic mechanisms used in industrial security activities are risk payments, risk quoting, risk redistribution, etc. However, questions emerge on the size of fines, quotes, etc. which all ensure effective operation of economic mechanisms of security provision.

Results. The distribution of restrictions on the maximum acceptable risk level for each building enterprise of the region, when the high penalty system is in action, for the purpose of the regional security provision at or above some minimum level and boosting overall profits of enterprises is discussed.

Conclusions. The conducted analysis of high penalties in the industrial security management in the region reveals that many of the management models implemented within the framework of the theory of the organizational and socioeconomic systems management could be (if appropriately adapted) efficiently used in the development and study of security management models.

Keywords: safety, building enterprise, penalty mechanism, emergency.

Introduction

The economic aspect has a vital role in addressing the problems of safe industrial operation of a certain enterprise and the whole region as well. It is imperative that sufficient funds are allocated and efficient economic mechanisms are in place to provide incentives for practical steps to be taken to reduce emergency risks.

At the level of the region and enterprise, systems are designed to assist management decision-making that include economic models, methods and software to provide a long-run survival and continuous safe operation of complex technical systems and highly hazardous industries.

The most common safety measures as applied to enterprises are such economic mechanisms as risk payments, risk quota, reallocation of risks, enhancement of risk reduction efforts. Penalty mechanisms are now emerging at the forefront of the measures.

1. A model of the region's enterprises

In this paper we look at the region with a number of operating industrial objects (e. g., enterprises) that are likely to pose an emergency threat and thus affect the region's safety levels. Let $N = \{1, 2, \ldots, n\}$ be a variety of the region's enterprises.

Local authorities (the Centre) are liable for the safety of the region. It is their duty to put forward various economic mechanisms to reduce risks. They are in charge of allocating funds among the centrally funded enterprises that are then invested to decrease the likelihood of emergencies erupting, incentives for enterprises' commitment to lower technological and natural risks, fines imposed whenever emergency risks arise.

In market economy, the performance of an enterprise is measured by the profit it makes. If assumingly all the products it has manufactured sell, the profit of the i-th enterprise is as follows

$$f_i = c_i\, u_i - z_i\left(u_i\right),\ i \in N, \tag{1}$$

where u_i is a production volume manufactured by the *i-th* enterprise; c_i is the price of the production manufactured by the *i-th* enterprise; $z_i\,(u_i)$ are expenses the enterprise incurred in the manufacture of a production volume u_i.

In fact, an enterprise is looking not to increase its entire profit but only that that they have at their disposal, since it is its profit that an enterprise uses for compulsory payments such as taxes, various fees and fines.

The size of these payments and the indicators governing them are defined by a current economic mechanism.

Let us designate a risk level as xi which is a likelihood of emergencies occurring in the enterprise and a safety level of the i-th enterprise as y_i which is a likelihood of incident-free performance of the enterprise. It is obvious that $x_i+y_i=1$.

The parameters of an economic mechanism are set out in compliance with the observed or measured risk level thus obviously $\chi_i=\chi_i(x_i)$ or $\chi_i=\chi_i(y_i)$. This being the case, a profit left at the disposal of the enterprise can be written as follows

$$f_i = c_i u_i - z_i(u_i) - \chi_i(x_i),\ i \in N. \tag{2}$$

If χ_i is a fine imposed for exceeding the acceptable risk level,

$$\chi_i(x_i, \hat{x}_i) = \begin{cases} h_i(x_i) & \text{if } x_i > \hat{x}_i, \\ 0 & \text{if } x_i \le \hat{x}_i, \end{cases} \quad i \in N, \tag{3}$$

where $\hat{x}_i$ is an acceptable risk level for the i-th enterprise.

Furthermore, we will consider that a risk level induced by the activities of the i-th enterprise or a likelihood of an emergency occurring in this enterprise is dependent on a volume of production u_i and funds allocated to prevent critical incidents and to maintain industrial and technological order [4], i. e. $x_i=x_i(u_i, v_i)$.

Since a region may be home to various enterprises and there may be a variety of losses incurred, it is critical that we take into consideration not just a likelihood of an emergency occurring but resulting damage as well.

Let us designate a possible total damage of the region in the event of an emergency in the enterprise as U_i. Then expected damage can be defined as

$$M_i = U_i x_i = U_i(1 - y_i),\ \ i \in N. \tag{3}$$

Accordingly, a possible total damage in the region M associated with the activities of all the enterprises located in its territory can be written as follows provided that likelihoods of emergencies are all independent

$$M = \sum_{i=1}^{n} M_i\ . \tag{4}$$

Expected damage reflects the expected negative impact on social and economic systems of an emergency forecast or already occurring [5].

2. Penalty mechanisms

Let us assume that a safety level in the region is not to be in excess of some permissible value $Y_{\min}$. If assumingly, the same value is specified for a safety level of all of the region's enterprises, a safety level $\hat{y}_i$ of the i-th enterprise is defined as follows provided that the risks the enterprise takes on are not interdependent

$$\hat{y}_i = \sqrt[n]{Y_{\min}}\,,\ i \in N. \tag{5}$$

Accordingly, an acceptable risk level is

$$\hat{x}_i = 1 - \hat{y}_i = 1 - \sqrt[n]{Y_{\min}}\,,\ i \in N.$$

An assumption is also made that there is a stringent penalty system in place [1]. This means that the enterprise gains no benefit in case a current risk level is in excess of that acceptable.

As in [1], we argue that whatever an enterprise engages in, it is all about boosting the profits left at their disposal. Let us assume that there is such a multitude of enterprises Q that at $i \in Q$

$$x_i\left(u_i^*, 0\right) < \hat{x}_i\,, \tag{6}$$

where u_i^* is the solution to the equation

$$\frac{df_i}{du_i} = c_i - \frac{dz_i\left(u_i\right)}{du_i} = 0\,,\ i \in Q.$$

This means that the enterprises numbered $i \in Q$ have such a volume of production u_i^* that they secure the maximum profit without having to invest into the risk level reduction. Furthermore, the actual risk level at $i \in Q$ is less than the acceptable one. At the same time, the enterprises numbered $i \in N \backslash Q$ solve the problem while their volume of production is determined

$$\begin{cases} f_i = c_i u_i - z_i\left(u_i\right) - v_i \underset{(u_i, v_i)}{\rightarrow} \max, \\ x_i\left(u_i, v_i\right) = \hat{x}_i, \end{cases} \quad i \in N \backslash Q, \tag{7}$$

with their actual risk level equaling the acceptable one.

Thus, the actual safety level in the region is as follows as the same equal acceptable values of the risk level for all the enterprises are specified

$$Y_{actual} = \prod_{i\in Q}\left[1 - x_i\left(u_i^*, 0\right)\right] \times \prod_{i\in N\backslash Q}\left(1-\hat{x}_i\right) = \prod_{i\in Q}\left[1 - x_i\left(u_i^*, 0\right)\right] \times$$
$$\times \prod_{i\in N\backslash Q} \hat{y}_i = Y_{\min}^{\frac{m}{n}} \times \prod_{i\in Q}\left[1 - x_i\left(u_i^*, 0\right)\right], \tag{8}$$

where $$m = \sum_{i\in N\backslash Q} 1.$$

I. e.

$$Y_{actual} > Y_{\min}. \tag{9}$$

Since (2) holds at $i \in Q$, for all of the enterprises numbered in this way, the acceptable risk level can be defined as

$$\tilde{x}_i = x_i\left(u_i^*, 0\right),$$

and accordingly a safety level is

$$\tilde{y}_i = 1 - \tilde{x}_i = 1 - x_i\left(u_i^*, 0\right).$$

with the acceptable safety level for the enterprises numbered $i \in N\backslash Q$ being determined by the expression

$$\tilde{y}_i = \sqrt[m]{\frac{Y_{\min}}{\prod_{i\in Q}\tilde{y}_i}},\ i \in N\backslash Q, \tag{10}$$

and accordingly

$$\tilde{x}_i = 1 - \tilde{y}_i = 1 - \sqrt[m]{\frac{Y_{\min}}{\prod_{i\in Q}\tilde{y}_i}},\ i \in N\backslash Q.$$

Let us show that

$$\tilde{x}_i > \hat{x}_i,\ i \in N\backslash Q.$$

For that, it will suffice to show that

$$\tilde{y}_i < \hat{y}_i,\ i \in N\backslash Q.$$

In fact, the inequality (9) gives

$$Y_{\min}^{\frac{m}{n}} \times \prod_{i\in Q}\left[1 - x_i\left(u_i^*, 0\right)\right] > Y_{\min},$$

or

$$Y_{\min}^{\frac{m}{n}} > \frac{Y_{\min}}{\prod_{i\in Q}\tilde{y}_i}. \tag{11}$$

When we raise both parts of the inequality (11) to the power *1/m*, we get $\hat{y}_i > \tilde{y}_i$, thus $\tilde{x}_i > \hat{x}_i$ which we set out to prove.

This means that there is less pressure on the enterprises numbered $i \in N\backslash Q$ to keep their levels of risks acceptable. As suggested in [1], the higher requirements there are to the industrial safety level with a penalty mechanism in place, the more badly the industry slumps thus resulting in a volume of production falling sharply. Conversely, more lenient requirements to the industrial safety levels with a heavy penalty mechanism in place help boost the volume of production.

To illustrate the results obtained, we are going to use the dependencies examined in [1] as an example.

Let us assume that

$$z_i = \frac{1}{2} r_i\, q_i \left(\frac{u_i^2}{q_i^2} + 1\right),$$
$$x_i\left(u_i, v_i\right) = \frac{w_i u_i^2}{w_i u_i^2 + k_i v_i + T_i},\quad i \in N, \tag{12}$$

where q_i is a volume of production that provides a minimum cost price; r_i is a minimum cost price; w_i is a coefficient that describes the effect the volume of production has on a level of natural and technological risks; k_i is a coefficient that describes the efficiency of the funds targeted for the reduction of a risk level; T_i is an indicator that describes the industrial safety.

Let us assume there are three (n = 3) enterprises operating in the region. Their characteristics are presented in Table.

Table

Characteristic	Enterprise № 1	Enterprise № 2	Enterprise № 3
q	65	80	95
r	20	25	30
w	0.0003	0.0004	0.0005
k	4	5	6
T	9500	8500	7500
c	60	90	120

Assumingly a minimum safety level is not pronounced in the region. This being the case, the enterprises are not to invest into the reduction of a risk level. The volume of production of each enterprise would be respectively

$$u_1^* = 195,\ u_2^* = 288\ and\ u_1^* = 380.$$

A safety level in each of the enterprises would be

$$y_1^* = 0.9988,\ y_2^* = 0.9961\ and\ y_3^* = 0.9905.$$

The region's safety level would be Y = 0.9854.

Assumingly a minimum safety level is pronounced as $Y_{\min}$=0.995.

Then according to (1), a safety level in each of the enterprises is not to be lower than

$$\hat{y}_1 = \hat{y}_2 = \hat{y}_3 = 0.9883.$$

Therefore obviously $y_1^* > \hat{y}_1$, i. e. Enterprise № 1 gains a maximum profit without no extra investment to reduce a risk level thus providing a higher safety level than set out in (1). At the same time, $y_2^* < \hat{y}_2$ and $y_3^* < \hat{y}_3$. Therefore, the second and third enterprises are to define their volume of productions in compliance to (3). For those specified in Table we have $u_2' = 220.49$ and $u_3' = 288.44$.

Furthermore, in order to provide a required safety level, all of the enterprises allocate extra funds of $v_2' = 625.8$ and $v_3' = 2907.49$. As a result, the total volume of production of all the enterprises in this region numerically speaking is 66060, the total funds for the reduction of a risk level is 3533.29 and the region's safety level is 0.995.

Given that the first enterprise sets out higher requirements for its safety level than it is required, we are going to differentiate the restrictions on a minimum safety level. For the first enterprise we will establish a minimum safety level to be $\tilde{y}_1 = 0.9988$. Meanwhile, according to (5) for the second and third enterprise is to be $\tilde{y}_2 = \tilde{y}_2 = 0.9981$.

It is plain to see that there are no changes for the first enterprise. It has the same volume of production with no extra investment made to reduce a risk level and thus provides a required safety level.

As for the second and third enterprises, their volumes of production are $u_2'' = 227.07$ and $u_3'' = 297.66$. Accordingly, in order to provide a required safety level, these enterprises are to invest as much as $v_2'' = 461.8$ and $v_3'' = 2619.74$.

Hence, in order to differentiate the restrictions on the requirements for a minimum safety level for the region's enterprises with a steady safety level, the total volume of production of all the enterprises is numerically speaking 67770, which corresponds to a 2.5 % growth. Meanwhile, the total funds to reduce this level fell to 3081.54, which corresponds to a 12.8 % drop.

Conclusions

1. The complexity of industrial and natural processes, their probabilistic nature makes the associated problems challenging to solve without a proper design and research of corresponding models.

2. A connection has been established between the level of requirements for the region's safety with the industrial activity of its enterprises.

3. The analysis of a heavy penalty mechanism in the region's safety management indicates that many of the management mechanisms created within the framework of the management theory of organizational and social and economic systems can be (if properly adapted) effi-

ciently and effectively used to design and study the models of safety management mechanisms of the region's construction enterprises.

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