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Modelling and economic risk estimation for accidents in underground building construction and exploitation

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Abstract. In order to estimate the probability of anthropogenic accidents during the process of underground works and the corresponding damage, the mathematical model of accident risk should include not only technological and geophysical parameters of the object of interest, but also level of labor discipline of workers and the internal technological rules of the enterprise. In our previous works we developed a game-theoretic model of underground mining enterprises. But the part of the model concerning the risk of accident and the corresponding damage was assumed "exogenous", and was previously never discussed. In this paper we develop the models of underground accidents emergence and damage caused by them, basing of the classic Ruin theory (Cramer-Lundberg model of Poisson risk process). As a result of our research we develop the analytical expressions allowing to give a numerical assessment to technical and economic characteristics of the enterprise working in especially dangerous conditions. We found the analytical expressions which give a numerical estimation of possible damage from accidents of anthropogenic nature, depending on different technologic strategies of the enterprise and on the workers' behavior.

1. Introduction

In recent years in a mining complex of Russia was outlined a steady tendency of decrease in operational injuries, especially in the coal industry. The deadly traumatism in a long-term retrospective decreases both in absolute, and in the relative values. In general, on branch the number of injuries from the death is lowered by 1 million tons of coal mining from 1 case in 1993 to 0,07, or by 14 times [11]. Level of deadly traumatism in mines per one thousand working became lower, than in some other branches, for example, is 30% lower, than at extraction of metal ores [7].

At the same time, in mines of Russia high scratches of emergence of major accidents remain. If to look at dynamics of deadly traumatism of last years, then the recurrence of accidents with a large number of the dead is obviously visible. Therefore, safety of productions, implementation of requirements of labor protection and the accident prevention, requirements of the industrial hygiene is one of the most important functions of the management of the enterprise.

In order to estimate the probability of anthropogenic accidents during the process of underground building construction and its usage and the corresponding damage, the mathematical model of accident risk should include not only technological and geophysical parameters of the object of interest, but also level of labor discipline of workers and the internal technological rules of the enterprise. In some of our recent works ([9-12]) we developed a game-theoretic model of underground mining enterprises. In these works, we analyzed the reasons of unsafe workers' behavior on the underground coal mines. This model featured two punishment options for the workers (fines and firing), and the scheme of effective controlling structure as the result of the work. But the part of the model concerning the risk of accident and the corresponding damage was assumed "exogenous", and was previously never discussed.

In this paper we develop the models of underground accidents emergence and damage caused by them, basing of the classic Ruin theory (Cramer-Lundberg model of Poisson risk process, see [1]). We start our analysis on firedamp explosions as the main type of accidents, however, the risk-theoretic approach is applicable to the various specter of underground anthropogenic accidents. Indeterminacy and unpredictability of the inflaming moment is the main source of accident at explosions at the mining enterprises. It should be noted that at the stage of active coal mining there are much more possible sources of inflaming (e.g., coal transportation, the vent system, …), than at a stage of expectation of a production conditions normalization (vent system). However, in both cases the anthropogenic component is determined by behavior of workers' behavior.

2. Model description and analysis

For all enterprises of mining branch the legislative rule of $\bar{r}$ on the extreme concentration of a methane in the atmosphere of the mine is defined. Works on coal mining have to stop if indications of devices indicate excess of content of gas of legislative rule. As a rule, at the enterprises the specialized equipment which in the automatic mode de-energizes the site of production at sharp strengthening of gas is installed.

The entire period of functioning of the enterprise is separable into nominal cycles which are approximately corresponding to changes. Each such cycle consists of two parts, namely, the period of the fissile production and waiting period of a normalization of conditions of production. At the first stage (the fissile production) mining works are performed. At achievement of concentration of a methane of an upper bound of r^a all works stop and evacuation of personnel is made. After that there comes the period of a normalization of working conditions. At this stage airing of the mine and expectation of decrease in concentration of a methane to the lower bound of r_0^a is made.

Concentration of a methane in the mine depends on amount of the methane allocated from coal and on amount of the air coming to a face. Speed of production is a stationary value. It is bound to technical features of an inventory which is used at coal mining in mines. There is some best value of drilling speed v. The deviation from this size in the larger/smaller party leads to the raised consumption of by-products, and further and to an inventory conclusion out of operation. As a first approximation concentration of a methane in an instant of t may be presented in the following form:

$$\boldsymbol{w_d(r_0^a, t) = r_0^a + (\mu v - v_c)t,} \tag{1}$$

where: r_0^a is initial concentration of a methane; μ is the average content of a methane in breed; v is drilling speed; v_c is speed of airing of production site.

The important component requiring an attention are sudden emissions of a methane. All mines of the coal-mining industry are divided into several categories, the higher is the category of the mine, the larger amount of gas may be released at sudden emission of a methane. The set of instructions and measures for prevention of such events is developed, however in practice it is impossible to bring to naught their probability therefore unplanned stops of work of the mining enterprise are inevitable.

Let's consider methane emissions as the sequence of random events. On a time term $(0, t)$ there is some number of events (methane emissions). We will designate the moments of emergence of these emissions $0 < \tau_1 < \tau_2 < \cdots$. Let's define $N(t)$ as stochastic process which realization characterizes the number of emissions of a methane on a time term $(0, t)$. As model of this process classical Poisson process – thanks to properties of an ordinariness (the probability of simultaneous emergence of two and more emissions of a methane is equal to zero) and lack of consequences well approaches (the probability of emergence of the following emission of a methane does not depend on previous).

Then the average number of emissions of a methane λt will be the characteristic of intensity of a stream of events. It follows from this that the probability of emergence of k of emissions during t will be equal to

$$P(N(t) = k) = \frac{(\lambda t)^k}{k!}\, e^{-\lambda t}$$

As a result of serial emissions concentration of gas in the atmosphere of development increases every time at some size. Their sequence we will designate $X_1, X_2, \ldots$, these are independent and equally the distributed random values. Stochastic emissions of a methane have exponential distributions with parameter $\delta > 0$: $F_X(v) = 1 - e^{\delta v}, v \geq 0$. Then concentration of a methane in an instant can be presented in the following form:

$$\boldsymbol{w_d(r_0^a, t) = r_0^a + (\mu v - v_c)t + \sum_{j=1}^{N(t)} X_j}, \quad (2)$$

According to safety rules (Safety rules for coal mines of PB 05-618-03 from 2004 g) the average speed of airing has to be above average amount of the methane which is emitted during coal mining i.e. $v_c > \mu v$. The schedule of change of concentration of a methane is presented in the Figure 1.

As it was already mentioned above, coal mining stops when the current concentration exceeds the standard of r^a established by the management, and is resumed when falls to the lower bound of r_0^a. Let's define the moments of a stop and renewing of production as t_d^* and t_w^*.

Let's estimate economic losses from a position of insurance payments in the beginning. Concentration of a methane in the atmosphere of development can be presented as casual process which can be described by means of classical process of risk [1]. Then payments for insured events, and the moment of a stop of work of t_d^* - the moment of suspension of insurance payments by insurance company can be compared to emissions of a methane. For such model the apparent type of a density function of the moment of ruin is known. Having applied this result to our model, we will receive that the density function of the moment $t_d^*(r^a, r_0^a)$ of achievement of r^a methane at initial concentration of r_0^a has the following form:

$$f_T(t, r^a, r_0^a) = e^{\delta(r^a - r_0^a + (v_c - \mu v)t)} \times \sum_{k=0}^{\infty} \frac{\delta^k (r^a - r_0^a + (v_c - \mu v)t)^k \lambda^{k+1} t^k e^{-\lambda t}}{(k!)^2} \quad (3).$$

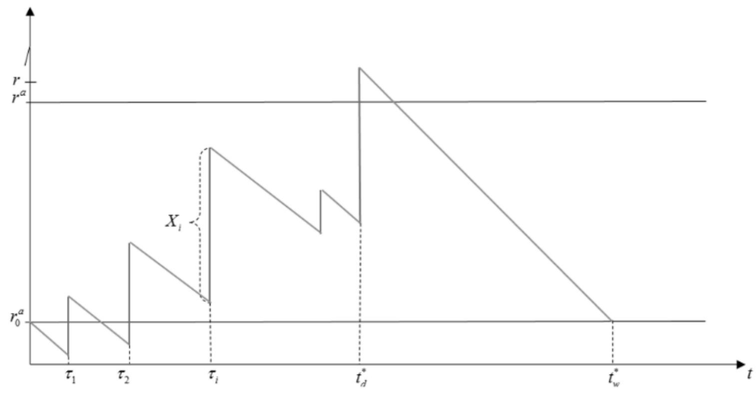

Figure 1. The methane concentration as a function of time.

After that coal mining stops and workers expect weakening to the lower mark r_0^a. Concentration of a methane at this stage changes under the law $w_w(R, t) = R - v_c t$, R stands for concentration of a methane at the time of a coal mining stop.

The value $R - r^a$ (excess of actual level of concentration of gas over the most admissible) may be interpreted for classical process of risk (in economic terms) as deficiency of the capital of the company.

Assessment of size of budget deficit are received in articles ([4], [15]). Let's enter a random value - budget deficit of the company with a cumulative distribution function $G_y(v) = P(y \leq v, t_d^* < \infty)$. In work [15] it is shown that for a case when payments for insured events have exponential distribution with parameter $\delta > 0$ cumulative distribution function of budget deficit has the following appearance: $G_y(v) = 1 - e^{-\delta v}$.

Having applied result of works ([4], [15]) to concentration model, it is possible to receive that distribution of the amount of excess of a methane of r_+^a at the time of a stop is exponential with parameter $\delta > 0$. Then concentration at the time of a stop equals

$$w_w(r^a, t) = (r^a + r_+^a) - v_c t \tag{4}$$

Workers resume mining works if $w_w(r^a, t) = r_0^a$. From this condition we will receive a latency period of a normalization of conditions of production:

$$t_w^*(r^a, r_0^a) = \frac{(r^a - r_0^a) + r_+^a}{v_c}. \tag{5}$$

However, coal mining may be stopped not only because of excess of concentration of a methane. As it was already mentioned above, the limit inferior of explosibility of a methane makes 5%. In actual practice explosion can happen on the mine also at smaller concentration. In works ([8], [10]) it is shown that the limit inferior of explosibility of a methane strongly depends on concentration of other gases in the atmosphere of the mine. One of such indexes is the content of coal dust on the site of production. According to the received results (Figure 2), at the high content of coal dust in the atmosphere of the mine explosion is possible, even when concentration of a methane does not exceed 2%.

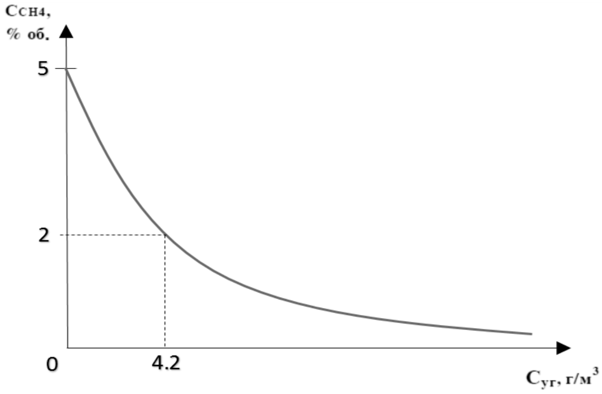

Figure 2. Dependence of a limit inferior of potential of explosion of a methane on concentration of coal dust.

Statistically, average indicators of coal dust during the periods of the fissile production are about 3 - 5. Thus, respect for legislative rule cannot always provide the complete fail-safety of the mine on a gas factor.

Explosion of firedamp represents coincidence of two events: first, concentration of a methane has to be above a limit inferior of explosibility of R_{NPV} and, secondly, the inflaming source has to appear. The limit inferior of explosibility, generally, depends on temperature in the mine, pressure and on concentration of coal dust therefore in our model we accept a limit inferior the fixed. On this basis it is possible to define areas in which emergence of explosion at a production stage, and expectations of a normalization of conditions of production is possible.

Indeterminacy and unpredictability of the moment emergence of inflaming is the main source of accident at explosions at the mining enterprises. It should be noted that at the fissile coal mining there are much more possible sources of inflaming (e.g., coal transportation, the vent system, …), than at a stage of expectation of a normalization of conditions of production (vent system). However in both cases the anthropogenic component determined by behavior of workers works. Let's consider random values X_d, X_w - the moments of emergence of a source of inflaming for each stage of works.

According to technical features of an inventory ([5]) which is used in mines, the sizes X_d, X_w have exponential distribution with parameters $\alpha_d > 0, \alpha_w > 0$. If realization of random values of X_d, X_w gets to a time interval when concentration is higher than a limit inferior of explosibility, then inevitably there is an accident.

The damage which is suffered by the mining enterprise depends on the power of explosion of firedamp. Than gas explosion is stronger, that the damage is more. In turn force of explosion depends on amount of the methane participating in it and a set of other factors (temperature, pressure, concentration of other gases). If to record all parameters, except the content of methane, then statistically ([8]) largest forces explosion occurs on average at concentration of equal 9,5%. At larger concentration a part of a methane remains to the unburnt because of a lack of oxygen (Figure 3).

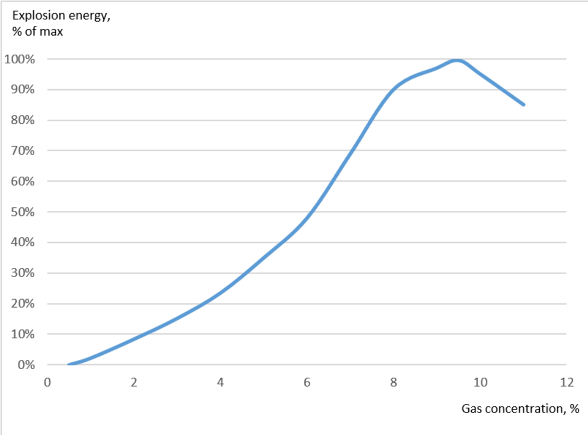

Figure 3. Dependence of power of explosion on methane concentration ([6])

The extent of damage may be in that case presented in the form:

$$Y(w) = \hat{Y} l_{ex}(w), \qquad (6)$$

where $\hat{Y}$ - the maximal cooperative damage from accident; $l_{ex}(w)$ - dependence of power of explosion on concentration of a methane of w.

Explosion of firedamp causes damage to property of mining company and health of workers of the mine [2]. The establishes the amount of compensations for various cases of harming of life and to health of workers of the mine. So, maximal compensation makes 2 million rubles and is paid when causing damage of life. Then the maximal extent of damage to the enterprise from accident can be presented in the form:

$$\hat{Y} = Y_m + \beta n, \qquad (7)$$

where: Y_m stands for costs of the complete recovery of functioning of the mine; β - the amount of compensation at death of the miner; n - number of workers of the mine.

Accidents in mines lead not only to payments of compensations and costs of restitution, but also to stops in work of the enterprise. Duration of the period of mitigation of consequences also strongly depends on the nature of accident. The more scale accident happened, the more it is required to time for its elimination. Thus, the period of elimination of accident of $t^{ex}(w)$ can be presented in the form:

$$t^{ex}(w) = \hat{t}^{ex} l_{ex}(w) \qquad (8)$$

where $\hat{t}^{ex}$ is a restoring time at the final fracture.

Let's consider strategy and prizes of the mining enterprise. Let's take a set of A from $n > 1$ mining enterprises, for all which the legislative rule of $\bar{r}$ on the extreme concentration of a methane is defined. The strategy of each $a \in A$ enterprise consists of two components: (r^a, r_0^a). The first of them defines marginal concentration of a methane in the mine, and $r^a < \bar{r}$.

Let's consider some cycle of production at the given strategy (r^a, r_0^a) and we will define value of profit of the company in unit of time. As it was already mentioned above, works on each cycle of production can proceed on one of three possible scenarios: accident at a stage of the fissile production; accident at a stage of expectation of a normalization of conditions of production; accident-free functioning.

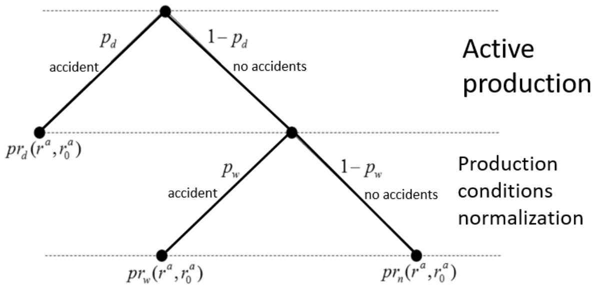

Figure 4. The scheme of works on each cycle of production depending on accidents

The strategy of the enterprise (r^a, r_0^a) will define probabilities of emergence of accidents and profit in unit of time for each mode of functioning of the mine. Let's designate profits in unit of time as $pr_d(r^a, r_0^a)$, $pr_w(r^a, r_0^a)$, $pr_n(r^a, r_0^a)$, and probabilities of emergence of accident at a stage of the fissile production and normalization of conditions as p_d and p_w, respectively. Then mean value of profit in unit of time can be presented in the form:

$$\mathbb{E}[pr(r^a, r_0^a)] = p_d\mathbb{E}[pr_d(r^a, r_0^a)] + p_w\mathbb{E}[pr_w(r^a, r_0^a)] + (1-p_d)(1-p_w)p_d\mathbb{E}[pr_n(r^a, r_0^a)] \quad (9)$$

Further we will define values of probabilities of emergence of accident and also mean values arrived for each case.

Let's consider an accident case at a stage of the fissile production. The accidents arising at a stage of the fissile production are possible only on condition of emergence of a source of inflaming at the moment when concentration of a methane exceeds a limit inferior of explosibility of r_{NPV}. Then the probability of emergence of accident will be equal to $p_d(r^a, r_0^a) = P(t_d^{ex} \in [t_{NPV}, t_d^*])$ where t_d^{ex} - the moment of emergence of a source of inflaming, $t_{NPV} = t_{NPV}(r_{NPV}, r_0^a)$ - the moment when methane concentration achieves its minimal value - r_{NPV}, and $t_d^* = t_d^*(r^a, r_0^a)$ - excesses of the standard of r^a. Let's define the probability that $t_d^{ex} \in [t_{NPV}, t_d^*]$:

$$P(t_d^{ex} \in [t_{NPV}, t_d^*]) = P(t_{NPV} - t_d^{ex} < 0, t_d^{ex} - t_d^* < 0). \quad (10)$$

Random variables t_d^{ex}, $t_{NPV}(r_{NPV}, r_0^a)$, $t_d^*(r^a, r_0^a)$ are independent and have density functions of $f_d^{ex}(t)$, $F_{NPV}(t)$, $f_d^*(t)$ respectively. Then

$$P(t_{\text{НПВ}} - t_d^{ex} < 0, t_d^{ex} - t_d^* < 0) = \int_0^{+\infty}\int_0^z\int_0^y f_d^{ex}(x)\, f_{\text{НПВ}}(y)\, f_d^*(z)\, dx\, dy\, dz \quad (11)$$

These density functions have the following appearance:

$$f_{NPV}(t) = e^{\delta(r_{NPV} - r_0^a + (v_c - \mu v)t)} \times \sum_{k=0}^{\infty} \frac{\delta^k (r_{NPV} - r_0^a + (v_c - \mu v)t)^k \lambda^{k+1} t^k e^{-\lambda t}}{(k!)^2} \quad (12)$$

$$f_d^{ex}(t) = \alpha_d e^{-\alpha_d t} \quad (13)$$

$$f_d^*(t) = e^{\delta(r^a - r_0^a + (v_c - \mu v)t)} \times \sum_{k=0}^{\infty} \frac{\delta^k (r^a - r_0^a + (v_c - \mu v)t)^k \lambda^{k+1} t^k e^{-\lambda t}}{(k!)^2} \quad (14)$$

Key indicator for assessment of the size of consequences from accident is the value of concentration of a methane at the time of explosion. Content of gas in the atmosphere of the mine changes according to the rule:

$$w_d(r_0^a, t) = r_0^a + (\mu v - v_c)t + \sum_{j=1}^{N(t)} X_j, \quad (15)$$

where: $N(t)$ stands for the number of emissions (a Poisson random variable with parameter λt); $X_j, j = 1, \dots, N(t)$ is the size of ith methane emission (the independent equally distributed random variables having exponential distributions with parameter $\delta > 0$: $F_X(v) = 1 - e^{\delta v}, v \geq 0$).

The cumulative distribution function of the random sum $S_N(t) = \sum_{j=1}^{N(t)} X_j$ will be equal:

$$F_{S_N}(x) = \sum_{k=0}^{+\infty} p_k(t) F^{*k}(x), \tag{16}$$

where $p_k(t) = P(N(t) = k) = \frac{(\lambda t)^k}{k!} e^{-\lambda t}$ is probability of events emergence during time t; $F^{*k}(x)$ stands for k-fold convolution of a cumulative distribution function of the amount of methane emissions.

Let's define a random variable τ_d^{ex} denoting the moment of emergence of a inflaming source on a time interval $[\underline{t}_{NPV}, t_d^*]$. The cumulative distribution function of this size may be presented in the form:

$$F_{\tau_d^{ex}}(x) = \frac{P(t_d^{ex} < x)}{P(t_d^{ex} \in [\underline{t}_{NPV}, t_d^*])} = \frac{1 - e^{-\alpha_d x}}{p_d} \tag{17}$$

Then the value of methane concentration at the time of explosion equals

$$w_d\left(r_0^a, \tau_d^{ex}, S_N(\tau_d^{ex})\right) = r_0^a + (\mu v - v_c)\tau_d^{ex} + S_N(\tau_d^{ex}) \tag{18}$$

Accidents at a stage of the fissile production cause damage to workers and break functioning of the mine. The management of the mining enterprise should spend money not only for restitution of the mine, but also for payments of compensations by the worker. As it was mentioned above, accident elimination costs may be presented in the following form:

$$c_{dy}^a(r^a, r_0^a) = (Y_m + \beta n) \times l_{ex}\left(w_d\left(r_0^a, \tau_d^{ex}, S_N(\tau_d^{ex})\right)\right) \tag{19}$$

where: Y_m denotes the total costs of mine functioning recovery; β - the amount of compensation at death of the miner; n - number of workers of the mine; l_{ex} - dependence of explosion power on concentration of a methane.

The time required to eliminate the accident, may be written as follows:

$$t^{ex}(r^a, r_0^a) = \hat{t}^{ex} l_{ex}\left(w_d\left(r_0^a, \tau_d^{ex}, S_N(\tau_d^{ex})\right)\right) \tag{20}$$

where $\hat{t}^{ex}$ is restoring time at the total fracture of the mine. Then profit on one cycle of production may be presented in the form:

$$pr_d(r^a, r_0^a) = \frac{q(r^a, r_0^a)(p - c_q^a) - c_{dy}^a(r^a, r_0^a)}{\underline{t}_{NPV}\,(r_{NPV}, r_0^a) + \tau_d^{ex}(r^a, r_0^a) + t^{ex}(r^a, r_0^a)} \tag{21}$$

$$q(r^a, r_0^a) = v\left(\underline{t}_{NPV}\,(r_{NPV}, r_0^a) + \tau_d^{ex}(r^a, r_0^a)\right) \tag{22}$$

where: p is the cost of unit of the extracted coal; v is drilling speed; c_q^a denotes marginal costs of the extracted coal; $c_{dy}^a(r^a, r_0^a)$ stands for accident elimination costs.

Explosion at a stage of a normalization of conditions of production is possible if concentration of a methane is higher than a limit inferior of explosibility and there is an inflaming source. Let's define probability of such event as $p_w = P\left(t_w^{ex} \in [0, \bar{t}_{NPV}]\right)$, where t_w^{ex} is the moment of emergence of a source of inflaming, $\bar{t}_{NPV} = \bar{t}_{NPV}(r^a, r_{NPV})$ is the moment of achievement of concentration of a methane of inferior limit of explosibility. Random variables $\bar{t}_{NPV}(r^a, r_{NPV})$ and t_w^{ex} are independent and have density functions $f_{t_w^{ex}}(x), f_{\bar{t}_{NPV}}(y)$. If at a stage of the fissile production there was no accident, then the probability of explosion when airing the mine equals:

$$p_w = P\left(t_w^{ex} \in [0, \bar{t}_{NPV}]\right) = P\left(t_w^{ex} - \bar{t}_{NPV} < 0\right) = \int_{\frac{r^a - r_{NPV}}{v_c}}^{+\infty} \int_0^y f_{t_w^{ex}}(x) f_{\bar{t}_{NPV}}(y)\,dx\,dy \tag{23}$$

where: $f_{\bar{t}_{NPV}}(y) = \delta v_c e^{-\delta(v_c y - (r^a - r_{NPV}))}$, $y \geq \frac{r^a - r_{NPV}}{v_c}$, $f_{t_w^{ex}}(x) = \alpha_w e^{-\alpha_w x}$

Let's define value of probability p_w. When we substitute the expressions above into the formula

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$$p_w = 1 - \frac{\delta v_c}{\delta v_c + \alpha_d} \exp\left(-\frac{\alpha_d}{v_c}(r^a - r_{NPV})\right)$$

To estimate the accident consequences, we will define concentration of a methane at the time of explosion. If the amount of emissions of a methane has exponential distributions with parameter $\delta > 0$, then concentration of gas in the mine atmosphere changes according to the the rule $w_w(r^a, t) = r^a + r_+^a - v_c t$, where r_+^a stands for the gas concentration excess over the normative value at the stop time (it is a random variable which has exponential distribution with parameter $\delta > 0$), and v_c stands for the airing speed of the production site. Let's define a random variable τ_w^{ex} - the moment of emergence of a inflaming source during time interval $[0, \bar{t}_{NPV}]$. The cumulative distribution function of this value may be presented in the form:

$$F_{\tau_w^{ex}}(x) = \frac{P(t_w^{ex}<x)}{P(t_w^{ex}<\bar{t}_{NPV})} = \frac{1-\exp(-\alpha_w x)}{p_w} \quad (24)$$

Then the value of concentration of a methane at the time of explosion equals

$$w_w(r^a, r_+^a, \tau_w^{ex}) = r^a + r_+^a - v_c \tau_w^{ex} \quad (25)$$

Explosion of firedamp at this stage causes less loss, than at the fissile production. After the concentration exceeds the upper bound r^a, all the workers should leave the mine, therefore such explosions do not cause damage to life and health of the mine staff. Thus, costs for elimination of accident consist only of costs of restitution of functioning of the mine:

$$c_{wy}^a(r^a) = Y_m l_{ex}\left(w_w(r^a, r_+^a, \tau_w^{ex})\right) \quad (26)$$

where: Y_m is the cost of the complete recovery of functioning of the mine; l_{ex} denotes power of explosion as a function of methane concentration. Elimination of accident will require the following time:

$$t^{ex}(r^a) = \hat{t}^{ex} l_{ex}\left(w_w(r^a, r_+^a, \tau_w^{ex})\right) \quad (27)$$

where $\hat{t}^{ex}$ stands for restoring time at the final fracture of the mine.

The profit of the enterprise at emergence of accident at a stage of expectation of a normalization of conditions of production may be presented in the form:

$$pr_w(r^a, r_0^a) = \frac{q(r^a, r_0^a)(p - c_q^a) - c_s^a - c_{wy}^a(r^a)}{t_d^*(r^a, r_0^a) + \tau_d^{ex}(r^a, r_0^a) + t^{ex}(r^a)}$$

$$q(r^a, r_0^a) = t_d^*(r^a, r_0^a) v \quad (28)$$

where: v is drilling speed; p is the unit price of the extracted coal; c_q^a stands for average marginal costs of the extracted coal; c_s^a is average cost of stopping the works and evacuation of personnel; $c_{wy}^a(r^a)$ denotes accident elimination costs.

3. Conclusion

As a result of the conducted researches the analytical expressions allowing to give a numerical assessment to technical and economic characteristics of the enterprise working in especially dangerous conditions are found. It is advisable at further continuation of works by realization of observations, measurements and an interview to obtain a necessary set of numerical data for exercise of model operation of work of the enterprise in actual practice.

Thus, the analytical expressions allowing to give a numerical assessment of possible damage from contingency situations in connection with natural and anthropogenic sources of accident rate are found and at continuation of works it is necessary to obtain by realization of observations, measurements and an interview a necessary set of numerical data for exercise of model operation of work of the enterprise in actual practice with determination of probable damage from contingency situations.

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