RELIABILITY OF MAIN FAN COAL MINING PLANTS

by

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In this paper, a mathematical model for determining the reliability of ventilation plants was given and said ventilation plant was checked using a specific example for two types of fans operating in different modes due to the difference in the age of the fans. Within the framework of the paper, the principles of arrangement of ventilation systems of mines are stated, after which the mathematical model for determining the probability of reliability of ventilation systems is presented. For checking and proving the given mathematical model, coal mines in Serbia have been selected. The experimental part presents the basic characteristics of the main fan plants of active underground coal mines in Serbia, and based on the given mathematical model and collected data on downtime in the operation of the main fan plants at coal mines, the reliability of their operation is calculated. The paper confirms that the proposed method of determining the mathematical probability of reliability of ventilation systems can be used as an initial indicator of ventilation systems, where regular plant maintenance and application of this mathematical model could predict and prevent the operation of ventilation systems, and thus extend their lifespan. By processing the data on the operation of ventilation plants, the appropriate empirical dependence of the reliability parameters was obtained with the corresponding dependence, which enables application in practice.

Key words: *coal, mine, pit, fan, ventilation, reliability, ventilation systems, stoppage*

Introduction

Within the scope of the technological process of underground coal exploitation, a significant phase that enables the execution of works is the ventilation which is significant in a technological as well as safety aspect and also has an impact on the economics of mine exploitation. The pit ventilation aims to ensure normal work conditions by supplying a sufficient amount of fresh air for breathing, forming normal microclimatic conditions for removing unpleasant physiological effects on the employees, removing gases that are released from the deposits or are a product of the technological process as well as removing dust from the air in the pit [1].

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The worsening of work conditions in the mines with underground exploitations of mineral sources due to their increasing depth enforced the need of providing more attention to the design and reliability of fan coal mining plants. Reliability means the property of the system to work without stopping under certain conditions and in certain periods. The sum of the probability of a correct operation and the probability of a stop occurrence equals one.

The accidents where the atmosphere in the mine is endangered may occur due to poor organization of mine ventilation, fan operation breaks, the inability to turn the air-flow, and damage to fan plants due to fire or explosions.

Within the scope of works, the principles of fan coal mining plants set-up are listed after which a mathematical model for determining the probability of fan plants' reliability is also shown. Coal mines in Serbia are selected for the verification and proving of the given mathematical model.

In the analysis, a working period of 20 years was observed for the NAVV-D fan and 10 years for the AVJ-1500 fan. By inspecting the ventilation logs of the coal mines in Serbia where these two fans are in use, and in which the failures of the ventilation plants were recorded, data on delays were taken and their processing was carried out.

After the processing and analysis of the data on delays and malfunctions of ventilation plants for the mentioned types of fans, a mathematical model was created based on which the corresponding mathematical form was attached.

The principles of fan coal mining plants set-up

The fan plant of a coal mine pit consists of the following:

- Main and spare fan with a diffuser and devices for regulation and change of air-flow direction. If the pit has no system of air-flow regulation through the pit premises, the fan plant must have a device for changing the direction of the air-flow. Constructing a device for changing the direction of air-flow enables that through its activation at least 50% of air can be supplied for the normal ventilation of the pit. The device should enable the change of direction within 10 minutes. The assessment of change in the air-flow direction should be done at least twice a year. The ventilation door for the separation of opposite air-flow directions in the pit must have a locking device in order not to open or a counter door with a counter direction opening system is installed between them. If an explosion of methane is expected to occur on their other side the door should be able to withhold the pressure of 1013 kPa.
- Fan-to-pit connection (ventilation duct) with a connection device and power supply. The fan plant connection (ventilation duct) is realized as per the principle of optimal aerodynamics and its length, as a rule, is 10 D_o, where D_o is the circumference of the fan operation circuit). If this condition is not met an air-flow router device is applied. The construction of the duct should be in such a way that potential explosions in the pit cannot damage the fan plant.

Every fan plant must have at least two independent engine-driven power supplies. Independent engine-driven power supply can be a generator or engine-width internal combustion. The correctness of the independent engine-driven power supply is monitored at least once a week.

Fan construction and the manner of its connection is done in such a way that noise level outside over a 30-meter perimeter does not exceed 80 dB(A). If this limit is exceeded a muffler is installed [2].

The fan plant must have a device for continuous depression registering and the methane pit with the CH_4 content in the outlet air-flow up to 0.5% and must also have a device for automatic registering of the concentration of this gas in the total pit air-flow. These devices can be single or a part of a system of remote control. The device for registering the total output air-flow of the pit is mandatory only for a pit where its premises were categorized as level II methane danger.

Even though the regulations on technical norms for metallic source mines do not separately norm fan plant devices, these must be normed in a similar manner but do not need a double ventilation system, the energy source for the start-up, and devices for turning the direction of air-flow. It is initially composed of a ventilation duct, a fan with an electrical or diesel engine, and a diffuser with a muffler. The construction of a fan metal mining plant it's simpler thus in some cases it is placed below the earth within the profile of the main outlet facility [3].

The surface fan plant is protected from weather conditions by constructing a building of a non-combusting material. It is mostly constructed from steel construction with a fillet of plates of light concrete and the roofing structure of selenite or concrete. Within the construction, a room for a guard has been arranged as well as a space for the storage of electrical equipment.

The reliability of fan coal mining plant systems is mostly dependent on the reliability of the fan plant the reforge their reliability must be at a high level. It is on a lower level than fan plants where the fan plant consists of one fan.

In mines, with methane and flammable or explosive coal dust, the fan plant must have a high-reliability probability. It is achieved through the installation of quality devices, doubling and reserving them in *hot or cold* reserves.

Doubling fans, electrical engines, and sources (supplies) of energy in fan coal mining plants ensures higher reliability of work of the plant and ventilation of the mine. Therefore, it is needed to design or define the reliability of the work of fan coal mining plans and reserve in cold or hot reserves those components that often break and affect the reliability of the whole system [4].

Mathematical model for determining the operation reliability of fan plants

Fan coal mining plant consists of several different components and subsystems where the failure of any component or subsystem leads to the failure of operation of the whole system since they are connected in a line. The pit fan plant consists of the following subsystems, fig. 1: Fan duct subsystem with a door system – 1, Fan subsystem with an electric engine powering and diffuser – 2, Energy supply and fan commissioning subsystem – 3, Environment air let out subsystem with a muffler and the subsystem for turning the air-flow direction –4, fig. 1(b) [5].

The probability of reliability of the subsystem operation in a determined time interval τ (year, day, or hour) is determined based on the statistical record of failures. The frequency of failures of subsystems is determined through the following formula:

$$\lambda = \frac{n}{\tau} \tag{1}$$

where λ is the frequency, n – the number of failures of the subsystem in time τ, and τ – the period of surveillance of the effective subsystem operation.

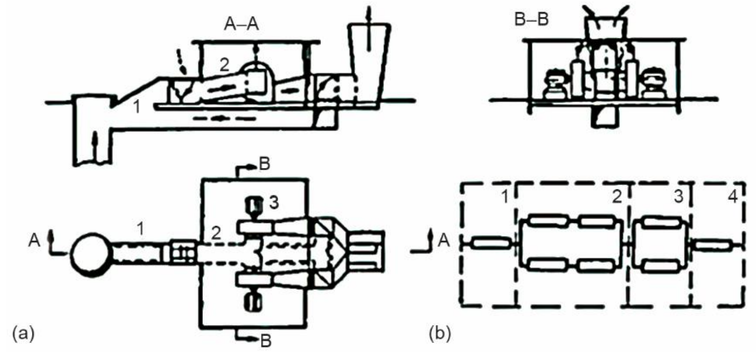

Figure 1. (a) Fan plant principled scheme and (b) subsystem connection scheme (positions 1-4 show the location of the subsystem) [5]

If the frequency of failures of the subsystems is continuous then the medial time of the component operation without failures could be determined:

$$\tau_k = \frac{1}{\lambda} \tag{2}$$

When a failure occurs on a component of the subsystem the stopping of operation of the whole system occurs thus it is needed to perform the urgent replacement of the component. The medial time of component replacement in the system in the observed period is:

$$\tau_r = \sum \frac{\tau_r}{n} \tag{3}$$

where τ_r is the medial type of component replacement in this subsystem.

The coefficient of availability or correctness of the subsystem is derived through the following relation:

$$K_r = \frac{\tau_k}{\tau_k + \tau_r} \tag{4}$$

This coefficient is the coefficient of sensibility of the system to subsystem failures. The probability of subsystem operation without failures in $\Delta\tau$' time that we are interested in is determined through the following equation:

$$p_{(\Delta\tau)} = \exp[-\lambda(\Delta\tau)] \text{ or } p_{(\Delta\tau)} = \exp-\frac{\Delta\tau}{\tau_k} \tag{5}$$

where τ_k is the medial time of component operation without failure. When its probability of reliability is known it is derived from the following relation:

$$\tau_k = \int_o^\infty p_{(\Delta t)} \mathrm{d}\tau \tag{6}$$

Fan coal mining plants should have high reliability. The mathematical model for the determination of the reliability of the systems or subsystems which are connected in a line so that they may function is defined by the multiplication theorem of independent probabilities of component reliability, thus the reliability of complex system operations is less than the reliability of components connected in a line [6]:

$$P_s = \prod p_i /xi/ P_s = p_1 \cdot p_2 \cdots p_n \tag{7}$$

where p_i is the probability of reliability of single components or subsystems of fan plants x_i.

The probability of failure or unreliability of a subsystem contrasts with the probability of reliability:

$$Q_s = 1P_s \text{ or } Q_s = \sum q_{i(xi)} - \prod q_{i(xi)} \tag{8}$$

where q_i is the unreliability of the element x_i or subsystem in the system.

For highly reliable systems composed of a large number of the same type x_i components in a line, the member $\prod q_{i(xi)}$ is a small scale that may be ignored, thus $Q_s = \sum q_{i(xi)}$ is the probability of system unreliability. (3)

For ensuring the certainty of operation in the coal mines standardised fan plants that consist of two parallel (hot reserve) connected complete fans on the same ventilation duct should be constructed. If the probability of reliability of the engine-fan set is known, in x_i components that are connected in parallel the probability of unreliability is determined through the following equation [7]:

$$Q_{s(xi)} = q_{xi}^{1=k_i} \tag{9}$$

where k_i is the number of in parallel reserved sets $x_i = k_i$ in hot reserves, thus when failure of one occurs, the other may immediately without interruption continue to work with no breaks in the ventilation.

The coefficient of sensitivity of a system where the subsystems are doubled $k_i = 1$ is closer to one $T_r \approx 1$ since the time of subsystem commissioning (fixing) is ugly the probability of reliability of a system or subsystem where the components are reserved in parallel, is one being in operation and the k_i in hot reserve is:

$$P_{s(xi)} = 1 - Q_{s(xi)} = 1 - q_{(x_i)}^{1+k_i} = 1 - \left\lfloor 1 - P_{s(xi)}^{1+k_i} \right\rfloor \tag{10}$$

The mathematical model for determining the total complex probability of reliability of a fan plant is derived based on the relation between the subsystem and the configuration of components in subsystems of a complex system, taking into account the coefficient of system sensitivity to failures in the subsystem, where its value is $\beta = 0$ when the system is not sensitive to subsystem failures, and $\beta = 1$, when the system is sensitive to subsystem failures and system operation interruptions occur. Fan coal mining plant consists of four subsystems, fig. 2. The coefficient of system sensitivity to all subsystems is close to or equal to one. The mathematical model for determining the total complex probability of the whole system is derived through the following equation:

$$P = p_{1(x_1)} p_{2(x_2)} p_{3(x_3)} p_{4(x_4)} \tag{11}$$

where p_1 is the probability of fan duct reliability, p_2 – the probability of reliability of fans with electrical engines, $p_2 = 1 - (1 - p_v)^{1+1}$, p_3 – the probability of energy supply subsystem reliability (doubled transmission, separate IC engines or generators), $p_3 = 1-(1-p_e)^{1+k_e}$, $k_e = 1$, and p_4 – the probability of reliability the air ejection subsystem and the rotation of the air stream:

$$P = p_1[1-(1-P_v)^2][1-(1-P_e)^2]p_4 \tag{12}$$

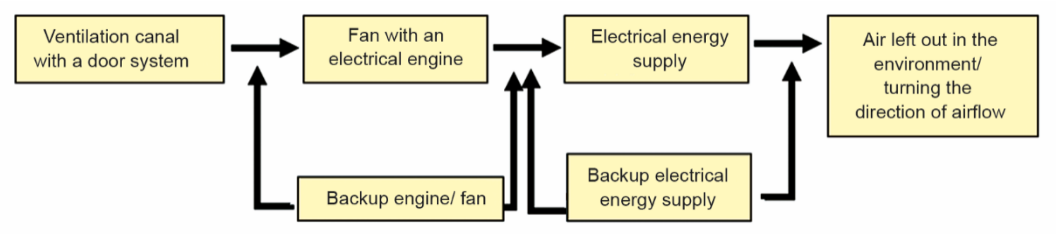

Figure 2. Graphic depiction of fan plant subsystems

If the $\beta \neq 1$ system sensibility to failure is added to the mathematical model for determining the probability of system reliability, it is needed to multiply the probability of subsystem reliability with the appropriate sensibility β_i. For achieving the optimal probability of system reliability it is possible to conduct the optimisation of hot reserved components in the subsystems or elements in the cold reserve [8].

Defining the conditions under which the research was conducted

In order to obtain relevant research data, mines operating in similar conditions were selected for analysis. In order for this to be fulfilled, several conditions must be met, namely [9, 10]:

– same or nearly the same technology conditions of operation,
– the same equipment and same digging and underground premises building technologies are used in the mines,
– the same work organization is applied in the mines,
– no production stops occurred in the mines, and
– the same type of fan plants.

Bear in mind that underground coal mines in Serbia fulfill four of the mentioned five conditions. The condition that the mines do not meet refers to the type of ventilation plant, therefore tab. 1 lists the types of installed fans in the active pits of coal mines in Serbia.

Based on the data in tab. 1, it is evident that in coal mines in Serbia fans manufactured by Klima, Celje are mainly used, and those have been in use for several decades, so for the reliability analysis, the fan type N-AVV-D, of the mentioned manufacturer, was taken into consideration. The analysis was performed for four mines-pits: Rembas – Strmosten pit – 1, Bogovina – Istočno polje pit – 2, Jasenovac – 3, and Štavalj – 4.

Also, as part of the analysis, data were collected for the new type of fan AVJ-1500, for three mines-pits: Rembas – pit Ravna Reka (A), Lubnica (B), and Štavalj (C).

Ventilation in the analysed pits is done artificially, it is depressed *via* a fan installed at the outlet of the ventilation duct. The air distribution system in the pits is generally diagonal with one inlet and one outlet air-flow. Fresh air-flow enters the pit through the main transport premises while the used air-flow goes through the main ventilation premises. In the pits, separate ventilation is done via appropriate fans and pipelines.

Table 1. Installed main fan types for active pit ventilation

Mine – pit	Fan use	Fan type	Fan manufacturer
Vrška Čuka – Avramica pit	Main	Reconstructed	Ventilator – Zagreb
	Spare	Reconstructed	Ventilator – Zagreb
Ibar mines – Jarando pit	Main	AVV-1000/4	Klima – Celje
	Spare	A-1250	Klima – Celje
Rembas – Senjski Rudnik pit	Main	AVV-12-154-2	Klima – Celje
	Spare	AVV-12-154-4	Klima – Celje
Rembas – Strmosten pit	Main	AVV-12-154-4	Klima – Celje
	Spare	N-AVV-D-125-1	Klima – Celje
Rembas – Ravna Reka pit	Main	AJV-1500	Delta – Air-Bg
	Spare	AVV-12-125-1	Klima – Celje
Bogovina – Istočno polje pit	Main	N-AVV-D-125-1	Klima – Celje
	Spare	N-AVV-D-125-1	Klima – Celje
Soko – Soko pit	Main	GVR-15-160	Turmag
	Spare	EN-125	Termoelektro
Jasenovac –Centralno Polje pit	Main	N-AVV-D-125-1	Klima – Celje
	Spare	N-AVV-D-125-1	Klima – Celje
Lubnica – Osojno pit	Main	AVJ-1500	Delta – Air-Bg
	Spare	SC-160	Minu – Beograd
Štavalj – Štavalj pit	Main	AVJ-1500	Delta – Air-Bg
	Spare	N-AVV-D-140/56	Klima – Celje

Within the fan plants, main and spare fans with appropriate characteristics are installed as well as accompanying equipment according to mining regulations. Having in mind that the same manufacturer fans are used for many years in the underground mines in Serbia it is possible to compare them from the aspect of operational reliability [11].

Fan plants' drive – electrical energy supply is organised two-sided, and in all plants, diesel generators are installed as a means of a backup power source in case of electrical energy supply failure.

Mine-pit main ventilation fans, and especially those in methane pits and pits where explosive gas and explosive coal dust may occur, are precisely monitored according to regulations, standards, norms, and ordinances [12].

Figure 3 shows the depiction of Štavalj mine's fan plant. The analysed fans (AVJ-1500 type fan, main; N-AVV-D type fan, spare) are installed in the said mine.

For the analysis of the mathematical model of fan plant operation reliability analysed mines are marked with numerals for the better transparency of N-AVV-D fan type data, while for the operational analysis of fan plants with AVJ-1500 type fans analysed mines are marked with letters in the tables.

Figure 3. Depiction of Štavalj mine main (AVJ-1500) and spare (N-AVV-D) fans

The N-AVV-D fan that operates in the subject pits is an old fan that operates in an automatic mode and needs time-to-time check-up – monitoring, while the new AVJ-1500 type fan operates in an automatic mode and the complete fan operation is monitored from the control centre.

Depiction of main fan plants reliability results and analysis

To ensure the reliability of the ventilation system, it is necessary to constantly control and regulate the air coming into the mine. The control of mine ventilation is regulated by a certain Ordinance.

The Ordinance stipulates that each pit must have a *ventilation logbook*, in which data related to pit ventilation are entered.

Through insight into the operation documents kept at the mine, for the N-AVV-D fan type data on the number of downtimes for each subsystem, for a period of 20 years, while the fans were in the function of the main fan was collected, meanwhile, in some mines, there were replacements, where these fans were placed in the function of a spare fan.

The collected data on the number of downtimes are systematized for each subsystem and are shown in tab. 2.

In the tables, the subsystems are shown in the following layout: I – Subsystem ventilation duct with a door system, II – Subsystem fans with electric drive and diffuser, III – Subsystem for power supply and fan start-up, IV – Subsystem for air let-out with muffler and turning the direction of the air-flow.

Table 2. The N-AVV-D type fan number of downtimes by mines

Subsystems	Mines			
	1	2	3	4
I	1	1	1	2
II	1	1	2	3
III	2	1	2	1
IV	1	1	1	1
Total	5	4	6	7

Through insight into the operation documents kept at the mine, for the AVJ-1500 fan type, data on the number of downtimes for each subsystem, for a period of 10 years was collected. The collected data on the number of downtimes are systematized for each subsystem and are shown in tab. 3.

Using the mathematical functions, forms (1), (2), (5), and (12), of the given model for determining the reliability of the fan plant and its indicators and the EXCEL programme, based on the obtained data, a basic reliability analysis was obtained.

Table 3. The AVJ-1500 type fan number of downtimes by mines

Subsystems	Mines		
	A	B	C
I	1	1	1
II	0	0	0
III	0	0	0
IV	0	0	0
Total	1	1	1

The analysis determined the frequency of downtime, the average operating time of the subsystem without failure, the reliability of the subsystem, as well as the reliability of the entire system, *i.e.* fan plant. By analysing the reliability of fan plants, the obtained results are depicted in static (tables) and graphical form.

Tables 4-9 show the results of the calculation of reliability parameters for each analysed mine. Table 10 gives a summary overview of the reliability by subsystems for each analysed mine.

Table 4. The Bogovina (1) pit fan plant subsystem reliability

Subsystems	I	II	III	IV
Frequency, λ	0.05	0.05	0.10	0.05
Middle operation time of components without failure, τ_k (year)	20	20	10	20
Reliability, p	0.9512	0.9976	0.9909	0.9512

Table 5. The Jasenovac (2) pit fan plant subsystem reliability

Subsystems	I	II	III	V
Frequency, λ	0.05	0.05	0.05	0.05
Middle operation time of components without failure, τ_k (year)	20	20	20	20
Reliability, p	0.9512	0.9976	0.9976	0.9512

Table 6. The Rembas – Strmosten (3) pit fan plant subsystem reliability

Subsystems	I	II	III	IV
Frequency, λ	0.05	0.10	0.10	0.05
Middle operation time of components without failure, τ_k (year)	20	10	10	20
Reliability, p	0.9512	0.9909	0.9909	0.9512

Table 7. The Štavalj (4) pit fan plant subsystem reliability

Subsystems	I	II	III	IV
Frequency, λ	0.10	0.15	0.05	0.05
Middle operation time of components without failure, τ_k (year)	10	6,67	20	20
Reliability, p	0.9048	0.9806	0.9976	0.9512

Table 8. The fan plant system reliability by pits

Subsystems	Mines			
	1	2	3	4
I	0.9512	0.9512	0.9512	0.9048
II	0.9976	0.9976	0.9909	0.9806
III	0.9909	0.9976	0.9909	0.9976
IV	0.9512	0.9512	0.9512	0.9512
Total	**0.8945**	**0.9005**	**0.8885**	**0.8420**

Table 9. The frequency of fan plant failures by pits

Subsystems	Mines			
	1	2	3	4
I	0.0500	0.0500	0.0500	0.1000
II	0.0500	0.0500	0.1000	0.1500
III	0.1000	0.0500	0.1000	0.0500
IV	0.0500	0.0500	0.0500	0.0500
Total	**0.2500**	**0.2000**	**0.3000**	**0.3500**

Table 10. The summary overview of frequencies and reliability by mines

Mines	Frequency, λ	Reliability, p
1	0.25	0.8945
2	0.20	0.9005
3	0.30	0.8885
4	0.35	0.8420

As the time interval of the observation of the fan plant is constant (20 years), the reliability of the subsystem and the reliability of the system are also constant, thus this system is called a time-independent system.

Given that the subsystems in the fan plant have a regular configuration, therefore the reliability of the entire system is less than the reliability of each separate subsystem. Diagram 1 shows the dependence of the reliability of the entire fan plant system on the reliability of the subsystem.

As can be seen from tabs. 4-10, Subsystems II and III are very reliable. This is primarily because these two subsystems work in the *hot reserve* mode, more precisely they have their reserves. If one of these two subsystems fails, its reserve is activated as soon as possible, which practically leads to the fact that due to a failure in these subsystems there is no downtime. Also, from the tables, it can be seen that Subsystems I and IV have the lowest reliability and for that reason, we must work on increasing their reliability with regular servicing, maintenance and control [13].

The dependence of reliability and failure frequency for the NAVV-D fan, tab. 10, is shown in graphic form, figs. 4 and 5, based on which the empirical model (13) was derived.

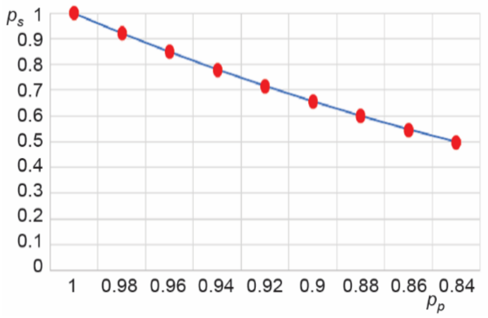

Figure 4. Dependence of the reliability of the entire system, p_s, on the reliability of the subsystem, p_p

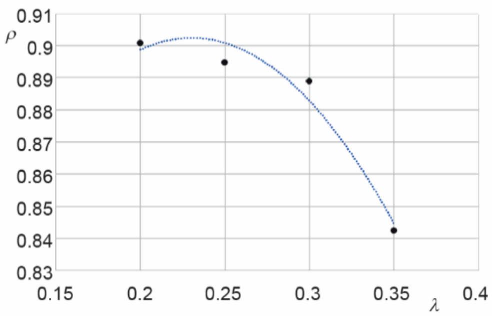

Figure 5. Dependence of reliability, *p*, on the frequency, λ, of fan plant failures

$$p = -4.04\lambda^2 + 1.8604\lambda + 0.6883 \; (R^2 = 0.9612) \tag{13}$$

From the diagram given in fig. 5, it can be seen that with the increase in the frequency of failures, the reliability of the fan plant also decreases, which gives the following relation $\lambda = 0 \rightarrow p = 1$, *i.e.* when $\lambda > 0 \rightarrow p < 1$.

The analytical dependence of the analysed parameters expressed by form (13) gives a very high degree of correlation (R^2 = 0.9612) so that the obtained form can be used with great reliability for practical purposes in non-automated fan plants.

The analysis of the reliability of non-automated fan plants showed that Subsystems I and IV have a great influence on the reliability of the whole system, having in mind that in some mines fans were replaced and automation was introduced, and the reliability analysis of automated fan plants was performed.

Table 3 shows a summary of downtime for the three analysed mines (automated fan plants) for a period of 10 years. The analysed mines in the function of the main fan have an AVJ-1500 fan type. Data analysis, tab. 3, was performed according to the same methodology as for the N-AVV-D type fan. The results of reliability and frequency of downtime of fan plants by pits are shown in tabs. 11 and 12.

Table 11. Reliability of fan plant systems by pits

Subsystems	Mines		
	A	B	C
I	0.9048	0.9048	0.9048
II	1.0000	1.0000	1.0000
III	1.0000	1.0000	1.0000
IV	1.0000	1.0000	1.0000
Total	**0.9048**	**0.9048**	**0.9048**

Table 12. Downtime frequency of fan plant systems by pits

Subsystems	Mines		
	A	B	C
I	0.1	0.1	0.1
II	0	0	0
III	0	0	0
IV	0	0	0
Total	**0.10**	**0.10**	**0.10**

Looking at tabs. 11 and 12, the newer fan operating in the automatic control mode in the observed period had significantly fewer failures compared to the old fans in the same time frame. This is primarily due to the newer construction of the fan and automatic control where all fan parameters can be monitored and read instantly. Therefore, as can be seen from the table, the reliability of Subsystems II, III and IV is equal to one, and these subsystems can be considered highly reliable. However, as can be seen from tab. 11, the ventilation duct subsystem with door system (I) has the lowest reliability, due to unit failures that occurred in this subsystem, thus the choice of a new fan should be done for the subsystem that needs to be addressed with the greatest attention so to increase the reliability of the entire ventilation system. This means that the ventilation ducts must be regularly maintained and monitored [14].

Conclusions

Many authors dealth with the research of the reliability system of the main ventilation plants, but within this paper, a completely new mathematical model and a new approach to determining the reliability of ventilation plants were developed. As part of the paper, the attached model was checked using the example of two types of fans, the old one that has been in operation for over 30 years and the new one that has been in operation for about 10 years.

By applying the proposed mathematical model, the influencing factors on the reliability of fan plants were observed and proven, which was also confirmed in practice. It was ascertained that the reliability of fan plants is most affected by Subsystem I, as well as Subsystem IV.

Bearing in mind that the data were taken from the relevant volumes that are kept at the mines for a period of 20 and 10 years, based on the obtained data, a graphical and empirical dependence was derived, shown by the form number (13), which shows a high degree of correlation ($R^2 = 0.9612$), which clearly indicates that the attached form can be used in future engineering practice as well, for fans of old construction and those that do not work in the automation system.

Based on the research carried out, it can be clearly stated and concluded that the proposed mathematical model is acceptable and that it makes a certain scientific contribution to the research of the treated topic, where with its application, the reliability of the ventilation system can be determined more quickly compared to some other methods developed by researchers who worked in this field.

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