Reliability assessment of tunneling flow charts

N A Antropova¹, V G Krets², V G Luk'yanov³ and A V Baranova⁴
Tomsk Polytechnic University, Tomsk, Russia

⁴baranskikh@yandex.ru

Abstract. When driving horizontal workings of different kinds it is typical to reserve excessive redundant equipment. However, the lack of resources (facilities, people) and poor management don’t ensure goal achievement [3]. The paper presents reliability assessment method of tunneling with the help of mathematical modeling. The mathematical model is developed on the basis of factual data of tunneling conditions and no-failure operation probabilities of the flow chart elements are estimated. The method of reliability assessment allows identifying organizational, technological and technical elements of the reserves to increases drive efficiency and improve feasibility characteristics.

1. Introduction
Tunneling is used while laying pipes and communication lines, prospecting works and etc. The reliability of tunneling flow chart is ensured by specification documents, experience of advanced crews and enterprise’s traditions. Thereby, the use of excessive redundant equipment and high amount of general labor often occurs. If there are insufficient resources (facilities, staff, number of faces and etc.) and poor management, the aim can hardly be reached.

The increase in exploration efficiency being one of the main challenges nowadays, tunneling flow chart reliability assessment becomes a relevant issue. It is also necessary to evaluate to what extend the flow chart reliability impacts the final results of tunneling.

Factual statistic data of tunneling show that there is great loss of working hours caused by several factors: shortage of equipment in productive workings (such as trolleys, perforators and electric locomotives), non-productive works to be fulfilled (equipment repair, derailed trolleys and electric locomotives replacement) and technical-organizational reasons (the absence of electric power or/and compressed air, high gas content). Thus, redundant equipment can’t guarantee continuous production process due to high breakdown rate of the machines. Therefore the method of reservation which is widely applied to increase reliability can’t be regarded as crucial.

2. Methodology
Mathematical modeling is one of the methods to represent reliability of tunneling flowcharts, estimate and improve failure-free operation. It is acceptable to describe reliability of any type of mine workings.

Let’s represent tunneling technology as a complex system of j-elements (j= 1, 2, k,…, n). The elements can be substituted by the machines to drill blast-holes, underground loaders, electric locomotives, fans, trolleys exchange schemes, number of shifts a day, salary system, mining and geological conditions and etc. The choice of elements is in direct relation to tunneling conditions and aims of exploration so that the results to be obtained will be easy to use.
The elements are united to perform a net-graph $G(\mathcal{E}_j)$, where $\mathcal{E}_j$ is a set of graph arcs [1]. According to the tunneling flowchart all the arcs are connected in such a way that parallel arcs represent independent network operation while successive arcs represent dependent one (figure 1). The most likely system elements are:

![Diagram of reliability graph $G(E_j)$](image)

**Figure 1.** Reliability graph $G(E_j)$, where $E_1$ is electric power; $E_2$ – compressed air; $E_3$ – drilling process; $E_4$ - fixing; $E_5$ – charging and blasting; $E_6$ - ventilation; $E_7$ – electric locomotive operations; $E_8$ – loading and exchange; $E_9$ - empties; $E_{10}$ – auxiliary operations; $E_{11}$ – temporary track laying.

The graph shows 11 arcs representing interconnected elements and technological processes. Each arc is estimated by failure distribution function $P_j(t)$, $j = 1, 2, k, \ldots, n$.

The research [2] proved that the function $P_j(t)$ may be expressed in terms of the exponential distribution of probability density function:

$$P_j(t) = 1 - e^{-\beta t_j}. \quad (1)$$

Function (1) is deduced by statistical manipulation of elements $E_j$ failure frequency during the observed period of time $[0, t]$.

By the exhaustion of arcs from $E_1$ to $E_{11}$ along path $\eta_j$ and basing on the hypothesis about independent random variables, we can express the probability of failure-free flowchart operation as all arcs paths product: $\eta_j$:

$$P_{\eta_j} = P_1 \cdot P_2 \cdots P_{11} = \prod_{j=1}^{11} P_j. \quad (2)$$

For technological system represented in Figure 1 these paths are the following:

$\eta_1 = (\mathcal{E}_1, \mathcal{E}_2, \mathcal{E}_3, \mathcal{E}_4, \mathcal{E}_5, \mathcal{E}_6, \mathcal{E}_7, \mathcal{E}_8, \mathcal{E}_{10})$,

$\eta_{11} = (\mathcal{E}_1, \mathcal{E}_2, \mathcal{E}_3, \mathcal{E}_4, \mathcal{E}_5, \mathcal{E}_6, \mathcal{E}_7, \mathcal{E}_8, \mathcal{E}_9, \mathcal{E}_{11})$.

As a result, we have 8 values of the reliability assessment of tunneling flowchart:

$P_{\eta_1} = 0.535, P_{\eta_2} = 0.528, P_{\eta_3} = 0.518, P_{\eta_4} = 0.512, P_{\eta_5} = 0.51, P_{\eta_6} = 0.54, P_{\eta_7} = 0.54, P_{\eta_8} = 0.521, P_{\eta_9} = 0.529$.

Let’s take $\eta_{\text{min}} = \min(P_{\eta_1}, \ldots, P_{\eta_9})$ as a minimum reliability evaluation among all the paths of tunneling, while path $\eta_{\text{max}} = \max(P_{\eta_1}, \ldots, P_{\eta_9})$ provides possible reserve for technological system reliability increase by value $\Delta P = P_{\eta_{\text{max}}} - P_{\eta_{\text{min}}}$ as long as it is impossible to increase the reliability along path $\eta_{\text{max}}$.

Thus having identified elements $E_j$ with low reliability of failure-free operation (table 1) we take measures to increase their reliability. New evaluation is $P_{\eta_j} > P_{\eta_i}$ and this increase can reach the level of $P_{\eta_{\text{max}}}$ which is to become new reliability assessment of the path.
3. Results and discussions

Statistic data over the period of 7.6 months were collected to test the reliability model. Within this period there were 4788 man-hours at Magianskaya prospecting expedition. The time spent for different operations of technological cycle is the following: rock loading \((E_8)\) – 1180 h.; rock haulage \((E_9)\) – 702 h.; track laying by auxiliary workers \((E_{11})\) – 540 h.; blast-hole drilling \((E_3)\) – 1252 h.; charging and blasting \((E_5)\) – 270 h.; ventilation \((E_6)\) – 250 h.; auxiliary operations \((E_{10})\) – 324 h.

The downtime at Magianskaya prospecting expedition makes about 22% or 1053 h. due to the following reasons: absence of compressed air or electric power – 311 h.; lack of materials – 105 h.; equipment failure – 242 h.; absence of transport – 134 h., bit and crown bit breakage – 37 h., derailed trolleys readjustment – 56 h.; other reasons – 169 h.

The reliability values of the system elements are given in table 1.

| \(E_j\) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|-------|---|---|---|---|---|---|---|---|---|----|----|
| \(P_j\) | 0.94 | 0.94 | 0.99 | 0.98 | 0.85 | 0.92 | 0.95 | 0.97 | 0.98 | 0.85 | 0.84 |

4. Conclusion

Analyzing the table we come to the conclusion that in most cases the downtime is caused by auxiliary operations, trolleys loading and exchange, equipment failure and idle time in working shifts which is caused by technical-organizational reasons. Reliability of these elements is low but there is potential to increase it. Thus the reliability of the system within element \(E_9\) (auxiliary operations) can be significantly improved if a shaft crew is exempted from nonproductive work (charging up the locomotive battery, rails and pipes delivery, perforators repair). The reliability of element \(E_3\) can be improved as well by using enhanced constructions of tracks in the face zone and improved schemes of trolleys exchange (loading elevators, cherry pickers). It is also possible to increase reliability within element \(E_5\) without any significant costs by supplying the face with certain service parts and improving maintenance service. Effective measures in this case are to streamline supply, stock the service parts which are often broken down, improve production standards and ensure continuous power and compressed air supply.

Calculation results demonstrate that it is possible to increase working efficiency by 29% at Magianskaya prospecting expedition only by managing logistic factors on the scientific basis without any additional investments. Thereby, the method of flowcharts reliability assessment let us identify element by element organizational, technological and technical reserves to increase tunneling efficiency and to influence engineering-and-economical performance in the whole.

References

[1] Venttsel' E S 1988 Issledovanie Operatsiy: Zadachi, Pprintsiipy, Mmetodologiya (Moscow: Nauka (Science)) p 208
[2] Gmurman V E 2003 Teoriya Veroyatnostey i Matematicheskaya Statistika (Moscow: Vysshaya shkola (Higher school) p 479
[3] Luk'yianov V G and Krets V G 2014 Gornye Mashiny i Provedenie Gorno-razvedochnykh Vyrabotok (Tomsk: TPU) 342
[4] Roginskii V M 1975 Nadezhnost' tekhnologicheskikh sistem i rezervirovanie oborudovaniya na podzemnykh gorno-razvedochnykh rabotakh Razvedka i Okhrana Nedr 5 34
[5] Burkov P V, Chernyavsky D Yu, Burkova S P and Konan A 2014 Simulation of pipeline in the area of underwater crossing Proc. IOP Conf.: Earth and Environmental Science [Electronic resources] (Bristol: IOP Publishing Ltd.) 21(1) 1-5