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Monitoring of Quarry Drill Rig Costs and Proposals for Their Reduction

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Annotation. This article deals with issues of the quarry drill rigs operation. They are the rigs with top hammer, or down the hole hammer drills, primarily used during the preparation of blasting. The article is focused on the monitoring of costs and economic management. The introductory part of the article provides a description of all costs, and their division to fixed and variable costs. In the next part, figures of particular costs are provided for specific selected locations in the Czech Republic. Also, the article deals with proposals for the monitoring, evaluation, and reduction of the costs. Separately, the fixed costs are covered, with the evaluation of turn points in various conditions. The proposals for the reduction of variable costs are provided separately. In the article conclusion, summary of recommended measures is provided.

Key words: drill rig, costs monitoring, blasting.

1. Introduction

The blasting is the most common way of rock pillar blasting within in the unit mining. Drilling is the integral part of this method of blasting. This work deals with the economic aspect of drilling within blasting. The costs associated with drilling are a significant part of total costs of rock blasting. Depending on yield, they have a proportion of approx. 50% in the rock blasting. The effective monitoring of blasting costs can result in savings within the overall economy of rock blasting. This work aims to find solutions in the area of drilling costs reduction, with respect to the quality of the drilling activities. The safety of consequent blasting activities is increasingly emphasized, and the risk rate is significantly associated with the quality of drilling. The selection of the proper drilling method is important not only for the economic aspect, but precisely for the safety aspect. Good quality monitoring of the drill rig costs can result in the detection of improperly selected drilling method, and thus, in the prevention of excessive flight during blasting.

Objectives of this article:

- Describe all kinds of costs connected with drilling,
- Divide costs from the economic point of view, into fixed and variable costs,
- Propose options of the fixed costs reduction,
- Propose options of the variable costs reduction,

2. Costs of drill rigs in the selected locations in the Czech republic

To obtain a more exact idea about the values of the costs, a complete overview of monitored costs is provided here for two selected locations. It is the Plešovice quarry, where drilling is performed using a top hammer drill rig, and the Mokrá quarry. In the Mokrá quarry, the top hammer drill rigs were



previously used, however, based on the assessment of monitored costs, they switched to the drilling technology using the down the hole hammer drills. [1]

2.1 Plešovice quarry

The major quarry of the Kámen a písek s.r.o. company is located in the cadastral areas of Plešovice and Holubov villages, and it extends to the forested eastern slope of the Klet' massive, not far from the Český Krumlov. Quarry walls are sloped under the angle of 70 degrees, mostly to the south-east. [1]

The deposit mostly consists of fine-grained granulite, which can hardly be drilled and blasted. The rock density is $2,630 \text{ kg. m}^{-3}$, the compressive strength is 156–180 MPa.

For drilling, the INGERSOLL – RAND ECM 660 drill rig is used. It is a machine manufactured in 2001, equipped with the MONTABERT type HC – 120R top hammer, with the output of up to 24 kW. The CUMMINS diesel engine is used as a drive, with the power of 176 kW. Compressed air for the bore flushing is delivered by the compressor with output of $0.15 \text{ m}^3. \text{ s}^{-1}$ at the pressure of 1.1 MPa. [1]

In the Plešovice quarry, approx. 25,000 meters of bore is drilled every year. See Table 1 for specific values of costs per one meter of the bore.

Table 1 Costs of drilling in the Plešovice quarry [1]

INGERSOLL – RAND ECM 660	lifetime in meters, or consumption per meter	Costs for one meter in CZK
Button bit	575	6.80
Drill rods	1,860	8.70
Other tools		2.30
Tools total		17.80
Fuel	0.9	22.80
Service and repairs		23.50
Labour		13.70
Depreciation		0.00
Overhead		8.60
TOTAL		86.40

2.2 Mokrá quarry

The exclusive unit deposit Mokrá at Chyše (deposit no. B 3 020 400) is located 1,500 m west from the Mokrá village, 500 m north-east from the Štoutov villages, and 2,000 m north-east from the Čichalov village, with the municipal office domicile. It is the Kamenolomy ČR s.r.o. company quarry.

The oldest rock detected in the deposit vicinity is the schist. They either form a direct bed of the basalt mass, or a deeper bed, if any tuff is placed above. The basalt mass bordered by the schist on the south and east side. The schist is distributed in the tuff bed (kaolinized), and falls into sand. The kaolinized schist was detected under the quarry base.

The basalt, exposed by the wall quarry, has irregular to massive basaltic jointing. The massive columns have up to 1 m in diameter. The basalt jointed in this manner is fissured according to more or less horizontal fissures to plates, having a thickness from dm to 1 m, being more fissured in plates when closer to the surface. The most of fissures are covered with coats of fox to white-grey colour, composed of ferrous carbonates and minerals. [1]

Currently, drilling is performed in the Mokrá quarry using an down the hole hammer drill rig. A small annular area between the bore wall and drilling rods, plus significantly higher pressure and amount of the flushing air are the reasons for the improvement of the drilling procedure and the bore quality. No load strikes, if any, of the down the hole hammer cause no, or only minimum damages. The down the hole hammer technology costs (Table 2.1) are lower in these conditions, compared to the previous used top hammer technology (Table 2.2). [1]

Currently, the drill rig used in the Mokrá quarry is INGERSOLL – RAND CM 695 D. Manufacture year 1998. The CAT 3306 DITA diesel engine is used as a drive, with the power of 231 kW. Compressed air for the 3.5” hammer drive and for the bore flushing is delivered by the compressor with output of $0.28 \text{ m}^3 \cdot \text{s}^{-1}$ at the pressure of 1.7 MPa. [1]

Table 2 Costs of drilling using the down the hole hammer - Mokrá quarry and costs of drilling using the top hammer- Mokrá quarry

Table 2.1			Table 2.2		
Ingersoll - rand CM 695 D	Lifetime (m), consumption per meter	Costs/meter in CZK	Atlas Copco ROC F9C	Lifetime (m), consumption per meter	Costs/meter in CZK
Tools total		18.10	Button bit	361	11.10
Fuel	1.8	44.50	Drill rods	909	14.50
Service and repairs		24.10	Other tools		4.30
Labour		14.30	Tools total		29.90
Depreciation		0.00	Fuel	1.1	28.00
Overhead		8.60	Service and repairs		30.20
			Labour		16.20
			Depreciation		29.60
			Overhead		8.60
TOTAL		109.60	TOTAL		142.50

2.3 Assumption for the monitored rig (rigs)

In the situation where an individual drill rig is analysed in this article as a production unit, the model described above can simply be applied, and a specific model can be prepared for the drill rig. [1]

In this case, empirically collected values from practise can be used for modelled fixed and variable costs, and consequently, for the unit selling price, the model can be confirmed (or, disproved), and a

practically useful conclusion can be made. As the model input data, values collected from the practical evaluation of the operation of several drill rigs have been used, and assembled to the attached calculation formula - Table 3. [1]

Table 3 Calculation of drilling costs [1]

Operating costs	Type of costs (F/V)	Usual UoM	Coeff.	UoM (base)	Description and assumption
Drill rig depreciation	F	CZK	n.a.	CZK	10% depreciation from the price of 8 mil. CZK, based on a yearly "ageing"
Depreciation	V	CZK/Mth	32 m per 1 Mth	CZK/m	10% depreciation by tear and wear at the annual output of 2000 Mth
Personal costs - basic amount	F	CZK	n.a.	CZK	1 worker time rate 80 CZK/h + 35% levy, 170 hour monthly working time, 12 months = 220 thousand; above the output of 1500 Mth 2 workers = 440 thousand. (i.e., above 48,000 m)
Personal costs - performance based bonus	V	CZK/m	n.a.	CZK/m	6 CZK/m above the time rate, 8 CZK/m in case of two workers
Service costs + lubricants	V	CZK/m	n.a.	CZK/m	17 CZK/m
Fuel	V	CZK/m	n.a.	CZK/m	28 CZK/m
Drilling tools	V	CZK/m	n.a.	CZK/m	16 CZK/m
Transport costs	V	CZK/km	conversion	CZK/m	6.5 CZK/m
Operating costs total		CZK	n.a.	CZK	
Productive overhead					
Drilling foreman and technical background	F	CZK	n.a.	CZK	250 thousand CZK at the operation of 3 machines
Productive overhead total		CZK	n.a.	CZK	
Overhead administrative expenses					
Overhead administrative expenses total	F	CZK	n.a.	CZK	400 thousand CZK at the operation of 3 machines
Revenues					
Revenues total	V	CZK	n.a.	CZK	130 CZK/m

Using the data collected in this way, the authors of this article will attempt to find the operational optimum of the drill rig when operated by a single worker, and by two workers, and based on the calculated data, to assess the suitability of the former or the latter way of the operation upon predefined conditions. [1]

2.4 Determination of the turn point when operated by single worker

When using the input data mentioned above, i.e. the values of particular kinds of costs and prices for 1 m of the bore completed, the drill rig used reaches the turn point, i.e. the minimum yearly performance required for reimbursement of operational costs, at the output of approximately 38,000 m. [1]

Table 4. Input data for the drill rig operated by a single worker

	Type of costs (F/V)	UoM (base)	Base	Output m	Output m	Output m
				37000	38000	39000
Operating costs						
Drill rig depreciation	F	CZK	800000	21.6	21.1	20.5
Depreciation	V	CZK/m	13	12.5	12.5	12.5
Personal costs - basic amount	F	CZK	220000	5.9	5.8	5.6
Personal costs - performance based bonus	V	CZK/m	6	6.0	6.0	6.0
Service costs + lubricants	V	CZK/m	17	17.0	17.0	17.0
Fuel	V	CZK/m	28	28.0	28.0	28.0
Drilling tools	V	CZK/m	16	16.0	16.0	16.0
Transport costs	V	CZK/m	7	6.5	6.5	6.5
Operating costs total		CZK		113.6	112.8	112.2
Productive overhead						
Drilling foreman and technical background	F	CZK	250000	6.8	6.6	6.4
Productive overhead total		CZK		6.8	6.6	6.4
Overhead administrative expenses						
Overhead administrative expenses total	F	CZK	400000	10.8	10.5	10.3
Total costs		CZK		131.1	129.9	128.8
Revenues						
Revenues total	V	CZK	130	130.0	130.0	130.0
Profit/Loss						
Profit/Loss		CZK		-1.1	0.1	1.2

Provided that the production capacity of a single drill rig operated by a one-man crew is approximately 50,000 m per year, any output above the 38,000 m starts to generate a profit to the operator. And if the presumed values of costs and revenues are applicable, the profit upon nearly full production capacity reaches approximately 700 thousand CZK, i.e. 14 CZK/m, which is well apparent from diagrams provided below.

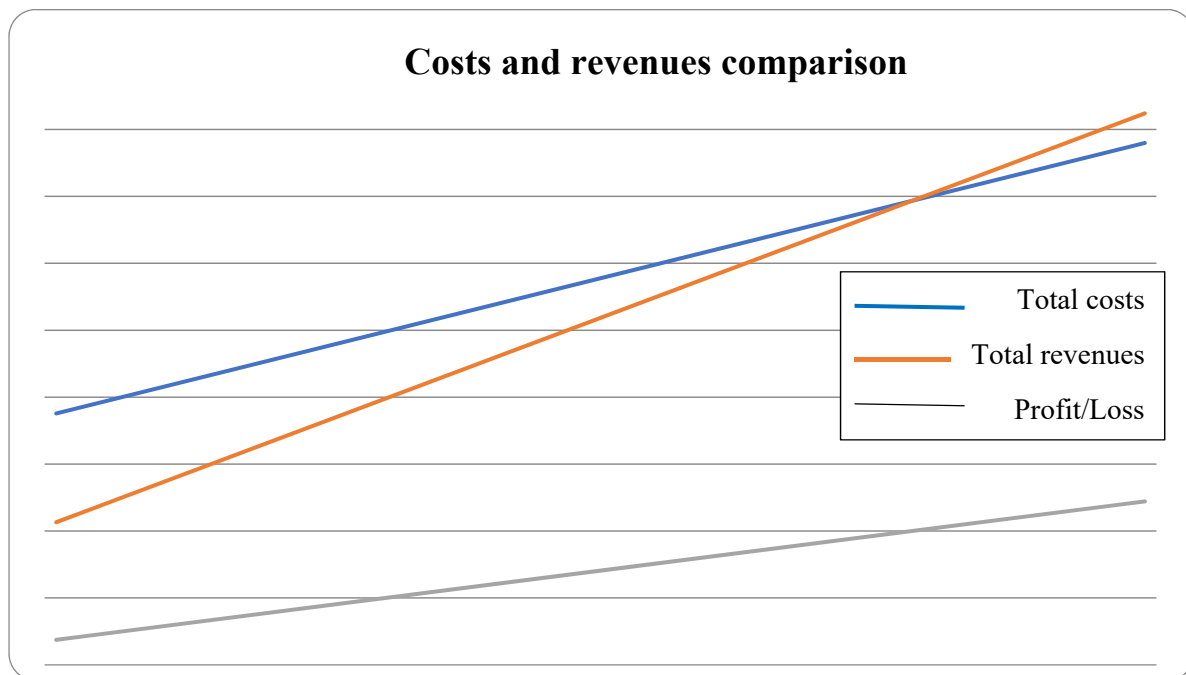


Figure 1. Costs and revenues comparison

In the common scale diagram – Figure 1, the turn point is well apparent at the profit/loss curve intersection point with axis, i.e. at the intersection projection of total costs and total output curves.

Even more clearly, the turn point and the profit development exceeded are shown on the same diagram (Figure 2) in logarithmic scale.

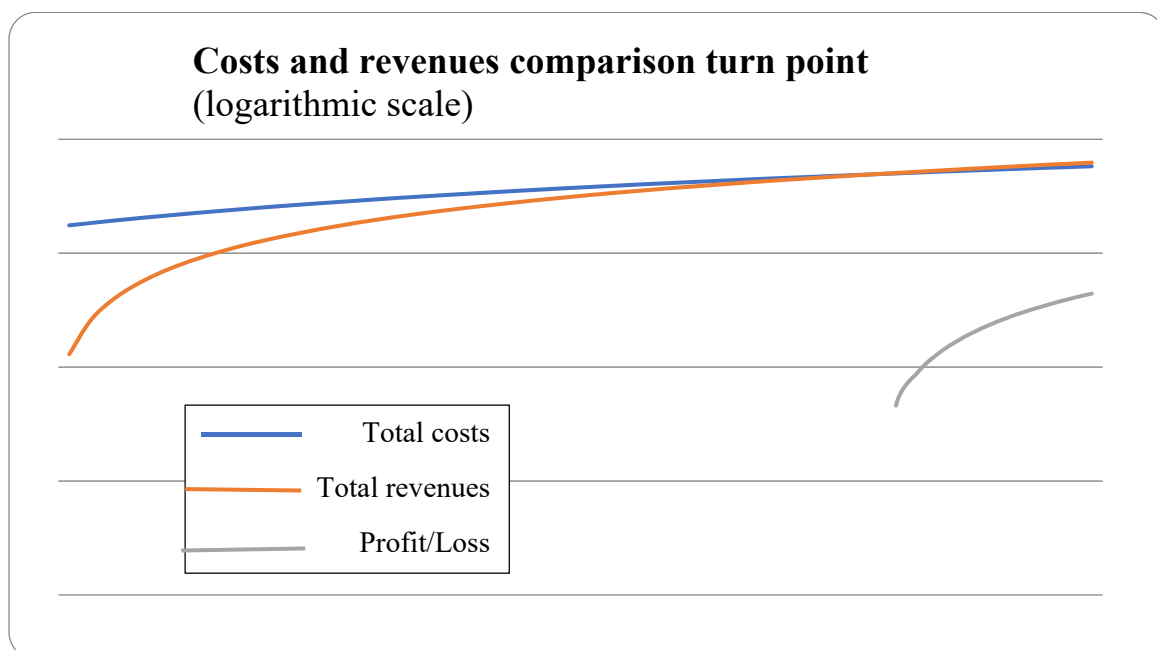


Figure 2. Logarithmic scale diagram – turn point when operated by a single worker [1]

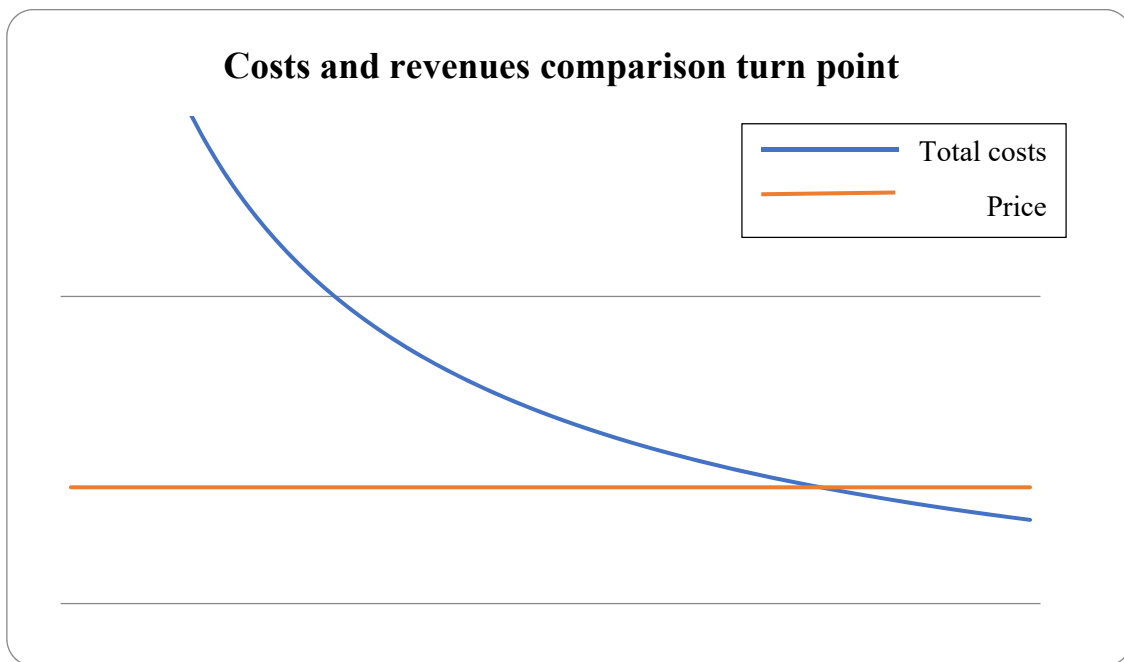


Figure 3. Average costs and revenues comparison turn point diagram – single worker [1]

The turn point in the diagram can also be determined using the comparison of values of average costs and unit price, where it is placed in the intersection of the both curves again – see Figure 14. Since a linear model is used, the value of average costs is decreasing steadily, and thus, any other increase of the production results in a greater difference between the selling price and the average costs, which always means higher profit, because the fixed costs are more and more dissolved into the output units.

2.5 Determination of the turn point when operated by two workers

The same way of the application of the input data described above will be used for the drill rig operated by two workers, too. In this case, the operated drill rig reaches the turn point at the output of approximately 45,000 m. [1]

On the other hand, provided that the production capacity of a single drill rig operated by a one-man crew is approximately 80,000 m per year, any output above the 45,000 m starts to generate a profit to the operator. So, the profit capacity is not 12,000 m as in case of 1 worker, but 35,000 m, [1].

In this case, if the presumed values of costs and revenues are applicable, the profit upon nearly full production capacity reaches approximately 1,400 thousand CZK, i.e. 18 CZK/m, which is again well apparent from diagrams provided below. (Figures 4 and 5) [1].

2.6 Practical usage

Using a simple linear model and predefined conditions (amount of fixed costs, amount of variable costs, unit price), the authors have defined turn points for the drill rig operated by a one-man and two-men crew. Based on the comparison of model data and empirical data, the authors have made a conclusion, that the theoretically stated facts reflect the practise, and the conclusions resulting from the model can be used for making proposals, provided that limitations are respected, given by the elimination of limit production (output) values, [1].

Table 5. Input data for the drill rig operated by two workers [1]

	Type of costs (F/V)	UoM (base)	Base	Output m	Output m	Output m
				44000	45000	46000
Operating costs						
Drill rig depreciation	F	CZK	800000	18	18	17
Depreciation	V	CZK/m	13	13	13	13
Personal costs - basic amount	F	CZK	440000	10	10	10
Personal costs - performance based bonus	V	CZK/m	8	8	8	8
Service costs + lubricants	V	CZK/m	17	17	17	17
Fuel	V	CZK/m	28	28	28	28
Drilling tools	V	CZK/m	16	16	16	16
Transport costs	V	CZK/m	7	7	7	7
Operating costs total		CZK		116	116	115
Productive overhead						
Drilling foreman and technical background	F	CZK	250000	6	6	5
Productive overhead total		CZK		6	6	5
Overhead administrative expenses						
Overhead administrative expenses total	F	CZK	400000	9	9	9
Total costs		CZK		131	130	129
Revenues						
Revenues total	V	CZK	130	130	130	130
Profit/Loss						
Profit/Loss		CZK		-1	0	1

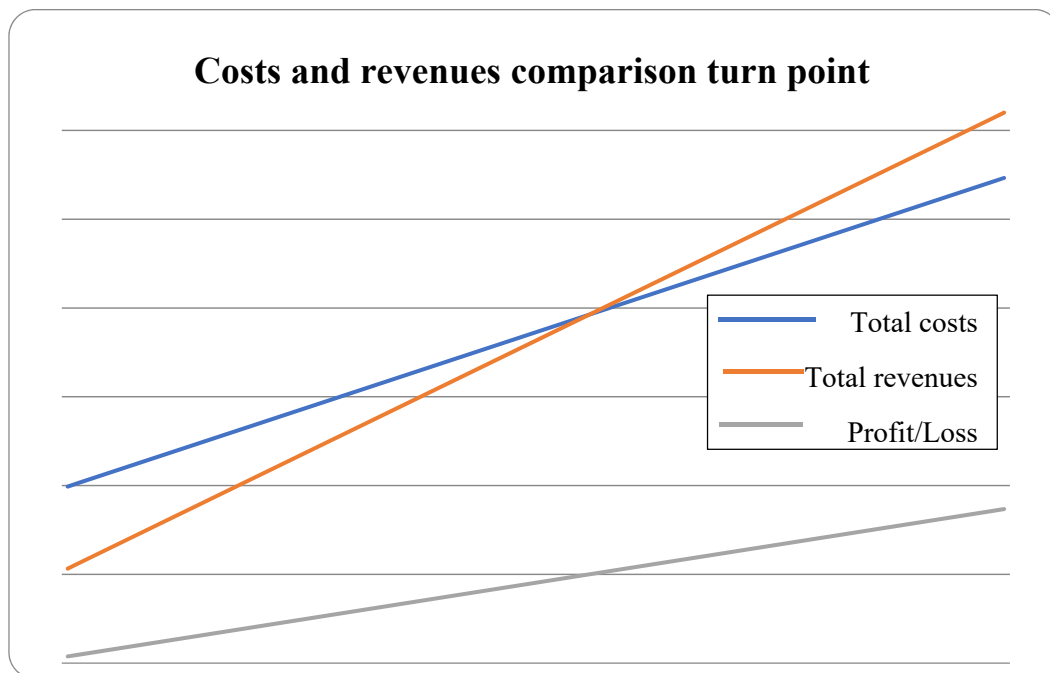


Figure 4. Common scale diagram – turn point when operated by two workers [1]

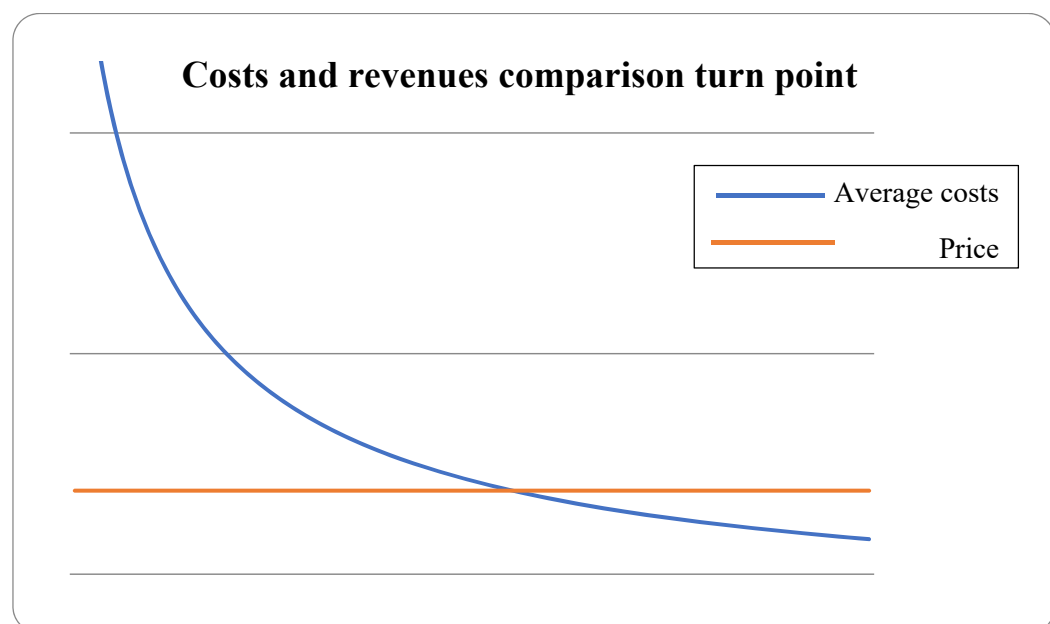


Figure 5. Average costs and revenues comparison turn point diagram – two workers[1]

What are the conclusions of the model applied? They can be split in several groups:

2.6.1 Production volume. The evaluation of processed data has confirmed the assumption of the linear model, resulting from its nature, i.e. the higher the output (drilled meters), the higher the level of dissolved fixed costs, and thus, the higher profit. So, if the drill rig will be operated in a manner respecting the production capacity (both for the one-man, and the two-men crew), the average costs will decrease upon the increasing output, and the production will increase; for that purpose, the actual usage

of the drill rig shall be provided, in values approaching its capacity, i.e. approximately 50,000 with a one-man crew, and 80,000 m with two-men crew [1].

2.6.2 Utilization of the drill rig, number of operators. The utilization of the drill rig, and the number of operators, must be planned with respect to contract-based or anticipated performance. The usage of one operator significantly reduces the turn point, compared to the usage of two operators (38,000 m, instead of 45,000 m), with the average costs of 130 CZK/m for this output, resulting in the difference of approx. 900 thousand CZK, on the other hand, the total profit potential of the machine is significantly reduced to about one half (700 thousand CZK, versus 1400 thousand CZK). Thus, the usage of two operators can be preferred in a situation, the sales is ensured, and the drill rig is operated close to its natural capacity, in particular, in case of newer powerful machines. On the contrary, older and less powerful machines should be operated in a situation, the capacity of approx. 1500 Mth per year is not presumed, which corresponds to 48,000 – 50,000 m of a bore [1].

2.6.3 Turn point and fixed costs. Since the turn point presumed in the considerations above is pre-determined by the amount of fixed costs (general operating costs and administrative expenses), it is the costs item which must be monitored in the company operation, and reduced, if possible. Remember, that its decrease/increase by one half would mean the turn point be shifted by approximately 7,000 m, which is the difference of a yearly usage of the second operator. Basically, the fixed costs can be reduced in two ways:

- i. Reduction of the absolute amount: elimination of useless activities and related costs, increasing the effectiveness of service activities, outsourcing of administrative activities, etc. No other than a general standpoint can be taken in this regard.
- ii. Dilution of fixed costs among other machines: many fixed costs items have absolutely the same level when two, three, or four drill rigs are used. In case of four ones, the overhead fixed costs per one machine will be one half of those per two machines. Each company should define their optimum state (also, based on their experience), and should remember to adjust the fixed (overhead) costs in the relationship with the production volume.

2.6.4 Variable costs. Surely, not only fixed, but also variable costs have impact on the drilling activities profitability. The most of variable costs are unchanging in the stable company situation within a short period of time, in a longer period of time, changes may occur. Some of the variable costs are absolutely non-influenceable by the drill rig operator (such as prices of fuel), another ones may be subject to common cost management by economic and managing persons in the company, another ones may change in the relationship with technological changes, improved procedures etc.. Both the advantage, and the disadvantage of the variable costs include the fact that they are bound to each output unit, and the quantity of operations do not change their unit value, unlike in case of the fixed costs. The following chapter is dedicated to the variable costs specifics.

3. Proposals for the costs reduction – variable costs

The fixed costs and fixed components of rather variable costs are approximately the same for the both drilling methods mentioned above. In case of purely variable costs, there is a non-negligible difference between the outer and the down the hole hammer drilling. In general, the top hammer drilling has lower variable costs. In particular, the consumption of diesel fuel can be up to one half per one drilled meter.

For these reasons, the most of drilling operation in the Czech Republic are performed using the top hammer drill rigs. The down the hole hammers are only used in necessary cases. Such a necessary situation occurs for the following reasons:

- Quarry wall higher than 25 m,
- Strongly disturbed rocks, karst fissures,

- Bore diameter required above 115 mm
- Geological composition of rocks, causing extensive curvature of the bore.

Whenever these adverse circumstances do not occur, the usage of drill rig with hydraulic top hammer is more economic. Average total costs per one meter of the bore completed by the down the hole hammer are approximately 130,- CZK. Using the outer hammer, this value is approximately 110,- CZK.

This work will mainly focus on the reduction of costs of machines using the outer hydraulic hammer drilling technology.

3.1 Fuel consumption reduction

Since the most of drill rigs work at constant engine speed, and thus, with constant fuel consumption per one Mth, this cost item can only be reduced by greater number of drilled meters per the same period of time. Although the hourly consumption of drill rigs differs in the range from 20 to approx. 45 litres per one Mth, the costs of fuel are very similar per one meter of the bore. The consumption differences are directly proportional to hourly output of drilled meters. The unit consumption is about one litre of diesel fuel per one drilled meter. The reduction of the unit consumption, if feasible, can only be provided by the higher hourly drilling rate.

The fuel consumption is mainly affected by the drilling rate and by minimizing times of another operation than the drilling itself. The most of measures proposed in next chapters have, among others, influence on the fuel costs, too.

3.2 Drilling tools – lifetime

Lifetime of drilling tools is an important indicator of the effectiveness of drilling. Based on the consumption of drill rods, suitability of the technology used at the specific location can be assessed. As already stated, the costs of drilling tools are about 13% of total costs. Any incorrect drilling method increases this portion, as well as negative impacts on other costs items appear. Any negative impacts of incorrect thrust result not only in greater wear of drilling tools, but also in slower drilling speed.

3.2.1 Button bit. Correct grinding of button bit provides maximum drilling rate, and maximum utilization of the button bit. Ideal working conditions of button bit are ensured, provided that the function surfaces of the buttons have correct shape and height. In such a case, they provide the highest output.

When a dull button bit is used, the following occurs:

- Shorter lifetime,
- Lower drilling rate,
- Abruption (breaking out) of the button, and devaluation of the whole button bit
- Higher stress and damage of the impact head.

The buttons must be ground in time. They should always be ground when the areas on the buttons have the size from 1/3 to max. 1/2 of the button diameter (see Figure 8). The button is re-ground to the original shape. Correct overlap of buttons from the button bit is shown on Figure 6. Re-grinding is performed using special grinding bodies fixed in an appropriate grinder. Mostly, the grinders pneumatically driven, [1].

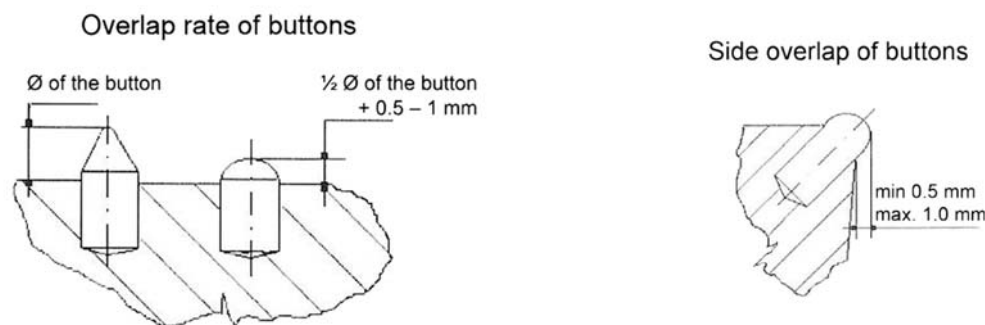


Figure 6 a), b) Parameters of correct overlap of buttons from the button bit

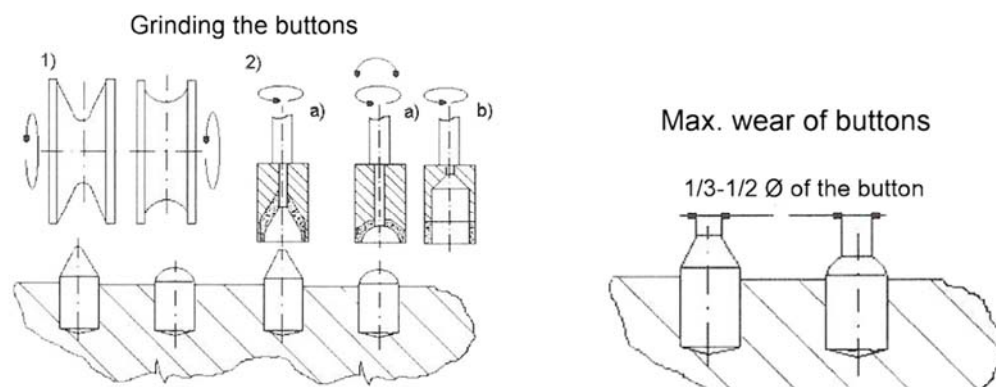


Figure 7 a) b) Maximum allowable wear of buttons

Another, often underestimated, yet the most important property of the drill bit is the ability of effective flushing. If no perfect cleaning of the bore face is provided after each impact to the rock, the drilling rate is reduced, as well as the drill bit lifetime. Any chipped grain of the rock must be removed after each impact not only from below the drill bit face, but also from the space between the adjacent drill bit side and the bore wall. If not provided, the impact energy is smaller at every other hit. Drill cuttings under the drill bit create a damping barrier, reducing the ability of buttons to chip the rock grains. Drill cuttings around the drill bit body causes an excessive resistance against fluent tool rotation, and increases the drill bit body wear by abrasion.

3.2.2 Drill rods. The lifetime of drill rods used with the top hammer is one of indicators reflecting the operator's quality and experience and correct adjustment of the drill rig. For the good lifetime of the rods, as well as for good drilling rate, the bore straightness is the most important. The bore straightness also has a great safety aspect. The most often mentioned reason when criticising the top hammer technology is the problematic bore straightness. Not always this criticism is justified. Very straight bores can be made when drilling with the outer hammer, if a correct thrust adjustment is followed for the specific rock.

Another effective measure for making straight bores is the usage of a leading rod. This rod has a greater diameter, and thus, significantly higher stiffness. Generally, very good straightness of the bore is provided by smaller annular area between the leading rod and the bore wall, plus the high stiffness. In combination with the button bit with recessed face centre (drop centre), very acceptable results are

achieved, absolutely comparable with the bore straightness achieved by the down the hole hammer technology.

The combination of the measures indicated above provides not only satisfactory straightness of bores, but also higher drilling rate by up to 20%, as well as lower costs of the drilling rods. In case of an optimum combination of an experienced operator, correct adjustment of drilling automation, usage of the tools indicated above, and correct grinding of button bit, even doubled lifetime of the drilling rod can be achieved.

3.3 Costs of service and repairs

The costs of service and repairs can only be affected in a limited manner. The service actions and intervals are defined by the manufacturer, and they must be followed, at least during the warranty period. After the warranty period, it is up to the owner's experience, whether or not these actions are performed by an authorized service of the manufacturer, or within the organization itself. Common replacement of oil fills and filters can be performed in a do-it-yourself manner, for significantly lower costs. However, it is definitely not recommended to intervene in the hydraulic hammer, pumps, engine, and overall machine setup without a trained technician.

There is a greater potential for savings within the prevention of defects. Using careful records of past repairs, information can be obtained about timing of necessary checks of the machine components. Example: Timely preventive replacement of bearings in the rotation head gearbox can prevent from its total damage. The replacement of bearings costs approx. 40,000,- CZK, however, a new gearbox costs approx. 500,000,- CZK. The prices of original spare parts for the drill rigs are in hundreds of thousand CZK, and any investment to the preventive repairs can result in significant savings. [1]

4. Technical – Economic Summary

In compliance with this article breakdown structure, the evaluation is also made for the fixed costs, and for the variable costs separately.

4.1 Summary of proposed measures – fixed costs

- Determine the turn point for each operated machine. In this article, only an example is provided, based on average costs values of various machines. Each owner should evaluate the turn point for each specific drill rig.
- Assess the machine utilization based on values for specific turn points, and decide whether the drill rig should be operated by one or two workers.
- Monitor and evaluate effectiveness of the fixed costs spent. Consider their amounts in every item, and if applicable, seek for options of the costs reduction, e.g. by the outsourcing.

4.2 Summary of proposed measures – variable costs

- Evaluate monitored costs, with focus on suitability of the technology used in specific locations. The usage of more expensive technology of the down the hole hammer can result in significant savings in specific geological conditions.
- Fuel. Put emphasis on reaching the maximum hourly performance of the machine, while keeping a good quality of the bore. Motivate the drill rig personnel to start bores carefully so that useless repeated cleaning is prevented, as well as prolongation of time required for making the bore.
- Use the button bit mentioned above, featuring a good ability to clean the bore face with a good quality flushing. Follow the frequency and geometry of correct grinding.
- Monitor the bore straightness. This is important not only for the economy, but also for the safety of consequent blasting. Use leading rods, being a significant benefit preventing from undesired

deviations of bores. Require and check the correct adjustment of thrust and automatic drilling systems.

- Make detailed records of service actions and repairs. Prepare a plan of preventive measures and repairs.

5. Conclusion

In this article, the goals have been achieved, as described in the introduction. In the introductory part, all kinds of costs spent for the drilling activities are described and divided in detail. Also, the article provides a guide for operating the drill rigs, in particular, from the economic point of view. The other goals are met in the second half of the article, providing proposals of measures resulting in the reduction of fixed and variable costs.

By careful monitoring and evaluation of the costs items indicated above, the total costs can be reduced by up to 30%. Based on the costs records, the owner obtains enough information to make correct and effective decisions, e.g. about the usage of specific machines in specific locations, selection of suitable tools, and human resources management. The influence of human factor is crucial, and the monitoring of costs is used for the verification of the personnel, including the drilling foreman.

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