Kuwait J. Sci. **44 (2)** pp. 112-120, 2017

The performance prediction of roadheaders with response surface analysis for underground metal mine

Kemal M. Özfırat[1]*, Tahir Mallı[1], Pınar M. Özfırat[2], Bayram Kahraman[1]

[1]*Dept. of Mining Engineering, Dokuz Eylül University, İzmir, Turkey*

[2]*Dept.of Industrial Engineering, Manisa Celal Bayar University, Manisa, Turkey*

* *Corresponding author : kemal.ozfirat@deu.edu.tr*

Abstract

Roadheaders are being used in development roads in underground mines. Especially, as total reserve is enough for large investments and mine roads, roadheaders are important to increase production rate. Roadheaders are classified according to the weight head drive or total power. In this study, the effects of several factors on roadheader performance is examined. The factors examined are power of the machine, weight of the machine, ratio of power to weight, drilling rate index, uniaxial compressive strength and rock mass rating. Instantaneous cutting ratio is used to define the performance of the machine. Response surface methodology and linear regression are used to investigate the relations between these variables. In the results of the study, machine performance is found to be highly correlated with machine power (P), weight (W) and the P/W ratio of the machine.

Keywords: Machine performance prediction; response surface method (RSM); roadheaders; underground metal mine.

1. Introduction

Today, metal prices are decreasing all over the world, which takes many of the mines into the risk of going bankrupt. Therefore, classical production methods in underground mines should be reorganized with mechanization (Tuncdemir & Bilgin, 2002; Ocak & Bilgin, 2010; Ergin & Acaroglu, 2007; Breitrick, 1998). Mechanized systems are both safer and less costly in operation.

The success of major improvements consists of steadily increased machine weight, size and cutter head power and improved design of boom.The machine weights vary from 9 tons, which could cut soft rock with uniaxial compressive strength (UCS) up to about 40 MPa, to machine weight of 120 tons, which could cut hard rock with UCS up to about 160 MPa.Modern machines have the ability to cut cross-sections over 10 m from a stationary point (Copur *et al.,* 1998, Neil *et al.,* 1994, Tucker, 1985, Thuro & Plinninger, 1998).

Selection of machinery and equipment without physical, mechanical and petrographic properties of rock may cause dramatic problems during working. There are many different criteria to be considered in selection of machinery. These may vary according to surface mining (Stojanovic *et al.,* 2015) or underground mining. In addition, these criteria may vary according to coal mining (Duane, 2014) or metal mining. In underground mines, it is important to find rock properties before starting operations (Fowell & Johnson, 1982; Schneider, 1988; Rostami *et al.,* 1994; Rostami, 2011). Also, geological factors are emphasized by Thuro & Plinninger (1999), Riedmuller & Schubert (2000) in their studies.

In this study, the data set obtained from the hypothetical studies was used to predict the performance of roadheader. Linear regression and response surface methodology (RSM) are used to find the relations between different important variables such as weight (W), power (P), ***kt*** ratio (P/W) and instantaneous cutting ratio (ICR).

2. Significance of roadheader selection and performance

As the number and the length of the preparation galleries increase, mechanical excavators become economical (Tuncdemir & Bilgin 2002, Ocak & Bilgin 2010, Ergin & Acaroglu 2007, Hekimoglu, 1984). In addition, opening preparation galleries by drilling and blasting may increase number of rips, affects work safety and decreases advance speed. It is important to make performance prediction of the excavator in order to determine the cost of excavation and select the right machine.

Field experiments are the first step and are important in order to understand the characteristics of the land (Ahmed & Al-Dousari, 2013). Small scale cutting experiments are formed as a result of many experiments carried out in both laboratory environment and in the field (McFeat-Smith & Fowell 1979). Then, ICR is computed using Equation (1) given below (Rostami *et al.,* 1994). Empirical performance prediction models are mostly based on interpretation of statistics obtained by previous experiences and previous studies. By help of this method, instantaneous excavation speed of drum type, spiral armed type machines and hydraulic hammer can be estimated (Bilgin *et al.,* 1990, Bilgin *et al.,* 1996, Bilgin *et al.*, 1997, Eskikaya *et al.,* 1998, Avunduk *et al.*, 2014). By using this method, it is revealed that performance of excavation machines is dependent on compressive strength and rock quality designation (RQD). ICR can be computed with Equations (1), (2), (3),(4),(5) and defined as rock mass cutting index (RMCI) (Copur *et al.,* 1998, Rostami, 2011, Thuro &Plinninger, 1999, Gehring, 1989). In this study, excavation performance prediction equations,that are used generally,are summarized in Table 1.

Table 1. Equations of performance prediction of roadheaders.

Equation number	Researcher	Mathematical relation state
(1)	Rostami, 2011	ICR =k (P / SE_{opt})
(2)	Bilgin *et al.* 2004	RMCI = UCS× $(RQD/100)^{2/3}$
	Bilgin *et al.* 2004	ICR = 0.28× P ×$(0.974)^{RMCI}$
	Bilgin *et al.* 2004	SE = 0.086 × UCS + 1.24
(3)	Gehring, 1989	ICR = 719 / $(UCS)^{0.78}$
	Gehring, 1989	ICR = 1739 / $(UCS)^{1.13}$
(4)	Thuro &Plinninger, 1998	ICR = 75.7 – 14.3 *ln*(UCS)
(5)	Balci *et al.* 2004	ICR = 0.8× P / (0.37) $UCS^{0.86}$

ICR: Instantaneous cutting ratio (m^3/h), RMCI: Rock mass cutting index, UCS: Uniaxial compressive strength (MPa), RQD: Rock quality designation,SE_{opt} Optimum specific energy kWh/m^3, P: Machine cutting headpower (HP), W: Machine weight (ton), k: Machine coefficient.

The best results are obtained by Bilgin (2004)'s approach (Equation 2) compared to Equations (1),(3),(4),(5). Bilgin's equations depend on RMCI and power of machine. This variable changes with uniaxial compressive strength (UCS) and RQD of rocks. This equation reflects intact rock and rock mass properties. That is why, this equation results are important for ICR.

3. Linear regression and response surface methodology (RSM)

There are many different methods in analyzing the relations between variables (Barakat *et al*., 2014; Al-Awadhi & Aly, 2014). When the relation between variables is not linear or is dependent on more than one variable, then response surface methodology can be used to define the relation. RSM analysis, originally described by Box & Wilson (1951), is capable of the evaluation of the effects of several process variables and their interactions on response variables. Linear regression is used to define a linear relation between a regressor variable, $\boldsymbol{x}$, (independent variable) and a response variable, $\boldsymbol{y}$, with the equation given in Equation (6).

$$y = \beta_0 + \beta_1 x + \epsilon \qquad (6)$$

In Equation (6), $\boldsymbol{\beta_0}$ is called the intercept, $\boldsymbol{\beta_1}$ is called the slope and $\boldsymbol{\epsilon}$ is the error. A fitted regression model can be tested for goodness-of-fit by using analysis of variance (ANOVA) and the F-test. Definition of the ANOVA table can be seen in Table 2. It is used to explain the sources of variation in a linear regression model. The first row in the table gives the sum of squared terms of regression (SS_R). Since the linear regression model used in this study has a single regressor (***x***) the degrees of freedom is 1. Mean of squares of regression terms (MS_R) is found by dividing SS_R to degrees of freedom (Hines & Montgomery, 1990).

The second row in the table gives the sum of squares of error terms (SS_E). The degrees of freedom is (***n***-2) where ***n*** is the number of data points. Similarly, mean of squares of error terms (MS_E) is found by dividing SS_E to degrees of freedom. Finally, the test statistic for the F-test (F_0) is found by taking the ratio of MS_R to MS_E(Hines &Montgomery 1990).

The third row in the table is the sum of first two rows. Sum of squares of all terms (S_{yy}) and total degrees of freedom can be seen in this row (Hines &Montgomery 1990).

Table 2. ANOVA Table

Source of Variation	**Sum of Squares**	**Degrees of freedom**	**Mean of Squares**	F_0
Regression	SS_R	1	$MS_R = \frac{SS_R}{1}$	$\frac{MS_R}{MS_E}$
Error	SS_E	n-2	$MS_E = \frac{SS_E}{(n-2)}$	-
Total	S_{yy}	n-1	-	-

SS_R: Sum of squared terms of regression; SS_E: Sum of squares of error terms; S_{yy}: Sum of squares of all terms; MS_R: Mean of squares of regression terms; MS_E: Mean of squares of error terms.

From an ANOVA table the value for F_0 can be read. Then by comparing the F_0value as in Equation (7), it can be said that ***x*** has an effect in the variability of ***y*** (Hines &Montgomery, 1990).

$$F_0 > F_{\alpha,1,n-2} \tag{7}$$

In addition, the coefficient of determination (R^2) can be computed to indicate the adequacy of the regression model as in Equation (8). SS_R and S_{yy} values can easily be read from the ANOVA table. A higher R^2 value indicates a more adequate model between 0 and 1(Hines & Montgomery, 1990).

$$R^2 = \frac{SS_R}{S_{yy}} \tag{8}$$

It is rather a second degree multiple regression model. The model in response surface can be a first degree model as multiple linear regression in Equation(9) or it can be a second degree model as polynomial regression in Equation (10) (Hines & Montgomery, 1990).

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \epsilon \tag{9}$$

In Equation (9), the effects of more than a single independent variables (x_1, x_2,…) are investigated on the response variable (Hines & Montgomery 1990).

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2 + \cdots + \epsilon \tag{10}$$

In Equation (10), the second degree effects (x_{12}, x_{22},…) as well as the interactions between variables (x_1x_2) are also included in the model (Hines & Montgomery, 1990).

4. Case study

Mine location is on the 70 km east of Izmir and on the 15 km northeast of Bayindir. The rock types are Muscovite and Chlorite schist. There are quartz band lense and calcareous-schist around. Generally strike of these schist are north-east and the dip is about 15-25°.
Ores are parallel to strata and include similar round rocks. Ores show ore-dyke. The average grades of the samples are Pb 4.02%, and Zn 7.48%. The ore and production model of the mine under study can be seen in Figure1.

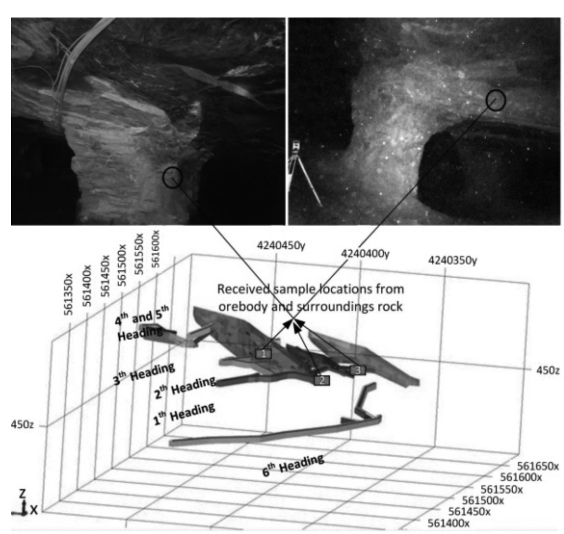

Fig. 1. Mine layout and study field

In order to select roadheader, mechanical and excavation characteristics of the ore and side formations should be defined (Avunduk *et al.,* 2014).

The sample cores are taken from the ore and rock materials in three different zones (Figure 1). Physical and mechanical experiments are made on these cores. UCS, Brazilian tensile strength (BTS) and Schmidt hardness are performed on these sample cores. The results of the experiments can be seen in Table 3.Drilling rate index (DRI) is an index used to estimate machine cutting performance. It is based on brittleness value and miniature drilling experiments value of rocks (Dahl, 2003; Yenice *et al.,* 2009, Yarali & Kahraman, 2011; Yetkin *et al.,* 2016).

Table 3. Mechanical and physical characteristics of project segment formation

Segment	Formation	UVW	SH	UCS	BTS	RQD	RMR	DRI
I	Ore zone	3.52	63.51	91.35	12.14	70	78	36
II	Ore zone	3.26	58.30	66.12	10.41	70	76	42
III	Ore zone	3.48	61.45	83.50	11.27	70	74	40
IV	Schist zone	2.66	52.10	43.31	9.59	55	66	53
V	Schist zone	2.59	47.11	29.40	7.02	55	64	63
VI	Schist zone	2.78	50.20	34.30	7.73	55	65	55

UVW: Unit volume over weight (kN/m^3), SH: Schmidt Hardness, UCS: Uniaxial Compressive Strength (MPa), BTS: Brazilian Tensile Strength (MPa), RQD: Rock Quality Designation (%), RMR: Rock Mass Rating, DRI: Drilling Rate Index

For 1st, 2nd and 3rd segments, RMR values are between 74 and 78, UCS values are between 66.12 and 91.35 and DRI values are found to be between 36 and 42. On the other hand, Segments 4, 5 and 6, which are of schist formation type, RMR values are around 64-66. UCS values falls down to 29.4-43.31 interval and drillability index increases to 53-63 interval.

5. Discussion and evaluation of results

Physical and rock mechanics experiments are carried out on samples from ore and schist zone and the properties given in Table 3 are found to predict machine performance. Mohr circle is formed by triaxial strength, UCS and tensile strength experiments. Ore cohesion value is 14.96 MPa and rock material cohesion value is 7.92 MPa. Internal friction angle of ore and rock material are found to be 48.66^o, 42.13^o respectively. In order to find rock mass rating (RMR) values of ore and rock materials, Bieniawski (1989) RMR_{89} parameters are used and points are calculated for mine conditions. In this study, it has been found that, the relation between specific energy (SE) and the product of UCS and BTS has a better correlation coefficient than that of the relations between SE and UCS, BTS, RMR, RMCI respectively.In addition, for segments with lower UCS, RMR and SE values are also decreasing in parallel and DRI values are increasing.

5.1. Prediction of performance and kt ratio of roadheader

The excavation characteristics of the ore and side formations should be defined (Tuncdemir&Bilgin, 2002). However, technical properties such as machine power, cutting head power and weight affect ICR. Based on previous experiments and empirical studies, a specific value for the selection of roadheader is suggested as in Equation (11). This value is the ratio of cutting head power (P) to the weight of the machine (W).

$$kt = P / W \quad (11)$$

The effect of roadheader cutting head power and the weight of the machine on ICR(m^3/h) values are examined in Table 4. It can be seen that for low cutting head powers and low weights, speed of excavation also decreases. This is due to the fact that reaction powers cannot be fulfilled by the machine and therefore speed decreases.ICR values increase linearly as cutting head power and machine weight increases. Excavation speed is also dependent on machine technical properties as well as RMR values. In addition, a linear relationship is observed between the instantaneous cutting rate values and head power values of machine in graphs (Figure 2).

Table 4. Experimental design points of performance prediction.

Segment/ Rock type	Rock Mass Cuttability Index (RMCI)	kt=P/W (kW/ton)	Instantaneous Cutting Ratio (ICR: m3/h)	Specific Energy (SE: kWh/m3)
I Ore zone	72.02	3.00	1.89	9.09
		2.60	2.73	
		2.50	4.20	
		3.33	8.40	
		3.53	12.60	
		3.64	16.80	
II Ore zone	52.13	3.00	3.19	6.92
		2.60	4.61	
		2.50	7.09	
		3.33	14.18	
		3.53	21.28	
		3.64	28.37	
III Ore zone	65.83	3.00	2.22	8.42
		2.60	3.21	
		2.50	4.94	
		3.33	9.89	
		3.53	14.83	
		3.64	19.77	
IV Schist zone	29.07	3.00	5.86	4.61
		2.60	8.46	
		2.50	13.02	
		3.33	26.03	
		3.53	39.05	
		3.64	52.07	
V Schist zone	19.74	3.00	7.49	3.13
		2.60	10.82	
		2.50	16.65	
		3.33	33.30	
		3.53	49.94	
		3.64	66.59	
VI Schist zone	23.03	3.00	6.87	4.18
		2.60	9.92	
		2.50	15.27	
		3.33	30.53	
		3.53	45.80	
		3.64	61.06	

Computational results conform to the SE values for roadheaders given in Table 4.

That is SE values are within the limits provided in Table 4 according to soft, medium and hard rock formations. Typical specific energy, mechanical efficiency and machine utilization for roadheader are given in Rostami (2011). For 1st, 2nd and 3rd ore segments RMCI and RMR are high and specific energy values are changing between 6.92 and 9.09kWh/m^3. Also, ICR values reach the largest capacity of 28.37 m^3/h for ore zone. For schist zone with low UCS values, DRI are increasing and RMCI are decreasing together with SE are found.

5.2. Response surface methodology (RSM) and analysis of variance (ANOVA)

In order to make sensitivity analysis and test confidence level of the study, variance analysis and F test methods are used. In addition ANOVA analysis is carried out on the data. The following null (H_0) and alternative hypothesis (H_1) are developed Equation (12). Then ***F*** test is performed (Hines &Montgomery, 1990).

$$H_0: b=0 \text{ and } H_1: b\neq 0 \qquad (12)$$

Looking at the ANOVA table, it can be seen that F_0 value is found to be 56.44 from Minitab (2013) software. The confidence level of the test is determined to be 95%. From the F table the value of $F_{0.05,70}$ is found to be 4.02. Since F_0=56.44>4.02= $F_{0.05,70}$ H_0 is rejected. This means that “with 95% confidence level, the regression between the instantaneous cutting rate values and head power of machine value is valid”. The response surface model given in Equation (13) explains the effect of P and W on ICR. The R value(Equation (8), Hines &Montgomery, 1990)is found to be 0.9, which shows the relation is very strong.

$$ICR = -13.9 + 0.102\,P + 0.249\,W \qquad R=0.9 \qquad (13)$$

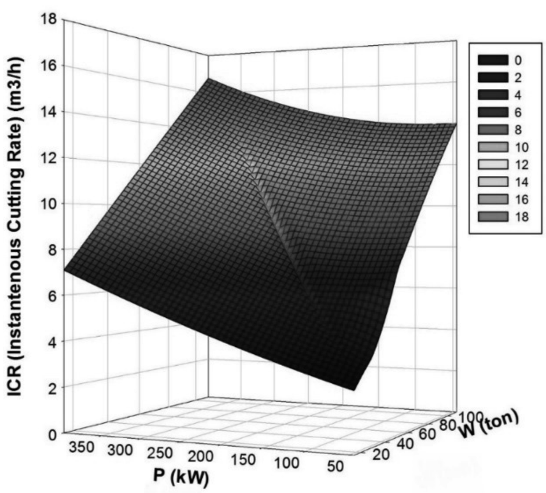

Fig. 2. Response surface graph effect of cutting head power and machine weight on ICR

5.3. Determination of optimum kt value

Effect of different machine weights and cutting head powers on excavation speed is studied. These two variables are integrated in the ratio of ***kt*** and the change in ***kt*** ratio is also provided.The effect of ***kt*** ratio and DRI on ICR is given in Figure 3. The R value is found to be 0.83. From Equation (14), it can be seen that ICR is directly proportional with both kt ratio and DRI. In addition, the effect of kt on ICR is much stronger than DRI.

$$ICR = -108 + 26.1\,kt + 0.951\,DRI \quad R=0.83 \qquad (14)$$

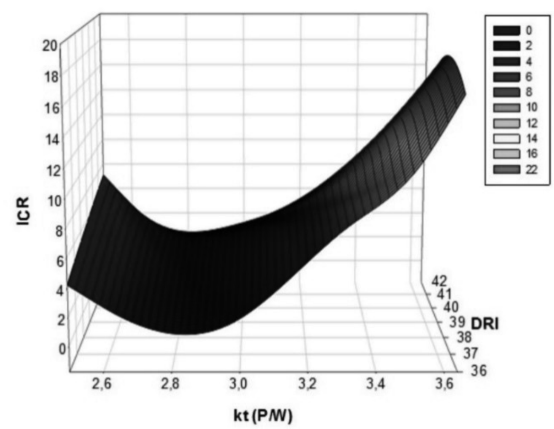

Fig. 3. Response surface graph on the relation of DRI, kt ratio and ICR

In Figure 4, it can be seen that as kt ratio increases, ICR also increases proportionally. On the other hand, As RMR value of the rock increases, ICR decreases non-linearly. The shaded region in the graph can be defined as the optimum area.

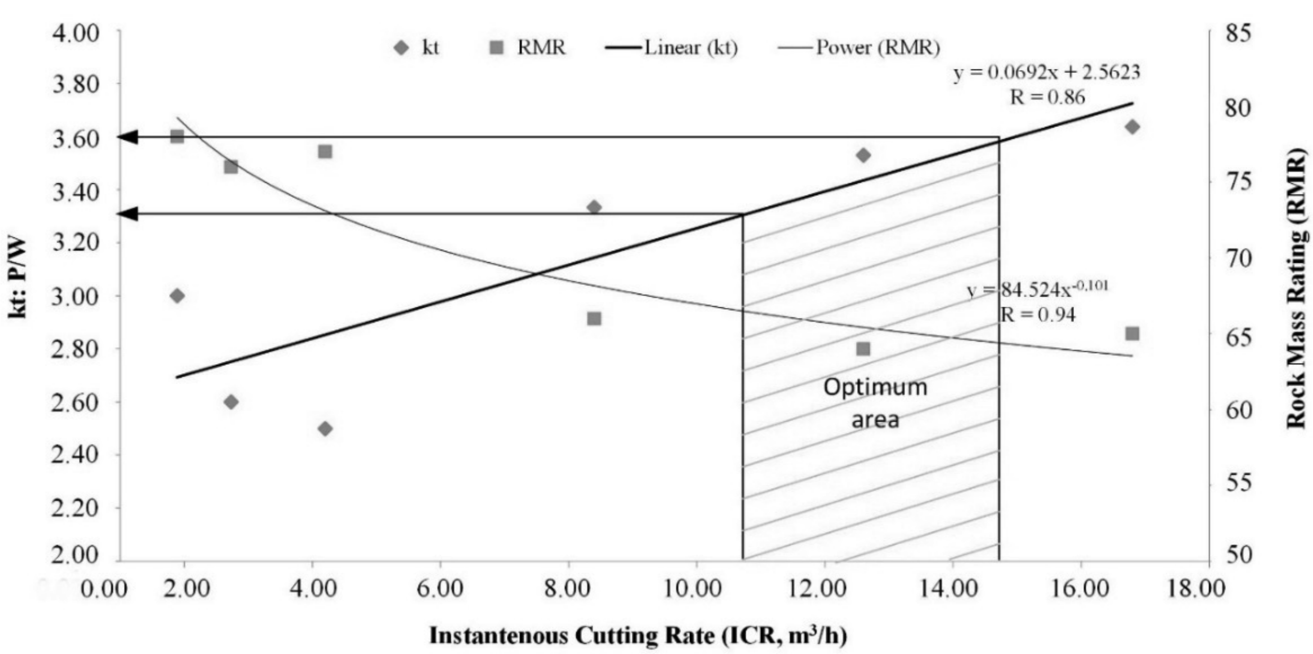

Fig. 4. The effect of ***kt*** ratio and RMR value for different ICR values.

Effects of kt, RMR, and DRI on ICR are given with the regression model in Equation (15) below. The R value is found to be 0.85.

$$ICR = -17 + 26.08kt - 0.90RMR + 0.397DRI \quad R=0.85 \qquad (15)$$

6. Conclusion

Selection of the suitable roadheader has become an important decision for metal mines. In selecting the right machine, ratio of the power to the weight of machine should be specified. Roadheaders with a higher power to rock mass rating and smaller cutting rate values are disadvantageous for these mines. In conclusion, the machine to be selected should have power to weight ratio and specific characteristics compatible with the rock mass rating values of the formation to be excavated. Optimum power to weight ratio is between 3.30 and 3.60 kW/ton for selecting roadheader machines. Therefore, power to weight ratio can be included in the performance prediction equations in the future studies.

7. Acknowledgements

This study is produced from a part of scientific research project of Dokuz Eylul University (DEU) (project no: 2012KBFEN59). Authors would like to thank to Scientific Research Coordinator for providing the financing of the project.

References

Ahmed, M. & Al-Dousari, A.M. (2013). Geomorphical characteristics of the Um-Rimam depression in northern Kuwait. Kuwait Journal of Science, **40**(1):165-178.

Al-Awadhi, F. & Aly, E.E.A.A. (2014). Multiple change point tests against the umbrella alternative. Kuwait Journal of Science, **41**(2):107-125.

Avunduk, E., Tumac, D. & Atalay, A.K. (2014). Prediction of Roadheader performance by artificial neural network, Tunnelling and Underground Space Technology, **44**:3-9.

Balci, C., Demircin, M.A., Copur, H. & Tuncdemir, H., (2004). Estimation of optimum specific energy based on rock properties for assessment of roadheader performance, December issue, The Journal of The South African Institute of Mining and Metallurgy.

Barakat, H.M., Nigm, E.M. & Khaled O.M. (2014). Statistical modeling of extremes under linear and power normalizations with applications to air pollution. Kuwait Journal of Science, **41**(1):1-19.

Bieniawski, Z.T. (1989). Engineering rock mass classifications. New York: Wiley.

Bilgin, N., Seyrek, T., Erdinc, E. &Shahriar, K. (1990). Roadheaders clean valuable tips for Istanbul Metro. Tunnels and Tunneling, 29–32.

Bilgin, N., Yazıcı, S. & Eskikaya, S. (1996). A model to predict the performance of Roadheaders and impact hammers in tunnel drivages, EUROCK ’96:710-721.

Bilgin, N., Kuzu, C., Eskikaya, S. & Ozdemir, L. (1997). Cutting performance of Jackhammers and Roadheaders in İstanbul metro drivages, World Tun. Congress, 1997.

Bilgin, N., Dincer, T., Copur, H. & Erdogan, M. (2004). Some geological and geotechnical factors affecting the performance of a roadheader in an inclined tunnel, Tunnelling and Underground Space Technology, **19**:629-636.

Breitrick, M.E. (1998). Using a Roadheader for underground gold mining. Mining Engineering, :43–46.

Box, G.E.P. & Wilson, K.B. (1951). On the experimental attainment of optimum conditions (with discussion). Journal of the Royal Statistical Society Series, B, **13**(1):1–45.

Copur, H., Ozdemir, L. & Rostami, J. (1998). Roadheader applications in mining and tun.ind.. The Mining Engineering :38-42.

Dahl, F. (2003). DRI, BWI, CLI Standards. NTNU, Angleggsdrift, Trondheim, Norway.

Duane, M.J. (2014). 19th Century lignite Mining (Germany): Hazards from non-ideal waste sequestration. Kuwait Journal of Science, **41**(3):191-202.

Ergin, H. & Acaroglu, O. (2007). The effect of machine design parameters on the stability of a Roadheader, Tunnelling and Underground Space Technology. **22**(1):80-89.

Eskikaya, S., Bilgin, N., Dincer, T. & Ozdemir, L. (1998). A model to predict the cutting performance of rapid excavation systems, Pro. of the 7. Int. Sym. on Mine Planning and Eq. S., Calgary, Rotterdam: 575–579.

Fowell, R.J. & Johnson, S.T. (1982). Rock classification and assessment for rapid excavation, Proc. of the Symp. on Strata Mech., Newcastle upon Tyne, 241-244.

Gehring, K.H. (1989). A cutting comparison. Tunnels & Tunneling November:27-30.

Hekimoglu, O.Z. (1984). Studies in the excavation of selected rock materials with mechanical tools, Ph.D. thesis, Uni. of Newcastle Upon Tyne, 342.

Hines, W.W. & Montgomery, D.C. (1990). Probability and statistics in engineering and management science. John Wiley & Sons, USA.

McFeat-Smith, I. & Fowell, R.J. (1979). The selection and application of Roadheaders for rock tunneling. In: Proceedings of the Rapid Excavation and Tunnelling Conference, Atlanta, **1**:261–279.

Minitab 2013. Statistical analysis program, Canada.

Neil, D.M., Rostami, J., Ozdemir, L. & Gertsch, R. (1994). Production estimating techniques for underground mining using Roadheaders. SME/AIME Meeting, New Mexico.

Ocak, I. & Bilgin, N. (2010). Comparative studies on the performance of a Roadheader, impact hammer and drilling and blasting method in the excavation of metro station Tunnels in Istanbul. Tunneling and Underground Space Technology, **25**:181-187.

Riedmuller, G. & Schubert, W. (2000). Tunneling in Fault Zones–innovative approaches, In: Pacific Rocks, Girard, Liebman, Breeds, Doe (Eds.), Balkema, Rotterdam, 113–124.

Rostami, J. (2011). Mechanical rock breaking, SME Society Mining Engineering Handbook, Darling, P., (Ed.), Third Edition, 417–434.

Rostami, J., Ozdemir, L. & Neil, D.M. (1994). Performance prediction:

A Key issue in mechanical hard rock mining, The Mining Engineering, **46**(11):1263–1267.

Schneider, H. (1988). Criteria for selecting a boom-type Roadheading, Min. Magazine Sept.:183-187.

Stojanovic, C., Bogdanovic, D. & Urosevic, S. (2015). Selection of the optimal technology for surface mining by multi-criteria analysis. Kuwait Journal of Science, **42**(3):170-190.

Thuro, K. & Plinninger, R.J. (1998). Geological limits in Roadheader excavation – Four Case Studies, 8th Int. IAEG Congress, Rotterdam, 21-25.

Thuro, K. & Plinninger, R.J. (1999). Roadheader excavation performance – Geological and geotechnical influences, 9th ISRM Congress Paris, Theme 3: Rock dynamics and tectonophysics/Rock cutting and drilling, 25-28.

Tuncdemir, H. & Bilgin, N. (2002). Investigation of using Roadheader in ore excavation. Itudergisi/d**1**(2):14-26 (in Turkish).

Tucker, A. (1985). Improvement of potential in mining development and tunneling systems in the National Coal Board, The Mining Engineering, 663-669.

Yarali, O. & Kahraman, S. (2011). The Drillability assessment of rocks using the different brittleness values. Tunneling and Underground Space Technology, **26**:406-414.

Yenice, H., Ozfirat, M.K., Kahraman, B. & Ozdogan, M.V. (2009). Examination of drilling rate index (DRI) of Rocks. Proceedings of the 3rd Balkan Mining Congress, Izmir.

Yetkin, M.E., Ozfirat, M.K., Yenice, H., Simsir, F., Kahraman, B. (2016). Examining the relation betweenrock mass cuttability index and rock drilling properties. Journal of African Earth Sciences, **124**: 151-158.

Submitted **:** 17/08/2015

Revised **:** 18/10/2015

Accepted **:** 27/10/2015

التنبؤ بأداء الحفارات الأرضية (roadheaders) عن طريق تحليل الاستجابة السطحية لمناجم التعدين تحت الأرض

[1]*كمال أوزفرات، [1]طاهر مالي، [2]بينار مزراق أوزفرات، [1]بايرام كهرمان
[1]قسم هندسة التعدين، جامعة دوكوز ايلول، إزمير، تركيا
[2]قسم الهندسة الصناعية، جامعة سيلال بايار، ما نيسا، تركيا
*kemal.ozfirat@deu.edu.tr

خلاصة

يجري استخدام الحفارات الأرضية في إنشاء الطرق في المناجم تحت الأرض. وخصوصاً، عندما يكون إجمالي احتياطي المنجم كافٍ للاستثمارات الكبيرة وطرق المناجم، تكون الحفارات الأرضية مهمة لزيادة معدل الانتاج. يتم تصنيف الحفارات الأرضية وفقاً لوزن قرص الرأس أو إجمالي الطاقة. في هذه الدراسة، يتم فحص تأثير عدة عوامل على أداء الحفارات الأرضية. والعوامل التي تم فحصها هي: قوة ووزن الآلة، نسبة القوة إلى الوزن، مؤشر معدل الحفر، مقاومة الضغط أحادية المحور وتصنيف الكتلة الصخرية. تم استخدام نسبة القطع اللحظية لتحديد أداء الآلة. تم استخدام منهجية استجابة السطح والانحدار الخطي لبحث العلاقة بين تلك المتغيرات. في نتائج الدراسة، وجدنا أن أداء الآلة مرتبط بدرجة عالية بقوتها (P)، ووزنها (W) ونسبة القوة إلى الوزن P/W.