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Development of Open-pit Mine Reclamation Cost Estimation Models: A Regression-based Approach

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ABSTRACT

In the recent decade, very few studies have been done on mine reclamation cost estimation and no study has been conducted on proposing mine reclamation cost estimation models based on historical data. This study aims to develop predictor models for mine reclamation costs. To this end, after collecting the historical cost data of 41 open-pit mine reclamation projects, a comprehensive data set of 16 mine reclamation costs groups and the extent of the disturbed mined land corresponding to each group was prepared. Given the advantage of the regression method in developing a reliable predictor model with few data, the proposed cost models are developed based on the regression analysis technique. The R square for all and more than 87% of the developed models was more significant than 85% and 90%, respectively, indicating the proper fits on the data sets. Also, the root mean square error ratio to the standard deviation of observed cost data (RSR) was lower than 0.7 for all developed models, indicating the predictor models' good performance on reliably estimating mine reclamation costs. These efficient and simple general models can help make the right decisions by mine reclamation planners and pave the way to achieve sustainable mining by considering mine reclamation cost in the mine planning and design process.

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1. INTRODUCTION

Mine reclamation is an accepted stage in the Modern Mining Life Cycle (MMLC) to keep mining in a Sustainable Development (SD) path by performing the responsible mining [1]. Given that the mine reclamation is a progressive activity, much of which is carried out in the last years of the MMLC, the primary concern of government agencies overseeing the reclamation plan is to ensure its successful implementation [2,3]. Estimation of mine reclamation costs to determine the amount of financial resources required is the key element of the successful implementation of the mine reclamation project. According to the World Bank report, mine reclamation costs range from less than $1 million for small-scale mines to hundreds of millions of dollars for giant mines [4].

Failure to finance the mine reclamation expenditures is synonymous with the inability to deploy the Post-Mining Land-Use (PMLU) option successfully. It will have consequences such as remaining the abandoned mines or bankruptcy of the mining company [2]. Therefore, to successfully implement the reclamation plan, its costs should be incorporated into the mine planning and design. Besides, considering these costs in the mine planning and design is one of the main requirements for achieving SD and performing responsible mining [5-10]. To this end, mine reclamation costs should be estimated at an acceptable level of confidence at the preliminary stages of the MMLC [11].

Mine reclamation costs are affected by PMLU option, mining method, mined land condition, mine waste and tailings characteristics, and the most important, the extent of earthworks required. Earthworks account for more than 70% of the mine reclamation costs [11, 12]. In a

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general classification, mine reclamation expenses can be divided into common and specific costs. Common costs are related to the activities that need to be performed according to the mine reclamation objectives for preparation operations before deploying the PMLU option. They are similar between reclamation projects regardless of the type of PMLU option. These cost items are generally affected by the extent of earthworks required in each mine. In the other group, specific costs are related to implementing the PMLU option selected [11,13].

Cost estimation is an essential part of all levels of studies for mining projects. There are several methods for cost estimation, such as the comparative method, unit cost method, detailed estimate, artificial intelligence-based methods, and regression-based methods. The appropriate estimation method is determined based on the amount and type of data required and the desired accuracy of the estimate [14-16]. Regression analysis and artificial intelligence-based methods are the most famous techniques for cost estimation purposes. Using artificial intelligence-based methods requires much historical data for training, validation, and testing the model [17]. In comparison, regression analysis techniques provide good results with a fairly small data set [18].

Despite the importance of the mine reclamation cost estimation, very few studies have addressed this issue, especially in the recent decade. Many of these studies [19-26] focus on reclamation cost estimation of United States (US) surface coal mines based on the unit costs of activities. Catlett and Boehlje [27] developed a multivariate regression model to estimate the reclamation costs of surface coal mines. This model considers only parameters related to slope, overburden height, and coal layer thickness. The US Office of Surface Mining Reclamation and Enforcement (OSMRE) [12] proposed a handbook for the calculation of reclamation bond amounts. The proposed model in this guide is based on detailed cost estimation by defining all reclamation cost items in detail. The main advantage of this study is the identification and classification of the types of mine reclamation direct and indirect costs based on the Surface Mining Control and Reclamation (SMCR) Act of 1977. The US Environmental Protection Agency (EPA) modified the OSMRE classification by aggregating similar detail cost items into some general items [3]. Some researchers [28-31] focus on developing simulation-based approaches to estimate mine closure and reclamation costs. In these studies, by defining different scenarios and using the Monte Carlo simulation method, a probabilistic distribution diagram of mine reclamation costs is presented, determining mine reclamation costs at varying levels of risk. Kaźmierczak et al. [11] and Ignatyeva et al. [32] proposed an approach for cost estimation of mine reclamation activities based on the unit cost method. Environmental organizations in some countries developed mine reclamation cost estimation models for reclamation bond calculation purposes in a standardized process. These models include the US Standardized Reclamation Cost Estimator (SRCE) model [33], the Australian Estimated Rehabilitation Cost Calculator (ERC) model [34], and the Canadian RECLAIM model [35].

Based on the literature review, there is no universal and perfect study in developing estimation models for common costs of open-pit mine reclamation projects by considering all activities required for different parts of the mined land. In the most of reviewed studies, it is not clear what type of mine reclamation activities are included in each cost item. For example, about earthworks costs, only grading has been considered in some studies, and in others, other operations such as topsoiling and cover placement have been considered. Therefore, it is required to specify the reclamation operations for each cost item based on a standard classification such as OSMRE handbook [12]. Besides, so far, no algebraic formula with a reliable range of error has been proposed to estimate the costs of different mine reclamation activities.

The aim of this study is to develop cost estimation models for cost items that are common in all mine reclamation plans. In this regard, after determining and classifying the mine reclamation cost items, the related historical cost data will be collected to develop reliable predictor models. Then, the regression analysis will be applied to develop estimation models for mine reclamation expenses. Finally, the reliability of models will be investigated and reported.

2. METHODOLOGY AND DATA SOURCES

Due to the lack of legal requirements in most countries (especially under development countries) to perform progressive mine reclamation activities, there is little data on mine reclamation costs. Therefore, the shortage of historical data existed on mine reclamation costs is the main limitation in developing cost predictors models. Given the limited number of available historical data and the advantage of regression-based methods in developing a reliable predictor model with a small number of data, in this study, the regression analysis technique is applied to develop the predictor models for mine reclamation cost estimation.

Statistical regression analysis is one of the best and most commonly used methods to develop a predictor model. This method generates the predictor model by establishing a relationship between independent input and dependent output variables. This model can estimate the target value based on the input value regarding the independent variables [18]. In the current study, the dependent variable in each model is the cost of mine reclamation activity, and the independent variable is the unit value of this activity (i.e., the extent of the disturbed area).

2. 1. Mine Reclamation Cost Classification Given the variety of mine reclamation costs, one of the most important issues in developing predictor models is providing a standard classification of these costs. In this study, the mine reclamation costs were classified based on the OSMRE's handbook [12]. Mine reclamation costs are classified into direct and indirect costs. The direct cost includes the costs associated with beginning a mine reclamation plan into production through site preparation and other activities. The classification of direct costs is given in Table 1. Indirect costs summarized in administration, engineering, and non-itemized services are classified into seven groups: mobilization/ demobilization, engineering design and redesign, contingency, contractor profit and overhead, contractor liability insurance, payment and performance bonds, and agency direct costs [12].

According to Table 1, there are five types of direct common costs for mine reclamation activities. Among these five cost groups, E & R is the major reclamation cost. Mine reclamation would require considerable earthwork activities, which its implementation requirements are different for different parts of the mined land. Therefore, it is needed to develop the cost predictor model separately for different parts of mined land include open-pit, waste rock dump, tailings facility, heap/dump leach, and process pond and reservoir. It is worth noting that depending on the type of mineral, an open-pit mine may not have all of these facilities. Therefore, in the cost estimation process of an open-pit mine reclamation project, only cost estimation models related to the facilities that exist in the mine will be used.

2. 2. Data Set Description Due to the long history of mine reclamation law in the US (SMCR Act of 1977), this country is one of the leading countries in mine reclamation. Accordingly, most of the available historical data on mine reclamation cost items are related to the US In this study, the reclamation cost data according to the extent of the disturbed areas of 41 open-pit mines were collected to construct the estimator models (Table 2). According to Table 2, this data set is related to different states of the US and has a wide variation range. These data have been gathered and reported by US EPA [3]. Given that the collected cost data were for different years (from 2007 to 2014), in this study, using the cost index provided by Engineering News-Record (ENR) Construction Cost Index [36], total costs were normalized to the 2020 US dollar. The descriptive statistics of the collected data are given in Table 3. It is worth noting that the cost data reported in Table 3 were normalized to the 2020 US dollar according to the ENR cost index. According to Table 3, the number of data collected varies for each reclamation cost group. Because, in none of the studied mines, all categories of mine reclamation costs have been reported. Thus, the number of data in each cost category depends on the number of mines, which reported that cost item. Accordingly, in this study, cost estimation models were developed separately for each mine reclamation cost category.

3. COST MODELS DEVELOPMENT

In the data set reported in Table 3, except for the water treatment cost, which depends on the volumetric flow rate (Q) of water treatment, other reclamation costs are a function of the extent of the disturbed areas considered in the reclamation plan. Therefore, the cost predictor regression models' independent variable is the area of part or all mined land (depending on the cost category). After collecting the cost data (Table 3), there is sufficient data to generate a numerical relationship between data on

TABLE 1. Mine reclamation direct costs classification [3, 12]

Num.	Direct cost	Reclamation acitivities
1	Earthworks & Revegetation (E & R)	Backfilling, grading, cover placement, ripping/scarifying, topsoiling, revegetation
2	Solid and hazardous waste disposal	Solid waste, hazardous material, contaminated soils, and organic solutions removal, haulage and disposal; structure, building and equipment demolition and disposal (i.e., buildings, haul access roads, crusher, foundation, fences, powerlines, etc.)
3	Surface water drainage	Diversion channels construction to collect and convey stormwater from the reclaimed land to prevent contamination through run-on or run-off
4	Annual water treatment	Minimize the toxicity of mine-influenced waters with chemicals (e.g., lime), Water management (prevent the release of contaminated water), process fluid stabilization, neutralization, and solution disposal, and seepage capture
5	Annual Operation & Maintenance (O & M) and monitoring	Groundwater and surface water monitoring, geotechnical stability monitoring, erosion and vegetation monitoring, fish and wildlife monitoring, road, stormwater, and revegetation repairs and maintenace

TABLE 2. General specifications of collected cost data

Num.		Mine Reclamation Cost item	Num. of Data	Type of Mineral (NUM.)	Country (NUM.)
1		Open-pit E & R Cost	17	Au (10), Cu (4), Fe (1), Ag (1), Au-Ag (1)	**USA**: Nevada (12), Arizona (1), California (1), Minnesota (1), New Mexico (1), Utah (1)
2		Waste rock dump E & R Cost	20	Au (8), Cu (4), Fe (3), Mo (2), Rare Earth (1), Au-Ag (1), Zn-Pb (1)	**USA**: Nevada (6), Alaska (3), Minnesota (3), Arizona (2), California (2), Colorado (1), Idaho (1), South Carolina (1), Utah (1)
3		Tailings facility E & R Cost	12	Au (7), Au-Ag (2), Cu (2), Mo (1)	**USA**: Nevada (5), Alaska (2), Arizona (2), Colorado (1), Montana (1), New Mexico (1) South Carolina (1)
4		Heap/dump leach E & R Cost	8	Cu (4), Au (2), Au-Ag (2)	**USA**: Nevada (5), Arizona (2), Montana (1)
5		Process pond & reservoir E & R Cost	14	Cu (7), Au (5), Au-Ag (1), P (1)	**USA**: Nevada (8), Arizona (3), Idaho (1), New Mexico (1), Utah (1)
6		Surface water drainage cost	8	Au (5), Cu (2), P (1)	**USA**: Nevada (4), Alaska (1), Arizona (1), Idaho (1), Utah (1)
7		Solid & hazardous waste disposal cost	7	Au (6), Cu (1), Au-Ag (1)	**USA**: Nevada (6), California (1)
8		Annual O & M and mointoring cost	15	Au (8), P (2), Cu (1), Rare Earth (1), Ag (1), Mo (1), Zn-Pb (1)	**USA**: Nevada (7), Alaska (4), Idaho (2), California (1), Colorado (1)
9		Annual water treatment cost	7	Au-Ag (4), Cu (2), Au (1)	**USA**: Colorado (2), Montana (2), New Mexico (2), Alaska (1)
10	Indirect costs	Mobilization/demobilization cost	12	Au (6), Cu (4), Ag (1), Mo (1)	**USA**: Nevada (7), New Mexico (2), Arizona (1), California (1), Colorado (1)
11		Engineering design and redesign cost	11	Au (7), Cu (3), Au-Ag (1)	**USA**: Nevada (6), Montana (2), Alaska (1), Arizona (1), New Mexico (1)
12		Contingency cost	16	Cu (6), Au (4), Fe (2), Mo (1), P (1), Rare Earth (1), Au-Ag (1)	**USA**: Nevada (4), Arizona (2), California (2), Idaho (2), Minnesota (2), New Mexico (2), Alaska (1), Utah (1)
13		Contractor profit and overhead cost	13	Au (9), Cu (2), MO (1), P (1)	**USA**: Nevada (6), Arizona (2), California (2), Idaho (2), Alaska (1)
14		Contractor liability insurance cost	9	Au (5), Cu (2), Ag (1), P (1), Mo (1)	**USA**: Nevada (4), Colorado (2), Alaska (1), Idaho (1), New Mexico (1)
15		Payment and performance bonds	12	Au (10), Mo (1), P (1)	**USA**: Nevada (6), Alaska (2), Colorado (2), New Mexico (1)
16		Agency direct costs	15	Au (9), Cu (3), Mo (1), Rare Earth (1), P (1)	**USA**: Nevada (6), Alaska (2), Idaho (2), California (1), Montana (1), New Mexico (1), South Carolina (1)

TABLE 3. Descriptive statistics of collected data

Variable	Unit	Acronym	NUM.	Mean	Median	StDev	Minimum	Maximum
Open-pit E & R cost	US$ 1000	$E \& R_{(O-P)}C$	17	234.58	90.78	380.73	1.82	1458.36
Waste rock dump E & R cost	US$ 1000	$E \& R_{(WRD)}C$	20	5046	3785.84	5188.08	307.73	22241.45
Tailing's facility E & R cost	US$ 1000	$E \& R_{(TF)}C$	12	11542.71	6676.25	12689.78	1171.15	44650.05
Heap/dump leach E & R cost	US$ 1000	$E \& R_{(HL)}C$	8	4551.59	4042.59	2770.72	910.45	8371.62
Process pond & reservoir E & R cost	US$ 1000	$E \& R_{(PR)}C$	14	634.6	423.98	817.25	23.33	3229.47
Surface water drainage cost	US$ 1000	*SWDC*	8	55.85	17.25	68.07	3.45	165.23
Solid & hazardous waste disposal cost	US$ 1000	*WDC*	7	170.98	43.67	238.39	5.25	652.04
Annual O & M and monitoring cost	US$ 1000	*O & MC*	15	366.61	266.15	434.35	57.08	1764.49
Annual water treatment cost	US$ 1000	*WTC*	7	3768.9	2859.82	2177.52	1918.86	7694.57
Mobilization/demobilization cost	US$ 1000	*MobC*	12	664.25	366.01	697.89	77.45	2181.82
Engineering design and redesign cost	US$ 1000	*EngC*	11	2727.61	2022.42	2375.49	716.85	8929.34

Contingency cost	US$ 1000	*ContC*	16	1698.29	1296.59	1462.66	175.32	4136.69
Contractor profit and overhead cost	US$ 1000	*P & OC*	13	4855.68	3301.50	4744.25	501.58	15815.64
Contractor liability insurance cost	US$ 1000	*LIC*	9	671.66	253.11	744.04	21.5	2115.82
Payment and performance bonds	US$ 1000	*PBC*	12	1312.36	934.6	1418.38	59.29	4744.69
Agency direct costs	US$ 1000	*AgenC*	15	3425.27	2716.52	3165.64	158.35	9918.01
Open Pit disturbed area	ha	$A_{(O\text{-}P)}$	17	120.81	45.32	185.37	1.62	647.50
Waste rock dump disturbed area	ha	$A_{(WRD)}$	20	386.43	278.02	405.68	17.00	1605.79
Tailings facility disturbed area	ha	$A_{(TF)}$	12	429.03	235.32	474.93	54.63	1711.42
Heap/dump leach disturbed area (ha)	ha	$A_{(HL)}$	8	233.76	223.18	143.85	52.61	442.32
Process pond & reservoir disturbed area	ha	$A_{(PR)}$	14	10.55	7.08	14.46	0.4	57.06
Total site-wide disturbed area	ha	$A_{(S\text{-}w)}$	41	823.66	491.29	879.92	5.26	3305.07
Volumetric flow rate of water treatment	l/min	*Q*	7	3374.42	2649.79	1732.26	1483.88	6056.66

each mine reclamation cost category and the variable related to the extent of mine reclamation activities in that category. The purpose is to select the regression model to achieve the best fit possible for the data with the lowest estimation error. To this end, the R square (R2) and Root Mean Square Error (RMSE) of each type of regression model were evaluated. Accordingly, the model with the highest R^2 and the lowest RMSE was selected. Equations (1) to (16) show regression functions to predict mine reclamation costs. The variables of these equations and their unit of measurement are described in Table 3. Also, the regression relationships and their R^2 are expressed as graphs in Figure 1.

$$E\,\&\,R_{(O-P)}C = 0.0018 \times A_{O-P}{}^{2} + 0.8925 \times A_{O-P} + 41.174 \quad (1)$$

$$E\,\&\,R_{(WRD)}C = 0.0021 \times A_{WRD}{}^{2} + 9.2605 \times A_{WRD} + 825.17 \quad (2)$$

$$E\,\&\,R_{(TF)}C = 26.19 \times A_{TF} + 303.76 \quad (3)$$

$$E\,\&\,R_{(HL)}C = -0.0144 \times A_{HL}{}^{2} + 25.263 \times A_{HL} - 303 \quad (4)$$

$$E\,\&\,R_{(PR)}C = 0.0623 \times A_{PR}{}^{2} + 51.918 \times A_{PR} + 67.788 \quad (5)$$

$$SWDC = 0.0666 \times A_{S-w} + 6.8855 \quad (6)$$

$$WDC = 8.9128 \times e^{0.0017 \times A_{S-w}} \quad (7)$$

$$O\,\&\,MC = 0.6309 \times A_{S-w} + 60.723 \quad (8)$$

$$WTC = 1.161 \times Q - 148.66 \quad (9)$$

$$MobC = 0.7266 \times A_{S-w} - 1.252 \quad (10)$$

$$EngC = 0.0002 \times A_{S-w}{}^{2} + 1.8552 \times A_{S-w} + 656.75 \quad (11)$$

$$ContC = -0.0002 \times A_{S-w}{}^{2} + 1.9076 \times A_{S-w} + 97.839 \quad (12)$$

$$P\,\&OC = 0.0008 \times A_{S-w}{}^{2} + 5.4103 \times A_{S-w} + 66.825 \quad (13)$$

$$LIC = 2.1065 \times A_{S-w} + 66.211 \quad (14)$$

$$PBC = 0.0006 \times A_{S-w}{}^{2} + 0.7689 \times A_{S-w} + 171.76 \quad (15)$$

$$AgenC = 3.3302 \times A_{S-w} + 529.27 \quad (16)$$

4. MODELS EVALUATION

After developing the cost models, the goodness of models fitness should be evaluated. The R^2 coefficient obtained from regression analysis is a good measure for explaining the model's capability. The R^2 values more than 0.5 are acceptable, and values greater than 0.75 are good for representing the accuracy. The high R^2 coefficients show that the developed cost models can properly estimate the mine reclamation costs [37]. Although the R^2 coefficient is widely used for model evaluation, this statistic is insensitive to proportional differences between observed and predicted values according to the developed model. Therefore, it is required to apply some of the error indices for model evaluation. The RMSE is the main error index for regression model evaluation. The RMSE value close to zero indicates a perfect fit in the regression model. Therefore, it is necessary to calculate the RMSE value based on Equation (17).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (y_{obs} - y_i)^2}{n}} \quad (17)$$

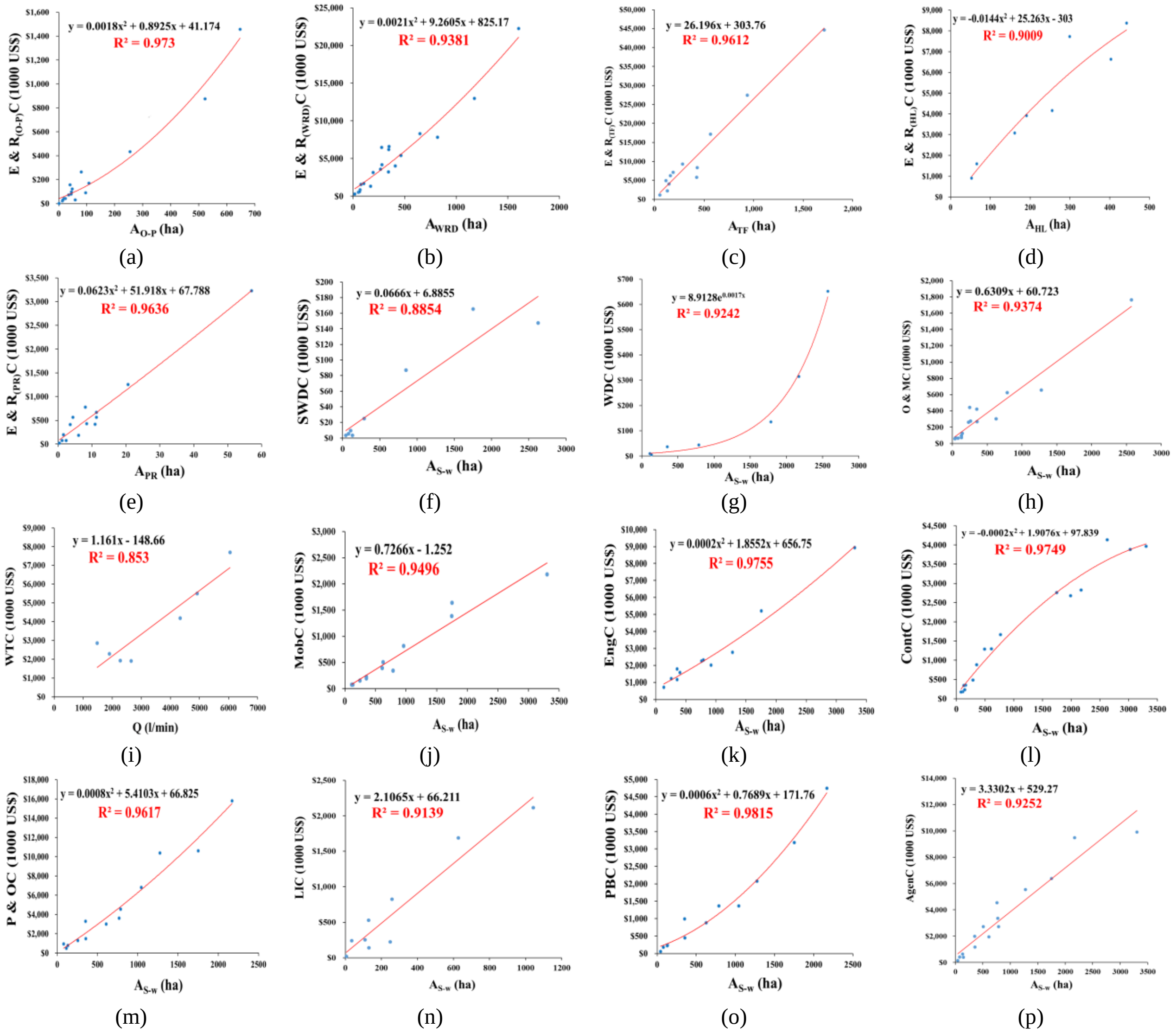

Figure 1. Univariable regression results for mine reclamation costs

where y_{obs} is the input value, y_i is the predicted value, and n is the number of data. Although the RMSE is the most commonly used index to evaluate the model's error, it alone cannot represent the model's accuracy and depends on the data's average value and Standard Deviation (StDev). To this end, the RMSE-observations standard deviation ratio (RSR) is applied to evaluate the model's performance. RSR is calculated as the ratio of RMSE to StDev of measured data according to Equation (18) [37].

$$RSR = \frac{RMSE}{StDev_{obs}} = \frac{\sqrt{\sum_{i=1}^{n}(y_{obs}-y_i)^2}}{\sqrt{\sum_{i=1}^{n}(y_{obs}-y_{mean})^2}} \tag{18}$$

where y_{mean} and $StDev_{obs}$ are the average value and standard deviation of the observed data, respectively.

After calculating the RSR ratio, the model's performance is evaluated according to the performance rating presented in Table 4. The amounts of the RMSE and RSR of the proposed cost estimation models are given in Table 5. The values of RSR for developed cost models show the good performance of these models in estimating mine reclamation costs.

TABLE 4. Model's performance rating based on the *RSR* [37]

Performance Rating	RSR
Very good	$0 \leq RSR \leq 0.5$
Good	$0.5 < RSR \leq 0.6$
Satisfactory	$0.6 < RSR \leq 0.7$
Unsatisfactory	$RSR > 0.7$

TABLE 5. RMSE and RSR of the cost models

Cost Model	RMSE	RSR	Performance
$E \& R_{(O\text{-}P)}C$	60.735	0.16	Very good
$E \& R_{(WRD)}C$	1258.315	0.24	Very good
$E \& R_{(TF)}C$	2393.06	0.188	Very good
$E \& R_{(HL)}C$	816.031	0.29	Very good
$E \& R_{(PR)}C$	562.315	0.68	Satisfactory
SWDC	21.556	0.31	Very good
WDC	33.049	0.14	Very good
O & MC	105.026	0.241	Very Good
WTC	773.015	0.354	Very Good
MobC	149.98	0.214	Very good
EngC	354.74	0.14	Very good
ContC	946.25	0.64	Satisfactory
P & OC	3215.66	0.67	Satisfactory
LIC	205.893	0.276	Very good
PBC	642.88	0.45	Very good
AgenC	836.676	0.264	Very good

5. DISCUSSIONS

This study developed the predictor models for mine reclamation cost estimation based on the statistical regression analysis. These new and general models, developed for different parts and facilities of the open-pit mines separately, cover all direct and indirect common costs of open-pit mine reclamation projects. Since the input variable of these models is based on the extent of the disturbed land area, these models can be used at any stage of MMLC by entering the extent of disturbed land area under reclamation operations. This study's main novelty is developing algebraic formulas for different mine reclamation cost groups based on a data set of mine reclamation costs. These novel generic models are responsible for calculating mine reclamation costs in a simple and systematic manner. Data collection from 41 open-pit mine reclamation projects and accordingly preparation of a comprehensive data set of mine reclamation costs and the extent of the disturbed area of the mined land corresponding to each cost group are the other superior aspects of the current study.

According to Figure 1, the R^2 amounts for all and more than 87% of the developed models was more significant than 85% and 90%, respectively, indicating the proper fits on the data sets. According to Table 5, the *RSR* values of all 16 developed models are at an acceptable level (lower than 0.7) that represents the acceptable performance of predictor models. It is worth noting that the *RSR* values for more than 81% of the proposed models was lower than 0.5, indicating very good performance of these models. The high amounts of R^2 and low values of *RSR* appear that the proposed models have a suitable capability for mine reclamation costs estimation with a reliable error range.

It is worth noting that each type of mineral has its own requirements for reclamation operations. Some of these requirements are related to specific mining facilities for that type of mineral. In a gold mine, for example, there is the heap leach and process pond. While in an iron ore mine, there are no such mining facilities. Therefore, the mine reclamation planner will not consider the cost estimation models related to these facilities in the cost estimation process of this mine's reclamation project. However, it is essential to note that much of the reclamation work in an open-pit mine is related to earthworks (more than 70% of reclamation costs), which can be considered common in all mines. For example, earthworks for waste rock dump in a gold mine is not much different from this type of operation in an iron or copper mine.

PMLU profoundly affects the mine reclamation cost. On the other hand, the main criterion for measuring the completion of the mine closure operation is the successful establishment of the PMLU option, which requires funding its related costs. Therefore, to calculate the final cost of the mine reclamation project, which is equal to the sum of common and specific costs, it is required to estimate the cost of establishing the PMLU option. However, the frontier of this research is the development of estimating models for the common costs of reclamation operations, and providing models to estimate the cost of implementing each of the PMLU options can be the subject of future researches. Nevertheless, the cost of establishing the desired PMLU option can be calculated based on unit cost method.

6. CONCLUSION

Mine reclamation cost estimation is the main prerequisite for successfully implementing the mine reclamation project and achieving sustainable mining by incorporate this cost in the mine planning and design. In this study, 16 predictor models for estimation of mine reclamation costs were developed based on the regression analysis. To this end, a comprehensive data set of 16 mine reclamation cost groups and the extent of the disturbed area of the mined land corresponding to each group was prepared based on the data collected from 41 open-pit mine reclamation projects. These new and general models, developed for different parts and facilities of the open-pit mines separately, cover all direct and indirect common cost categories of open-pit mine reclamation projects. The results show that developed algebraic models are suitable for estimating mine reclamation costs with a reliable error range. These novel generic models are responsible for calculating mine reclamation costs in a simple and systematic manner. Developing algebraic formulas for different mine reclamation costs based on a comprehensive data set of 16 mine reclamation cost groups gathered from cost data of 41 open-pit mine reclamation projects is the main superiority and novelty of this study. These efficient and simple general models can help make the right decisions by mine reclamation planners and also can be a helpful tool for mine reclamation bond calculation required for government agencies. This work contributes to establishing a paradigm for future studies related to incorporating mine reclamation cost in the mine planning and design process.

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Persian Abstract

چکیده

در دهه اخیر، مطالعات بسیار محدودی در زمینه تخمین هزینه‌های بازسازی معدن انجام شده است و تا کنون هیچ مطالعه‌ای در زمینه ارائه مدل‌های تخمین‌گر هزینه‌های بازسازی بر اساس داده‌های تاریخی انجام نشده است. هدف این مطالعه توسعه مدل‌های تخمین‌گر برای هزینه‌های بازسازی معدن است. بدین منظور ، پس از جمع آوری داده‌های مرتبط با هزینه‌های تاریخی پروژه بازسازی ۴۱ معدن روباز، مجموعه داده‌های جامعی از ۱۶ گروه هزینه‌های بازسازی معدن و مساحت زمین تخریب شده مربوط به هر گروه تهیه شد. با توجه به مزیت روش رگرسیون در توسعه یک مدل تخمین‌گر با تعداد داده تاریخی کم، مدل‌های ارائه شده در این مطالعه بر اساس روش آنالیز رگرسیون توسعه یافته‌اند. مقدار ضریب همبستگی به دست آمده از فرایندهای مدل‌سازی، نشان می‌دهد که مدل‌های توسعه یافته در این مطالعه به خوبی بر داده‌ها برازش یافته‌اند. همچنین نسبت جذر میانگین مربعات خطا به انحراف از معیار داده‌های هزینه ورودی در تمامی مدل‌های توسعه یافته، مقدار کمتر از ۰/۷ است که معرف عملکرد مناسب این مدل‌ها در تخمین قابل اعتماد هزینه‌های بازسازی معدن است. این مدل‌های کارآمد و ساده می‌توانند به تصمیم‌گیری صحیح توسط برنامه‌ریزان بازسازی کمک کرده و راه دستیابی به معدنکاری پایدار را با لحاظ کردن هزینه‌های بازسازی در فرایند طراحی و برنامه‌ریزی معدن هموار کند.