Statistical Functions for the Development of Heap Leach Pads Cost Estimation

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Abstract

In Peru, mining facilities and especially heap leach pad construction for metal production such as gold, silver, and copper is mainly carried out in the Andes region. There, heap leach pad construction faces many adverse and aggressive environments including weather, physical and topographic conditions, high altitude, and others, which have impacts on construction cost, both for the start-up of operations and for the expansion of the following phases of the leach pad. The construction cost represents a major part of a heap leach pad project and directly impacts the mining project's viability.

The purpose of this paper is to provide a useful tool for a construction cost estimation of a heap leach pad project under certain conditions. Such an estimation is necessary during viability evaluation and decision-making stages in investment projects of this type.

For the development of the cost estimation tool, an analysis using the database of projects executed in Peru during the last ten years was carried out. This was used to generate cost functions of the main heap leach pad construction activities such as topsoil removal, earthworks, underdrain system, liner system, solution collection system and overliner, which are the most significant costs in the construction of these types of facilities. Furthermore, the paper includes the cost function development of the main complementary facilities for start-up of operations, such as the PLS pond, the emergency pond, and the underdrain pond.

This tool will help to quickly estimate the cost of a heap leach pad construction with minimum effort, which is very useful in the early stages of an economic evaluation; as a result, this tool can help to expedite decision-making in mining investment projects. In addition, with the objective of evaluating the application of this tool, simulations were carried out with information from projects already built to verify that the costs obtained are within an acceptable margin compared with the actual construction costs.

Finally, this tool is provided in this paper and the authors hope to serve as a reference for designers, contractors, and professionals associated with this market for the cost estimation of future heap leach pad projects.

Introduction

Heap leach pad construction in Peru, mainly for gold and silver recovery, has increased significantly over the last ten years as a result of the low cost of construction and operation associated with the exploitation of low-grade ore deposits. Different works are required for the construction of heap leach pads, such as earthworks to reach the foundation and grading surfaces, construction of the underdrain system, installation of the liner system and leachate solution collection system, and finally the placement of overliner on the lined area, onto which ROM, crushed or agglomerated ore, and overliner are usually placed as protection and/or drainage materials, as appropriate.

Currently, there are no documented records of the costs associated with the construction of heap leach pads in the Andean regions of Peru that would serve as a basis for assessing the feasibility of this type of projects in such regions. Construction costs are often determined based on previous projects in a pre-bidding process; in many cases, without considering the specific characteristics of the area where the project is to be located. Therefore, in view of the aforementioned limitation and the importance of estimated construction costs in the initial stages of the evaluation of a mining project – which is important and necessary information for mining companies, consultants and government agencies – we concluded that it is of major importance to have a statistical tool, such as a cost-based function, that allows one to estimate construction costs at a conceptual level with greater accuracy and in accordance with the surrounding environment.

This paper outlines the methodology, the collection and processing of data, and the results obtained in terms of statistical functions associated with the construction costs of heap leach pads. To obtain the cost functions, this research focused on the analysis of the main activities and/or associated systems such as the foundation, surface grading, underdrain system, liner system, solution collection system, and overliner.

Objective

The objective of this paper is to introduce a statistical methodology that allows us to obtain a reliable estimation of the costs of the various components of a heap leach pad in Andean regions, so that it can be used as a tool for a more accurate estimation of conceptual costs. In addition, statistical analysis (correlation, control charts, etc.) will be used to determine the equations or intervals that will allow the determination of the estimated a priori costs of the components of a heap leach pad system.

Research methodology

The proposed analyses are intended to draw inferences from population values (proportions, means) based on a sample. For a finite population, the sample size is determined using:

$$n = \frac{N \, x \, Z_{\alpha}^{2} \, x \, p \, x \, q}{d^{2} \, x \, (N-1) + \, Z_{\alpha}^{2} \, x \, p \, x \, q}$$

Where:

N: total population size;

Z_a: 1.96^2 for a 95% level of confidence;

p: expected proportion;

q =1-p;

d: precision.

In this case, p=5%, q=1-0.05=0.95 and d=3%. In order to estimate a proportion, the following must be identified:

- The level of confidence (1-a). The preset level of confidence yields a coefficient (Z). a=1.96 for 95% level of confidence and a=2.58 for 99% level of confidence.
- The desired precision of the study.
- An approximate value of the parameter to be measured (in this case, a proportion, p). It may be obtained from existing literature or previous pilot studies. If such information is not available, a p=0.5 (50%) will be used.

We considered 21 projects at the detailed engineering level, executed between 2015 and 2022; therefore, the sample size is as follows:

$$n = \frac{21 \; x \; 1.96^{2} \; x \; 0.05 \; x \; 0.95}{0.03^{2} \; x \; (21-1) + 1.96^{2} \; x \; 0.05 \; x \; 0.95}$$

$$n = \; 19$$

Therefore, only 19 engineering studies will need to be evaluated for a 95% level of confidence with a precision of 3%. This methodology involves three steps: 1) data collection and compilation; 2) data processing in parallel to collection; and 3) statistical analysis.

Data collection

Data was collected from the Anddes database, which contains a digitalized version of the projects. From the information on heap leach pad project costs from various mines, a total of 21 projects were selected.

It should be noted that the costs of the investment projects correspond only to direct costs. Local taxes, profits, general expenses, supervision, CQA, among others, were not included to avoid the fluctuation inherent to these items and obtain closed cost function data, except for the statistical analysis of the total CAPEX of the project. Variables were identified for each of the components of the heap leach pad projects after being identified in the Anddes database.

Database

The 21 projects located in Peru are depicted in Figure 1, where the highest incidence is observed in 2019 and 2020.

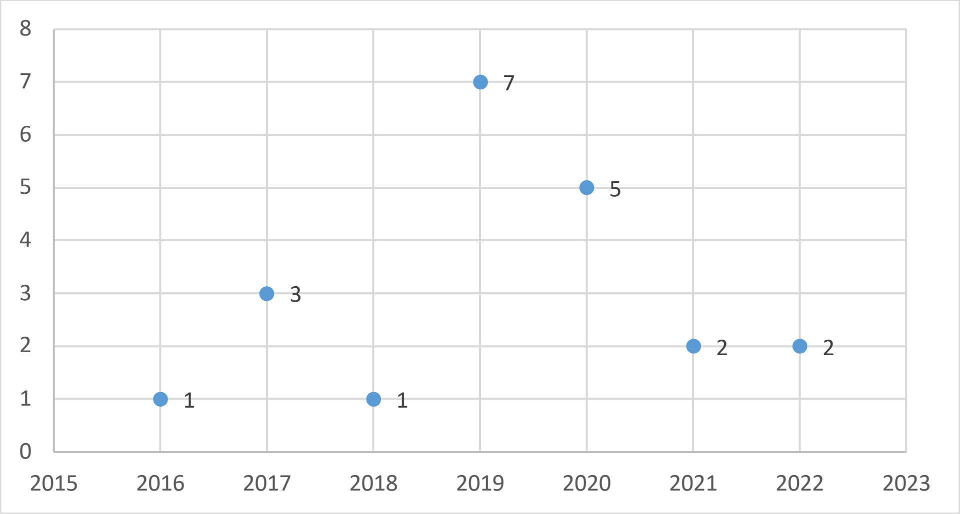

Figure 1: Number of projects timeline

Data processing

Each of the main characteristics of each system of heap leach pad projects was identified. The systems considered were: foundation, surface grading, underdrain system, liner system, solution collection system, and overliner (Wills and Finch, 2016). For further information and understanding of the activities and systems associated with heap leach pad construction, a summary of each of them is presented below.

Foundation

The foundation refers to the surface where the heap leach pad will be founded and is estimated based on geotechnical field and laboratory investigations. Costs associated with this activity include clearing and grubbing, and cutting of topsoil and unsuitable materials until the depth of competent foundation is reached.

Surface grading

Surface grading refers to the final surface where the heap leach pad liner system will be installed. A gradient should be configured towards a point of concurrence for drainage and discharge of the leachate solution to the process ponds.

Costs associated with this activity include cut and fill works to achieve the levels set in the leach pad design.

Underdrain system

Its function is to capture groundwater flows originating within the limits of the heap leach pad and divert them underneath the liner system to the underdrain ponds located downstream. The underdrain system is composed of main and secondary drains installed in the lower areas of the pad, consisting of trenches with dual-wall HDPE perforated pipes at the bottom, covered with drainage gravel and nonwoven geotextile on top as protection to prevent fine-particles migration.

Costs associated with this system include excavation for trench construction, installation of pipes and geosynthetics, placement of drainage material.

Liner system

Its function is to serve as an impermeable barrier to prevent leakage of the leachate solution into the ground. It consists typically of a 300 mm thick low-permeability soil layer or geosynthetic clay liner (GCL) as secondary liner, and a geomembrane as primary liner.

Costs associated with this system include earthworks for the placement of the low-permeability soil (or installation of the GCL) and the installation of the geomembrane.

Solution collection system

Its function is to collect and quickly convey the leachate solution, accumulated within the bottom of the leach pad, to the operating pond. The solution collection system is composed of primary and secondary dual-wall HDPE perforated pipes installed in the lower areas of the pad on the geomembrane, which are covered with drainage gravel or leached ore to ease solution conveyance.

Costs associated with this system include the installation of pipes and placement of drainage material.

Overliner

The overliner corresponds to the layer of granular material, with a thickness varying between 0.50 to 0.80 m, designed to protect the geomembrane and/or drain the leachate solution. Such material must be durable and must be placed on top of the geomembrane and collection pipes. When used as protection, the overliner is intended to reduce damage and rupture of the geomembrane due to ore discharge and the operation of the ore transport and spreading equipment; when the overliner is used as drainage, relatively high permeability coefficients are required to facilitate the collection of the leachate solution at the bottom of the heap.

Costs associated with this system include the placement of granular material.

Statistical analysis

Following the methodology described above, data was extracted and organized in specific and detailed tables, sorted by each characteristic of each of the heap leach pad systems described above. The methodology used to determine the cost functions was based on the statistical analysis of the information obtained from the records of the heap leach pad characteristics (21 projects). In Appendix A of this chapter, a table showing the characteristics of each heap leach pad project used in this study is presented.

Data analysis

A first estimation of the standard deviation (σ) and the average updated cost or average updated unit cost, as appropriate, was performed to detect extreme records in the data sample that might distort the results. Considering that according to Chebyshev's Theorem, at least 75% of the data in any set of observations lies within at most two standard deviations from the mean, and that about 95% of the data from data sets that have a normal distribution lies within less than two standard deviations from the mean, the range "average $\pm 2\sigma$" (Aguilar, 2021) was set as the limit. All data outside this range were removed from the sample.

Determination of the mathematical model

Upon discarding the sample data that exceeded the limit range set (average $\pm 2\sigma$), the standard deviation and the final average were calculated. The latter represents the Average Unit Cost of the construction component; thus, the cost function equation is as follows:

$Y = K * X$ (constant function)

Where:

Y: total cost of the system
K: average unit cost of the system
X: quantity of the system (m, m^2, m^3, etc.)

Upon obtaining the data sample from the first analysis, a table was drawn. The first column contained the data regarding the system characteristics (capacity or dimension, height, volume, pipe length, etc.), which correspond to the independent variable (X). The second column contained the information regarding the updated cost/updated unit cost, which corresponds to the dependent variable (Y). For example: capacity vs. CAPEX, cut volume vs. cost, foundation area vs. cost, underdrain pipes length vs. cost, etc.

Statistical software Microsoft Excel 2021 was used to determine the mathematical models for cost functions that depend on a single variable (Valentin, 2022), for which purpose the data obtained from the data processing was input. Thus, after verifying their statistical validity, functions were obtained for each group of data according to each system of the leach pad; therefore, the cost function obtained has the highest correlation coefficient among the various charts that could be obtained using Excel. In addition, charts with a correlation coefficient (R^2) lower than 0.7 were discarded based on the fact that the data set has a medium or strong level of dispersion. An example is shown in Figure 2.

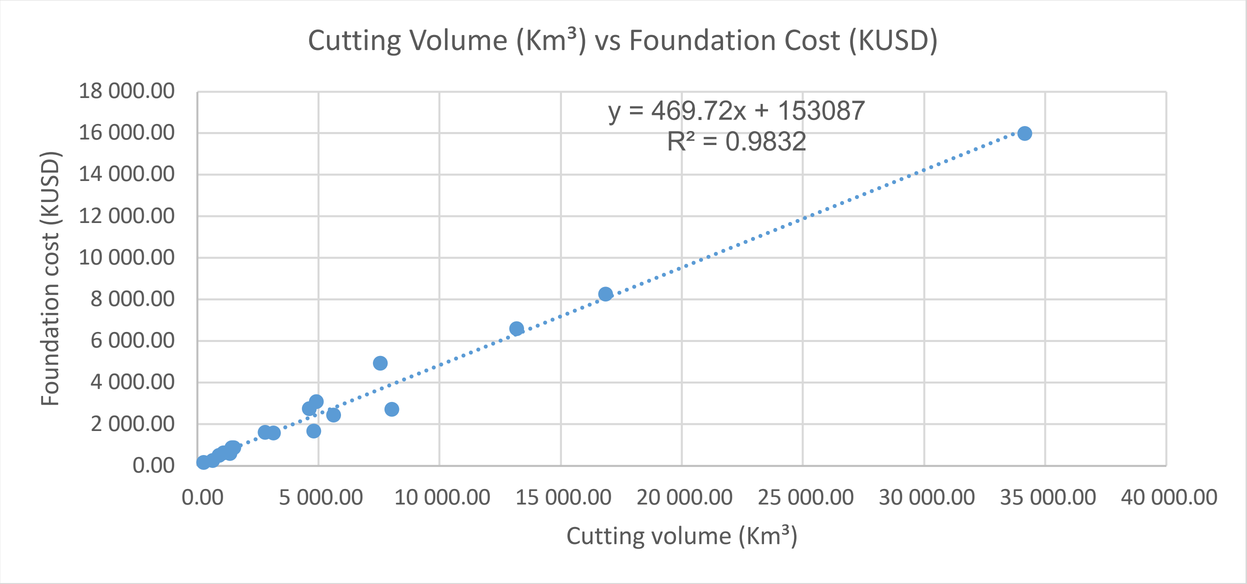

Figure 2: Example of one variable cost function

Similarly, GMDH Shell 3 software (Koshulko, 2022) was used to establish a correlation between more than two variables, where a number of variables were input and iterated to obtain an equation for several variables with a good correlation according to parametric estimation standards (Hastak, 2015). Functions with a correlation coefficient (R^2) lower than 0.7 were also discarded. An example is shown in Figure 3.

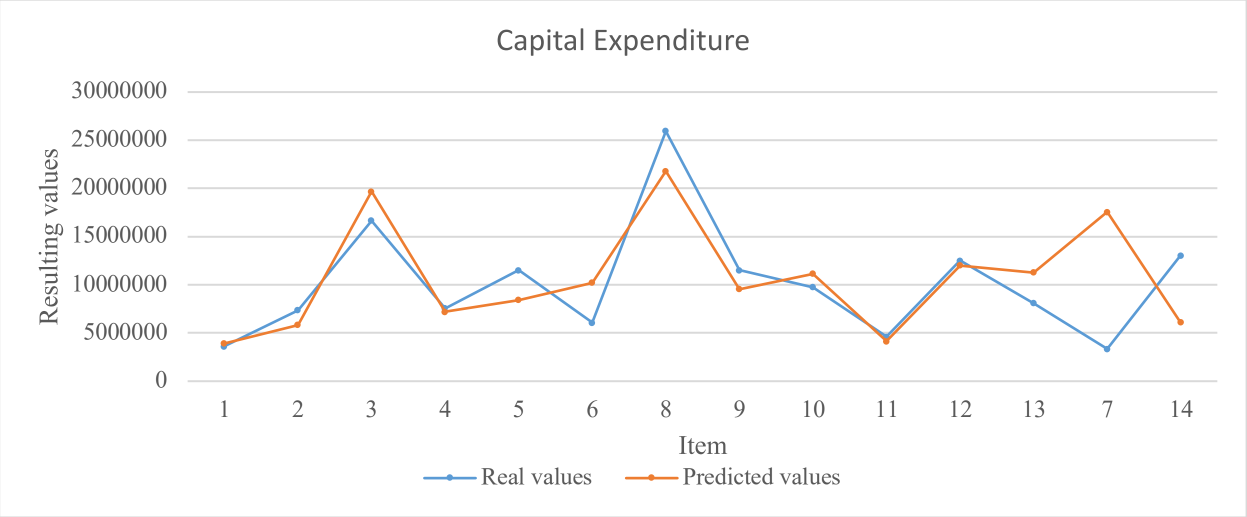

Figure 3: Example of many variables cost function

Results

After obtaining the representative values, regression was determined to obtain the cost function formula for each component found in the projects analyzed, resulting in the cost functions shown in Table 1. From the data analyzed, 16 cost functions with an adequate correlation were determined, as shown in Table 1.

Table 1: Cost functions

Item	Components of the system	Parameter	Unit	Cost function	Type of function	R^2
1	FOUNDATION					
1.1	Cost of foundation cut	Volume, V	m^3	4.6972V + 153087	Linear	0.98
1.2	Cost of foundation cut	Area, A	m^2	C=-9E-15A4+5E-09A^3-0.0009A^2+48.709A+460428	Polynomial	0.75
1.2	Volume for foundation	Site area, Asite Average Df, Df Area of foundation, Af	m^2	-7.46719e-09 + 730476*A*6.69275e-07 + A*0.511111 A = –44133.5 + Asite*B*4.61247e-06 B = 316330 + Df*C*0.0950892 C = 305429 - ((58280 + Df^2*28859.5 + Af*0.46544))*((251827 + Df^2*29571))*6.60125e-07 + ((158280 + Df^2*28859.5 + Af*0.46544))^2*9.91017e-07	Polynomial	0.95
2	GRADING					
2.1	Cost of cut	Volume, Vcut	m^3	7.93Vcut – 402886.26	Linear	0.93
2.2	Cost of fill	Volume, Vfill	m^3	5.37Vfill + 891945	Linear	0.81
3	UNDERDRAIN					
3.1	Total cost of piping	Pipe length, L	m	0.0002L^2 + 29.74L – 32325.70	Quadratic	0.89
3.2	Cost of installation	Pipe length, L	m	0.0007L^2 + 3.9923L – 1528.7	Quadratic	0.92
3.3	Cost of procurement	Pipe length, L	m	-0.0005L^2 + 25.754L – 30797	Quadratic	0.93
3	COLLECTION					
3.1	Number of pipes	Max. slope area of 10%, Ar	m^2	1.29E-06Ar^2 + 0.057Ar + 6222.55	Quadratic	0.88
3.3	Total cost of piping	Pipe length, L	m	-0.0002 L^2 + 31.391L – 16740	Polynomial	0.67
4	LINER					
4.1	Total cost of liner	Lined area, Alined Area greater than 25%(GCL), A25	m^2	229265 + A25*11.654 + Alined*7.10	Polynomial	0.86
5	OVERLINER					
5.1	Cost of overliner placement	Volume, V	m^3	y = 2E-05V^2 + 2.2454V + 498514	Polynomial	0.93

Item	Components of the system	Parameter	Unit	Cost function	Type of function	R^2
5.2	Cost of overliner placement	Lined area, Alined Area greater than 25%, A25 Area greater than 40%, A40	m^2	Alined*3.11 –13.8*A40 + A25*23.11 + 1093981.3	Polynomial	0.59
6	CAPEX					
6.1	CAPEX	Site area, Asite Lined area, Alined Average Df, Df Site area>40%, Asite40		Y1 = 1.74215e-07 - Asite*2.8135e-12 + "A"*1 "A" = 1.3689e+06 + "B"*1.11307 - "D"*0.244371 "B" = -4.04774e+06 + Df*2.16951e+06 + "C"*0.994604 "C" = 2.02666e+06 - Asite40*69.7453 + Alined*80.2128 "D" = 1.92584e+06 + Asite*20.7416 + "E"*0.387097 "E" = 3.14215e+06 + Asite*33.8416	Polynomial	0.82
6.2	Site area	Volume, V Gorge length, L Crest area, Acrest		-27855 - V*9826.86 + A*1.52949 A = -29609.4 + L*60.9164 + B*0.967463 B = 100803 + V*18908.7 - Acrest*13893.3	Polynomial	0.85

Conclusions and recommendations

The cost functions obtained provide an order of magnitude estimate of the potential costs associated with the construction of a heap leach pad project. Said functions have a good correlation and were obtained using a single variable. Nonetheless, several variables can be considered, such as the classification of areas according to a set range of slope gradients to obtain a function to determine a rough estimate of the cost.

The costs associated with the most frequent activities performed during the construction of a heap leach pad such as foundation, grading, underdrain, solution collection, liner, and overliner were obtained in this research.

The development of cost functions is applicable for Class 4 and 5 estimates in accordance with the cost-estimate classification system established by AACE International (Bredehoeft et al., 2019). It constitutes a baseline to achieve accuracy in cost estimates ranging from –50% to +100% variance.

It is recommended to use the largest possible source of data to broaden cost functions, not only for the location of a new mine or its expansion on typical Andean areas of Peru, but also considering the complexities and unique characteristics of each region in the world, such as Latin America and North America, among others.

It is recommended to look for different variables, as well as the various correlations existing between them, using methodologies focused on data analysis such as neural networks.

Although cost functions presented in this paper are limited, it is advisable to conduct research on this subject to serve as tools in the mining industry and provide benefits from the conceptual engineering level, and thereby save time and resources during the engineering stages of the project.

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