An Exploratory Factor Analysis on Issues and Constraints in Sri Lankan Aggregate Quarry Industry

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Abstract

Mining activities are influenced by stakeholders such as regulators, operators, service providers, customers, residents, and other interest groups. The governing bodies seem to fail to adopt a stakeholder inclusive approach to gain the balance between the interest of the stakeholders and the organisational plans and revenues. Such issues are known at the surface level, but no solid quantitative approach has been used to scientifically prove their existence and associations. Thus, this study aims to find the issues with statistical evidence. Convenient sampling was used due to time restrictions and new work norms to pick a substantial number of respondents. A numerical assignment and logical ordering to qualitative data were done to perform the quantitative analysis. Factor analysis was used to find the principal components and the variables which mainly loaded the components showed significant interpretable correlations. The most significant factors associated with issues in quarry operations and management are found in terms of quality, reliability, and usage of monitoring, application of safety measures, quarry type based hazardous conditions, planning and maintaining quarry activities, combatting drilling issues via site planning, use of initiation technique by quarry type, the impact of environmental and social issues, handling public complaints and strategies to improve quarry operations.

Keywords: Correlations, Principal components

1. Introduction

Quarrying is a branch of surface mining method that is used to extract minerals. By the end of 2019, Geological Survey and Mines Bureau (GSMB) had issued 3918 valid mining licenses, out of which 1812 were representing aggregate quarries. Western and Northwestern provinces have marked 25.88% and 20.31% out of the total quarries licensed in Sri Lanka. Mining and quarrying activities account for Rs. 358,287 million from Gross Domestic Product at Current Market Prices in 2018, showing a 2.1% growth compared to 2017 [1]. Aforesaid statistics reveal that there is a significant contribution by mining and quarrying to the economy of the country.

Quarries are categorised considering the type of their mining license and the minerals that they mine by the GSMB. However, quarries can be characterised by the development concept, category of the mining licenses, and the absolute land right of the mine.

The mining industry has a wide range of stakeholders, including regulators, operators, service providers, customers, residents, and other interest groups. However, in the execution of its governance role and responsibilities, the governing body should adopt a stakeholder-inclusive approach that balances the concerns, interests, and expectations of material stakeholders in the best interests of the organisation over time.

Procedural complications will accompany the operational complications. 20-30% of energy dissipated by explosives is directed to rock fragmentation, and the rest is wasted as ground vibration (GV), air blast overpressure (ABOP), noise, and fly rocks [2]. Guidelines have been formulated to determine the safe levels of blasting vibrations to minimise the damage by GV, ABOP, and annoyance.

Generally, issues will emerge when the provided guidelines are not managed and when those are not feasible for every quarry due to site-specific conditions and more. Apart from that major technical, procedural, environmental, and sociological aspects will generate issues and constraints for the operation of a quarry in many ways. Issues and constraints in the aggregate quarrying industry are known, but the extent of existence and the distribution of them are not analysed properly, and no solid quantitative approaches have been taken to scientifically prove the existence of the issues with their interrelations [3]. This research paper will explore the extent of existence, interrelations of the known issues, and the underlying traits which have not been exposed yet.

2. Methodology

2.1 Data collection

A questionnaire was developed to collect the opinions of the stakeholders. Most of the questions in the questionnaire were made available with multiple choices with comprehensive answering options, which made the questionnaire more familiar to the respondents.

Intending to collect responses from the mining operatives (mining engineers/ managers/ owners), the questions were reordered rationally into two clusters, namely technical aspects and general opinion. The questionnaire consists of 38 questions, out of which the first 8 questions were informative, and the rest of 30 questions were classified orderly into aforesaid clusters.

The google form-based questionnaire was intended to reach the mining engineers/ managers and owners to collect opinions of them regarding the issues and constraints in the aggregate quarrying industry.

Data collection was carried out not only through online services (Google Form) but also by interviews through mobile phone calls (most of the quarry owners). The respondents were asked the same questions in brief, and the required data was collected contemporarily.

Altogether from the online surveys as well as from interviews over the phone, it was able to collect 67 responses within the time frame.

2.2 Sampling plan

The sampling plan was developed considering the quarry categorisation criteria in Figure 1. Quarries were classified by considering the license type, absolute ownership of the land, and development type of the quarry.

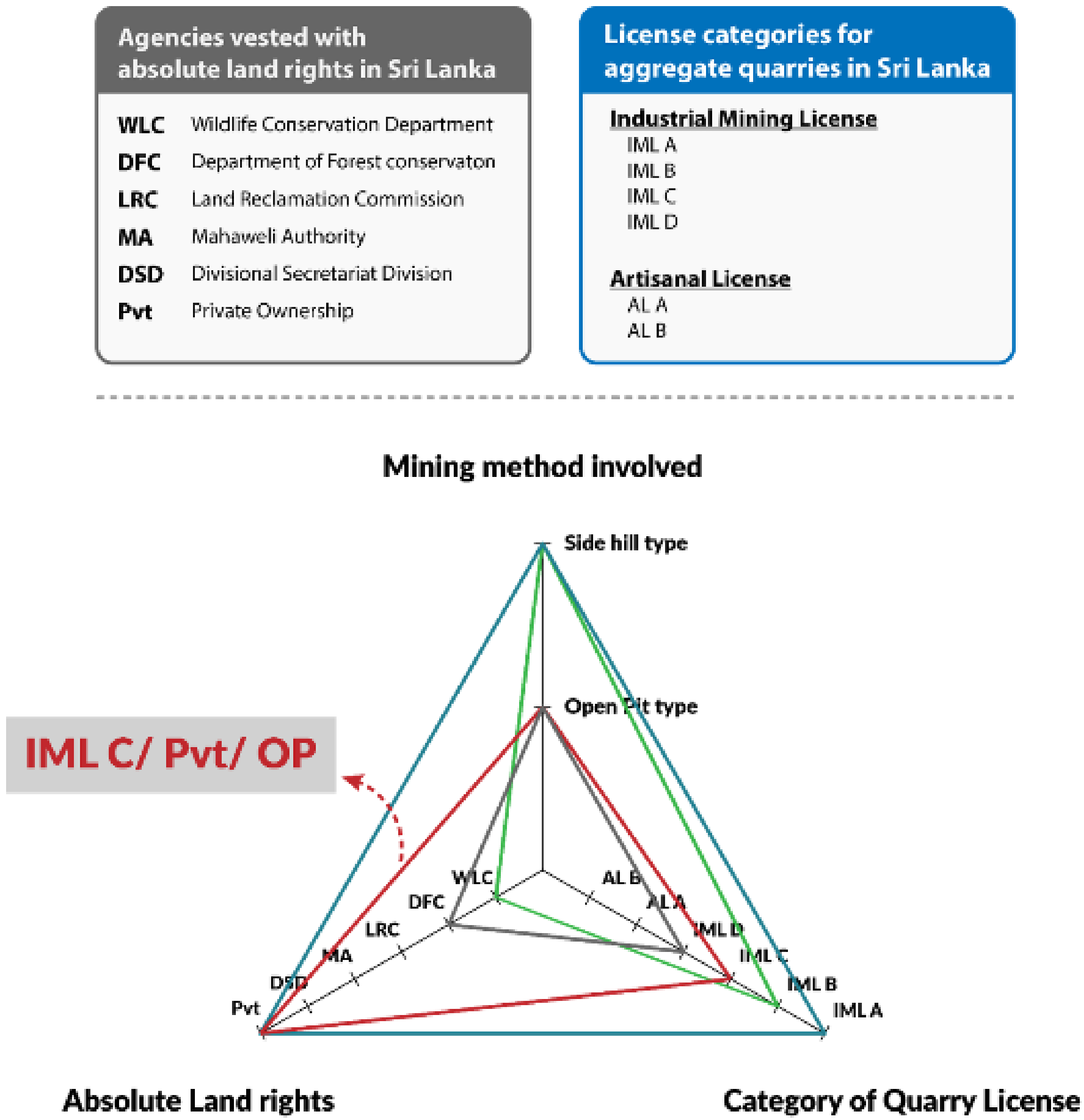

Figure 1: Quarry categorisation criteria.

The total sample size was determined using the "Table for Determining Sample Size for a Finite Population" [4]. It was planned to apply a multistage stratified random sampling technique to gather data from stakeholders. This sampling plan was intended to launch in two stages to select the quarries and the stakeholders.

Stage 1: Sampling by quarry type

The population is classified into 72 substrata according to quarry categorisation criteria in Figure 1; the sample size from each substratum is calculated, proportioning the stratum to the population. Then the sample is selected from each substratum utilising simple random sampling technique.

Stage 2: Sampling by the stakeholder

A selected quarry from sampling stage 1 will undergo steps in sampling stage 2.

The following factors were considered in stage 2.

i. Operators are limited in number, so that no sampling was done.

ii. Environmental activists in the region were considered.

iii. Regulators are regional.

iv. The residents around active zones need to be determined by site investigation. A residential population for each quarry must be identified within a radius of 0.3km from the quarry site. Adhering to that sample frame, a random sample of residents can be determined.

NB: Instead of the described two-stage stratified random sampling, convenient sampling had to be used, obeying the work norms and time restrictions due to the pandemic situation.

2.3 Quantifying responses

Questions were constructed in a strategic way whilst their answering options were ordered with logical reasoning. Then the responses received were treated as ordinal, and the principal component analysis was successfully performed. As the first step of quantifying data, a numerical assignment was done to the responses, as shown in Table 1.

Table 1: Quantifying Question 1

Q1. How frequently are the production blasts conducted at your site?	
Responses	Ordinal Value
Daily basis	1
Several times a week	2
Once a week	3
Once in a few weeks	4

2.4 Data Analysis

The factor analysis was performed using ordinal data and extracted the required principal components. Their factor loadings indicated the contribution to each principal component by the questions. Thus, the correlations were examined only between the questions identified with the highest factor loadings within each principal component. Correlation analysis was done at a 5% significance level.

Factor analysis was carried out for 10 classes of questions that correspond to the concerns under analysis, as shown in Table 2.

Table 2: Variables of Class 1

Class 1	Frequency of blasting / GV and ABOP monitoring (Significant overlapping check)
Var. No	Variable
1	Frequency of production blasts conducted at a site
7	Frequency of monitoring Ground Vibration (GV) due to quarry operations
8	Frequency of monitoring Air Blast Over Pressure (ABOP) due to quarry operations
10	Vibration monitoring mechanism in the site
11	Type of monitoring activities
12	Quality and management of the vibration and air blast overpressure measurements

3. Results and discussion

3.1 Factor Analysis

Quantitative statistical analysis was performed to identify the factors underlying the variables. The correlations between the components/variables which contributed highly towards composing factors under each class of variables are used for interpretations. The following data shows the results of the factor analysis. The results of factor analysis of variables under class 1 only are listed and explained below in detail.

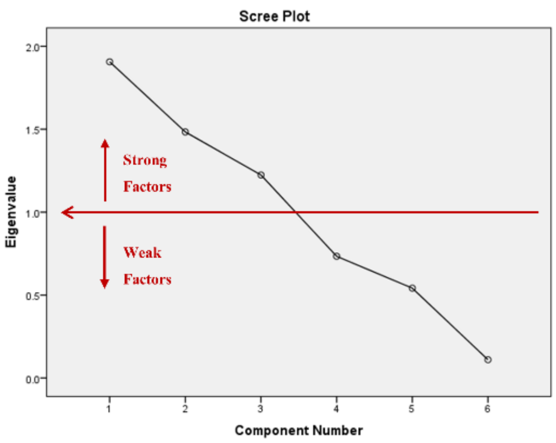

Figure 2: Scree plot for the components (Class 1)

Class 1

Extraction Method: Principal Component Analysis

Principal component analysis extracts strong factors with high loadings which are expected to represent real underlying factors. In Table 3, components with eigenvalues greater than 1 are shown with a name for the latent factor. The low eigenvalues are not assumed to represent real factors underlying the traits in the quarrying industry.

Table 3: Class 1 Total Variance explained.

Component	Extraction Sums of Squared Loadings		
	Eigen Value	% of Variance	Cumulative %
1-Monitoring Quality	1.907	31.776	31.776
2-Reliability of Monitoring	1.483	24.724	56.500
3-Usage of Monitoring	1.224	20.403	76.903

76% of the total variability of the data gathered under the 6 variables is explained by the three principal components extracted, as shown in Table 4.

Following Figure 2 clearly shows the difference between the eigenvalues associated with components.

Table 4: Class 1 Correlations Matrix.
**Correlation is significant at the 0.05 level.*

		V1	V7	V8	V10	V11	V12
V1	Pearson Correlation	1	0.166	-0.018	0.258	-0.237	0.034
	Sig. (2-tailed)		0.175	0.885	0.055	0.055	0.784
	N	68	68	67	56	66	67
V7	Pearson Correlation	0.166	1	0.860*	0.152	0.000	0.121
	Sig. (2-tailed)	0.175		0.000	0.263	0.998	0.331
	N	68	68	67	56	66	67
V 10	Pearson Correlation	0.258	0.152	-0.004	1	0.087	0.419*
	Sig. (2-tailed)	0.055	0.263	0.977		0.522	0.001
	N	56	56	55	56	56	56

Table 5: Component matrix of class 1.

	Component 1	Component 2	Component 2
V1	0.141	0.311	**-0.762**
V7	**0.958**	-0.164	-0.019
V8	**0.923**	-0.289	0.104
V10	0.252	**0.795**	-0.148
V11	0.021	0.288	**0.749**
V12	0.231	**0.750**	0.222

After examining the three factors, according to the factor loadings, the most important variables were recognised and followed to look at their relationships through a correlation analysis. The following matrix shows the correlations, which were significant at the 0.05 level.

The highest contributions were made by variables 7 and 8 on composing component 1: Monitoring Frequency. The significant correlation between V7 and V8 (0.860) indicates that when the ground vibration monitoring frequency increases, the frequency of air blast overpressure monitoring has also been increased. Variables 10 and 12 have made the highest loading on the second component: Quality of Vibration Monitoring Management. It reveals that by using a regulated monitoring mechanism, the sites tend to obtain reliable data. Consequently, their decision-making has been effectively supported by these data. Although V1 and V11 make the major contribution to defining the third component: Usage of Vibration Monitoring, they do not depict any significant relationship between the two variables.

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In general, the above-mentioned monitoring exists in IML A quarries where a mining engineer is essentially occupied. Thus at these sites, they will monitor ABOP and GV and adjust their specific charge suiting to the local conditions using the given limits as reference under a mining engineer's observation.

3.2 Summary of Findings

i. The existing regulatory guidelines and procedures seem not to be conducive for quarry operations even though they are highly influential and controlling.

ii. The stability of rock slopes is more important than maintaining design parameters for the quarries at which mining activities are continuing based on site conditions and production requirements.

iii. Lack of induction and training for employees regarding their work responsibilities and practices at quarry sites leads to malpractices.

iv. Stable quarry slopes and regularly updated site-specific blasting parameters are common in the sites where mining engineers are present.

v. The fact that the public complaints on vibration and fly rocks become high when the blasting frequency increases is contradicted to a considerable extent by the responses received regarding public complaints by the quarry owners.

vi. Public complaints are found to be false and are made to receive compensation mostly at the sites where the blasting frequency is comparatively low.

vii. IML B and C categories rely more on annual monitoring compared to the A category, which conducts frequent monitoring. This reflects that they do not tend to analyse the effects of ABOP and GV on the surroundings unless any issues occur since they focus mainly on production.

viii. Environmental and social issues can be highly influential to the quarry operations as environmental issues amplify the social issues.

ix. Although all the mining entities are complying with the permitted initiation mechanisms provided by the license conditions, they still face practical issues while adopting and maintaining such practices.

x. Misfires and hazardous conditions in IML C quarries are mostly due to the malfunctioning of fuse caps.

5. Conclusion

The most significant factors associated with identifying traits in the mining industry are,

- Monitoring Quality.
- Reliability of Monitoring.
- Usage of Monitoring.
- Application of safety measures.
- Quarry type-based hazardous conditions.
- Planning and maintaining quarry activities.
- Combatting rock drilling issues via site planning.
- Use of initiation technique by quarry type.
- Impact of environmental and social issues.
- Handling public complaints.
- Strategies to improve quarry operations.

6. Recommendations

Any researcher can take the listed factors, in conclusion, to investigate more on the traits faced by the mining industry in detail along the prioritised dimensions with reference to any selected group of quarries.

By regulations, there are restrictions on the amount of production per month that a licensed quarry should comply with [5]. If any effort is taken to exceed the prescribed amount, that will be considered as a violation of the law.

i. Engineers should monitor and assess the harm caused by altering the design parameters.
ii. Production management plans should be formulated.
iii. Try not to enter contracts that request production levels that the quarry cannot cater for.
iv. Change the design parameters by keeping the guidelines by GSMB as the reference.
v. In-house training programs should be initiated to train the employees for specific jobs.
vi. People should be hired not in relation but with suitable skills.
vii. New recruitments should be done checking whether the candidate possesses a training certificate related to mining or heavy machinery.

Acknowledgement

We express our heartfelt gratitude to the Geological Survey and Mines Bureau staff members who helped us with the necessary information for the study. We would like to thank the Department of Earth Resources Engineering, University of Moratuwa, for facilitating this research.

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