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Research Paper

# Introducing a Holistic Framework for Assessing the Performance of Sustainable Mine Development Based on the SBSC and FANP Approaches

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***Abstract:*** This study presents a tool for evaluating sustainable development in the mining industry. We identified indicators related to four dimensions: growth and learning, economy, environment, and society. A total of 75 primary indicators were determined. Indicators with a mean weight of over 3.6 were considered suitable, resulting in the selection of 28 final indicators. The top-ranked indicator was "number of lost days" with a mean weight of 10.9, followed by "total amount of waste produced" with a mean weight of 7.73. The indicators of "waste management" and "efforts to restore the mine" had mean weights of 5.9, ranking third. To assess the weight of each dimension in evaluating sustainability performance, the researchers used the FANP method and a pairwise comparison questionnaire. The inconsistency rate of the pairwise comparisons, estimated using the Gogos and Butcher's method, was below 0.1 for all questionnaires, indicating consistency. The results showed that the "growth and learning" dimension had the highest mean weight of 0.48, followed by the "community" dimension with a mean weight of 0.24. The "environment" dimension ranked third with a mean weight of 0.22, while the "economy" dimension ranked fourth with a mean weight of 0.16 among all dimensions.

***Keywords:*** Sustainability balanced scorecard (SBSC), Sustainability report, Fuzzy Delphi technique, Fuzzy network analysis, Fuzzy pairwise comparisons.

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## INTRODUCTION

The pursuit of economic benefits in industrial development has resulted in significant environmental and social problems. To address these challenges, the concept of sustainable development has emerged, encompassing economic, environmental, and social dimensions. The mining industry, which supplies materials for various sectors, faces numerous developmental challenges related to mineral extraction and exploitation. Effective performance control is crucial in strategic matters like sustainable development [1].

Different models have been employed to evaluate performance, including ISO14031, GRI, BSC, AHP, ANP, and Composite Index, each with its own approach to sustainability performance evaluation [2]. Among these models, the Balanced Scorecard (BSC) has gained considerable attention due to its international experience and practical success [3]. The BSC is a comprehensive framework that uses quantitative criteria aligned with an organization's strategies to establish connections between macro objectives, quantitative measures, goals, plans, and initiatives. Modified versions of the original BSC, which explicitly incorporate environmental, social, or ethical considerations, are often referred to as a Balanced Scorecard for Sustainability (SBSC). The SBSC framework addresses the essential requirements of sustainability, enabling continuous improvement in business performance and facilitating the implementation of organizations' strategic environmental and social objectives.

## METHODS

### Determining the perspectives of SBSC

The perspectives of sustainability, namely economic, environmental, growth and learning, and social perspectives, were identified based on an extensive review of relevant research literature and the primary objective of this study.

### Selecting the indicators for each perspective

The selection of performance criteria is a challenging task in developing performance measurement systems (PMSs). To identify indicators for each of the four main perspectives of SBSC, a comprehensive literature review was conducted. Additionally, performance reports from four organizations (Ayandeh Bank's Sustainability Performance Report 2016, SSR Mining's Sustainability Report 2018, FORTUNA Silver Mines INC's Sustainability Report 2018, and Endeavor Mining's Sustainability Report 2017) available on the Global Reporting Program website were analyzed. The Environmental Performance Indicators Guideline for Organizations developed by the Japanese Ministry of the Environment was also utilized. As a result, a total of 75 primary indicators were identified.

### Screening and selecting indicators using a questionnaire and experts' opinions

Data collection involved the use of an employee questionnaire that incorporated 75 indicators as checklist tools. These indicators were categorized into four dimensions: "learning and growth", "social", "economic", and "environmental", which included 4, 18, 11, and 42 sub-criteria, respectively. The expert panel was then provided with the indicators to provide their opinions on each indicator using the verbal variables included in the questionnaire. Table 1 presents the linguistic terms and their corresponding fuzzy numbers.

To screen the indicators from the fuzzy average column, we calculated the geometric mean values (which were equal to 2.56, 3.84, and 4.45) and the non-fuzzy number of this result (i.e., 3.6). Therefore, indicators with an average of less than 3.6 were excluded. Table 2 compares the number of indicators before and after the experts' opinions.

**Table 1.** Linguistic Terms and Fuzzy Delphi Numbers

| Linguistic term | Triangular fuzzy numbers |
|---|---|
| Highly unsuitable | (0, 0, 0.25) |
| Not suitable | (0, 0.25, 0.5) |
| Moderately suitable | (0.25, 0.5, 0.75) |
| Suitable | (0.5, 0.75, 1) |
| Highly suitable | (0.75, 1, 1) |

**Table 2.** Comparison of the number of indicators before and after experts' opinions

| Row | Perspective | Number of indicators in each perspective before the experts' opinions | Number of indicators in each perspective after the experts' opinions |
|---|---|---|---|
| 1 | Growth and learning | 4 | 2 |
| 2 | Social | 18 | 7 |
| 3 | Economic | 11 | 5 |
| 4 | Environment | 42 | 14 |
| Total | | 75 | 28 |

**Ranking the perspectives**

Based on the identified sustainable performance evaluation indicators in mining and mineral industries, we now rank the SBSC and the identified perspectives using the Fuzzy Analytic Network Process (FANP) method. We designed paired comparison questionnaires and distributed them among experts to achieve the research goal. According to the fuzzy approach in this research, verbal terms and fuzzy numbers listed in Table 3 were used.

**Table 3.** Fuzzy set scale and the corresponding verbal term

| Definition | Triangular fuzzy numbers | Crisp number |
|---|---|---|
| Equal superiority | (0, 0, 0.25) | 1 |
| Low superiority | (0, 0.25, 0.5) | 3 |
| Moderate superiority | (0.25, 0.5, 0.75) | 5 |
| High superiority | (0.5, 0.75, 1) | 7 |
| Very high superiority | (0.75, 1, 1) | 9 |

**Validity and reliability of the questionnaire**

To assess the validity of the questionnaire, experts' opinions were utilized. The questionnaire employed paired comparisons, and the concept of inconsistency rate was employed to measure its reliability and validity. The Gogos and Butcher's inconsistency rate method was employed for this purpose.

**Evaluating the consistency rate of pairwise comparison matrices**

Before calculating the weights of the perspectives, we need to ensure the consistency rate of the opinions. It is better to include the opinions of different decision-makers in the group calculations when the inconsistency rate of the opinions of each decision-maker is less than 0.1. If the inconsistency rate is less than or equal to 0.1, there is consistency in pairwise comparisons, and the process can be continued; otherwise, the decision-maker should revise the pairwise comparisons. The matrix consistency shows the extent to which the priorities specified in the matrix are reliable. In other words, the matrix will be inconsistent if the equation aik * akj= aij is not true for each of i, j, and k. All the questionnaires used in the analyses were found to be consistent.

**Determining the geometric mean of the pairwise comparisons matrices to determine the final fuzzy weight and the final crisp weight of each perspective**

To mitigate any biased attitudes, a group decision-making approach was employed to form the paired comparison matrix. The geometric mean method was used to incorporate the attitudes and judgments of the group members in this matrix. The details of the paired comparisons, including the attitudes and judgments of the group members, were not included in the table due to its extensive nature. By calculating the geometric mean for each matrix array, pairwise comparisons of the criteria were obtained. Subsequently, by normalizing the geometric mean matrix of pairwise comparisons and calculating the geometric mean of each row, the weights of the perspectives were determined. Tables 4 and 5 present the geometric mean matrix of pairwise comparisons and its normalized values.

**Table 4.** The geometric mean of pairwise comparisons

| | Growth and learning | Environmental | Social | Economic |
|---|---|---|---|---|
| Economic | (0, 0.38, 0.64) | (0, 0.57, 0.84) | (0, 0.52, 0.75) | (0, 0, 0.25) |
| Social | (0, 0.56, 0.8) | (0, 0.42, 0.68) | (0, 0, 0.25) | (0.6, 0.8, 1) |
| Environmental | (0, 0.4, 0.66) | (0, 0, 0.25) | (0.5, 0.16, 0.95) | (0, 0.56, 0.78) |
| Growth and learning | (0, 0, 0.25) | (0, 0.5, 0.69) | (0.64, 0.89, 1) | (0, 0.59, 0.83) |

**Table 5.** Normalization of the geometric mean matrix of pairwise comparisons

| | The first normalized column | The second normalized column | The third normalized column | The fourth normalized column |
|---|---|---|---|---|
| Economic | (0.42, 0, 0) | (0.66, 0.34, 0) | (0, 0.39, 0) | (0, 0, 0) |
| Social | (1.67, 0.42, 0.23) | (0.22, 0, 0) | (0, 0.29, 0) | (0, 0, 0) |
| Environmental | (1.3, 0.29, 0) | (0.84, 0.1, 0.17) | (0, 0, 0) | (0, 0, 0) |
| Growth and learning | (1.39, 0.3, 0) | (0.88, 0.57, 0.22) | (0, 0.34, 0) | (0, 0, 0) |

Table 6 presents the weights of the four main criteria of the BSC calculated using the FANP method. The relative weight of the perspectives of sustainability, which is equal to the geometric mean of each line, was achieved in a fuzzy manner as given in the Table 6:

**Table 6.** Final weight of the perspectives of SBSC

| Perspective | Average fuzzy final weight | Average finalized crisp weight |
|---|---|---|
| Economic | (0.27, 0.19, 0) | 0.16 |
| Social | (0.48, 0.18, 0.06) | 0.24 |
| Environmental | (0.6, 0.01, 0.04) | 0.22 |
| Growth and learning | (0.57, 0.3, 0.55) | 0.48 |

**Determining the sustainability weight**

The final weight of each perspective was calculated by multiplying the fuzzy weight of the perspectives of SBSC to the scores of the indicators.

$$\text{Scores of indicators*weight of perspectives = weight of sustainability} \quad (1)$$

**FINDINGS AND ARGUMENT**

The main objective of this study was to identify, rank, and assess the factors influencing sustainability and develop a comprehensive model for evaluating sustainability performance in the mining industry. The study aimed to address challenges such as the lack of standards, information validity, bias, transparency, and independence in sustainability rating. By adopting the Sustainable Balanced Scorecard (SBSC) with economic, social, environmental, and growth and learning perspectives, this study contributed to the literature by providing an advanced theoretical model for sustainability performance measurement.

Fuzzy sets were employed in this research to align with linguistic and human explanations, using triangular fuzzy numbers. Additionally, the fuzzy network analysis method was utilized to rank the factors affecting sustainability. Through a literature review, 75 primary indicators related to the four main perspectives of SBSC were identified. Experts were consulted to analyze the factors affecting sustainable performance in the mining industry using a questionnaire. Eventually, the indicators were evaluated for research ability and relevance, and 28 indicators were selected as the final indicators based on an average weight threshold of 3.6.

The weight of each perspective in evaluating sustainability performance in the mining industry was determined using the Fuzzy Analytic Network Process (FANP) method and the paired comparison questionnaire. The reliability and validity of the questionnaire were assessed using the concept of inconsistency rate, which was found to be consistent with values lower than 0.1. The evaluation of sustainability performance indicators in the mining industry revealed that among the SBSC indicators, “number of lost days”, “total number of production waste”, “waste management”, and “effort to reconstruct the mine” ranked as the top indicators with mean weights of 10.9, 7.73, and 5.9, respectively. The “growth and learning” perspective had the highest mean weight of 0.48, indicating its superiority over the other perspectives. The social, environmental, and economic perspectives ranked second, third, and fourth, respectively, with mean weights of 0.24, 0.22, and 0.16.

## CONCLUSION

In conclusion, this study aimed to identify, prioritize, and assess factors influencing sustainability in the mining industry and proposed a comprehensive framework for evaluating sustainability performance based on the SBSC model. The findings indicated that the “number of lost days” and “total number of production waste” were significant indicators. The “growth and learning” perspective exhibited the highest level of sustainability, followed by the “society”, “environment”, and “economy” perspectives. However, the research has limitations regarding sustainable development indicators and the lack of comprehensive research in the mining sector. The reliance on the opinions of company managers and experts also poses limitations in terms of comprehensiveness. It is recommended to replicate the study in organizations operating in similar industries to facilitate comparisons.

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