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専攻分野の名称	博士（資源学・理学・工学）
学 位 記 番 号	国博甲第 21 号
学位授与の日付	令和 6 年 3 月 22 日
学位授与の要件	学位規則第 4 条第 1・2 項該当
研 究 科 ・ 専 攻	国際資源学研究科・資源学専攻
学位論文題目（英文）	Application of Artificial Neural Network for the Prediction of Mineral Ore Grades・・・ (人工ニューラルネットワーク法を用いた鉱石品位の予測…)
論 文 審 査 委 員	（主査）教授 TSUYOSHI ADACHI （副査）教授 TADAO IMAI （副査）教授 ATSUSHI SHIBAYAMA

論文内容の要旨

Mineral ore grade estimation is a critical process in the mining industry, involving the assessment of the concentration or quality of valuable minerals within an ore deposit. Accurate grade estimation is essential for several reasons, including resource evaluation, mine planning, optimization of extraction methods, and economic feasibility studies. Here, we discuss mineral ore grade estimation, its limitations, and the potential of artificial neural networks (ANNs) and machine learning algorithms in improving grade estimation. Accurate grade estimation influences investment decisions and determines the economic viability of mining operations. It helps in optimizing resource extraction, reducing waste, and increasing resource recovery. Precise grade estimation contributes to minimizing the environmental impact of mining activities. Conventional methods such as geometric and geostatistical are the most popular techniques in mineral resource estimation, but they fail to capture the complexity of the orebody. Ore deposits are often characterized by complex spatial variability, making it challenging to interpolate grades accurately. Data from drilling and sampling may be sparse and irregularly distributed, leading to uncertainty in grade estimation. Additionally, human interpretation and judgment in conventional methods can introduce subjectivity and errors. Due to these limitations, the grades are incorrectly estimated leading to inaccurate mine plans and costly financial decisions.

The advancements in technology have shown an immense potential of machine learning (ML) algorithms over other interpolation techniques for ore grade estimation because artificial neural networks (ANNs) and machine learning algorithms can handle large and complex datasets, capturing nonlinear relationships and patterns that may be missed by conventional methods. These algorithms can automatically select relevant features, improving the accuracy of grade estimation by focusing on the most influential factors. ANNs and machine learning algorithms can achieve high levels of accuracy, reducing the risk of costly errors in mining operations. Furthermore, machine learning models can be continuously updated with new data, allowing for real-time grade estimation and adjustment of mining plans. ANNs and machine learning algorithms

offer a promising alternative by leveraging their data-driven, spatial modeling, and feature selection capabilities, ultimately improving the precision and reliability of grade estimation in the mining industry.

In this study, we propose ore grade prediction using artificial neural network for copper and gold grades. Fourteen thousand, two hundred and ninety-four (14294) datasets were collected from Jaguar mine in Western Australia. First, the proposed model was developed by incorporating lithology, alteration, eastings, northings, altitude, dip, and azimuth to predict the copper ore grade. The performance evaluation metrics were measured based on mean absolute error (MAE), mean square error (MSE), root mean square error (RMSE) and coefficient of determination (R^2) and ANN model outperformed the classic machine learning methods s with R^2, R, MAE, MSE, and RMSE of 0.584, 0.765, 0.0018, 0.0016, and 0.041, respectively. The Shapley technique was conducted to evaluate the feature importance of the input parameters on copper ore grade prediction. Lithology demonstrated the highest influence on ore prediction while the eastings showed the less impact on the output. This proposed approach is promising in ore model predictions.

The study then shifts the attention to the prediction of gold ore grade. We present a multilayer feed-forward artificial neural network that incorporates correlation coefficient feature selection methods for estimating gold ore grade. The study aims to identify the critical features or variables that can enhance the accuracy of predicting gold ore grade using artificial neural networks (ANNs). By pinpointing these important features, the research seeks to reduce prediction errors and improve the overall performance of the model. The feature selection method yielded six significant input features, namely lithology, alteration, dip, azimuth, and the coordinates X and Z, and these essential features were used to train the ANN model for the prediction of gold ore grade. A comparative analysis was conducted to evaluate the performance of predictive models with and without feature selection. The performance of the ANN model was assessed using various metrics, including the correlation coefficient, mean absolute error, mean square error, and root mean square error. The findings indicate that the ANN model with feature selection exhibited superior performance compared to the model without feature selection with R, MAE, MSE, and RMSE, of 0.720 ,0.264,0.374 and 0.653 respectively. In addition to improving model accuracy, the correlated features model had lower computing efficiency. This comparison provides valuable insights into the actual benefits of using feature selection techniques in tasks related to predicting mineral grades.

The study's final comparison of the use of ANN for gold and copper grade prediction revealed that the suggested model accurately predicts copper grades. The predicted outcomes revealed higher accuracy and fewer errors for copper ore grade predictions. The proposed model is considered innovative because it integrates various types of data that were not commonly combined in existing literature. This innovative approach has the potential to advance techniques for mining exploration and ore grade estimation, suggesting that it may contribute to improving the efficiency and accuracy of mining operations. Although the ANN model moderately predicted the mineral ore grade, it did not consider the geological structure of the orebody, faults, and discontinuities. Future research can explore alternative feature selection techniques to enhance the accuracy

and precision of the model and to ensure comprehensive model analysis and these results can be compared to existing methods in literature.

論文審査結果の要旨

The academic degree review committee held an international resource screening meeting on Monday, February 5, 2024, from 14:30 to 15:30. The thesis defense was held in Classroom S301, International resource sciences building.

1. Tsuyoshi Adachi, Chief Examiner,
2. Tadao Imai, Examiner
3. Atsushi Shibayama, Examiner

Youhei Kawamura watched the recorded video of the presentation and sent his questions. In the presence of reviewer Hitoshi Toriya and Hajime Ikeda (participating via Zoom), we discussed matters related to the paper. A detailed question-and-answer session and an oral academic confirmation were held. Insights from my doctoral thesis regarding the application of artificial neural network for the prediction of Mineral ore grades have been discussed.

1. What is the comparison of Artificial Neural Network and the actual ore grades?
2. How can the research results be used on the orebody?
3. How can the model be applied to other mineral resources?
4. Do you think applying artificial neural networks to mineral reserves can improve the results?
5. What does the MSE Plot for "Gold without feature" look like?
6. Why did the R value decrease in the Test for "Gold without feature"?
7. What are the reasons for the decrease in model accuracy for Gold when compared between Copper and Gold?
8. What happens to the Train MSE when you increase the Epoch for each of the three models?

The applicant responded to questions and comments with clear academic answers.

Following the public hearing, the degree examination committee ruled that Miss Ntshiri Batlile Tsae passed the final examination and is completely qualified for the PhD degree in engineering.