ABSTRACT

This study addresses the quality control problems associated with the mineral industry using geostatistical and image analysis techniques. Several geostatistical and image analysis techniques were developed and subsequently applied to two case study mines (a limestone mine and an iron ore mine) in Indian scenario. In these case specific applications, main emphasis was put on quality control planning (geostatistics, simulation, and neural network) and quality monitoring (image analysis) techniques to control the overall quality of ore in the mines.

It is understood that for an accurate grade control planning, a reliable ore grade model is essential. In this thesis, various ore grade estimation techniques viz. ordinary kriging, principal component kriging, stochastic simulation, and neural network were investigated to predict the ore grade of mining blocks. Estimated ore grade values of mining blocks help to identify the suitable mining blocks which will be mined out in a particular time period to supply the desired grade of ore. A comparative study of the various geostatistical reserve estimation techniques in the limestone mine showed that the principal component kriging provided slightly better performance than the ordinary kriging. This might be due to the high spatial cross-correlation of the quality attributes (CaO, Fe_2O_3, Al_2O_3 and SiO_2). The study results also revealed that for the variable CaO, which is skewed towards the left, the application of the lognormal kriging using a suitable transformation provided the better estimates than the other two geostatistical techniques. The application of the stochastic simulation technique namely the sequential Gaussian simulation technique showed that the technique performed better than the ordinary kriging especially in risk mapping of the estimated values. However, the neural network models applied in this study outperformed all the reserve estimation techniques for the quality attributes. It is noteworthy to mention that the neural network model developed in this study incorporated the spatial location as well as the lithological information for modeling of the orebody. The network was constituted with three

layers: an input, an output and a hidden layer. The input layer consisted of three spatial coordinates (x, y and z) and nine litholotypes. The output layer comprised of all grade attributes of limestone ore including silica (SiO_2), alumina (Al_2O_3), calcium oxide (CaO) and ferrous oxide (Fe_2O_3). The lithological classification results revealed that the indicator kriging successfully classified the geology of the deposit with an average misclassification error of 5%. In case of the iron ore mine, information for one quality attribute (Fe) was available. The application of the aforementioned grade estimation techniques demonstrated that the sequential Gaussian simulation performed better in comparison with the other techniques. The lithological classification results of this deposit revealed that the indicator kriging performed fairly well to classify the geology of the deposit with an average misclassification error of 6%.

In addition to the investigation of the above grade estimation techniques, this thesis aims at developing an off-line inferential vision based quality monitoring of the minerals at a mine face using various advanced image analysis techniques. The images for various types of ore material were captured in a simulated environment in the laboratory, where illumination and other environmental constraints were kept constant throughout the experimental procedure. These images then underwent some preprocessing stages and several important features such as colour, morphological and textural features were extracted from the images. For a limestone mine, a total number of 189 features was extracted from the images. The principal component analysis was then used to reduce the number of features. Ultimately five principal components (for limestone), which capture 95% of data variance, were extracted to develop a neural network model for prediction of the limestone grade and classification of rock type for an image. The network model had three layers: an input, an output and a hidden layer. The input layer consisted of five principal components extracted from the feature map. The output layer comprised of all grade attributes of limestone ore including SiO_2, Al_2O_3, CaO and Fe_2O_3. The vision based neural regression model results showed that the model is a good predictor for all the variables in the case study mine (The R^2 values of CaO,

Al_2O_3, Fe_2O_3 and SiO_2 are 0.89, 0.78, 0.85 and 0.87 respectively). In this case study mine, the ore grade classification using image analysis results revealed that the rock classification at the face level can be successfully preformed by neural classifier with an average misclassification error of 3%. The off-line monitoring studies at three benches showed that the bench 4 has less variance as compared to the other two benches for the variables CaO and SiO_2. The prediction errors of CaO varied within 4% in case of the bench 4 whereas for the other two benches it varied upto 7%. In the case of the iron ore, five principal components were extracted that captured more than 95% of the data variance. The neural network model with five input nodes and one output (Fe) node were used. The results showed that the model is a reasonably well predictor for the variable in this case study mine (R^2 value 0.77). The ore grade classification using image analysis results revealed that the rock classification at the face level can be effectively preformed by the neural classifier with an average misclassification error of 1 %. The off-line monitoring studies at three benches of this case study mine showed that the bench 8 has less variance as compared to the other two benches for the Fe attribute. The prediction errors of Fe varied within 5 % in case of the bench 8; whereas, for the other two benches it varied upto 10%. The off-line monitoring results for these case study mines revealed that the vision based system can be successfully applied for the grade monitoring at the face level.

The thesis made a wide contribution for quality control of the mineral industry. The general methodology can be successfully used for other conditions with slight modification of the models.