

Predicting TBM penetration rate in Cretaceous limestone of the south of Tehran by machine learning method

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Abstract

So far, extensive research has been conducted on predicting the performance of tunnel boring machines in rock. However, previous studies have often been conducted under conditions where chipping was the predominant mode in boring, and performance prediction models have been developed in these conditions. In situations where, for any reason, the thrust force of disc cutters is insufficient to penetrate the rock adequately and chipping does not occur, the performance of existing models decreases, necessitating the development of new models for grinding conditions. One of the projects in which the chipping process under the disc cutters were incomplete and grinding was the dominant mode, was the southern extension of Tehran subway Line 6 (SEL6), where grinding occurred due to machine design requirements and insufficient thrust force. The aim is to implement various machine learning algorithms to predict the penetration rate of cutterhead in Cretaceous limestone units of the south of Tehran under grinding conditions. To this end, various linear and nonlinear regression algorithms have been implemented, and ultimately the results have been compared. Since some of these algorithms are among the newest approaches in machine learning, the prediction error is much lower than conventional regression methods.

Keywords: *Grinding, Machine learning, Penetration rate, Regression analysis, TBM performance*

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Extended Abstract:

1. Introduction

Tunnel Boring Machines (TBMs) are one of the most common equipment used in tunneling industry and are employed in various geological conditions. TBM performance Prediction in different conditions is crucial in tunnel design and selecting the appropriate machine type and related specifications. The most influential parameters affecting machine performance are divided into two main groups: operational parameters of the machine and geological parameters. Numerous researches have been made to predict TBM performance and investigate their correlation with machine operational and geological parameters. Although some of these studies have been somewhat successful, they often have limitations in their usage. These models fall into two groups: 1) theoretical models developed based on laboratory rock fragmentation and 2) empirical models derived from real machine performance data. In recent years, computer modeling and machine learning techniques have also been employed by some researchers to develop empirical performance prediction models. The results of these studies indicate a strong correlation between predicted and actual machine performance.

2. Materials and methods

It's important to note that previous studies on TBM performance prediction have often been conducted under conditions where chipping is the dominant mode in boring, and performance prediction models have been developed under these conditions. In cases where, for any reason, the thrust force of the disc cutter is insufficient for penetration into the rock and complete chipping does not occur, the performance of existing models decreases, and new models need to be developed. Studies show that initial penetration rate must exceed approximately 4-5 mm/rev for effective chipping to occur. When radial cracks resulting from disc cutter excavation in the rock do not sufficiently propagate, grinding occurs, usually due to insufficient disc cutter thrust force or high rock strength and inadequate initial penetration. The thrust force required (F_n) to transition from grinding to chipping in the rock and initiate chipping is called critical thrust force. Previous studies indicate that rock strength is an important parameter for determining critical thrust in different rocks. One of the projects where incomplete chipping under disc cutters and predominance of grinding occurred was the southern extension of Tehran subway Line 6 (SEL6), due to machine design constraints and insufficient thrust force. In this project, initially, based on the geological conditions of the tunnel route, which was predicted to be entirely in soft ground, the type of machine and cutting tools were selected. Subsequent engineering geological studies revealed that about 1200 meters of the route would be in hard Cretaceous limestone units of the south of Tehran. However, the selected machine was not primarily designed for hard rock excavation, and it was anticipated that tunneling with this machine would face challenges, including inadequate cutter penetration into the rock. Therefore, the boring data of this tunnel is suitable for studying the relationship between penetration rate and engineering geological characteristics of Tehran limestone under grinding conditions.

3. The database

The first step in development a TBM performance prediction model is selecting appropriate input parameters. These inputs are divided into two categories: rock mass characteristics and machine

operational parameters. The selection of input parameters is the most important and critical part of modeling. Thus, using independent variables such as F_n , UCS, RQD, GSI, and the angle between tunnel axis and discontinuity or bedding planes (α), we attempt to predict the dependent variable PR. The selection of these parameters was based on a study conducted on the same project by Pourhashemi et al. (2021), followed by correlation analysis between variables, providing a general understanding of the relationship between them. As expected, the highest correlation was related to UCS at -0.82, having the greatest influence on cutter penetration, followed by F_n at +0.78, and then GSI at -0.51, showing the highest correlations with the penetration rate. Therefore, it was expected that these three parameters would have the greatest impact on the regression. The parameter α shows a low correlation with the dependent variable PR, and have the least effect on regression. Previous studies, including Robbins 1992, Laughton 1998 and Hassanpour et al. 2008, 2011, 2015, also indicate that uniaxial compressive strength of rock is a very important factor in rock boring using TBMs. Since the dependent variable PR is continuous, regression algorithms are suitable for modeling. In this study, machine learning methods based on supervised learning techniques have been employed to predict the penetration rate. 10 different regression algorithms were implemented on the database, each with different approaches. Models that required tuning had their optimal hyperparameters selected using K-fold Cross Validation, and the final model was then built and applied to the Test dataset to evaluate its performance.

4. Conclusion

In this study, TBM performance prediction models in grinding conditions in the Tehran Cretaceous limestone were proposed based on real machine performance and engineering geological characteristics of the rock mass using statistical and machine learning methods. Linear modeling based on t-test results was initially employed, followed by attempts to improve model performance using Stepwise Regression algorithms. Subsequently, by utilizing Regularization techniques, model performance improved within the linear regression. The best linear regression model achieving the least error was the Stepwise Regression model using K-fold CV with a mean absolute error (MAE) of 0.15. In the next stage, a non-linear decision tree model was implemented, which, due to the limited number of observations, resulted in increased model error. However, more modern approaches such as Bagging and Random Forest had better performance, with the Random Forest model having the highest R^2 and the lowest MAE of 0.13. Overall, ensemble learning approaches yielded better results, with Random Forest outperforming among these approaches.

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