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Three dimensional transition solid elements for mesh gradation

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ABSTRACT

This study presents an advanced cross-modal knowledge fusion system for Tunnel Boring Machine (TBM) performance prediction that addresses the critical challenges in complex geological environments. The system was developed and validated using operational data from the dual-line metro tunnel project in Korea. The methodological innovation lies in our proposed Spatio-Temporal Fusion Attention Network (ST-FAN), which establishes dynamic correlations between geological parameters, mechanical responses, and temporal sequence data. This architecture integrates a Bayesian knowledge graph with a multi-level self-supervised learning framework, effectively mitigating data distribution shifts across heterogeneous geological formations and enabling efficient knowledge transfer between project sections. Experimental validation demonstrates the system's capability to predict geological anomalies 35-50 minutes in advance of encounter—significantly earlier than conventional methods—with a prediction accuracy of 93.7% in fault zones. The adaptive parameter optimization module achieved a 29.6% increase in excavation efficiency while reducing energy consumption by 18.2% compared to manual operation. Notably, the system implements a continuous knowledge cycle that integrates geological information, equipment performance data, and operator expertise, establishing a foundation for enhanced decision support in mechanized tunneling. These results provide valuable insights for intelligent control systems in underground construction and contribute to the advancement of data-driven approaches in geotechnical engineering applications.