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Introduction

e mining industry has long been a backbone of global economic development, providing essential raw materials for various sectors. However, mining has also faced signi cant challenges, including high operational costs, environmental concerns, and the safety risks posed to workers in hazardous environments. In recent years, advancements in automation and smart technologies have begun to reshape the industry, o ering solutions that enhance operational e ciency, improve safety standards [1,2], and minimize the ciency, imty, imtyn0hmTucg6thingg has a Tw 0 -1.s a Tw 0 -ow5ihfsaal intel6c tG832 Tddddda5z-But0scr euw-t 2h tasks traditionally carried out by human workers, o ea5zdangerous or repetitive environments. Smart mining, a more recent development, leverages automation in combination with data-driven technologies such as IoT, AI, and machine learning to optimize mining processes, enhance decision-making, and facilitate real-time monitoring and control.

Key Technologies in Automation and Smart Mining

Robotics and autonomous equipment

e adoption of autonomous vehicles and robots in mining operations is one of the most signi cant changes in the industry. Autonomous trucks, drills, and loaders are increasingly used in open-pit mining, where they can operate continuously without the need for human intervention [3]. ese vehicles are equipped with sensors, GPS,

analytics to gain actionable insights from the vast amounts of data generated by sensors and IoT devices. Big data analytics can be used to identify trends, improve operational strategies, and drive innovation in mine design and resource extraction [6].

One key application of data analytics is the creation of "digital twins"—virtual replicas of physical mining operations that enable real-time simulations and predictive modeling. Digital twins provide valuable insights into the performance of mining assets, enabling companies to optimize processes, reduce ine ciencies, and plan for future operations more e ectively.