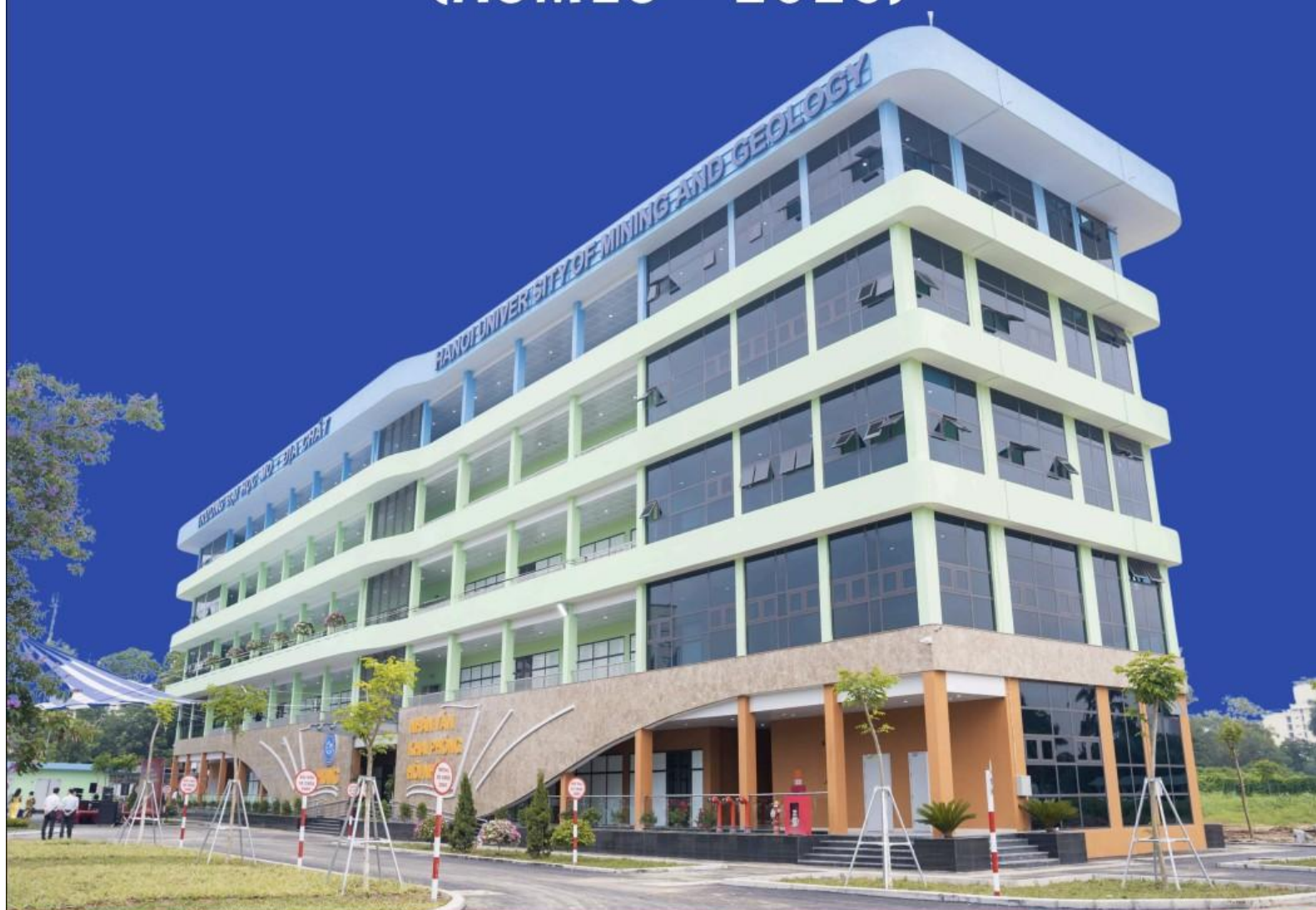


PROCEEDINGS OF THE INTERNATIONAL WORKSHOP ON ADVANCES IN
SURFACE MINING FOR ENVIRONMENTAL PROTECTION AND SUSTAINABLE
DEVELOPMENT 17 OCTOBER 2025, HA NOI, VIET NAM



ADVANCES IN SURFACE MINING FOR ENVIRONMENTAL PROTECTION AND SUSTAINABLE DEVELOPMENT-2025 (ASMES - 2025)



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Development of a Management and Monitoring System for Production Activities in Open-Pit Quarries in Vietnam

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ABSTRACT

Open-pit mining operations in Vietnam face significant challenges in adopting advanced management and monitoring systems widely used in developed countries, primarily due to technological, financial, and contextual limitations. To address this gap, this study proposes the development of an integrated management and monitoring system tailored for small- and medium-sized quarries producing construction materials. The system architecture incorporates both hardware and software subsystems, including customized air quality–vibration monitoring stations, GNSS devices, UAVs, and surveillance cameras, as well as six functional software modules for blasting vibration control, air quality monitoring, equipment management, excavation–haulage supervision, volumetric assessment, and general mine information management. A case study was conducted at the Hong Son quarry operated by VICEM But Son Cement JSC, where the system demonstrated its effectiveness in monitoring blast vibrations, issuing environmental alerts, managing equipment, tracking excavation and haulage operations, and calculating production volumes with reliable accuracy. The results highlight the system’s potential to enhance data transparency, operational efficiency, and environmental protection while remaining cost-effective for domestic mining enterprises. Despite limitations in sensor specifications and advanced analytics, the research provides a practical foundation for future integration of artificial intelligence, machine learning, and IoT technologies. This study contributes to advancing digital transformation and sustainable development in Vietnam’s open-pit mining sector.

Keywords: Open-pit mining, Management and monitoring system, Industry 4.0, Air quality and blast vibration, Digital transformation

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1. Introduction

Open-pit mines in developed countries have widely adopted intelligent monitoring and production management systems based on Industry 4.0 technologies, combined with surveillance cameras installed at appropriate locations within and around the mine. However, due to differences in technological capabilities, financial resources, and local conditions, it is difficult to directly apply these advanced systems to open-pit mining operations in Vietnam. The deployment of foreign solutions for mine operation management faces challenges related to high equipment costs and expensive software licensing.

In recent years, the rapid development of geospatial technologies and Industry 4.0 innovations such as Artificial Intelligence (AI) and the Internet of Things (IoT) has enabled researchers in Vietnam to propose solutions for specific open-pit mine management tasks. Nevertheless, these studies mainly focus on isolated problems and lack a comprehensive, integrated system that can be applied to an actual mining enterprise.

Based on this context, our research identifies the necessity of developing a mine management and monitoring system designed and implemented by Vietnamese researchers, leveraging geospatial technologies, Industry 4.0 solutions, and information technology. Such a system must be adaptable to real mining conditions, meet the specific requirements of individual sites, and support digital transformation of mine management, especially for small and medium-sized mining companies in Vietnam.

In open-pit mining, each mineral type and production scale requires different monitoring and management approaches. Even within the same mineral category, mines of varying capacities often demand distinct operational and monitoring functions. Developing a universal system capable of addressing all possible requirements represents a considerable challenge and requires multiple development phases.

In the first stage, our study focuses on designing a management and monitoring system for an open-pit quarry producing construction materials. The system aims to address five critical problems in open-pit mining operations:

- Management of blasting operations and blast-induced vibration monitoring
- Air quality monitoring around the mine site
- Equipment management (drilling rigs, excavators, and haul trucks)
- Monitoring of excavation and transportation operations
- Computation of mining volume

Due to the complexity of fully solving each problem, which requires extensive hardware, time, and human resources, this paper presents some basic solutions designed for practical application in small- and medium-sized open-pit mines in Vietnam. Additionally, the research emphasizes system development, both hardware and software, based on existing approach rather than proposing new ones.

2. Background & Related Works

Blast vibration monitoring in Vietnam is a critical task to ensure the safety of surrounding communities, infrastructure, and the environment. Recent studies in Vietnamese open-pit mines have applied advanced methods such as Artificial Intelligence (AI), Artificial Neural Networks (ANN), real-time monitoring systems, and optimization algorithms to predict and control blast-induced ground vibration (Nguyen et al., 2018; Nguyen et al., 2023; Bui et al., 2019). These models demonstrate high accuracy in predicting peak particle velocity (PPV), enabling preemptive identification of risks to structures and the environment (Nguyen et al., 2023; Bui et al., 2019).

Air quality monitoring around open-pit mines in Vietnam primarily focuses on dust indices (PM_{2.5}, PM₁₀, TSP), toxic gases (CO, CO₂, NO_x, SO₂, NH₃), and microclimatic factors such as temperature, wind, and humidity (Bui et al., 2022; Nguyen et al., 2020). Advanced approaches, including UAVs equipped with

dust and gas sensors, have been deployed in coal mines such as Coc Sau (Quang Ninh), providing high-resolution three-dimensional datasets for air quality assessment and hotspot identification (Bui et al., 2022). Fixed monitoring stations have also been installed to continuously measure wind speed, direction, temperature, and pollutant concentrations, supporting dispersion modeling and air quality forecasting inside and outside mine sites (Nguyen et al., 2020).

In order to ensure the effective management of excavation, transportation, and waste dumping activities in open-pit mines, it is necessary to establish a specialized system of equipment dedicated to monitoring and controlling production-related data. The core components of such a system include excavators, haul trucks, and electronic weighing stations. Among these, weighbridges assume a particularly critical role, as they enable the precise determination of the volume of transported materials, thereby facilitating more effective control and optimization of the entire excavation–transportation cycle.

Findings from the present study indicate that a considerable number of open-pit mines in Vietnam have already deployed weighbridge systems. Furthermore, the integration of advanced monitoring technologies—such as surveillance cameras, GPS-based positioning sensors, and load sensors—allows for real-time tracking of equipment locations and operational conditions. This integration substantially enhances the accuracy, reliability, and overall effectiveness of the monitoring process.

Unmanned Aerial Vehicle (UAV) imagery and the generation of three-dimensional point clouds are increasingly applied in the calculation of excavated volumes in open-pit mining due to their rapid data acquisition, high accuracy, and cost-effectiveness. Recent studies have demonstrated that the volumetric error associated with this method typically ranges from 0.4% to 1.2% when compared with actual volumes or reference models, particularly when advanced point cloud processing algorithms are employed in conjunction with a sufficient number of ground control points (GCPs) (Meng et al., 2023). Experimental investigations further indicate that, in the absence of GCPs, the volumetric error may remain below 10%; however, to achieve high accuracy (i.e., error rates below 2%), a GCP density of approximately 15 points per square kilometer is recommended (Siqueira et al., 2019).

In comparison with traditional techniques such as GNSS-based surveying, UAVs enable rapid measurements over extensive areas while maintaining volumetric accuracy that fully meets the technical requirements of mine management. Moreover, UAV-based surveys facilitate more frequent data updates while reducing both costs and occupational risks relative to manual surveying approaches (Cánh et al., 2020, Nguyen et al., 2020).

3. Methodology & System Architecture

The proposed management and monitoring system for open-pit quarry operations consists of hardware and software components. The hardware subsystem includes the following elements:

- Air quality and vibration monitoring stations
- Central server
- GNSS positioning devices
- Camera surveillance system
- UAV platforms

Among these, custom-designed air quality–vibration stations and GNSS devices were developed by the research team. Data collected from these stations are transmitted to the central server via 4G networks. Cameras were deployed to monitor excavation and hauling processes, while UAVs were used to collect topographic data for volumetric calculations.



Figure 1. Monitoring Station and GNSS Device

Software Architecture: The software subsystem comprises six modules addressing the five identified research problems and one additional module for general mine information management:

- General information management module
- Blast vibration monitoring and control module
- Air quality monitoring module
- Equipment management module (drilling rigs, excavators, haul trucks)
- Excavation, haulage, and dumping monitoring module
- Mining volume calculation module (based on UAV and terrestrial LiDAR point clouds)

Each module is designed to improve operational efficiency, enhance transparency, and support real-time decision-making. For instance, the blasting module enables operators to track planned and historical blasting events, automatically notify local communities via mobile applications, and issue pre-blast warnings to improve transparency. Simultaneously, vibration data from monitoring stations are processed for archival, analysis, and exceedance alerts.

The air quality module collects data from monitoring stations and delivers information via WebGIS and mobile applications to both operators and local communities. It also issues alerts when AQI exceeds 150 and provides short-term PM_{2.5} forecasts. The equipment management module supports digitalization of equipment status, maintenance, and repair activities. The excavation and haulage monitoring module leverages GNSS, cameras, and weighbridge data to provide real-time monitoring of operations and transportation performance. Finally, the volumetric calculation module, based on UAV and LiDAR point clouds, provides accurate assessments of extracted quantities, improving production control.

4. Case Study

The system was tested at the Hong Son quarry operated by VICEM But Son Cement Joint Stock Company. Four monitoring stations were installed at key locations near sensitive infrastructure and communities to monitor both air quality and blast vibration. Six surveillance cameras were also deployed across the quarry and at the company's control center.

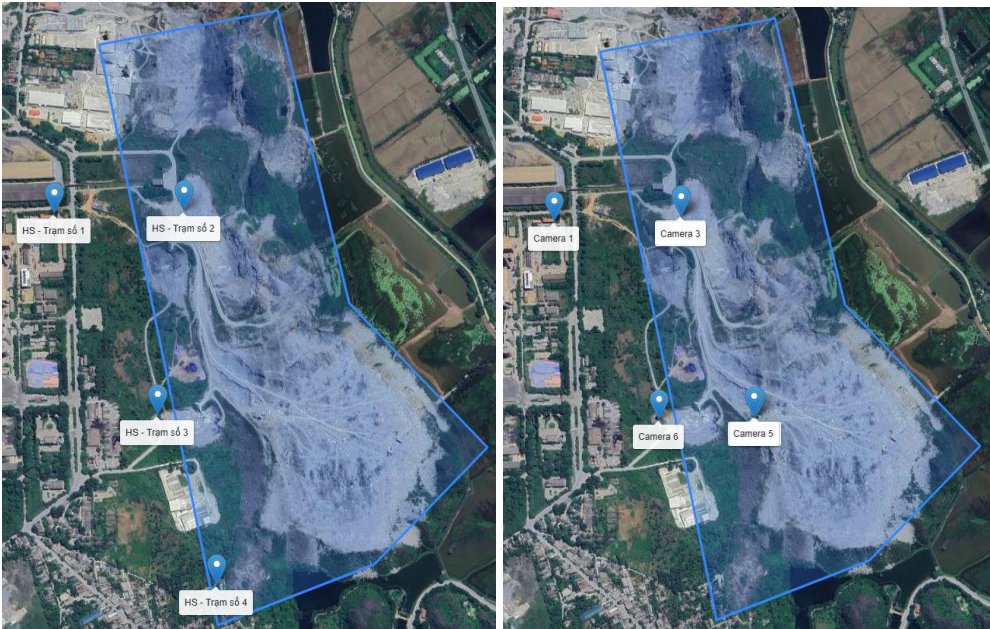


Figure 2. Monitoring Station and Camera Deployment Locations

The blasting and vibration monitoring module allowed operators to track planned and historical blasting events, send notifications to communities, and generate exceedance alerts from station data. However, due to the limited sampling frequency of sensors, some blasting events were not fully recorded—an issue attributed to sensor technical specifications rather than the IoT framework.

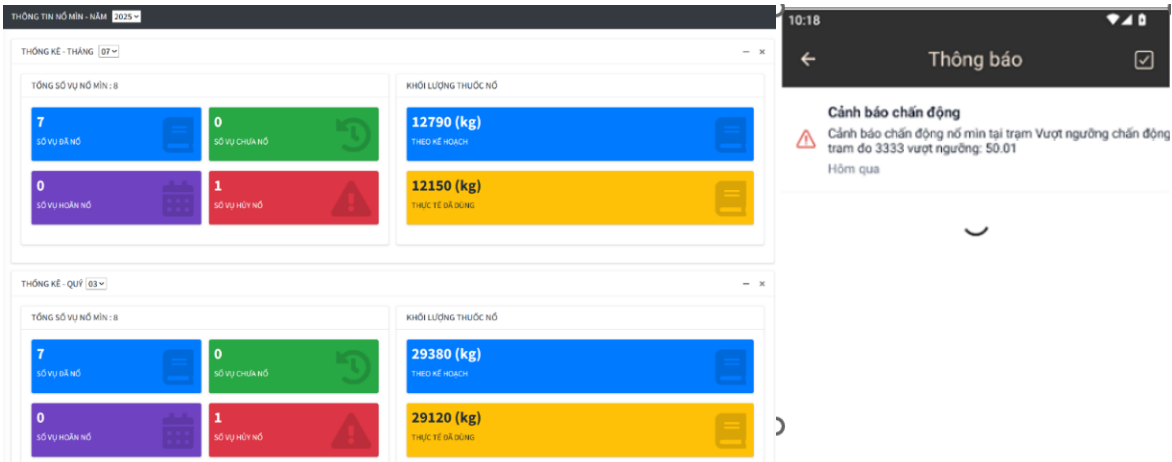


Figure 3. Blasting Dashboard & Vibration Alerts

The air quality module successfully collected and visualized monitoring data, generated alerts when AQI exceeded 150, and produced reliable short-term PM2.5 forecasts.

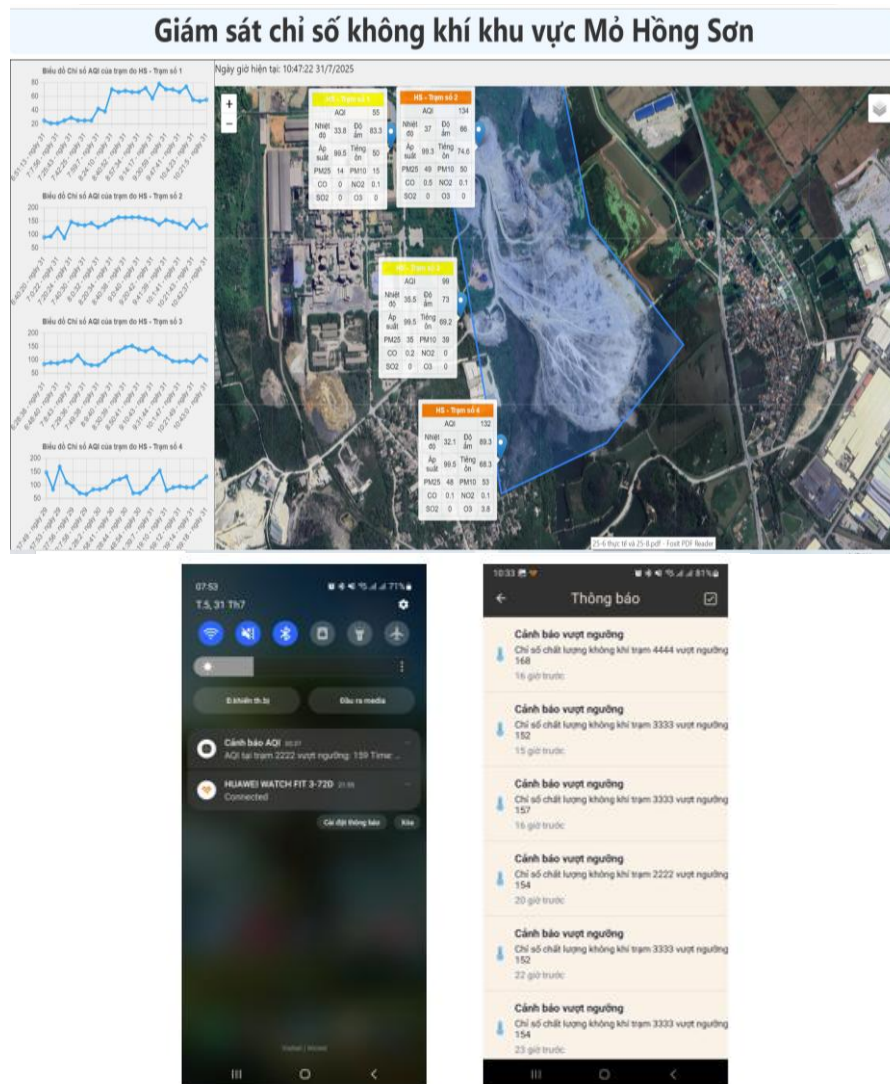


Figure 4. Air Quality Monitoring – Hong Son Mine; Mobile Alerts – Threshold Exceeded

The equipment management module enabled digital tracking of equipment condition, maintenance, and repair schedules. The excavation and haulage module, integrating GNSS and cameras provided real-time operation monitoring and transportation performance metrics. Finally, the volumetric module, validated with both sample and real datasets, demonstrated reliable accuracy compared with commercial software.

5. Discussion

The results demonstrate that the proposed system, integrating both hardware and software, addresses five basic challenges in open-pit mine management. By combining multiple functional modules, the system simultaneously tackles blasting, air quality, equipment management, transportation monitoring, and volumetric assessment. A notable feature is that the system was developed domestically, with cost-effective hardware and software solutions adapted to the financial capacity of small- and medium-sized mining enterprises in Vietnam.

Nonetheless, certain limitations remain. First, the accuracy of vibration monitoring is constrained by the technical specifications of the available sensors, which currently lack high-frequency sampling

capabilities. Second, the equipment and haulage monitoring modules primarily focus on data collection and visualization, without fully leveraging advanced analytical techniques such as AI and Machine Learning to predict equipment failures, optimize haul routes, or forecast production efficiency.

The case study at Hong Son quarry confirmed the feasibility and practicality of the system. However, broader deployment across various mine types and scales is required to validate long-term stability and reliability.

6. Conclusion and Recommendations

This study developed and tested an integrated management and monitoring system for open-pit mining operations, comprising modules for blasting and vibration monitoring, air quality monitoring, equipment management, excavation and haulage monitoring, and volumetric assessment. The system demonstrated potential performance during real-world deployment at the Hong Son quarry, providing benefits in data transparency, operational efficiency, and environmental protection. Importantly, the system was designed with cost-effective, domestically developed technologies suitable for small- and medium-sized mining enterprises in Vietnam.

However, the system still faces several limitations, including a limited scope of testing, the absence of advanced data analytics, and incomplete coverage of environmental factors. Future work will focus on: (i) expanding testing to different mine types and operational scales, (ii) integrating additional environmental monitoring indicators, (iii) applying AI, Machine Learning, and IoT for automated analytics and operational optimization, and (iv) developing user-friendly, scalable management interfaces suitable for industrial deployment. With these improvements, the system has the potential to evolve into a smart monitoring and management platform, contributing to the digital transformation and sustainable development of the Vietnamese mining sector.

7. Contributions of authors

Nguyen Hoang Long, Tran Thi Hai Van, Dinh Bao Ngoc, Tran Truong Giang - writing & editing, supervision; Xuan-Nam Bui – reviewing & editing.

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