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Key Words

Harmonised Explosive Management System; Invisible QR Codes; Explosive Device Traceability; Explosive Device Diversion; Minerals Commission

Abbreviations

Eds: Explosive Devices; HEMS: Harmonised Explosive Management System; CID: Criminal Investigation Department; ATF's: Bureau of Alcohol, Tobacco, Firearms and Explosives; IED: Improvised Explosive Device

Review Article

Enhancing Traceability of Explosive Devices in Ghana: Addressing Challenges and Proposing Solutions

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Abstract

The traceability of explosive devices in Ghana's mining and construction industries is essential to ensuring safety and regulatory compliance, and preventing misuse, especially in combating illegal mining and terrorism-related activities in the sub-region. Despite existing regulations, the lack of an efficient and transparent tracking system has resulted in challenges, including the stealing and diversion of explosives for unauthorised use, posing significant risks to public safety and the environment. This study examines the current state of Explosive Device (ED) traceability in Ghana, identifying key challenges, including insufficient data management, limited technological infrastructure, and the prevalence of illegal small-scale mining activities. This study proposes a multi-faceted approach to address these challenges, focusing on deploying and integrating a web-based Harmonised Explosive Management System for real-time inventory management, integrated with advanced technologies, such as invisible QR coding, as an added layer to enhance security. Additionally, this study highlights the importance of stakeholder collaboration, involving the government, regulatory bodies, and private sector stakeholders in the management of an integrated, efficient traceability system. Through these proposed solutions, this study aims to strengthen the monitoring and control of EDs in Ghana, ensuring that they are only used for their intended legitimate purposes while mitigating the risks associated with illegal activities and enhancing overall safety in the mining and construction sectors.

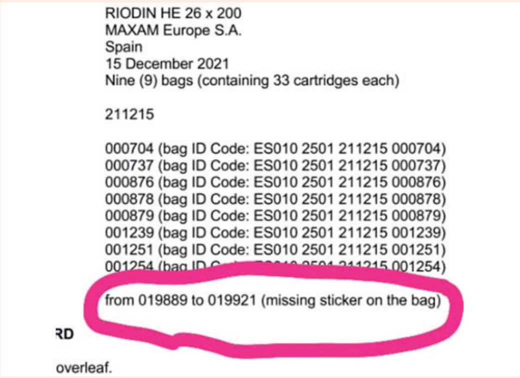
Introduction

Explosive Devices (EDs) are essential tools used in various industries, particularly mining, civil engineering, construction, and defence. In Ghana, where mining is a critical economic sector, the use of EDs for activities such as blasting rocks to access valuable minerals is widespread [1]. However, the potential for these devices to be diverted for unauthorised use poses a significant risk [2], particularly in regions susceptible to illegal mining activities and terrorist threats. The effective management of EDs is not only a matter of operational safety but also one of national security [3]. The Ghanaian government, through the Minerals Commission, has implemented various regulations to oversee the safe use of EDs [4]. Despite these efforts, challenges remain in tracking the movement of EDs throughout their lifecycles from manufacture to end-use or disposal [5,6]. There is, therefore, a need to adopt and deploy efficient traceability techniques to improve public safety, combat illegal mining (galamsey), curb criminal activities, and prevent terrorist incidents. The lack of comprehensive traceability systems has led to incidents where explosives have been diverted to illegal or unregulated mining operations or smuggled across borders for use in criminal activities as shown in Figures 1 & 2.

Figure 1: Diverted explosives seized at an illegal mining site in Nzema, Ghana.

Figure 2: Diverted explosives seized at an illegal mining site in Kenyase, Ghana.

The traceability of explosives refers to the ability to track and identify the origin, movement, and ownership of EDs throughout their lifecycles [7]. Traceability typically involves the serialisation and aggregation of products [8] as shown in Figure 3.



RIODIN HE 26 x 200
MAXAM Europe S.A.
Spain
15 December 2021
Nine (9) bags (containing 33 cartridges each)

211215

000704 (bag ID Code: ES010 2501 211215 000704)
000737 (bag ID Code: ES010 2501 211215 000737)
000876 (bag ID Code: ES010 2501 211215 000876)
000878 (bag ID Code: ES010 2501 211215 000878)
000879 (bag ID Code: ES010 2501 211215 000879)
001239 (bag ID Code: ES010 2501 211215 001239)
001251 (bag ID Code: ES010 2501 211215 001251)
001254 (bag ID C[illegible] 211215 001254)
from 019889 to 019921 (missing sticker on the bag)

RD

overleaf.

Figure 3: Serialisation and aggregation of explosives.

At the core of EDs, serialisation involves assigning unique serial numbers to each article or unit to allow for complete traceability. Aggregation involves grouping individual units such as detonators or boosters into larger units such as pallets or cases and assigning each of them a unique identifier (lot number). This is crucial for ensuring public safety, preventing illicit use, and complying with regulations [9]. Table 1 shows a record of some incidences of explosive diversions, and Table 2 shows a record of diverted explosives traced to Ghana. Thus, with the HEMS and other peripheral integrations, the trace request as seen in Table 1 can easily be completed and the last chain of custody identified. Some key aspects of ED traceability are outlined below:

a. Marking and Tagging: EDs are marked with unique identifiers, such as serial numbers, colours, or barcodes, to facilitate tracking.

b. Record Keeping: Manufacturers, distributors, and users maintain records of ED materials, including production, storage, transportation, and use.

c. Chain of Custody: A documented chain of custody ensures that EDs are accounted for at every stage, from production to disposal.

d. Tracking and Tracing: Electronic tracking systems, such as Radio Frequency Identification (RFID) or Global Positioning System (GPS), monitor the movement of EDs in real time.

e. Regulatory Compliance: Adherence to national and international regulations, such as the Legislative Instrument (L.I.) 2177 in Ghana and the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF's) ED regulations in the United States of America (USA), ensures standardised traceability practices.

f. Forensic Analysis: ED materials can be analysed to identify their composition and origin, aiding in post-blast investigations.

g. International Cooperation: Global agreements, such as the United Nations (UN) International Ammunition Technical Guidelines, facilitate cross-border traceability and cooperation.

h. Digital Solutions: Blockchain technology and other digital platforms are being explored to enhance explosive traceability and security. High-definition camera technology such as the high-definition camera EX360 can be integrated for efficient tracking and tracing with a real-time audio-visual feed.

Table 1: Trace matrix of explosive losses and diversions.

Name of Author	Ghana Police	Conflict Armament Research	Conflict Armament Research	Conflict Armament Research	Conflict Armament Research	Conflict Armament Research
Year	**May, 2019**	**July, 2021**	**July, 2021**	**January, 2021**	**July, 2022**	**May, 2023**
Research Focus	Police Divisional CID investigating case of possession of explosives without authority.	Tracing of Improvised Explosive Device (IED) items seized in Burkina Faso and Cote d'Ivoire.	Tracing of explosive items seized in Burkina Faso, Cote d'Ivoire and Mali.	Explosive storage and record keeping assessment 23-30 November 2021.	Analysis and tracing of seized explosive cartridges.	Trace of supply routes of explosives.
Incident Summary	Police asked Store Manager of an explosives manufacturer to determine whether serial numbers on exhibits in police custody originated from the company.	Diversion of RIODIN HE cartridges (mining explosives) from Ghana.	Diversion of mining explosives from a mining services company in Ghana.	The most significant shortcoming observed at nearly all companies assessed relates to Regulation 131-Receipt and delivery of explosives	April 2022 seizure of mining explosives in Manga, Burkina Faso.	Explosives manufactured in Ghana and shipped to Ghanaian company subsequently documented in Niger.
Conclusion		Trace investigations of regional seizures of commercial explosive material indicate that there are multiple companies in Ghana that are likely sources of diversion.	Indication that the mining services company involved is a recurring source of diversion of explosive material in the region.	The assessment team unanimously agreed that the record-keeping shortcomings outlined herein should be addressed urgently.	Deliberate removal of labels and markings indicating intent to conceal origin of explosives. This is the first time such intent has been observed.	The trace request required the provision of information as to whether the recipient company was authorised to export/ transfer the explosive material.

Table 2: Summary of regional explosive seizures traced to Ghana.

Year	Burkina Faso	Cote d'Ivoire	Ghana	Mali	Niger
Unknown	1083				99
2016	33				
2017	20			17	
2018					
2019				495	
2020		2		991	
2021	459		165		
2022	3138				362
2023	1188				

These measures collectively contribute to a robust traceability system, helping to prevent the diversion of EDs into unauthorised channels and ensuring their safe and secure use. This study sought to address the challenges of ED traceability by proposing the implementation of a web-based piece of software called a Harmonised Explosive Management System (HEMS) integrated with invisible QR codes to boost regulatory oversight [6]. This system seeks to enhance the traceability of EDs in Ghana, ensuring their secure use and compliance with national and international regulations. By leveraging modern technologies, the Inspectorate Division of the Minerals Commission can realize real-time monitoring and control over the movement of EDs, thereby reducing the risks associated with their misuse and diversion.

The importance of explosive devices

Eds have a wide range of applications, in both civilian and military contexts [10]. In the hard rock mining industry, Eds are crucial for blasting operations [11], enabling the efficient extraction of minerals. In civil construction, Eds are used to demolish structures to make way for new developments [12]. However, the very properties that make Eds useful such as their ability to cause controlled explosions also make them dangerous if not properly managed. The threat posed by Eds is not limited to their legitimate uses. These devices can be repurposed for harmful activities, including terrorism [13], illegal mining [14], and other criminal enterprises [15]. The global rise in the use of Eds by terrorist groups highlights the need for the stringent control and monitoring of all ED materials [6,16].

Regulatory framework in Ghana

Ghana's regulatory framework for the management of EDs is primarily governed by the Minerals and Mining (Explosives) Regulations [17] (L.I. 2177). These regulations provide guidelines for the licensing, transportation, storage and use of explosives. The Minerals Commission, through its Inspectorate Division, is responsible for enforcing these regulations, ensuring that all entities handling EDs comply with the required safety standards [18, 19]. Despite the robust regulatory framework and its associated enforcement, the traceability of EDs is a real challenge for both regulators and industry. One of the most significant issues is the lack of a unified system for tracking the movement of explosives throughout their lifecycles. Currently, only a few companies use standalone software systems to manage their operations, and these are not integrated with the national regulatory framework. This fragmentation has led to gaps in monitoring, making it difficult for the Inspectorate Division to effectively oversee the use of EDs in the country [6].

Traceability systems for explosive devices

Traceability is a critical component of effective ED management. It involves tracking the movement of explosives from the point of manufacture through to their final use or disposal [20]. Effective traceability systems ensure that every transaction involving explosives is recorded, making it possible to trace the source of any unauthorised usage. Several technologies have been developed to enhance the traceability of EDs. These technologies include RFID tracking, blockchain technology, sensor technologies, GPS and geo-fencing technologies, invisible QR codes, etc. Table 3 lists notable research on ED traceability.

Table 3: Notable research on ED traceability.

Author	Paper Topic	Methodology	Gap
Adu-Gyamfi [9]	Regulation challenges in management of explosives	Review of regulatory and safety standards	Limited discussion on technological solutions like QR or RFID for improved traceability
Kumara et al. [21]	RFID for tracking explosives in mining	RFID technology implementation	This study did not address the challenges in rural or remote tracking where connectivity issues arise
Johnson and Lee [22]	RFID and security in management of explosives	RFID tracking and remote monitoring	Focuses on general applications; lacks tailored methods for combating illegal mining activities
To et al. [23]	Tracking explosives in Ghana's mining industry	Overview of current tracking challenges in Ghana	Missing practical solutions or case studies on traceability improvements in the Ghanaian context
Ricci and Gregory [24]	Importance of serialisation in explosive traceability	Examination of serialisation practices	Lacks real-time tracking insights or methods for end-to-end monitoring
Comert [25]	Blockchain in explosive traceability	Review of blockchain potential for traceability	No practical case studies or examples of blockchain in explosive traceability systems
Ahmed and Kannan [26]	Cloud-based RFID for security	Cloud-supported RFID for smart IoT applications	Not directly applied to explosives; lacks insights into local regulatory integration

Resources and Methods

Resources used

This research required various resources to effectively analyse the challenges of ED traceability and propose actionable solutions for managing EDs in Ghana. The resources used were categorised into data sources and technical tools, as described below.

Data sources:

A. Governmental and regulatory bodies:

i. Minerals Commission of Ghana provided data on licenses and the use and distribution of explosives within the mining industry. The Commission also provided information on incidents and all other activities involving explosives.

ii. Ghana Police Service (Explosives Unit) offered insights into incidents involving the misuse of explosives, including theft and illegal use.

iii. Ghana Chamber of Mines provided industry-level data on explosive management and distribution within mining companies.

iv. Ghana Revenue Authority (Customs Division) provided data on the importation of EDs, precursor substances and related equipment.

B. Explosive manufacturing and supply companies:

i. Companies that manufacture or import explosives, such as Maxam Ghana or AECI Mining Services, provided details about the supply chain and distribution practices.

C. Field surveys/interviews:

i. Interviews with mine operators, law enforcement officials, and experts in explosive management to gain practical insights into existing challenges.

Technical tools:

A. Computer system

i. A Dell G5 15 laptop with an Intel Core i7 (3.1 GHz base frequency, 6 cores) was used. The system is a CUDA-capable device and runs on the Windows 11 Professional operating system. It features 16GB of RAM with a 128-bit interface. The computer system was used to design the Invincible QR code.

B. Best code next-generation marking and coding printer

i. This was utilised to print invincible QR codes (invisible QR codes) for enhanced traceability and security on products, particularly in sensitive industries such as explosives, pharmaceuticals, and high-value manufacturing. Figure 4 shows an image of the UV printer used.

Figure 4. Best code UV printer.

QR Code Generation and Management Systems were used for integrating invincible QR codes onto explosive packages for tracking.

C. Software tools for analysis:

i. We deployed the HEMS, a web-based database with query features, to take an inventory of all the Eds in Ghana [6].

D. Legal and regulatory frameworks:

i. We reviewed the Minerals and Mining (Explosives) Regulations [17] (LI 2177), to understand existing policies/frameworks and the scope for implementing enhanced traceability measures.

Methods used

The following section outlines the steps involved in creating the invincible QR codes, the printing process on EDs and QR code integration into the HEMS software to enhance their traceability in real time. This process involved two key approaches: (i) deploying the HEMS and (ii) using specialised marking technology and QR code systems to ensure that each explosive device has a unique and tamper-proof code that can be scanned only by authorised personnel, thereby improving security and traceability.

System design and planning:

A. Objective

i. Objective: To improve the traceability of EDs by marking them with invisible QR codes, which can only be scanned by authorised personnel.

ii. Scope: The QR codes will provide unique identifiers linked to the central database of the HEMS software to log the manufacturing, distribution, and usage patterns of each ED.

B. Requirements analysis

i. Equipment and Software:

a) QR Code Design: Generate unique QR codes for each ED.

b) Invisible Ink Printer: Make use of a specialised printer (i.e., Best Code Next Generation Marking Printer) that can print invisible ink.

c) UV/Infrared Scanners: Devices to scan invisible QR codes.21

d) Central Database System: A secured HEMS database to store the unique QR code data, linking them to the lifecycle of each ED.

ii. Material considerations

a) Ensure that the printing surface on the explosive device can hold the invisible ink and is resistant to environmental wear (e.g., temperature and humidity).

Invisible QR code generation:

The flowchart shown in Figure 5 outlines the streamlined process for managing explosive inventory by leveraging the invincible QR code-based identification system. The system was designed to enhance the traceability, safety, and regulatory compliance of explosive materials. Outlined below is the detailed explanation of each stage in the process.

The invisible QR code generation process involves the following five steps:

A. Step 1: Collection of Explosive Details

The process initiates with the collection of essential information regarding the explosives. This includes the following:

i. The identification code of the cartridges contained within the bag or case, which ensures that each cartridge is uniquely traceable.

ii. The country and factory code, which indicate the origin of production.

iii. The product code specifies the type of explosive.

iv. The date of production or manufacture is vital for tracking the shelf life and ensuring safe usage.

v. A unique bag identification code, which serves as an identifier for each storage bag.

B. Step 2: Data Storage in the Database

The collected information is then stored in a centralised database. This database acts as the primary repository for all explosive-related data, enabling structured storage and easy retrieval. By maintaining an organised database, the system ensures that the explosive details are readily accessible for subsequent processing, thereby reducing manual errors and improving data management.

C. Step 3: QR Code Generation

The system utilises a QR code generator, which employs web technologies such as HTML, CSS, and JavaScript to convert the stored explosive details into QR codes. The generator retrieves the necessary data from the database and encodes them within the QR codes. These codes offer a compact, machine-readable format that encapsulates all pertinent information about the explosives.

D. Step 4: Output of QR Codes

Once generated, the QR codes are ready for use. Each QR code contains the encoded details of a specific bag of explosives and is produced in a format that can be easily printed. This stage prepares the QR codes for the subsequent labelling process.

E. Step 5: Labelling Explosive Storage

The QR codes are then embossed on the body of the explosive device or article or onto stickers that are placed on the respective explosive storage bags because these stickers can easily be removed Figure 3. This labelling ensures that each explosive device or article is marked with a unique QR code, allowing for quick and efficient identification. By scanning the QR code, inspectors can instantly access the stored data, which is essential for operational tasks such as inventory audits, regulatory inspections, and safety checks, in accordance with Regulation 44 of LI 2177 of the Ghanaian Regulations.

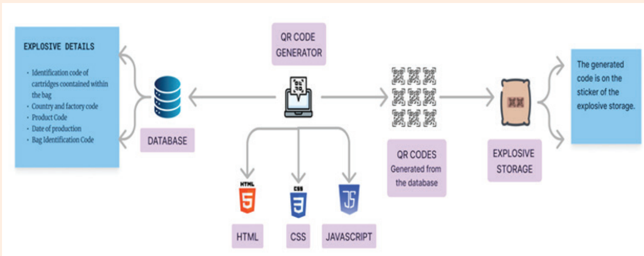


Figure 5: Flowchart of system setup for QR code generator.

System benefits and purpose:

This QR code-based system significantly enhances the traceability of explosive materials. It facilitates precise tracking from production to storage, supports compliance with legal requirements, and improves inventory management. Additionally, the use of QR codes minimises the risk of human tampering with explosives and accelerates data access, therefore promoting a safer and more efficient approach to handling explosives. Overall, the flowchart demonstrates a robust and systematic method for managing explosive details through the integration of database storage and QR code technology. This approach not only optimises operational processes but also strengthens safety protocols within the explosive industry.

Selection of invisible ink printing technology:

A. Printer Selection
i. A specialised type of printer that can print invisible QR codes using UV-reactive or infrared-reactive ink was chosen (i.e., the Best Code Next-Generation Marking and Coding Printer).
ii. The printer had the ability to print the following:
a) High-resolution invincible QR codes that can be accurately scanned.
b) Durable ink that remains invisible under normal conditions but is detectable under UV/infrared light.

B. Ink Selection
i. Invisible ink that can withstand or is resistant to several environmental factors was used. Such factors include the following:
a) Heat, humidity, and friction (common in the storage and transportation of explosives).
b) They remained invisible in normal light but visible under a UV/infrared scanner.
ii. It was necessary to ensure that the ink adhered well to the materials used in explosive devices (e.g., plastic and metal).

Printer process:

A. Preparation for Printing
i. Surface Preparation: The surface of the ED where the QR code was to be printed was cleaned and prepared to ensure ink adhesion.
ii. Calibration: The Best Code printer was calibrated for the specific size and resolution required for the QR code. This was necessary to ensure that it would be readable under UV or infrared light.

B. Printing Execution
i. The Best Code printer was programmed with the generated unique QR codes.
ii. The QR code was then printed using the invisible ink on each ED.
iii. It was necessary to ensure uniform application, with no distortions or incomplete prints.
iv. Random samples of printed QR codes were then inspected using a UV/infrared scanner to verify their visibility and readability.

QR code registration in HEMS database:

A. Code Scanning and Recording
i. Immediately after printing, each invisible QR code was scanned using a UV/infrared scanner to capture the data.
ii. The scanned data were then uploaded to the HEMS central traceability database. The following data, which are of the utmost importance, were registered for each QR code:
a) Manufacturing information;
b) Batch number;
c) Explosive type;
d) Date of manufacturing;
e) Intended user or distributor.

B. Linking to HEMS
i. The QR code data were then integrated into the HEMS to track EDs from the point of manufacture through the distribution chain to storage and eventual use.
ii. The HEMS made it possible for the status of each ED to be updated in real time.

C. Security and Maintenance
i. Data Security
a) The Salt and Pepper approach to securing password hashes using MD5 Authentication was employed to secure the HEMS. This approach was adopted due to the significance of the technique in protecting the system against unauthorised access, data breaches, or the manipulation of explosive traceability information. The Salt is a unique random value generated for each password. This prevents rainbow table attacks and the detection of users with the same password. The Pepper is a server-side secret key that adds an additional layer of security. The key benefits include the fact that, even if the database is compromised, the attacker needs the Pepper to gain access to the database. It also makes brute-force attacks more difficult.

D. Routine Maintenance
i. Routine checks were performed on the printing equipment, QR code scanners, and HEMS to ensure that all the components were functioning correctly.
ii. Periodic reviews were carried out to ensure that the QR code printing and verification process met security standards.

Results and Discussion

The implementation of the HEMS integrated with the invisible QR codes led to significant advancements in the traceability and security of EDs during the pilot phase of this study. The key results are presented as follows:

Results for enhanced traceability and accountability

Each ED was equipped with an invisible QR code, uniquely identifying it within the HEMS. This allowed regulatory bodies to monitor devices from production through to their final use. The visibility of data within the HEMS enabled immediate tracking and significantly reduced the unrecorded or unauthorised movement of EDs across the entire value chain. The results further showed that integrating the invisible QR codes into the HEMS revolutionised traceability by introducing unique identifiers for each device. The digital logging of movements and usage, visible on the centralised dashboard, enabled efficient tracking and accountability, thereby preventing unrecorded handling or misuse. Figures 6 & 7 show the authentication page and the dashboard of the HEMS.

Figure 6: Authentication page of HEMS.

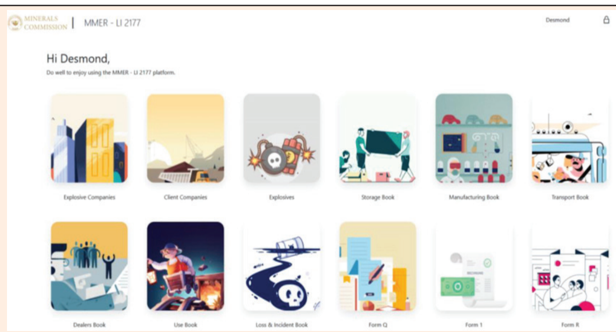


Figure 7: HEMS dashboard-real-time tracking for explosive devices.

Results for improved security against tampering

The applied invisible QR codes using secure ink technology have made unauthorised access and tampering very challenging. Figure 8 depicts an image of an ED equipped with a generated invisible QR code visible only under UV light. This security feature reduced incidents of tampering significantly, as only trained personnel with access to UV scanners could verify the device information. The results further showed that the use of secure, invisible ink technology ensured that the QR codes remained undetectable to unauthorised personnel. Additionally, the centralised nature of the HEMS, coupled with the encrypted invisible QR data, ensured that only designated personnel with UV access could verify device information.

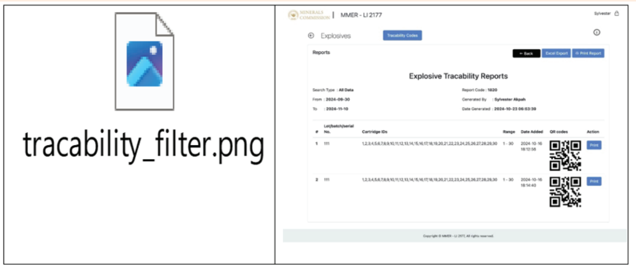


Figure 8: Invisible QR codes for explosive devices under UV light.

Results for regulatory compliance efficiency

The results showed that the HEMS streamlined compliance, reducing the inspection time by approximately 40% compared to previous manual systems. Automated reports and alerts were generated from the HEMS dashboard as shown in Figure 9, allowing for the quick detection and resolution of discrepancies in device inventory or usage records. In addition, the centralised HEMS digitised data capture and verification, eliminating extensive manual records. This automation allowed regulatory bodies to conduct efficient, timely audits, leading to improvements in compliance check speed and a reduction in human error, as shown in Figure 9.

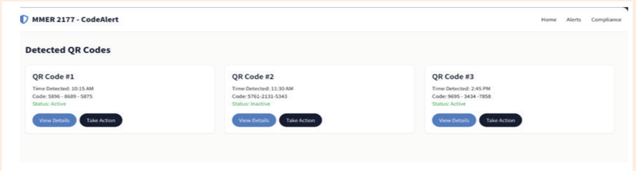


Figure 9: HEMS alert and compliance dashboard.

Results for operational efficiencies in data entry and management

The results demonstrated that field operators could enter data instantly via a mobile app linked to the HEMS, leading to a drastic reduction in manual errors, and presented a significant improvement in data entry efficiency. Figure 10 shows the mobile interface used by field agents, illustrating the ease of real-time tracking and data entry.

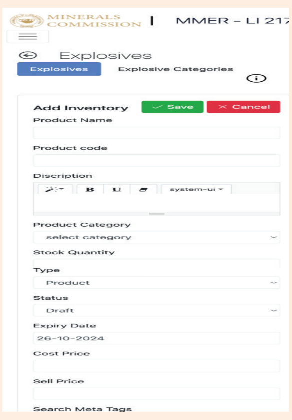


Figure 10: Mobile interface for HEMS data entry.

Conclusions

Deploying the HEMS with invisible QR codes has proven effective in enhancing the traceability, security, and regulatory compliance of explosive devices in Ghana. The system's integration across the explosive supply chain promotes safer handling and reduces unauthorised use, positioning Ghana as a regional leader in explosive management. The deployment of the Harmonised Explosive Management System (HEMS) combined with the invisible QR codes presents a promising solution to enhance the traceability of EDs in Ghana. This approach addresses current challenges, including regulatory gaps, untracked distribution channels, and unauthorised use, especially in sectors like mining and quarrying. By integrating the HEMS with invisible QR codes, each ED is marked with a unique identifier that links to a centralised database, which enables continuous tracking from production to end-use. This dual approach enhances security, facilitates regulatory compliance, and provides real-time data access for authorities, fostering greater accountability in the handling and usage of EDs.

Recommendations

Based on the work carried out in this research, the following are recommended for implementation by mineral regulatory bodies in every jurisdiction, including the Minerals Commission of the Republic of Ghana:

Adopt a Harmonised Explosive Management System (HEMS)

Implement the centralised HEMS across the entire supply chain, encompassing the production, distribution, storage, and end-use of explosive devices. This system should integrate data inputs from manufacturers, suppliers, and end-users, providing a unified platform for monitoring all registered explosives.

Deploy invisible QR code technology for secure marking

Use invisible QR codes to mark each explosive device with a unique, tamper-resistant identifier. These QR codes can be printed using specialised invisible ink and only viewed under specific lighting, ensuring that they remain secure and accessible to authorised personnel.

Strengthen regulatory framework and compliance

Update regulations to mandate HEMS adoption and invisible QR code marking for all EDs used in Ghana. Also, establish penalties for non-compliance and provide incentives for early adopters, fostering a culture of compliance among manufacturers and users.

Enhance inter-agency coordination and information sharing

Improve collaboration among regulatory bodies, mining companies, law enforcement, and other stakeholders. A shared database within HEMS can facilitate information exchange and ensure swift responses to any discrepancies or misuse of explosives.

Invest in training and capacity building

Train all stakeholders including manufacturers, distributors, law enforcement, and regulatory agencies on how to operate the HEMS and scan the QR codes. This training will ensure effective system utilisation and build capacity for tracking explosives securely.

Implement continuous monitoring and auditing

Conduct regular audits and assessments to evaluate the effectiveness of the HEMS and the QR code system. Continuous monitoring will identify areas for improvement and enhance the system's resilience to emerging threats or technological advancements. Author Contributions: This is a PhD research article prepared by Desmond Boahen, a PhD Candidate, under the supervision of Dr. Bright Afum and Dr. Sylvester Akpah.

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