Designing a Sustainable Control Room for Tracking Excavators in Ghana's Small-Scale Mining Sector – A Case of Minerals Commission Control Room

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ABSTRACT
The tracking of Earth Moving and Mining Equipment particularly excavators operating in mining districts in Ghana has become necessary due to the level of environmental degradation associated with their use in the Artisanal and Small-Scale Mining sector. To this end, the Minerals Commission of Ghana, mandated by the Legislative Instrument 2404 has established the Ghana Mine Repository and Tracking Control Room to take inventory, track and monitor the movement of all excavators. The control room is segmented into five main sections namely; the excavator monitoring section, explosive carting trucks monitoring section, call centre section, tactical island, mini server room section and coffee area. A dedicated fibre optic internet connection with an upload and download speed of 60 MB has been installed to support the monitoring operations of the control room. With a sitting capacity of 8 people per shift, operating a three-shift system, the control room will be manned by 24 people each day. The significance of this paper is to bring to bear the technological innovations employed by the Minerals Commission to monitor the activities of excavators and other earth-moving equipment operating in the mining areas thus minimising the effects of environmental degradation.

General Terms
Control Room Design, Artisanal Small-Scale Mining, Information System Infrastructure, University of Mines and Technology

Keywords
Excavator Tracking, Ghana Mine Repository and Tracking Control Room, Artisanal and Small-Scale Gold Mining, Minerals Commission of Ghana.

1. INTRODUCTION
Artisanal Small-Scale Gold Mining (ASGM) contributes significantly to the economic development of the country [1], [2], employs over one million people [3], [4], [5], [6] and improves the living standards of local indigenes [7], [8]. However, its activities are largely uncoordinated, adopt the use of inappropriate mining methods, and have total disregard for the environment, thereby leading to significant environmental degradation. In recent times, the environmental degradation arising out of ASGM has attracted much public outcry. Of particular interest is illegal ASGM popularly known as "galamsey", which has become a nuisance as its activities can be directly linked to very destructive impacts on rivers and other water bodies [9], [10], [11], as well as agricultural lands and forest reserves [12]. The problem of environmental degradation is further exacerbated by the introduction of heavy-duty mining equipment such as excavators, bulldozers and payloaders into the ASGM sector. Even though the introduction of this equipment is replete with numerous benefits such as; easy navigation of rough terrains, typically ASGM sites, guaranteed timely completion of projects, and labour cost reduction, amongst others. Their usage in the ASGM sector has led to severe environmental degradation, as this equipment are used indiscriminately to remove large tracts of forest/vegetative cover within a short time frame to make way for mining [13] [14], [15]. Consequently, these have led to the abuse of the country's small-scale mining laws [16]. In line with the Government's strategic plan to regularise the ASGM sector and control the use of this heavy equipment in mining activities, the parliament of Ghana promulgated the Minerals and Mining (Minerals Operation – Tracking of Earthmoving and Mining Equipment) Regulations, 2020, Legislative Instrument 2404 (L.I. 2404) in 2020 to provide for the registration and real-time tracking and monitoring of all Earth Moving and Mining Equipment (EMME), particularly excavators used in mining operations across the country. To this end, the Minerals Commission of Ghana which is the Governments regulator in charge of mining has established the Ghana Mine Repository and Tracking Control Room (GMRTCR) to strengthen its monitoring capabilities over the use of excavators in mining and allied operations in the country.

The GMRTCR was established to perform four main functions namely:

(i) To track and monitor all EMME, particularly excavators operating in mining districts in the country;
(ii) To track and monitor the movements of all explosive carting trucks in the country;
(iii) To track and monitor the activities of speed boats deployed to monitor alluvial mining on river bodies; and
(iv) To monitor the operations of quarries, sand-winning, and industrial minerals in the country.

The significance of this paper is to bring to bear the giant strides undertaken by the Minerals Commission of Ghana by way of introducing technology into its operations as a first step to formalise the ASGM sector thus minimizing the effects of environmental degradation arising from the use of excavators.

2. RESOURCES AND METHODS
2.1 Resources
The GMRTCR is situated on the second floor of the main Minerals Commission head office building located in Accra, Ghana. The facility is the first of its kind to be established to take inventory and monitor the use of excavators in mining

activities both small and large scale in Ghana. The GMRTCR operates a three-shift system every day with eight people manning each shift. The daily workforce for the GMRTCR is 24.

2.2 Methods

The study adopted a "User-centered design" approach in all the project phases to set up the GMRTCR. By this, the views and needs of all stakeholders (i.e., project manager, architect/interior decorator, project sponsor and GMRTCR supervisor) were considered through participatory ergonomics activities by way of personal interviews, and on-site surveys [17].

A checklist was adapted from "A Guide to the Ergonomics of Manufacturing" [18]. This list was filled out simultaneously whilst conducting the interviews. During the interview process, several facets of how the GMRTCR should look, the various sections to be developed, the lightning system to be employed, and the kind of activities the operators will be involved in were all documented, including pictures of the entire workspace. Based on the findings, the development phase was conducted. This includes the 3D design of the new ceiling as well as the entire model of the GMRTCR, taking cues from the ergonomic criteria and requirements for the design and implementation of control rooms.

2.2.1 Proposed Control Room Floor Plan

The entire working area of the GMRTCR is approximately 884.0 cm long by 552.0 cm wide as shown in figure 1. The space was managed very well to adequately accommodate all blocked-out operational sections. The sections include; three workbench areas, a visitor's area, a tactical area, a coffee area and a mini server room area. The sections were carefully designed for the GMRTCR to conform to the ISO 11064-1: 2000 standard [19]. These standard spells out the need to adopt ergonomics in the design of control rooms, as well as layouts and dimensions of workstations to achieve maximum efficiency and safety for equipment and work floor operators. The plan shows one three-seater workbench overseeing the west wing wall of the room, another three-seater workbench directly opposite the waiting area and a two-seater workbench overseeing the east wing wall of the room. There are five windows and four built-in bookshelves. Figure 1 shows the image of the floor plan of the control room.

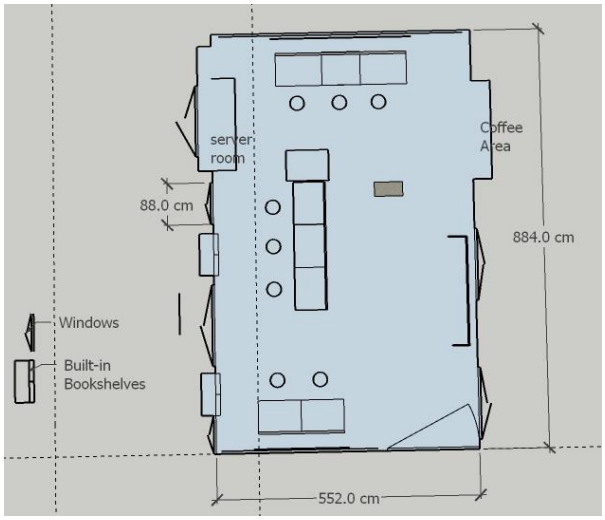


Figure 1. Proposed Control Room Floor Plan

2.2.2 Installed Lighting System

Control room safety and efficiency benefit greatly from adhering to and incorporating best control room lighting practices that meet the ISO standards and requirements. Efficient lighting is a critical factor in ensuring a safe working space for control room operators. The lighting needs to be reliable and the luminaires must achieve the required level of light intensity. However, there is much more to lighting than light distribution and intensity levels; we believe that the floor operators should also feel comfortable in their working environment and the lighting should help them remain focused while working. To support the efficient deployment of the intended lighting system in the GMRTCR, the ceiling was redesigned as shown in figure 2. The new ceiling has three main chambers to accommodate the intended lighting system. The three lighting systems used are spotlights, warm lights and dimmable lights.

(i) **Spot Lighting** – Spot Lights were introduced in the GMRTCR to enhance the well-being of the floor operators. The lighting rigs fitted to the ceiling with lighting reflecting down into the control room also offered a similar concept as a mood enhancer without creating glare.

(ii) **Warm Lighting** - Warm lighting was installed to introduce low-temperature lighting which exposed the GMRTCR operators to a calmer working environment. This was important as it helped to preserve the eyesight of the floor operators from the high ultraviolet rays emitted from the installed LED screens.

(iii) **Dimmable lighting –** Dimmable lights were introduced into the GMRTCR to prevent reflections and glairiness from the installed screens as well as change the visual appearance of the space whilst conserving energy.

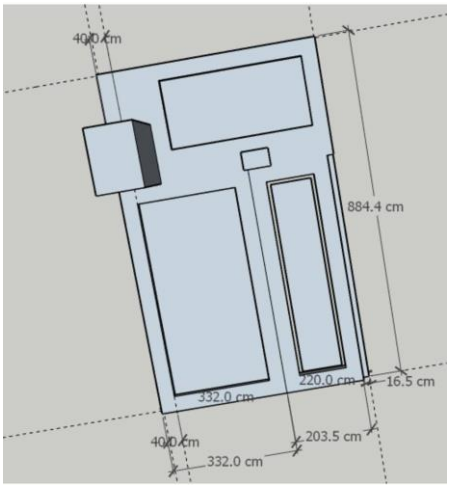


Figure 2 Ceiling Plan of the Proposed Control Room

2.2.3 Functional Sections of the Control Room

Figure 3 shows the four main functional sections of the GMRTCR:

(i) **Earth Moving and Mining Equipment Monitoring Section -** Situated on the west wing wall of the control room, this section holds six 56-inch Light Emitting Diode (LED) screens which are controlled by three all-in-one hp client computers.

Manned by three field operators per shift, this section is designated for monitoring the activities of all EMME especially excavators, payloaders and bulldozers operating in all mining districts in Ghana. The field operators here are responsible for creating geofences around concessions and pairing excavators to each concession;

(ii) **Explosive Trucks Monitoring Section** – Situated on the East wing wall of the control room, this section holds four 56-inch LED screens which are controlled by two all-in-one hp client computers. Manned by two field operators per shift, this section is designated for monitoring the activities of all explosive carting trucks in the country. Monitoring of the trucks is achieved by way of five cameras affixed in and around each truck;

(iii) **Call Centre Section** – Situated right opposite the waiting area, this section is manned by three call centre operators per shift. Operated through three client laptops, the call centre operators are to respond to all client requests from the field; and

(iv) **Tactical Analytics Section** – Situated right in the middle of the GMRTCR, this section is controlled by a 46-inch touchscreen table. This section helps floor operators to perform detailed analytics on issues happening on the field.

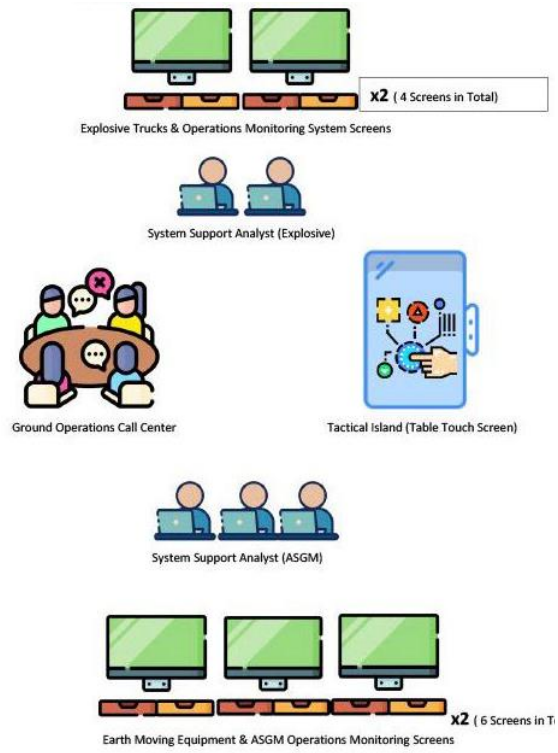


Figure 3 Functional Sections of the Proposed Control Room

2.2.4 IT Infrastructure of the Control Room

Figure 4 shows the internet infrastructure design deployed in the GMRTCR. The main Local Area Network (LAN) backbone is a point-to-point internet connection with a download and upload bandwidth speed of 60 MB from the main Network Exchange Centre (NEC) of the Minerals Commission to the mini server room created in the GMRTCR. The point-to-point connection from the NEC and mini server room were established by a fibre optic cable which is terminated into two rack-mountable Optical Distribution Frames (ODF) setup at both ends. From the ODF in the mini server room, the LAN connection is transmitted through fibre patch cords to a fibre Media Converter (FMC) for onward transmission to a 24 port USW-Pro Ubiquiti switch by way of a Cat 6 ethernet cable. An ethernet cable is then connected from the switch to a Linux box which also serves as a firewall to probe all incoming and outgoing network traffic. From the switch, the network is distributed to eight client computers and a touchscreen table computer by way of Cat 6 ethernet cables and further distributed wirelessly to mobile users through a Cisco RV134W Wireless-AC VPN Router. To ensure the network performs at 100%, two network management measures were put in place:

(i) Network cables connected to the client computers and the touchscreen table were accurately labelled, tagged and terminated into the patch panel before being connected to the respective ports on the switch. This enabled easy traceability and troubleshooting of the network in case of any unforeseen eventualities; and

(ii) To ensure network longevity as well as avoid unnecessary downtimes, 18 network cables were installed instead of nine. To this end, each client computer had a duplicate ethernet cable installed to serve as a backup in case the primary network cable goes down. This will ensure that the network operated at all times.

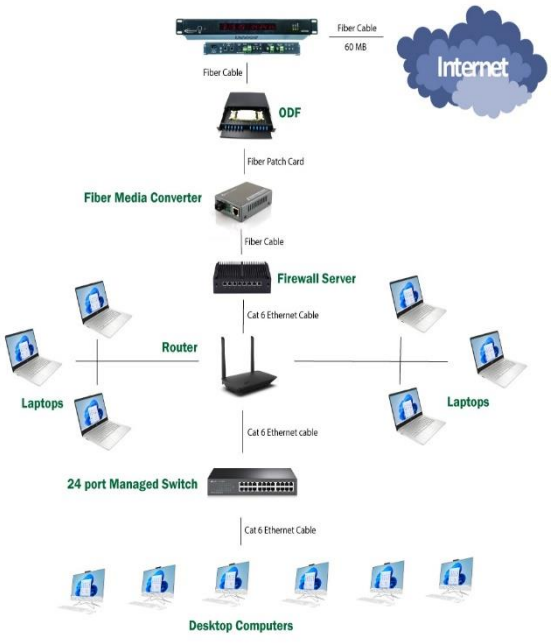


Figure 4 ICT Infrastructure Setup in the Control Room

2.2.5 Workstations Installed in the Proposed Control Room

To ensure that the GMRTCR operated optimally and at all times, high-end computer and server systems were installed.

(i) For the main workbenches, five 24-inch touchscreen All-in-one hp computers were installed. All computers are running on a 64-bit Windows 11 Home Edition operating system. Their processors are 11th Generation, Intel (R), Core (TM) i5 running on a speed of 2.4GHz, with a Random Access Memory of 12GB and a Hard Disk Drive (HDD) of 1 Terabyte (TB) and a 256 Gigabyte (GB) Solid State Drive (SSD) respectively. All the computers are running on the original and licensed operating and application software;

(ii) To adequately support the call centre staff in their day-to-day operations at the GMRTCR, three hp pavilion 360 convertible touchscreen laptops were installed. The laptops are running on a 64-bit Windows 11 Home Edition operating system with an 11th generation Intel (R) Core (TM) i5 processor operating on a speed of 2.40GHz. The RAM and SSD card sizes are 8GB and 256GB respectively for all the laptops. All the computers are running on the original and licensed operating system and application software;

(iii) The tactical area is equipped with a 46-inch Elo 5053 4K Interactive touchscreen display table. The display table runs on a Windows 10 Home Edition operating system and is compatible with the android operating system as a Full HID Human Interface. It is equipped with a RAM of 16GB and an SSD of 256 GB; and

(iv) The mini server room is equipped with two, 9U rack cabinets. Each cabinet has a dimension of 12U 19", 590 (H) x 600 (W) x 440 (D) mm, 370mm working depth indicating the distance from bars to the rear of the panels. Each cabinet comes with a 4mm toughened glass door to allow for see-through. Each cabinet has an inbuilt fan system to cool all affixed devices. One of the cabinets houses the video wall processor server and two 24-port Hp ProCurve switches that coordinate the activities of the five client computers on the working floor, the ten video wall screens as well as the touchscreen display table. The second rack cabinet holds a rack-mountable server that holds the firewall, an ODF device, a 24-port switch, a router, a fiber media converter, and a HIKVISION rack-mountable switch which controls all the cameras installed in the GMRTCR.

2.2.6 Network Cable Management and Maintenance

Maintaining efficient communication in every control room depends largely on the type of network cables deployed, its management, and how the cables are maintained [20], [21]. In the GMRTCR, all installed network cables are category six (Cat 6) twisted pair ethernet cables connected to the Network Interface Cards (NIC) of the client computers on the operational floor. This cable type was selected as it supported data transfer speeds of up to 10 Gigabits per second (Gbps) at 250 Megahertz (MHz) with less or no crosstalk interference. Two cable management techniques were employed to ensure efficient network performance.

(i) All the cables were terminated with registered jack 45 (RJ 45) connectors and connected to the client computers by way of wall jacks installed beneath the workbenches. To avoid cable congestion on the GMRTCR floor, all the cables were organised and passed through the newly installed ceiling, and dropped directly inside the mini server room. This was necessary thus to edge off any future upgrades or repairs and gave the setup a professional look; and

(ii) To avoid network downtimes, duplicate cables were also laid to support the primary cables which were connected to the client computers. In the mini server room, all the network cables were terminated into a patch panel before being connected to the switch by way of patch ethernet cords. This ensured that all the cables were correctly aligned and labelled to the right ports on the switch. This was essential as it helped to easily identify and troubleshoot a faulty cable and where it is connected to.

2.2.7 Data Storage

Data storage forms a crucial part of any information system architecture [22]. Even more critical are the techniques employed to secure the stored data. To this end, in the GMRTCR, two main forms of data storage mediums were adopted namely:

(i) Onsite Data Storage – To support onsite data storage, a Dell PowerEdge R730xd – 2U Rack Mountable Server with an inbuilt random-access memory (RAM) of 128 GB, 3.0 Gigahertz (GHz) speed, 12.5 Terabyte of Hard Disk (HDD) space and 2 * 256 Solid State Drive (SSD) space. Additional slots for RAM and HDD are available for future upgrades. The server runs on two operating systems (i.e. Windows Server 2022 and Linux); and

(ii) Cloud-based Data Storage – Cloud-based storage was the second medium adopted for the GMRTCR to store and access large amounts of data (i.e., still images and video feeds) generated by mining operations of the excavators being tracked. The cloud-based storage has been integrated with the Ghana Mine Repository and Tracking Software to support data storage and analysis which will provide real-time insights and improve the efficiency of the monitoring efforts of the Minerals Commission.

2.2.8 Alarm System

Despite the low rate of fire incidence in the GMRTCR, there is a need to deploy safety precautions in the space. This was necessary because the installed computers require more power and generate more heat, the installed LED screens generate more heat, and the uninterruptible power systems (UPS) and storage batteries also pose an additional level of risk by requiring more power. For this reason, four (4) fire alarm systems were installed in the room. The alarm system was carefully positioned in the GMRTCR so that it can detect the occurrence of any glitch that goes off in the GMRTCR. Additionally, one Eco Fire Co2 4.5kg cylindrical tank fire extinguisher has been installed.

2.2.9 Access Control

A facial recognition access control lock has been installed to grant access where necessary to authorised personnel of the GMRTCR. The system was installed at the main entrance of the control room to register all persons entering and verify whether they are authorized or not.

The access control system includes:

(i) Facial recognition system;

(ii) Fingerprint access; and

(iii) Personal Identification Cards.

3 RESULTS AND DISCUSSION

Based on the design standards for control rooms that conform to the ISO 11064-1: 2000 standard, the following ergonomic and safety considerations that ensured effective and efficient operations were met:

(i) Layout: The GMRTCR was designed with a clear and logical layout that allows floor operators to easily access the information and equipment they need to enhance their operations at all times;

(ii) Ergonomics: The GMRTCR was designed with ergonomics in mind to reduce operator fatigue and improve overall comfort;

(iii) Lighting: Adequate lighting has been introduced into the GMRTCR to ensure that operators can see the information and equipment they are working with;

(iv) Acoustics: The interior fixtures and fittings in the GMRTCR were designed to minimize noise and echo thus improving communication within the space;

(v) Equipment: The GMRTCR was well equipped with the necessary technology and equipment to enable operators to effectively monitor and control the system.

(vi) Redundancy: The GMRTCR was designed with redundancy in mind thus ensuring that operations can continue even if equipment or systems fail.

(vii) Security: The GMRTCR was designed with security in mind to prevent unauthorized access and protect sensitive information and equipment.

(viii) Accessibility: The GMRTCR was designed to be accessible to all operators, including those with disabilities.

(ix) Scalability: The GMRTCR was designed to be easily expandable as the system grows and evolves.

(x) Human factors: The GMRTCR was designed to take into account the cognitive and social aspects of human behaviour thus improving operator performance and reducing errors.

3.1 Results of 3D Visualization

The results of the 3D viisualisation design are shown in figure 5. To achieve excellent design results, it was necessary to develop a 3D visualisation design of the GMETCR at the concept development phase that enabled the architect and interior decorator visualize the project from various perspectives, revealing different angles, and spaces and even highlighting design details that may need to be more carefully distinguished. The results depict a computer-generated representation of the physical layout of the GMRTCR, including the various consoles, monitors, and other equipment used to monitor and control various systems. This visualization can be interactively navigated, allowing the architect/users to view the control of the room from different angles and perspectives. The visualization further shows the different operational scenarios, allowing the designers/users of the space to simulate and analyze different system behaviours in the virtual environment.

Figure 5 3D Visualization Design of the Proposed Control Room

3.2 Results of Videowall Display Screens

The installed video wall display screens to monitor the activities of excavators in mining areas, as well as explosive carting trucks, provided a comprehensive and real-time view of the mining operations, allowing for better decision-making for the GMRTCR floor operators. As shown in figure 6 (a) and (b), the following factors contributed to the results achieved by the installed screens:

(i) **Screen size and resolution:** Ten (10) 56-inch large LED screens were installed and conjoined. The screens had high resolutions that displayed the images and video feeds from the excavators and other mining equipment being monitored;

(ii) **Viewing angle:** The viewing angles of installed screens were wide enough to ensure that the images and video feed were easily viewed from different positions in the GMRTCR.

(iii) **Brightness and contrast:** The screens had a high level of brightness and contrast that ensured that the images and video feed were easily viewed even when the lights in the GMRTCR were turned off.

(iv) **Durability:** The installed screens are durable and remain usable over a long period.

(v) **Network connectivity:** The screens are connected to the installed LAN and the videowall processor server which allowed for real-time data transmission and remote monitoring.

(vi) **Installation:** The installed screens were installed in such a way that allows for easy maintenance and replacement of faulty parts where necessary.

(vii) **User Interface:** The screens have an easy-to-use interface that allows the GMRTCR operators to quickly and easily access the data and images they need.

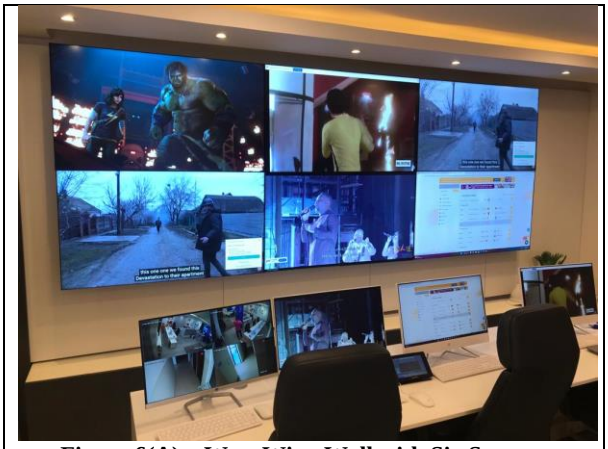


Figure 6(A) – West Wing Wall with Six Screens

Figure 6(B) – East Wing Wall with Four Screens

3.3 Results of Viewing Angles of the Videowall Display Screens

The viewing angles are very important when it comes to video wall display screens. In the GMRTCR, the screens were carefully installed taking into consideration the range of angles from which the display can be viewed without significant loss of image quality. From the results, it can be deduced that the wider the viewing angle, the more people comfortably viewed the display from different positions in the room. Per the design of the GMRTCR, the operator's workstation was carefully positioned in such a way that they have a clear view of the installed monitors that are critical to their job function as shown in figure 6. By this, the operators have access to multiple screens and control panels, which allowed them to easily switch between different views or perspectives. The monitors were placed at a comfortable viewing angle and eye level to avoid neck and eye strain. Additionally, there were measures in place to minimize glare and reflections on the monitors to improve visibility and reduce eye strain. The sitting poster of the floor operators further improves their viewing angle. To achieve this, the furniture used in the GMTRTCR was designed in such a way that ensured sufficient rest so that the operators feel comfortable and prevent spine compression when sitting on them Colombia.

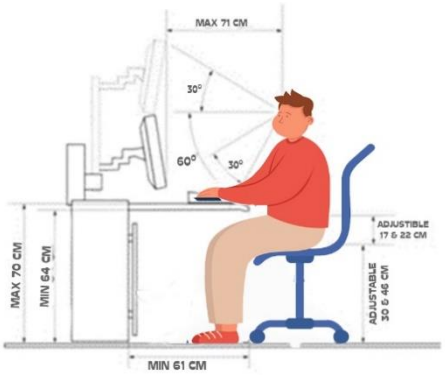
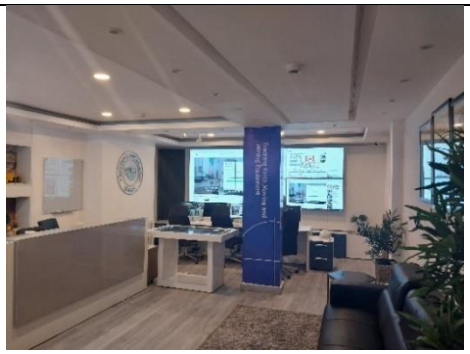


Figure 6 Viewing Angle of Control Room Operators when Sitting

3.5 Results of Completed Ghana Mine Repository Tracking and Control Room

Figure 8 shows some images of the completed GMRTCR.



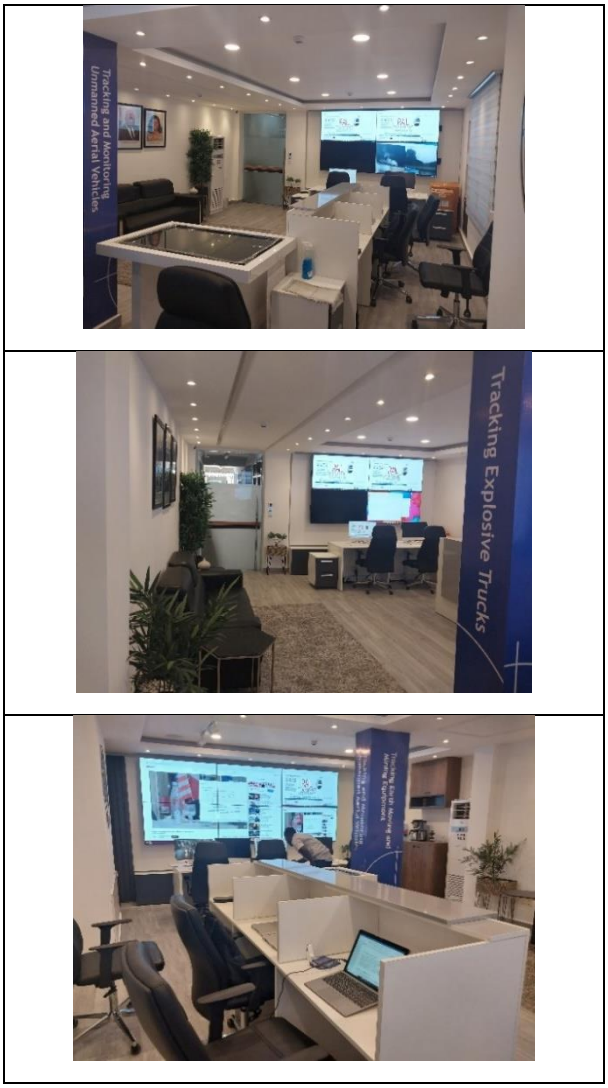


Figure 8 Images of the Completed Control Room

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

The following conclusions are drawn from the paper:

(i) The GMRTCR has been fully established to reinforce the monitoring arm of the Minerals Commission of Ghana concerning the movement of excavators in all mining districts in Ghana,

(ii) The entire floor area as well as the installed equipment, fixtures and fittings conformed to the ISO 11064-1: 2000 standard; and

(iii) The GMRTCR floor operators have been adequately trained.

4.2 Recommendations

From the paper, the following recommendations are made:

(i) There should be a well-structured maintenance schedule for the installed hardware and software equipment;

(ii) The installed software packages should be upgraded periodically; and

(iii) Even though the upload and download capacity of 60 MB is considered sufficient, the managers of the GMRTCR can consider increasing the bandwidth of the LAN to at least 100 MB should the workload increase.

5. ACKNOWLEDGMENTS

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