AUGMENTED REALITY AND MOBILE SYSTEMS FOR HEAVY EQUIPMENT OPERATORS IN SURFACE MINING

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AUGMENTED REALITY AND MOBILE SYSTEMS FOR HEAVY EQUIPMENT OPERATORS IN SURFACE MINING

Juan David Valencia Quiceno

Thesis submitted to the
Benjamin M. Statler College of Engineering and Mineral Resources
At West Virginia University

In partial fulfillment of the requirements for the degree of

Master of Science in
Mining Engineering

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Morgantown, West Virginia
2023

Keywords: Augmented Reality, Mobile Application, Heavy Equipment Operators, Surface Mining, HoloLens 2, Mining Training

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ABSTRACT

AUGMENTED REALITY AND MOBILE SYSTEMS FOR HEAVY EQUIPMENT OPERATORS IN SURFACE MINING

Juan Valencia

U.S. federal laws mandate that mining companies ensure a safe workplace, implement approved training programs, and promptly report work-related injuries. The mining industry’s commitment to innovation reflects a history of adopting advancements to enhance environmental sustainability, workplace safety, and overall productivity, while simultaneously reducing operational costs. This thesis proposes the integration of Augmented Reality (AR) technology and digital applications to enhance the surface mining industry, presenting two innovative solutions: an AR Training System and an Operational Digital System. These business solutions have been developed and applied at a surface mine in the southwest of the US, having the potential to improve the mining industry by enhancing safety, training, operational efficiency, and data-driven decision-making, which comprehends a significant step toward a more sustainable, effective, and technologically driven mining sector, contributing to the industry’s evolution and growth.

The AR Training System leverages Microsoft’s Power Platform and HoloLens 2 capacities to provide operators with immersive and step-by-step training guides in real working conditions for Dozers, Motor Graders, and End Dump trucks. These AR guides combine 3D models, videos, photos, and interactive elements overlapping mining equipment to enhance learning and safety. The system also offers an efficient approach to data collection during operator training, which has the potential to modify the training guides based on user performance. On the other hand, the Operational Digital System addresses the industry’s operational challenges. It streamlines the pre-operation inspection process, tracks equipment status, and accelerates defect identification, shift timing, delays, and loaded tonnage. The system offers a holistic approach to mining operation optimization, facilitating data sharing and management among different departments, enhancing collaboration, and expediting maintenance processes.
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Acknowledgements

I want to express my sincere gratitude to everyone who contributed to the completion of this thesis. Their continuous encouragement and invaluable contributions have been essential throughout this academic journey.

First and foremost, I want to acknowledge my mother, sister, and wife. Their constant encouragement, understanding, and support have been my stronghold, motivation, and inspiration in this stage of my life.

Dr. Vladislav Kecojevic, my advisor and mentor, deserves my deepest appreciation. His guidance and assistance have been invaluable throughout this process. I am especially grateful for the opportunity he gave me to pursue my master’s degree in the United States, which has been both the best and most challenging experience of my academic career.

Dr. Dragan Bogunovic deserves special recognition for opening the doors at the mine, where I completed the experimental portion of my research. His assistance, resources, and the multiple opportunities for growth have considerably contributed to the project’s success.

I also extend my appreciation to Ernest Arviso for his exceptional patience, passion, and motivation throughout this process. His commitment to the project, together with the expertise and work experience he shared, has been crucial in meeting the objectives established. The Mine Community deserves sincere gratitude for embracing a culture of safety and excellence. Their readiness to answer inquiries and provide frequent feedback has improved the quality of my work significantly.
Chapter I

Introduction

1.1 Background

In the United States, federal laws for health and safety in the mining industry establish the essential requirements for companies to ensure both a safe operation and the well-being of employees regardless of hazardous mining conditions. These regulations mandate the provision of a safe workplace, the implementation of an approved training program, timely reporting of work-related injuries, regular maintenance of heavy equipment, among others (U.S. Department of Labor, 2018). Additionally, The Code of Federal Regulations outlines the permissible training methods, including classroom instruction, on-site training, interactive computer-based instruction, or any other technology-based training method. Furthermore, the Mine Safety and Health Administration (MSHA) recognizes computer-based and interactive training technologies as viable methods and establishes that the presence of a competent person may not necessarily be required in the training room.

MSHA provides guidelines and support for the development of training programs for Heavy Equipment Operators (HEOs) that fulfill MSHA requirements. The following bullet-points illustrates the essential knowledge and capabilities that HEOs are expected to acquire during their training:

→ HEOs must have a comprehensive understanding of how and where to report equipment problems or malfunctions.

→ HEOs should be proficient in executing startup and shutdown procedures for their equipment.
→ HEOs must possess and validate their skills to perform tasks safely before operating equipment.

→ HEOs should be able to demonstrate safe operation and correct procedures for addressing any changes in the equipment, road, or weather conditions.

In addition to these federal requirements, mine safety involves a collective commitment from every employee, reinforced by corporate values towards zero harm in mining that reduces both hazards and risks in the industry. Multiples researchers have investigated mine health and safety to propitiate the integration of technological equipment designed to mitigate hazards and detect major problems related to mining employee’s health and safety. In this context, Janicak (2011) indicated transportation accidents as the leading cause of occupational fatalities in the mining industry. This study highlighted young employees as the most vulnerable individuals in a mine to suffer accidents due to their limited work experience and risk-taking behavior.

Noraishah Ismail et al. (2021) conducted a comprehensive analysis of mining accidents between 2015 and 2019, concluding mechanical failures was the root cause of those accidents. Their research also emphasizes in the potential of software and safety training to predict and prevent hazards or risks. Moreover, McMahan et al. (2010) analyzed the most significant factors that directly impact work-related injuries with powered haulage equipment in surface mining, suggesting lack of training, improper equipment inspection, and human error as recurring root causes of accidents. A national survey conducted by Margolis (2010) involving individuals who suffered work-related injuries in an underground coal mine revealed that 66% of employees had not received training on predicting and avoiding hazardous scenarios while working.
The mining industry has a rich history of adopting technological advancements to address environmental, workplace, and productivity challenges. From drone technology to automation, mining companies have made significant investments in innovations and digital software to enhance performance while reducing operational costs. However, achieving a technological transition in mining toward the goal of zero harm demands not only the integration of advanced machinery but also training employees in roles where human factors are critical. In this sense, Yang et al. (2021) emphasize that technological tools and safety regulations are essential, but do not guarantee a safe working environment. Besides, according to the same author, neglecting periodical employees training or delaying equipment maintenance can potentially lead to hazardous scenarios.

To address health and safety challenges and enhance workforce development, the mining industry has recently turned to immersive technologies such as simulators, virtual reality, and augmented reality, making employees gain confidence with their equipment and workflows. Virtual Reality (VR) offers a digital and immersive environment into computer-based models, increasing its significance in product design and safety training (Zhao, 2009). Besides, VR has proven to be an efficient technology for training in extreme scenarios, providing a safe and controlled environment for replicable testing, reducing training costs, improving retention rates, and enhancing safety performance (Pedram et al., 2017).

Augmented Reality (AR) overlays digital content onto real-life objects, offering precise instructions in the work environment, allowing employees to visualize and interact with digital content in a real-life space. De Souza Cardoso et al. (2020) conducted a review of 121 AR related publications in industrial application, suggesting a remarkable industrial adoption in manual assembly processes, maintenance, training activities, quality inspections, and machining setups, highlighting the
versatility, replicability, and adaptability of AR in engineering problems.

Even though there is no substitute for real-life experience, emerging technologies have gained attraction to standardize safety and training programs by enhancing training experiences through experiential engagement. This approach enables employees to comprehend training materials more efficiently, maintain focus, improve information retention, and practice through experiential learning (Zhang, 2017). In the industrial context, Gavish et al. (2015) compared VR and AR technologies for training operators in maintenance and assembly tasks, favoring AR over VR due to its superior knowledge transferring and usability. AR training has demonstrated the ability to reduce errors in tasks involving component placement or inspection. Therefore, this research involves the development of an AR system for training of pre-shift equipment inspections in the mining field.

Numerous studies have showcased the efficiency and effectiveness of Augmented Reality and Mixed Reality technologies in multiple industrial companies, enhancing task performance and reducing training time across a range of manufacturing domains, including assembly (Lai et al., 2020; Vanneste et al., 2020), maintenance (Erkoyuncu et al., 2017; Siew et al., 2019), and safety inspections (Runji & Lin, 2020; Urbas et al., 2019). For instance, AR guidance has demonstrated remarkable improvements in vehicle maintenance and repair, by significantly reducing time tasks after training compared to other computer-based methods (Henderson & Feiner, 2009; Woollaston, 2014; J Jacobs et al., 2016; Mourtzis et al., 2020; Moghaddam et al., 2021).

In addition, Hou et al. (2015) conducted a comparative study of AR instructions versus traditional isometric drawings for assembly tasks, revealing that AR instructions have led to a reduction between 50 - 60% in assembly times and errors, lowering mental task loads. They also identified
secondary benefits, including a 50% reduction in labor costs and a 66% reduction in rework costs due to assembly errors. Therefore, Moghaddam et al. (2021) states that AR is an effective tool for providing intelligent and personalized guidance, notifications, and task information during training, emphasizing the substantial potential of AR in the domains of maintenance and inspection.

Several mining companies and equipment manufacturers have started to explore and adopt AR solutions for equipment inspections. For example, a study by Lim et al. (2018) demonstrated the usefulness of AR for underground coal mine equipment inspections, highlighting its potential in enhancing safety and efficiency. Moreover, Moghaddam et al. (2021) explored the implications and design process for a cloud-platform management system for developing, assigning, and analyzing AR trainings for HEO in the mining industry. Likewise, companies like Caterpillar have been experimenting with AR to improve equipment maintenance and assembly training in the mining sector. However, the potential of AR technology has not been fully explored yet in the mining industry.

AR is a flexible technology developed through smart devices such as smartphones or tablets, as well as Head Mounted Displays. Microsoft HoloLens is an Augmented Reality Head Mounted Display (AR-HMD) device based on computer vision, graphical processing, display technologies, input systems, and cloud computing (Microsoft, 2018). This AR-HMD device provides a great cost-effectiveness and wide integration with Microsoft's ecosystem platforms, providing robust security, reliability, and scalability (Microsoft, 2018). Hoover (2018) conducted a mock assembly task using Microsoft HoloLens and found 15% fewer errors and faster assembly times compared to other AR devices such as Oculus and Magic Leap. However, the same author suggested the possibility of toggling the AR overlay on and off to improve visibility for close tasks.
The use of Augmented Reality through HoloLens 2 has been recently incorporated as an innovative training methodology with remarkable employee enhancement. Research conducted by Forrester Consulting indicates a 60% increase in task efficiency and a 50% reduction in rework, resulting in annual savings of $6,540 per on-site worker (Brown et al., 2021). Furthermore, this technology frees up 30% of leaders’ time for project coordination, planning, and customer enablement, generating additional savings of $15,600 per manager or supervisor (Brown et al., 2021). Multinational companies such as Honeywell (Marr, 2018), Porsche (Polladino, 2017), and Mercedes-Benz (O'Donnell, 2018) have also reported up to a 50% improvement in production time and an over 80% reduction in error rates with AR technology using HoloLens.

On the other hand, the integration of cloud-based applications has emerged as a disruptive trend to optimize operational processes. Smith et al. (2020) stated that cloud technology offers mining companies the possibility to efficiently store, manage, and share information. Besides, data management not only enhances decision-making processes but also promotes real-time updates, contributing to improve productivity (Jones & Wang, 2019). The adoption of cloud-based applications within mining operations serves as a foundation for technological advancements and innovation, aligning with the industry’s commitment to environmental sustainability and cost-effectiveness (Brown & Miller, 2021). In this context, cloud platforms provide a robust data infrastructure for the implementation of business solutions, fostering a more agile, connected, and data-driven mining sector (Smith et al. 2020).

The mining industry’s pursuit of innovation is exemplified by multiple technological adoptions. For instance, mobile systems enhance operational processes through connectivity and communication, improving traditional workflows, providing real-time information to on-field personnel (Gupta & Sharma, 2018). Mobile applications facilitate pre-operation inspections,
defect identification, and tracking equipment status, contributing to a more agile work environment (Chen et al., 2022). Mobile systems not only optimize workflow but also aligns with the mining industry's dedication to safety and innovation, empowering mining employees with tools for timely decision-making, enabling them to address operational challenges and contributing the industry's evolution (Wang & Li, 2017).

The integration of Microsoft Power Apps applications has emerged as a powerful tool for custom application development, offering a user-friendly interface and robust functionality, particularly streamlining processes and improving collaboration (Johnson & Smith, 2019). Moreover, Power Apps applications facilitate efficient data collection, enabling custom modifications for training and operation in the mining industry (White & Brown, 2020). The adaptability and ease of use of Power Apps is based on its low-code development technology, which enable people with no advanced computing or coding skills to develop custom-made applications and digital solutions to address specific operational needs, workflows, and processes in a variety of business scenarios. ensure that mining personnel can efficiently navigate and utilize the system (Martinez & Pfister, 2023)

### 1.2 Problem Statement

Safety training has become a high priority for the mining industry due to demanding federal regulations imposed by the historical injury and fatality rate of employees in the sector (Wallace, 1987; Monforton & Windsor, 2010; Morantz, 2012; Schulte et al., 2022). The Code of Federal Regulations (CFR) mandates that every mining operation in the United States establish a comprehensive training program, subject to approval by the Mine Safety and Health
Administration (MSHA). These programs must encompass the latest regulations outlined in 30 CFR Part 46 and Part 48 and enforced by periodic MSHA Inspections.

A mine in the US can expect MSHA Inspectors four times a year for underground operations and two times per year for surface mines, making sure the implementation of training programs, adherence to record-keeping procedures, and compliance with health and safety standards (U.S. Department of Labor, 2018). This regulatory landscape related to health and safety training represents a persistent challenge for mining companies, as training programs can be perceived as passive cost centers in time and space, causing potential obstacles to both productivity and profitability.

On the other hand, the mining industry faces a dual challenge of attracting and retaining skilled young employees towards a workforce transition. Indeed, 86 percent of mining executives concluded is harder to recruit and retain talent, particularly in specialized fields such as mine planning, process engineering, and data science (Abenov et al., 2023). Consequently, mining companies may confront immediate challenges in securing skilled labor and professionally training new employees. Knowledge transfer during training is especially critical as the aging workforce takes its wealth of experience into retirement. However, this process is often inefficient and unstructured, jeopardizing new employees, machinery, and exposing companies to financial penalties (Roldán et al., 2019). Therefore, modernizing and innovating training programs that effectively engage young and inexperienced employees is an urgent challenge for the mining sector to ensure continued production and safety in the years ahead.

Mining regulations stipulate that new miners must undergo an extensive 40-hour training for underground or 20-hour training for surface employees, and an 8-hour annual refresher (U.S. Department of Labor, 2018). Traditional training for HEOs typically involves textbooks, classroom
lectures, and unstandardized on-the-job instruction (Masters, 2010). Exposing trainees to a large amount of theoretical information within a limited time, often leading to a lack of employees’ focus and low retention rates in both inexperienced and experienced operators. Despite a company’s aspirations to maintain a zero-accident rate within a mine, vocational training programs frequently fail in providing the practical knowledge needed for the complexity of mining equipment and high-risk procedures associated with it, leaving gaps in practical task procedures, thereby potentially creating hazardous situations on the workplace (Moghaddam et al., 2021).

Furthermore, heavy equipment used in mining operates under extreme conditions, resulting in exponential wear and the potential for abrupt breakdowns and failures (Ruff et al., 2011). A critical responsibility for HEOs is to conduct a pre-shift inspection before operating heavy equipment to evaluate its operational safety. The failure to conduct a proper pre-shift inspection may lead to machinery wear-related accidents and causing considerable damage to equipment, employees, and cause repercussions for a company’s profitability and reputation. The complexity of inspections relies on factors such as machinery type, operator experience, machine wear, allotted time, and knowledge gained through training (França & Hollnagel, 2022). In traditional training programs, HEOs poorly interact with the machinery until they operate it, causing misjudgment of risks, and an increase in hazardous situations within the workplace.

A pre-shift inspection traditionally relies on a binary checklist where the operator’s criteria determine the functionality of critical equipment parts before operating the equipment. HEOs should fill up the checklist in a limited time, verifying and making crucial decisions about unfamiliar pieces of equipment. Zujovic (2020) describes equipment components to consider during an inspection, which includes, but not limited to body structure, lights, sensors, tires, rims, bolts, leaks, fluid levels, and extinguisher system. His research also mentioned that inspection length varies depending on the type of machine, and the operator’s awareness of the proper procedure,
but typical pre-shift inspections for a dozer or end-dumps trucks takes approximately 10-15 minutes when no defects are identified, and more complex machines, such as Surface Miners, demand inspections lasting between 15-30 minutes. Thus, standardizing the HEO’s training can bring a high value to the entire mining process, minimizing mistakes and improving equipment efficiency (Zujovic, 2020).

Apart from equipment inspection training, the mining industry faces numerous challenges that impede the integration of technological solutions related to safety, operational efficiency, and collaborative decision-making. A significant issue throughout the industry is the lack of a unified and efficient data management system, limiting the potential of cloud-based applications due to fragmented data systems, thus impeding mining companies from accessing real-time information about equipment status, safety protocols, training records and operational performance. (Molaei et al., 2020). Additionally, the reliance on traditional and paper-based workflows results in inefficiencies in pre-operation inspections, defect identification, equipment status tracking, operational time, and equipment production, leading to potential risks and productivity delays.

While cloud-based applications offer promising solutions, their implementation within the mining sector has yet to be fully analyzed, requiring more examination of their potential to streamline processes, enhance collaboration, and contribute to overall operational efficiency. Addressing these challenges is crucial for the mining industry’s evolution toward a safer, more efficient, and technologically advanced sector, empowering collaboration, and real-time decision-making. This problem statement aims to promote research and innovation to overcome the existing limitations towards a more connected, data-driven, and sustainable mining industry.
1.3 Scope of Work

In the mining industry, Heavy Equipment Operators (HEOs) play a critical role in every aspect of surface mining process, from ore extraction to transportation and processing, HEO are constantly facing hazardous scenarios that may place themselves or co-workers in danger of equipment-related accidents. Hence, HEOs must acquire high-level skills to safely complete their responsibilities, ensuring the protection of their workplace environment and preventing mine accidents. This research aims to assist HEO to properly conduct a pre-shift inspection, by deploying both an AR Training System and an Operational Digital System as an end-to-end solution for capturing and managing information.

Microsoft Power Platform is the ecosystem selected to host and connect both systems proposed for this research. The AR Training System is based on HoloLens 2 capabilities, developed in Dynamics 365 Guides to create training sessions, and connected to Power Apps to display a training evaluation application in an AR space. The Operational Digital System is developed in Power Apps to create a mobile and website application connected to Microsoft Power BI and SharePoint resources for visualization and storage, respectively. Both systems offer a robust and secure application for multiple users working in the same application.

The AR System provides trainees and training supervisors access to a holographic in-situ application for self-guided step-by-step instruction of pre-shift inspection procedures, aiming that operators can learn faster, with fewer errors and greater retention rate. On the other hand, Operational System gives employees from operation, maintenance, engineering, and payroll departments a versatile application, which provides details on equipment and employee work responsibilities. Adoption of this technology will depend on not only the importance of safety
training, but also on the ease of use of the systems proposed in this investigation. The specific objectives to achieve in this project encompass the following:

- **Content Collection**: Gather traditional training materials, encompassing user manuals, classroom presentations, and on-paper checklist inspections. Additionally, capture multiple images with various stages of wear and defects. Create informative videos where experienced operators perform proper inspections. Edit these photos and videos to illustrate a clear and informative training message for operators.

- **Server and Cloud Deployment**: Synchronize and connect Microsoft Power Platform to resources such as Dynamics 365 Guides, Power Apps, Power BI, and SharePoint, assigning user roles and system requirements.

- **AR Application Development**: Transfer the collected training information into Dynamics 365 Guides to develop the outline training. Physically attach virtual content to real working areas with a QR code using HoloLens 2 device.

- **Mobile Application Development**: Develop a Mobile and Website application in Power Apps to innovate the management of pre-operation inspection in the mining industry. This application enables real-time data communication between mining departments, aiming to optimize outdated procedures.

- **Assessment Tool**: Development of assessment quizzes during the training session and evaluation application launcher to assess the knowledge acquired during training.
Chapter II
Methodology

2.1 Introduction

This research aims to design, implement, and evaluate an augmented reality system for the annual refresher training of heavy equipment operators demanded by MSHA in surface mining operations in the United States. In the pursuit of this goal, various AR devices were considered, including the Magic Leap One, Epson Moverio BT-350, and Google Glass Enterprise Edition 2. Each of these devices comes with distinct price points and deployment options; however, they share a common limitation. They do not provide a centralized cloud engine for comprehensive system development, thereby necessitating the integration of third-party tools such as Unity 3D, Visual Studio, and device-specific software applications.

In contrast, Microsoft HoloLens 2 stands out as a superior choice in the market given that Microsoft licensing grants access to the Microsoft Power Platform and all the cloud computing services required to develop both an AR Training System and an Operational Digital System, thereby enabling the deployment of multiple training programs and operational applications for various purposes, procedures, and equipment, serving as an integrated solution for employee training and operational data management, benefiting hundreds of employees in mining companies. HoloLens 2 is a simple and intuitive device controlled via hand movements and voice commands. At first, users might feel unfamiliar, however, user learning is accelerated due to engaging and intuitive actions. HoloLens 2 offers capabilities that are useful in a variety of situations, helping employees to smooth the learning process.
2.1.1 Technical Approach

Microsoft Power Platform provides an ecosystem to host both the AR Training System and Operational Digital System, harnessing the capabilities of cloud computing services to develop end-to-end mining applied solutions, which are versatility organized by secure environments and user roles from a corporate Admin Center. These environments contain packages and connection to Microsoft resources, explained in detail later in this chapter, to enrich the system capabilities. Under the Microsoft ecosystem of this research, Dynamics 365 Guides license granted access to Microsoft Power Platform Admin Center, Power Apps, Power BI, and Azure resources to develop both systems proposed in this investigation.

Dynamics 365 (D365) Guides software facilitates back-end training management and configuration, while the front-end provides a friendly interface for different user roles. To access to D365 Guides resources, users require a permit granted by a system administrator in the Admin Center, as well as an email and password. This software allows users to create, modify, or operate AR applications, in such a manner that the holographic information is anchored to the physical equipment in real working conditions. Figure 2.1 offers a comprehensive visualization of creating an AR training System using Microsoft services.
Three main user roles categorized as admin, author, and operator were considered in this study, each of them possessing unique responsibilities in the AR system development and operation. Training supervisors primarily serve as authors and administrators in charge of managing the Admin Center, anchoring holograms and instructions in the equipment, analyzing data performance, and maintaining records of training sessions in the cloud. On the other hand, HEO serves as the end user and conducts self-guided training sessions, completing quizzes throughout the session and a session evaluation. The following figure shows the employees’ responsibilities in this training system.
Parallelly, the Operational Digital System presents a comprehensive solution leveraging Microsoft Power Apps with the Power FX programming language to address and streamline operational challenges within the mining industry. The proposed system is hosted within the Microsoft Power Platform to offer a centralized solution for managing users and connecting with diverse resources across the Power Platform ecosystem, ensuring a dynamic and user-friendly interface for different users. This system provides five main screens for mining employees, as is presented in Figure 2.3, offering resources for Heavy Equipment Operators, Operation Supervisors, Maintenance Supervisors, and Managers.
This application is designed to optimize mining operations by focusing on operational scheduling, pre-operation inspection process, equipment status tracking, defect identification, shift timing, delays, and loaded tonnage as is illustrated in Figure 2.4. Supervisors play a key role in this process by approving the collected information by operators, ensuring accuracy and efficiency with operational information. Moreover, the application encourages interdepartmental data sharing among different departments involved in mining operations.
2.2 Hardware requirements

The hardware components essential for the successful execution of this project are diverse, each of them serving for different purposes. They include:

➔ Digital camera
➔ Microsoft HoloLens 2 for Augmented Reality
➔ PC or laptop capable of supporting AR content.
➔ Tablet or Cellphone
➔ Miscellaneous components

2.2.1 Digital Camara

This research chose a Sony a7 III camera to serve as the primary tool for capturing images and videos of heavy equipment, thus facilitating the acquisition of multimedia assets for training content creation. The camera provides a 24 Megapixel and 4K resolution with a dynamic full frame for continuous shooting bursts.

Key Features are:

➔ 24MP full frame BSI CMOS sensor
➔ 93% autofocus coverage (693 phase-detection points, 425 for contrast detection)
➔ Oversampled 4K/24p video taken from full width 6K (cropped-in 5K for 30p)
➔ Image stabilization
➔ 10 fps continuous shooting
→ Dual SD memory card slots
→ USB 3.1 Type C

Figure 2.5 Digital Camera

2.2.2 Microsoft HoloLens 2 Trimble XR10

As mentioned, several augmented reality (AR) devices are available on the market, each offering a range of features and prices. Among the options considered for this project were Magic Leap One, Epson Moverio BT-350, and Google Enterprise Edition 2. However, the Microsoft HoloLens 2 was carefully selected by its compelling features related to reliability, security, and scalability of Microsoft’s Cloud.

The Microsoft HoloLens 2 Trimble XR10 exhibits distinctive characteristics that distinguish it as a suitable choice for the project. HoloLens 2 stands out for its user-friendly interface, primarily managed by hand movements and voice commands with a full view range of 43 degrees
horizontally, facilitating the perception and understanding of holographic information within the user’s surroundings, even at considerable distances. Although users may initially encounter some unfamiliarity when interacting with floating controller screens or buttons, intuitive actions allow for rapid adaptation. In addition, the device is equipped with voice commands, eye tracking, and real-world anchoring to help users to naturally interact with a mixed reality environment. This is especially useful for workers who need their hands free for other work tasks.

In terms of hardware, the HoloLens 2 contains three integrated cameras and an array of sensors. The principal camera positioned at the front center of the visor has an 8-megapixel resolution and supports video recording at 1080p and 30 frames per second, offering a precise and clear visual record of the user’s augmented reality experience. Additionally, it contains two tracking cameras situated on the left and right fronts of the visor to capture essential data for real-world environment tracking system, encompassing user hand movements and the positioning of objects. In terms of audio, it is equipped with two integrated speakers positioned at ear level on each side. These speakers deliver sound with remarkable clarity and volume, ensuring that operators can be engaged with narrative instructions.

The Microsoft HoloLens 2 Trimble XR10 was chosen for this project because of its outstanding technical capabilities, which perfectly match the project’s goals. The device provides a solid ecosystem for the development and deployment of AR training systems, allowing immersive and intuitive training experience for heavy equipment operators. However, it is essential to acknowledge that despite its powerful capabilities, the Microsoft HoloLens 2 Trimble XR10 does have certain limitations, particularly when operating in outdoor environments. One of the most noticeable limitations is the display’s sensitivity to intense sunlight. Excessive brightness reduces
the visibility of content on the display, limiting the user’s ability to see and interact with augmented reality aspects effectively.

According to Microsoft HoloLens 2 (2023). The device’s components are:

- **Visor**: Contains the HoloLens sensors and displays.
- **Headband**: Use the adjustment wheel to expand or adjust the headband.
- **Brightness buttons**: are located on the visor’s left side to adjust the bright conditions.
- **Volume buttons**: are located on the visor’s right side to adjust the speaker volume.
- **Power button**: Is located on the right side of the rear outer cover to turn on/off the device.
- **USB-C port**: The port is located on the right side of the rear outer cover below the Power button.

HoloLens 2 is available in three different versions, each with its own pricing for a range of different working conditions and requirements. The Trimble XR10 version was chosen for this study because it is OSHA-compliant and intrinsically safe hardhat-integrated, compatible with most hardhat-mounting PPE. The price for this version is USD 5199 at the time of this research, and its aspect is indicated in Figure 2.6.
According to Microsoft HoloLens 2 (2023). The device’s capabilities are:

- **Hand Tracking**: Fully articulated hand tracking allows users to touch and grasp holographic objects.

- **Voice Enabled**: Built-in voice commands allow users to quickly navigate and operate when hands are occupied with a task.

- **Eye Tracking**: understands eye-intent and adapts holograms to the user's eyes in real time to precisely know where the user is looking at.

- **Spatial Mapping**: Seamlessly map the physical environment and allow digital content to be anchored to objects or surfaces.

- **Collaboration without boundaries**: Connect with remote experts in real-time to quickly resolve issues on the worksite.

- **Large Field of View**: See twice as much as previous AR headsets, allowing for precise interactions with holograms.
To render holographic information on PCs or laptops, HoloLens uses an emulator known as Hyper-V with RemoteFX (first Gen Emulator) or GPU-PV (HoloLens 2 Emulator) for hardware-accelerated graphics. The computer must meet the following hardware requirements to run a holographic emulator:

- 64-bit Windows 10 Pro, Enterprise, or Education, Windows 10 Home Edition does not support Hyper-V or the HoloLens Emulator.
- CPU with four cores (or multiple CPUs with a total of four cores)
- 8 GB of RAM or more
- In the BIOS, the following features must be supported and enabled:
  - Hardware-assisted virtualization
  - Second Level Address Translation (SLAT)
  - Hardware-based Data Execution Prevention (DEP)
- GPU requirements
  - DirectX 11.0 or later
  - WDDM 1.2 graphics driver or later (first gen)
  - WDDM 2.5 graphics driver (HoloLens 2 Emulator)
  - The emulator might work with an unsupported GPU but will be slower.

### 2.2.3 Laptop

The laptop employed for the development of this research project was the ASUS VivoBook 17. This laptop, as shown in Figure 2.7, comes equipped with an integrated AMD Radeon Vega 3 graphics card, offering a variety of options onboard with the processors. This laptop is fully
compatible with the HoloLens 2 and Microsoft Power Platform, and meets the requirements listed previously. The following items describe the capabilities of the laptop.

➔ Processor Intel Core i7 8250U
➔ 1.6 Base speed
➔ Memory RAM 8GB expandable up to 24GB
➔ Nvidia GeForce graphics processor
➔ SSD 256GB

Figure 2.7 ASUS VivoBook Laptop

2.3 Software requirements

The deployment of this project required the utilization of various software and tools to create, develop, and edit the necessary content for the implementation of both the AR Training System and an Operational Digital System
2.3.1 Microsoft Power Platform

The Microsoft Power Platform shown in Figure 2.8, is a low-code platform designed for creating end-to-end business solutions that includes application development and data management. This platform comprises seven primary components, among them: Power Apps, Power Automate, Power BI, Dynamics 365, and Power BI. These extensions within the Power Platform can be employed individually or collaboratively. These components collectively serve to link complex solutions and enable the realization of business intelligence objectives, including analytics, process automation, and data-driven applications. Power Platform’s approach empowers every member of an organization to actively participate in the development of business solutions, regardless of their technical expertise, from front-line workers to professional developers. The following figure provides a high-level overview of each core product area and its associated extensions.
2.3.1.1 Microsoft 365 admin center

The Microsoft 365 Admin Center serves as a centralized hub for the management of common administrative tasks across various applications within a Microsoft Cloud. This platform empowers administrators to execute a range of actions, including user management, license management, password resets, invoice viewing, and more, all from a unified location. To access the Microsoft 365 Admin Center, users can navigate to admin.microsoft.com, where they will find a suite of tools and features designed to facilitate administrative tasks. Additionally, the Admin Center offers customization options aimed at enhancing productivity. Users can pin essential information and actions to the home screen for quick and easy access. Furthermore, they can choose between two viewing options: Dashboard or Simplified view.
The Microsoft 365 Admin Center serves as an essential component within the research’s methodology, enabling administrators and trainers to efficiently manage user roles, permissions, and training sessions, thus contributing to the successful deployment of the augmented reality training system. Figure 2.9 shows the Admin Center main interface.

![Power Platform Admin Center](image)

**Figure 2.9** Power Platform Admin Center

### 2.3.1.2 Microsoft Power Apps

Microsoft Power Apps offer a robust environment for developing highly customizable and low-code applications that can be shared with internal users or resources across the Microsoft ecosystem. Power Apps gives developers the option to choose between a Data-driven App or Canvas App, empowering them with comprehensive control over the visual elements of their applications. These Power App can integrate data and services from various sources of Microsoft
such as Teams, Power BI, and Dynamics 365, enhancing the utility within an application and aiming to offer the tools to build an end-to-end business solution.

Here are key features that highlight the extensibility of Power Apps when working with Canvas App:

✓ **Custom UI Components:** Power Apps provide the flexibility to design and implement custom user interface components, allowing developers to build an app's interface to their specific requirements.

✓ **Custom Connectors:** Power Apps allow the development of custom connectors that establish communication with external data sources and services. This capability ensures that the app can be integrated with a wide range of systems and services.

In the context of this research, Microsoft Power Apps play a crucial role in the development and deployment of both an evaluation app that is connected to the AR Training System at the end of each training cycle, and as an end-to-end mobile app for the Operational Digital System. It serves as a platform for creating and managing the content, interfaces, and employee's data that are essential for both systems. Figure 2.10 illustrates the main interface of Microsoft Power Apps.
2.3.1.3 Dynamics 365 Guides

Dynamics 365 Guides is a mixed reality application designed to provide step-by-step, heads-up, and hands-free holographic instructions that are visually anchored to the physical locations where tasks are performed. This innovative solution offers real-time guidance, presenting information about what needs to be done and how to do it directly in the workplace, enabling employees to learn and execute complex jobs following step-by-step tasks. The instruction cards in Dynamics 365 Guides can incorporate a variety of multimedia elements, including text, images, videos, 3D models, AR objects, and Power Links, making it a versatile tool for standardizing training and procedures, closing knowledge gaps in refresher training, and enhancing the overall employee’s safety awareness.

The key advantages of Dynamics 365 Guides in the context of this research include:
✓ **Training Efficiency:** Self-guided training session offers multimedia guidance that is visually tethered to the physical equipment, helping operators to perform complex tasks with fewer errors and greater speed and accuracy.

✓ **Enhanced Skill Retention:** The combination of multimedia instruction and immersive hands-on training contributes to better skill retention among operators. This ensures that the knowledge and skills acquired during training are retained and applied in real-world scenarios.

✓ **System Connectivity:** Power Links serve as connector to other Microsoft resources, enabling the visualization and data exchange between different components of the training system.

✓ **Data Storage and Analysis:** Dynamics 365 Guides automatically stores employee data within Dataverse. This data can be used for automated data-driven analytics and reports, facilitating the measurement of training effectiveness and employee performance.

However, Dynamics 365 Guides relies on a stable internet connection to collect and synchronize data. In cases where operators work in offline mode or face intermittent internet connectivity, data collection may not be continuous. This limitation was considered when deploying the AR training system, which will be explained later in detail. Figure 2.11 indicates the main interface of D365 Guides.
2.3.1.4 Power BI Services

Power BI Services is an integral part of the Microsoft Power Platform, which is designed to provide a powerful tool of business analytics and data visualization. It offers features for data preparation, data discovery, and the creation of automatized dashboards and business reports. Users can integrate data from various sources, including SharePoint, SQL databases, and structured files like CSV, XML, and JSON. This service also includes connectors for Microsoft Dynamics 365 Guides, known as Guides Analytics, which provide administrators with valuable insights of training sessions. Figure 2.12 shows the main interface of Power BI.
Microsoft Dataverse serves as a robust cloud data management engine, offering secure storage for data derived from Microsoft applications like Power Apps and Dynamics 365 Guides. It can also integrate with various Microsoft products, including Azure Event Hub, Azure Service Bus, and Microsoft SQL, through data connectors. The Dataverse information can be connected through APIs, allowing data to be utilized by other services. This allows businesses to control information through data tables and individual records for different employees within the organization.

Figure 2.12 Microsoft Power BI

2.3.1.5 Microsoft Dataverse
2.3.2 AutoCAD 3D

AutoCAD 3D, developed by Autodesk, stands out for creating professional 3D models that incorporate solids, surfaces, and objects. AutoCAD provides extensive editing capabilities within the software for different engineering problems. This research utilized AutoCAD 3D to generate 3D objects and labels, enhancing the augmented reality experience. It is important to note that 3D models in Dynamics 365 are required to be prepared and optimized 3D by rendering them, which minimizes both size and run-time processing requirements, improving their performance in AR spaces. Preparing CAD content for Dynamics 365 required two steps:

- Convert 3D models from parametric geometry into polygonal geometry.
- Optimize by rendering converted 3D models to ensure the best possible performance in real-time applications.

2.3.3 Vectary Application

Vectary is an open-source software for 3D CAD rendering into glTF files and other advanced optimized formats. It provides a friendly interface to quickly create all kinds of rendering for 3D models such as CAD objects, 3D logos or texts, and more. Vectary App was crucial for this AR Training System due to equipment CAD models and informative text required rendering before importing them to Dynamics 365 Guides. Figure 2.13 indicates a rendered End Dump Truck Model, note that rendered models are represented as triangulated polygon surfaces with glTF format to be able to run in AR spaces.
The following factors should be considered when converting and optimizing CAD models in the rendering process.

✓ Reduce surfacing quality.
✓ Reduce pixel sizes.
✓ Reduce textures.
✓ Reduce draw calls.
✓ Reduce hierarchy complexity.
✓ Increase distance between geometry faces.

2.3.4 Synthesia Website

Synthesia is an AI-powered software that allows users to create professional video by converting text into speech in over 120 languages and featuring 50 avatars that gesture words, making the
videos highly realistic, as real individuals were recorded. This versatile platform offers templates, backgrounds, music, and a range of tools to produce character-based videos without the need for a camera, microphone, or production team. In this project, Synthesia was employed to create safety videos and introduction materials, which were then integrated into Dynamics 365 Guides, serving as crucial components for the training system to guide and engage operators through pre-inspection procedures.

Figure 2.14 Synthesia AI application

2.3.5 Clipchamp

Clipchamp is a user-friendly video editor developed by Microsoft for simplifying video creation, even for inexperienced editors. With this tool, users can easily merge videos, images, audio files, incorporate text, effects, and more. In this project, Clipchamp played a vital role in editing videos
and photos captured directly from HoloLens 2. This content showcases both the real-world environment and holograms, offering a comprehensive illustration of the training application interfaces, thus employees can become acquainted with the AR training process.

![Figure 2.15 Clipchamp application](image)

### 2.4 Augmented Reality System

The augmented reality system proposed in this research is hosted in the Microsoft Power Platform, utilizing capabilities of Microsoft Cloud to create, store, and analyze training sessions. This system is designed to enhance traditional mining training, aiming to engage employees more effectively and provide supervisors with integrated record-keeping and analytics processes. The device HoloLens 2 blends the real and virtual worlds, allowing operators to be immersed with the training content, while interacting with equipment in real-life. Below are some important features that HoloLens 2 grants to this research project.
→ **Environmental understanding:** This feature captures the position of employees, their hand movements, real-world surfaces, and spatial boundaries, being able to understand the physical environment.

→ **Spatialized sound:** the system provides sound that replicates the depth and position experienced in the real world, enhancing the immersive quality of the training.

→ **Human understanding:** The system incorporates human understanding technology, enabling employees to interact through eye tracking and voice commands.

The principal component of this AR Training System is Dynamics 365 Guides, where each heavy equipment has an associated training guide and employees can create or operate an AR training session. However, a new user entering to the system is required first, to be registered and assigned with a user role in Microsoft 365 Admin Center. Training system administrators can manage different roles for employees and supervisors, grant permissions and credentials for specific roles within the Dynamics 365 Guides Application.

It is important to note that to access the training system, users need to log in to either the Dynamics 365 Guides PC App or the HoloLens App using credentials generated by the system administrator. The table below presents important terminology that users should be familiar with when using the application.
Dynamics 365 Guides PC application grants access to Guides Analytics through Power BI, allowing system administrators to analyze insights derived from training guides usage across the organization. Guides Analytics offers visual reports that provide a comprehensive overview of operator training adoption and usage patterns, enabling training supervisors to gain a deeper understanding of performance and identify areas for improvement over time.

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D models</td>
<td>3D content that authors can holographically place in a real-world.</td>
</tr>
<tr>
<td>3D toolkit</td>
<td>A library of predefined objects such as arrows, hands, pointers, etc.</td>
</tr>
<tr>
<td>Air tap</td>
<td>A hand gesture that is equivalent to a “click” with a mouse.</td>
</tr>
<tr>
<td>Anchoring</td>
<td>Procedure to ensure that a guide aligns correctly with the corresponding objects in the physical world</td>
</tr>
<tr>
<td>Calibration</td>
<td>Necessary step for new employees before using a HoloLens device</td>
</tr>
<tr>
<td>QR code</td>
<td>Physical object that serves as an anchor for a guide and all the holographic data to the physical world.</td>
</tr>
<tr>
<td>Dotted line</td>
<td>Represents a holographic connection that associates a step with the specific location where users should position themselves for a clearer focus view.</td>
</tr>
<tr>
<td>Gaze</td>
<td>The act of looking at the training interface elements, users can select or click elements in the application just by gazing at them.</td>
</tr>
<tr>
<td>Task</td>
<td>Set of steps that the operator must follow to complete a task</td>
</tr>
<tr>
<td>Step card</td>
<td>Authors utilize it within the PC application to incorporate text and 3D objects, linking them to individual steps within a real-world</td>
</tr>
<tr>
<td>Step</td>
<td>Training tasks are made up of steps that need to be followed in a step-by-step manner.</td>
</tr>
</tbody>
</table>
As operators utilize the Dynamics 365 Guides HoloLens App, their every gaze and interaction with the training are meticulously recorded. This data includes date and time of interactions, step number, task number, guide name, and more. All this information is securely stored within each environment in Microsoft Dataverse. Figure 2.16 indicates in red, the URL launcher that facilitates the connection between Microsoft Dynamics 365 Guides and Power BI analytics.

The Guides Analytics reports are designed to help training supervisors to perform an in-depth analysis of training performance and keep historical records of previous training sessions. Some of the key questions that can be addressed using Guide Analytics include:

➔ How many training sessions have been conducted in the last month?
➔ Is the training time increasing, decreasing, or remaining stable over the session?
➔ Which guides and steps take the most time to complete?
➔ Which step of a guide has the most variability in operator time?
➔ Is the operator completing the training or just skipping information?

![Figure 2.16 Link to access Power BI from Dynamics 365 Guides](image-url)
2.4.1 Manipulate holograms

As mentioned, Dynamics 365 Guides HoloLens App offers two user modes: Author and Operator. In the Operator role, employees can access and follow a training session but cannot manipulate or place holograms. In contrast, the Author role assigned to training supervisors requires the comprehension of how to manipulate holograms, aiming that supervisors can learn and replicate the process of creating an AR System for other types of training and procedures. Navigating the AR Training System proposed in this research involves various actions and gestures that both authors and operators must be proficient in to successfully fulfill the system requirements. Below are the initial key actions and gestures for interacting with the AR content.

→ **Touch**: The most straightforward and intuitive approach involves directly touching or grabbing holograms with the user hands.

→ **Hand ray**: To target objects at longer distances, users should extend their hand with the palm facing away, and a laser pointer (hand ray) will appear for precise interactions.

*Figure 2.17 Gestures while working in Augmented Reality*
→ **Gaze**: By gazing at objects for two seconds until a point circle reflecting user’s gaze is filled, objects can be selected or clicked and then manipulated with head movements.

→ **Air tap**: The main menu can be opened by performing an air tap gesture. Users simply hold one hand straight out and tap down with their index finger, then quickly raise the finger back up.

→ **Air tap and hold**: This gesture is particularly useful for grabbing objects at a significant distance. Users air tap but keep the finger down to hold object, and then move them around.

Wearing the HoloLens 2 device, users must first open the main menu to access to the device applications. This action can be executed using one or two hands, by performing an air tap gesture with one hand or extending one hand while using the other hand to touch a holographic Microsoft Windows logo on the wrist, as illustrated in Figure 2.18.

![Figure 2.18 Access to the HoloLens’ Main Menu](image)

Authors play a crucial role in placing holograms in the Dynamics 365 Guides HoloLens App, overlaying them on specific equipment parts to guide operators during training. Holographic
objects can be moved, rotated, scaled, and customized with different color styles to provide visual emphasize to essential aspects, as shown in Figure 2.19. For instance, using a warning or avoid style can indicate hazardous zones that operators need to be aware of during their tasks.

![Figure 2.19 Manipulation and Styles of Holograms in a Guide](image)

### 2.4.2 Voice commands

HoloLens 2 technology allows users to trigger actions through voice commands as a substitute for hand gestures or gaze, offering a more efficient and hands-free approach to interact with the application. To enable voice commands, users need to grant microphone permission to Dynamics 365 Guides. Below is a table listing the available voice commands that employees can utilize, however, they are most effective when are used on the appropriate interface or screen.
### Table 2.2 Voice Commands

<table>
<thead>
<tr>
<th>Voice Command</th>
<th>Trigger Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sign in</td>
<td>Start the sign-in process</td>
</tr>
<tr>
<td>Main menu</td>
<td>To open HoloLens main menu.</td>
</tr>
<tr>
<td>Try a guide</td>
<td>Open the Dynamics 365 Guides</td>
</tr>
<tr>
<td>Rescan</td>
<td>Rescan the anchor if holograms are not aligned</td>
</tr>
<tr>
<td>Confirm</td>
<td>Confirm the position of the anchor, so operators can start to use the guide</td>
</tr>
<tr>
<td>Minimize</td>
<td>Hide the content panel and the main menu</td>
</tr>
<tr>
<td>Scroll up</td>
<td>Scroll up the list</td>
</tr>
<tr>
<td>Scroll down</td>
<td>Scroll down the list</td>
</tr>
<tr>
<td>Clear search</td>
<td>Delete the text in the guide as an author mode</td>
</tr>
<tr>
<td>Previous step</td>
<td>Go back to the previous step of the guide</td>
</tr>
<tr>
<td>Next step</td>
<td>Go forward to the next step of the guide</td>
</tr>
<tr>
<td>Author</td>
<td>Select Author mode</td>
</tr>
<tr>
<td>Operate</td>
<td>Select Operate mode</td>
</tr>
<tr>
<td>Take a Photo/video</td>
<td>To take a photo or video of both real and virtual world.</td>
</tr>
</tbody>
</table>
2.4.3 Offline Mode Limitations

The AR Training System relies on a stable connection to the Microsoft Cloud to navigate and use all the training resources. Without an internet connection, employees will be unable to access guides or make real-time changes. However, there is an option to download a guide onto the HoloLens 2 device as a standalone application. In this scenario, the downloaded guide would work offline, but it would not have access to online updates or real-time features. It is important for users to ensure a reliable internet connection through Wi-Fi or Hotspot.

2.4.4 Augmented Reality System for Administrators

At the organizational level, managers, supervisors, and IT personnel perform an administrator role within the Microsoft 365 Admin Center and D365 Guides. Their responsibilities include purchasing and configuring a subscription license for Dynamics 365 Guides, creating, and updating developing and testing environments in Microsoft Power Platform, which serve as the foundation for the entire training system.

Each environment functions as a unique space for storing, managing, and sharing data, providing a container for different training data sources or departments within the company. Employees should be assigned by an administrator to a particular environment to access its resources. Figure 2.20 showcases the specific environment created for this project, denominated as "AR Mining Training."
Microsoft Dynamics 365 Guides consist of two main applications that administrators and authors can download from the Microsoft Store to develop an AR training guide. D365 Guides PC Authoring App is utilized for creating step cards, tasks, and uploading all the training resources, including 3D models, photos, and videos, which are then displayed in the AR application. The D365 Guides HoloLens 2 App, on the other hand, allows authors to place holographic content previously uploaded over equipment in the real world. Administrators are also in charge of analyzing training data and making reports. These tasks are essential for ensuring the effective operation of the AR Training System.

2.4.4.1 Add users.

In Dynamics 365 Guides, users are employees who have specific permissions to access the AR Training System or Operational Application environments. To add users, administrators should
begin by creating user accounts in Microsoft Admin Center, as depicted in Figure 2.21. Subsequently, a Dynamics 365 Guides license should be assigned to an either new or existing users, providing them with an email address and password that grants them access to the training system. Administrators should also configure user roles based on the specific duties and responsibilities in the training system.

![Adding a User in Microsoft Admin Center](Figure 2.21 Adding a User in Microsoft Admin Center)

Security Groups are created within an environment in the Microsoft 365 Admin Center, which serve as collaboration spaces where users can share workspace applications, files, and schedule calendar events, including training sessions. Administrators can choose between Distribution Groups and Security Groups. Distribution Groups are used for broadcasting information and notifications, while Security Groups are used for managing user access to Microsoft resources. Security Groups enable the automated addition or removal of members based on user attributes such as department, location, or job title, streamlining employees’ management within the organization.
2.4.4.2 Activate, deactivate, or delete a Guide.

Dynamics 365 Guides provides an organization with the possibility to create as many guides as possible within the same environment, centralizing multiple training guides in a unique place protected by security groups. Administrators have the capability to manage guides by activating, deactivating, deleting, or updating them based on evolving needs. When a guide is created, it becomes accessible for authors and administrators for editing via the Dynamics PC application, as showcased in Figure 2.22. However, only administrators have the authority to activate or delete guides from an environment. Therefore, administrators need to activate, deactivate, delete, or update a Guide as circumstances demand.

![Figure 2.22 Training Systems from Dynamics 365 Guides](image-url)
2.4.5 Augmented Reality System for Authors

An employee assigned with an author role in Dynamics 365 Guides is responsible for creating Training Guides using the D365 Guides PC App and the HoloLens App for each heavy equipment. When an administrator grants an employee the author role, the worker receives an email and password, facilitating their entry into both applications, as depicted in Figure 2.23.

![Welcome to Guides]

*Figure 2.23 Sign into Dynamics 365 Guides*

Authors equipped with multiple resources within D365 Guides to enhance the quality of training materials. This system uses holographic information to educate employees effectively, providing visual aids such as images highlighting the good and bad conditions of equipment components, instructional videos for inspection procedures, and holographic elements like arrows, hands, and
zones to guide operators within the real world. Creating a Training Guide involves the applications previously mentioned, each serving a specific purpose, as outlined in Figure 2.24.

![Figure 2.24 Working as an Author in Dynamics 365 Guides PC and HoloLens application (Microsoft, 2023).](image)

The following bullets points are key tasks that highlight the process of training guide in D365 Guides. Note that this research was conducted for types of mining equipment, demonstrating a replicable process for a variety of equipment or procedures.

➔ **Dynamics 365 Guides PC application.**
  - ✓ Creating a guide for each equipment.
  - ✓ Selecting an anchoring method.
  - ✓ Adding tasks and steps.
  - ✓ Writing the instructions for each step.
  - ✓ Assigning different types of content to support the steps such as 3D parts, 3D objects (arrows, hands, zones, and numbers), 2D media (images and videos)
  - ✓ Creating quizzes assignments
  - ✓ Connecting a Power Apps Training Evaluation
Dynamics 365 Guides HoloLens application After creating the guide outline in the PC application, an author should use the HoloLens application in Author mode to place holograms in the real world and test the training cohesion.

- Anchoring the guide.
- Placing holographic 3D content for each task in the workplace.
- Add dotted lines to illustrate where the operator should stand up.
- Add styles to 3D content to indicate warning or caution signs.
- Test the evaluation training and overall workflow.

2.4.5.1 Create a Guide

The process of creating a guide in the Dynamics 365 Guides PC App is simple and straightforward. To initiate this process, authors must follow these basic steps as illustrated in Figure 2.25.

1. Sign in: This step ensures users are granted with the necessary permissions to access and create new guides.
2. Create a New Guide: Within the app, navigate to the option to "Create a new guide."
3. Guide Name: Descriptive name that accurately represents the content and purpose of the guide. For instance: Motor Grader AR Training, End Dump Pre-op Inspection Training, etc.
4. Select Create: This action officially establishes the guide within Dynamics 365 Guides.
2.4.5.2 Anchor a Guide to the real world

Anchoring a guide to the real world is a crucial step that ensures holograms are positioned accurately in the physical environment. The chosen anchoring method serves as a reference frame for the holograms, and this spatial anchoring creates a virtual in-world reference for the guide. The first step involves selecting an appropriate anchoring method, it is crucial to ensure the anchoring method is always placed in the same position as precisely as possible, due to if the anchoring method is misaligned, instructions may show actions at incorrect locations, which can result in operator confusion during the training. There are three anchoring methods to choose from:
→ **QR code anchor.** This method is highly recommended for its accuracy and precision for large-scale applications. QR codes can be printed in various sizes and attached to physical equipment parts.

→ **Circular code anchor:** Suitable for small to medium-sized objects and spaces, circular code anchors may introduce minor angular errors during scanning, which can affect the overall accuracy of instructions.

→ **Holographic anchor:** Aligning holographic anchors with physical objects can be challenging, especially for larger holograms. This method is better suited for quick demos or virtual classroom training but may not be ideal for precision-intensive training.

The QR code was the anchoring method chosen for this project, as indicated in Figure 2.26. This method is particularly effective for large-scale holographic applications as mining equipment.
Here are some key considerations when printing and placing a QR code on the equipment.

➔ **Printing Paper** – The QR code should be printed on matte stock paper, when it is illuminated or laminated could cause problems due to reflected light.

➔ **Size** – The QR code should be with a width of 101 mm to 400 mm, sizes outside of this range might result in detection failure or reduced alignment precision.

➔ **Position** – The QR code must always be positioned flat, never distorted, or placed on curved surfaces. Otherwise, alignment and detection will be affected.

➔ **Location** - The QR code must always be in the same place and orientation.

### 2.4.5.3 Structure Guide Outline

The Dynamics 365 Guides PC App offers an Outline page, which is a fundamental tool for authors to create a structured framework for training guides. This framework helps authors plan and organize the training content effectively through a step-by-step approach for developing clear and well-organized guides. This high-level structure helps authors visualize the guide's structure and flow, ensuring it is logical sequence.

Once the initial guide structure is created in the Outline page, as shown on Figure 2.27, authors can proceed to the Step Editor. In the Step Editor, authors can add various types of content to support each step, such as text information, 3D models, multimedia, and Power Apps links. As mentioned, tasks represent groups of steps that operators must follow to complete specific parts of their training, while steps are individual, standalone work items that detail specific actions.
2.4.5.4 Placing Holograms in the real world

After creating the guide structure and adding holographic content in the Dynamics 365 Guides PC application, the next step is to bring this content into the real world. Wearing the HoloLens 2 device in Author mode, user can place the holographic content, including 3D objects and dotted lines, onto the physical equipment parts. The HoloLens 2 application provides a user-friendly interface, as illustrated in Figure 2.28, where authors can interact with the holograms and position them precisely within the real-world environment. These holograms serve as visual cues for operators, offering clear instructions on what actions need to be performed and where they should be completed.
The following list provides descriptions for each button and user interface (UI) element employed within the author's step card.

1. **Save** - Save the guide in the Microsoft Cloud.
2. **Undo** - Undo the last change.
3. **Redo** - Redo the last change.
4. **Home** - Navigate to a different guide.
5. **Follow Mode** - Makes the Step Card follow or lock it in a location.
6. **Anchor** - If the training guide is used in various locations, authors need to re-anchor it by directing your gaze toward the QR code.
7. **Setting** – Access the App settings.
8. **Profile** - Sign in or out of Dynamics.
9. **Outline** – In the Outline page employees can quickly move step cards around.
10. **Step counter** - Number of steps in the current task.
11. **Task name** - The name of the task.
12. **Gem** - By dragging the gem, authors can create a dotted line to draw attention to focus areas where operators should stand up.
13. **Bin** - Place where 3D objects previously added will appear and can be dragged into the real world by grabbing with the hands.

### 2.4.6 Augmented Reality System for Operators

The Dynamics 365 Guides HoloLens App offers operators an interactive experience within the AR Training System. Before conducting the training session, operators need to follow a few steps using the HoloLens device. Firstly, they should calibrate the eye tracking technology on to ensure optimal performance. Next, operators will sign in using the email and password provided by the administrator in the Microsoft Admin Center. This steps grants access to the main screen of D365 Guides.

After selecting a training guide in the Dynamics 365 Guides HoloLens application, operators should proceed to scan the QR code to spatially anchor all the holographic content at the equipment’s physical location. The correct synchronization ensures that the step-by-step instructions are perfectly aligned with the real-world environment, enabling operators to efficiently comprehend the training tasks. Throughout the training, operators have the convenience of utilizing voice commands and gazing over user interface (UI) buttons to execute actions. This
hands-free approach facilitates the inspection of equipment components, performing the necessary actions as guided by the training spatial sound, making the entire training process both engaging and effective.

2.4.6.1 Enabling Eye Tracking Technology

Eye tracking technology is a component integrated into HoloLens 2, offering functions such as biometric authentication and eye intent recognition. To ensure a personalized and precise AR experience, employees are required to conduct an initial eye tracking calibration test during their first use of HoloLens 2. This calibration process is essential for adjusting holograms to match the operator's field of vision, aligning hand gestures with holograms, and accurately determining the position of the operator's eyes within the AR space.

The calibration test is straightforward and involves operators gazing at a series of holographic targets presented within their field of view. Once this calibration is successfully completed, the device stores the biometric information, eliminating the repeated calibration tests. As a result, operators can enjoy a more comfortable, precise, and high-quality viewing experience while engaging with the AR training system. The calibration is automatically triggered when the system recognizes unfamiliar eye iris. Operators should just tap on the Adjust button as it is indicated in Figure 2.29.
HoloLens 2 can internally store up to 50 employee profiles, once this number is reached, the device automatically deletes the oldest unused profile. Eye tracking calibration test should work for most of the cases, however, if the device cannot calibrate an employees’ eyes successfully, here are some commons reasons for the process to fail.

✓ The operator got distracted and did not follow the calibration targets.
✓ The operator had contact lenses or glasses that the system does not support.
✓ The operator has certain eye physiology, eye conditions, or had eye surgery.
✓ External factors inhibiting reliable eye tracking such as smudges on the HoloLens visor, intense direct sunlight, or occlusions.

2.4.6.2 Operating a Guide in Dynamics 365

In the operator role, employees are granted access to conduct AR training sessions using the HoloLens 2 device. To enter the training system, operators need to login using an email and
password previously provided by an administrator. Once logged into the Dynamics 365 Guides HoloLens application, users should select the operator mode, as illustrated in Figure 2.30.

![Select Mode](image)

*Figure 2.30 Selecting Operator Mode*

After accessing the application, the operator should select the specific training for the equipment they operate. This training system is anchored to a QR code physically attached to the heavy equipment in the real world, as previously explained. To initiate the training session, operators must focus on the scan button displayed on the initial step card, as indicated in Figure 2.31, by gazing at the "initiate scan" button on the physical QR code, the training will synchronize the information and the system will be activated and ready for use.
It is important to note that the scanning process should be repeated whenever the heavy equipment's orientation or location changes to update the AR training to the new location. If the equipment's position does not change, re-scanning may not be necessary. However, in cases where holograms become misaligned, re-scanning the QR code is recommended to ensure a optimum training experience.

Operators can follow the training session by using voice commands or gazing at buttons to trigger actions on the step card, enabling them to perform training tasks without manual hand interactions. Furthermore, Dynamics 365 Guides HoloLens App allows the step card to follow the operator’s gaze or be locked in a static place. Another important aspect to consider while an employee is conducting this AR training, is to be focused on the dotted lines, which serve as visual cues, indicating where operators should position themselves to gain a better understanding of the training information.
2.4.7 Application Development

To achieve one of the objectives of this research project, two essential applications were developed using Microsoft Power Apps. These applications are integrated to various resources from the Microsoft’s ecosystem, serving as critical components within the AR Training System and Operational Digital, enhancing the system extensibility and capabilities as is explained in Chapter 3. The development methodology relies on real-world case studies carefully selected to demonstrate the versatility and applicability of the Microsoft ecosystem across diverse industries and use cases, which are explained in detail in Chapter 1. This investigation provides tangible and business-applied solutions for a coal mine in the U.S., where multiple phases of this project were conducted.

The development of these applications involved using HTML and Power FX coding as the programming language. Power Apps empowers developers to integrate databases, connectors, automated workflows, and various other functionalities, ensuring the robustness of the system. As mentioned in chapter 2.3.1.2, This research utilizes Power Apps connectors for Power BI to visualize data, and Dataverse, SharePoint and SQL to store data from the systems. In essence, Power Apps makes the process of developing applications more straightforward by offering an intuitive interface and connectors to various data sources.

The AR project required the creation of an evaluation application. The training application is created with headers and footers components through various screens, as depicted in Figure 2.32 (a) and (b) respectively. This app is accessible at the end of each equipment training within Dynamics 365 Guides using the HoloLens 2 device. Its primary purpose is to assess the
operator's knowledge and skills acquired during the training session by performing a real-life pre-operation inspection.

Figure 2.32 Power Apps for the AR Training Application

On the other hand, the Operational Digital Application utilizes a Portrait view instead of Landscape view and it contains multiple screens to efficiently encompass all the user actions within the application, serving as a comprehensive solution for managing the company's operational shift. This versatile application can be accessed through various devices, including tablets,
smartphones, and computers. It facilitates the recording of essential operational data, such as pre-operation inspections, time delays, load tonnage, employee work hours, and more, as demonstrated in Figure 2.33.

![Figure 2.33 Operation Digital Application](image)
3.1 Mine Description

This research was conducted at a surface coal mine located in New Mexico, which is owned by one of the largest coal producers in the United States with mining operations across Montana, New Mexico, and Wyoming, resulting in a production of over 50 million Tons in 2022. The company's commitment to enhancing health and safety through training has gained recognition and awards such as:

- 2020: National Mining Association’s Sentinels of Safety (Coal Handling Facility)
- 2020: Safety Award for Large Surface Mine – Rocky Mountain Coal Mining Institute
- 2019: Good Neighbor Award – Office of Surface Mining Reclamation and Enforcement
- 2019: National Mining Association’s Sentinels of Safety (Coal Handling Facility)
- 2018: Sentinels of Safety from National Mining Association – Awarded for Large Coal Processing

The Mine supplies an average of 5 million tons of coal annually to a Power Plant via a 5-mile rail line connecting the mining operation to the power plant. The mining method employed is an open pit with multiple operational fronts. The mining process encompasses the removal of topsoil and overburden materials by dozer equipment and controlled blasting. Two draglines are utilized for overburden removal, placing material in a previously mined pit, until the coal seam is reached.
Coal is extracted using highly efficient surface miners, which in turn load end dump and Kress trucks. Additionally, other equipment such as dozers, loaders, and haulage trucks contribute to reclamation efforts to restore mined sites. The heavy equipment fleet at the mine includes 20 haulage trucks, 10 dozers, 10 loaders, 5 motor graders, 2 draglines, and 2 surface miners, all operated by a workforce of over 200 employees. The mine operates 24 hours per day, utilizing two 12-hour shifts. Prior to operating equipment and after breaks, heavy equipment operators are required to complete a pre-operation inspection. Currently, paper-based cards are used for recording their operational equipment checklist, delays, times, and load tons.

This research focused on developing and evaluating an AR Training System for Haulage, Dozers, and Motor Graders trucks, given their extensive use within the mine and wide rotation between employees. Furthermore, an Operational Digital System is developed in this research, which centralizes a considerable part of the company’s operational data, streamlining communication between maintenance, operations, and payroll departments throughout real-time data storing and visualization tools, while meeting MSHA standards.

3.2 Holographic Content

The AR Training Applications developed with Dynamics 365 Guides utilizes a blend of holographic content that includes 3D models, step-by-step instructions, interactive elements, photos, and videos. This combination of multimedia elements provides precise and visually enriched guidance overlaid onto real mining equipment or step cards. This approach improves the training experience for a wide range of users, from newly hired employees to those rotating mining equipment or needing the MSHA mandatory annual refresher training. Microsoft HoloLens 2
serves as a projection device for integrating holographic content within the workplace environment, allowing users to follow instructions of how to conduct a proper pre-shift inspection. As explained, this research developed three AR training guides for Dozers, Motor Graders and End Dumps Trucks, as main components of the AR Training. Figure 3.1 provides an overview of the various methods used for uploading the content within the step-card instructions, which were previously edited and programmed.

The holographic content was linked to each training session and step-card instruction in both virtual and real world as illustrated in Figure 3.2, offering comprehensive guidance on the inspection of specific equipment components. This allows employees to visualize and immediately understand instructions within their actual working conditions, empowering them to replicate these actions and steps during the working time.
3.2.1 Images for the AR System

In this research, Images play a crucial role as visual references and support materials incorporated into the holographic content. These images provide the most relevant information about an AR training step, offering specific details regarding to the location and components that required inspection. Numerous photos were captured from each heavy equipment incorporated in this study, edited, and then uploaded into the Dynamics 365 Guides for projection within the AR space. Figures 3.3, 3.4, and 3.5 showcase some of the images integrated into the Dozer, Motor Grader, and End Dump Training Systems, respectively. Notice that elements like arrows,
text labels, and circles, are placed to highlight specific areas or components, ensuring the trainee’s attention is directed toward essential real-world elements.

Figure 3.3 Edited images attached to the Dozer training system.
Figure 3.4 Edited images attached to the Motor Grader training system.
Furthermore, employees have the flexibility to zoom in or out on these uploaded images, allowing a closer examination of specific features. The transparency can also be adjusted to bright on or off the holographic training experience.
3.2.2 Videos for the AR System

Interactive videos are crucial for this AR Training System, as they effectively explain complex actions, simplify multi-step inspections, and provide dynamic instructions for operators. These videos are integrated into Dynamics 365 Guides PC Application to enhance the training experience and ensure employee’s understanding of different procedures when conducting a pre-operation inspection. In cases where specific techniques are required, videos showcase these techniques, allowing operators to observe, learn visually, and replicate these techniques in the mining environment. In addition, voice commands can be utilized to pause, rewind, or fast-forward videos, enabling operators to review specific processes during the heavy equipment inspection process.

Each task within the training session is introduced with a video explanation, as detailed in section 3.3. Additionally, a safety video is provided at the beginning of each training section, ensuring compliance with MSHA regulations, as demonstrated in Figure 3.6.

![Personal Protective Equipment](image)

*Figure 3.6 AI Safety Video.*
Each training equipment session includes six primary tasks: Safety, Equipment Front View, Left View, Rear View, Right View, and Cabin or Deck. For each task, operators are required to watch a video summarizing the task and the associated steps for each type of heavy equipment. Moreover, these videos include text annotations and additional visual content to highlight essential pieces of the equipment or relevant information to successfully complete the equipment inspection demanded by the Federal mining law.

Therefore, when a trainee begins a new task, an introductory video guides them through the inspection task, highlighting key considerations that operator should inspect. Figures 3.7, 3.8, and 3.9 illustrate one video per equipment training guide. However, in the AR training system, operators should watch a total of six comprehensive videos for each type of heavy equipment studied in this research.

Figure 3.7 Video attached to the first step-card of each task during the Dozer training.
3.2.3 Additional Content for the AR System

The AR Training System relies on 3D models and objects to provide digital representations of physical objects and location, enabling users to interact with them during guided instructions. These 3D representations encompass various elements such as arrows, hands, zones, numbers, symbols, or other objects that have been previously rendered, optimized, and uploaded to the

Figure 3.8 Explanatory Video attached to step-card.

Figure 3.9 Explanatory Video attached to step-card.
system, serving as precise indication where actions should take place and in what sequence. Figure 3.10 illustrates some of the holographic content that is extensively employed for this AR Training System.

![Figure 3.10](image)

**Figure 3.10** 3D objects displayed in the training system.

In addition to the holographic content, Dynamics 365 Guides provides the capability to connect Power Pages and Power Apps within the training systems. This integration allows for the training evaluation, which has been developed in this study, to open and display the application in an AR space, as explained in session 3.4. In this research, a Pre-operation Inspection Application has been linked to the training system, as depicted in Figure 3.11. Employees should use this app as
a final requirement for this training, and to assess their knowledge based on what they have learned during the AR training session, ensuring their readiness for real-world inspections.

![Figure 3.11 Power Apps and Power Page utilized in the training system](image)

### 3.3 Augmented Reality Training System

This research encompasses the development of three different AR training guides in Dynamics 365 Guides, each designed for specific heavy equipment most frequently used within surface mining operations. These three training guides, as well as an application evaluation and data management from the Augmented Reality Training System developed through this research, which can be easily scaled to operations and maintenance training for multiple equipment or procedures. This Training system can be used in other mines and locations due to QR code technology. However, to utilize a specific training guide, the equipment must be of the same type and reference. Different equipment models, i.e., versions, may not have identical component locations, affecting the precision of the training guide.
The selected equipment for this research, as outlined in Table 4, is divided into three main training guides for Haul Truck, Dozer, and Motor Grader. Each guide covers the knowledge required for walk-around and pre-operational inspection as well as proper, start shutdown, and emergency procedures in addition to brake, steering, and back-up alarm pre-op tests. The Dynamics 365 Guides HoloLens Application provides access to these training sessions, where users can login with generic credentials for specific roles such as operator, author, or admin assigned in the Power Platform Admin Center and created to test the system for any user.

**Table 3.1 Equipment Selected for the AR Training System**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>CAT 789 &amp; 785</td>
</tr>
<tr>
<td>2.</td>
<td>CAT D10 &amp; D11</td>
</tr>
<tr>
<td>3.</td>
<td>CAT 16M &amp; 24M</td>
</tr>
</tbody>
</table>

Within this training system, author mode allows creating, editing, and modifying step-cards in each training guide, while operator mode should follow the training cycle step by step, however, users in operator mode are restricted from making edits. Figure 3.12 provides an overview of the three essential steps required to access to the AR training system hosted in Dynamics 365 Guides HoloLens App, which is logging in, selecting a training guide, and selecting a user role.
After accessing the system, the initial step to start the training session is to anchor the heavy equipment in the current workplace to the QR code placed in the equipment, which contains the holographic content and instructions. Figure 3.13 depicts the location of Haul Truck QR Code. This location must always be positioned in the same place, as previously explained.

*Figure 3.12 Accessing to the Training System.*
Subsequently, operators are required to watch a safety video that highlights critical safety aspects to consider before beginning the AR training, ensuring compliance with MSHA regulations, as explained in Figure 3.14. This video consists of a comprehensive explanation of PPE required, purpose of pre-operation inspections, commons hazardous conditions, and more.

---

Figure 3.13 Anchoring the system to the Real-World Environment.

Figure 3.14 Safety video displayed in AR.

- **Recognize work hazardous conditions**
  1. Muddy ground
  2. Uneven surfaces
  3. Tripping hazards
  4. Falling material
Each AR Training Guide comprises six primary tasks, each with multiple steps within them, varying in number and location depending on the equipment’s complexity. These tasks are aligned with the main training objective, provide a comprehensive AR training for HEO, which includes:

- Safety Task
- Front View
- Right View
- Rear View
- Left View
- Cabin/Deck
- White Card / Pre-op inspection Test

At the end of each training task, trainees are expected to demonstrate their knowledge of each task through a quiz before progressing to the next task. This ensures that operators are adequately trained for these tasks before they perform them on the equipment. Additionally, the final step of each training guide, users are required to complete an evaluation test, which reflects the actual checklist inspection that operators must conduct every shift.

Figure 3.15 and Figure 3.16 display the outline of the training guide designed for Dozers and End Dump Truck respectively. The training content is structured into tasks and steps, facilitating the operator’s ability to follow the inspection cycle systematically. As previously mentioned, this
approach ensures that operators can easily navigate through the training content and get the necessary information for each step.
Figure 3.15 AR training Outline for Dozer Training.
Figure 3.16 AR training Outline for End Dump Training.
Figures 3.17, 3.18, and 3.19 provide a real-world view of how this training guide for Dozers, Motor
Grader and End Dump Trucks respectively appear in the mining workplace. Within these training
sessions, each step is equipped with holographic content to show the exact location of the pieces
of equipment that require inspection in that step. It also includes edited photos, and videos, as
well as informative text tips.

*Figure 3.17 Dozer AR training system in the mining environment.*
Figure 3.18 Motor Grader AR training system in the mining environment.
Figure 3.19 Motor Grader AR training system in the mining environment.

This dynamic content automatically appears when the user initiates a new step and the system reads the information containing that step, eliminating the need for employees to read instructions. The integration of virtual content overlapping the real equipment enhances employees'
comprehension of the training materials and their ability to apply the knowledge effectively. Furthermore, Figure 3.20 demonstrates the quizzes integrated into the Dozer training. These quizzes are strategically positioned at the end of each task, allowing operators to assess their understanding and knowledge acquired. The quizzes serve as a valuable tool for ensuring that operators have successfully absorbed the training content.

Figure 3.20 Dozer quizzes for the AR training system.
3.4 Augmented Reality Application

Upon the completion of a training guide, a website link triggers from the last task and launch of a Power Apps application designed to assess the trainee’s acquired knowledge. This application serves as a digital version of the pre-operation inspection checklist, often referred to as a White Card in this research due to company conventions, which all operators are required to complete at the beginning of their shifts. Figure 3.21 offers a visual comparison between the traditional paper version and the updated digital version proposed in this research.

![Operational Safety Checklist](image1.png)  
![WHITE CARD](image2.png)

**Figure 3.21** Traditional pre-op inspection and the updated digital version
The training application offers numerous advantages, not only keeping training records, but also, managing and reporting data in compliance with MSHA, facilitating the efficient transformation of training data into management reports and analytics. Figure 3.22 indicates the Evaluation Training App launched in an Augmented Reality space.

Figure 3.22 Evaluation Training App launched in an Augmented Reality space
3.5 Website and Mobile Application

As a complement to the AR Training System, this research project developed two main applications designed to address the needs of pre-inspection checklist and operational data management, covering everything from training to operational. These applications leverage the capabilities of Microsoft Power Platform, including Power Apps, Dynamics 365 Guides, Power BI, SharePoint, and OneDrive. Consequently, they can be accessed across multiple devices, including HoloLens, tablets, computers, and smartphones.

3.5.1 Website Application for the AR Training System

The website application has been developed to fulfill the record-keeping and analytical requirements for training purposes. This website serves as evaluation criteria at the end of each training guide, and stores training information. It also contains a help section where trainers and trainees can access to get guidance on how to manage or operate the AR System, as well as creating new training guides. Figure 3.23 showcases the website application launched from a computer, in which trainers can upload supplementary task training information, encompassing classroom training, simulator sessions, operational guidelines, and more.
3.5.2 Mobile Application for the Operational Digital System

The mobile and tablet application goes beyond meeting training needs. The proposed application primarily serves as a hub for data administration during the operational shift at the mine. This application comprises five main screens accessible through the footer menu, each tailored to user permissions and mining job. For instance, users can access operator, maintenance or management resources or navigate in the home screen to access quick or frequently used screens or pages as illustrated in Figure 3.24 (A).
Figure 3.24 (A) Quick Access from the Mobile Application. (B) Equipment status. (C) Operational schedule. (D) AI Chatbot

The application screen indicated in Figure 3.24 (B), allows all the users of the Operational Digital System to review previous equipment inspections. Users can execute various filter actions to localize specific inspections or equipment. The filtering options are date, shift, equipment number or employee name. Once identified a particular inspection, users can click on the black arrow to
access the complete pre-operation information for that equipment, including operator findings, supervisor approval, and maintenance details.

On the other hand, Figure 3.24 (C), represents the operational scheduling view, in which crew supervisors should assign employees to working dates, shift, equipment, or other job-related tasks. The calendar view indicates the next shifts that an operator has been selected to work in the current month. Operators can click on a specific date to access their job information, including assigned supervisor, equipment, work code, work area, and job details. Furthermore, Figure 3.24 (D) presents a preview chatbot version was included in this system aiming to provide managers with the capability to ask questions related to the database that contains data from the application. The system utilizes ChatGPT in conjunction with Microsoft technology to supply responses based on the queried data.

An operational shift starts with supervisors scheduling their crew operators. Users are required to enter their employee number, after which the system performs a database query and permits or rejects access according to the assigned permission level. As indicated in Figure 3.25 (A), the Operational Digital System allows weekly, monthly, or daily scheduling for employees to consult their working days and details. This process involves navigating through Operator Resources screen in the main menu, as depicted in Figure 58 (B).

Supervisors are also responsible for reviewing and approving pre-operation inspection as illustrated in Figure 3.25 (D), eliminating the necessity for supervisor to drive through the mine looking for the paper-based pre-operation inspection. The system proposed automatically processes the operational data as operators input data in the application, thus supervisors,
maintenance and payroll can easily access to the operation information within minutes the operator sends it.

Figure 3.25 Supervisor Resources in the Mobile Application
From the operator’s perspective, users should navigate to Operator Resources screen in the application, as displayed in Figure 3.26, where they need to enter their employee number to access these resources. After clicking on the start shift button, an operator should first conduct a pre-operation inspection required by MSHA before operating the equipment. Figure 3.26 (B) indicates the pre-op interface for this operational system. Operators are tasked to examine critical equipment components to ensure safe operation. The first six items highlighted in red represent shutdown items; defects in these components make the equipment inoperable, and operator must conduct Lockout/Tagout procedures. During the inspection, operators can capture photos, add comments, and assign an equipment status, indicating whether the equipment is operational, requires future attention, or demands immediate maintenance.

Additionally, operators can submit timing, delays, and load information, as depicted in Figure 3.26 (D). The four primary buttons at the top of the screen facilitate the recording of timing information related to shift check-ins, check-outs, and breaks. One useful tool for operators is that when recording delays and loads, the system updates the screen for verification or editing. Once all data is input, operators can submit the operational shift information and finish their shift.
Once an operator submits a pre-op inspection, the system identifies any shutdown items marked as defective and triggers a code that generates email notifications to the operation and maintenance supervisors, alerting them about the shutdown items. These notifications contain the information featured in Figure 3.27. This innovative approach of collecting operational
information offers advantages over traditional paper cards, enhancing efficiency and streamlining information sharing among production, maintenance, and payroll departments.

![Email notification for shutdown Items](image)

**Figure 3.27 Email notification for shutdown Items**

The following video provides an overview of the Operational Digital Application, offering a comprehensive explanation of how this system affects production, maintenance, payroll, and safety. The application has been optimized for use on cellphones and rectangular tablets to meet the specific requirements of the mine. The video guides viewers through the operational shift, commencing with scheduling and moving on to the responsibilities of operators. It also covers the approval processes conducted by operation and maintenance supervisors. Finally, it demonstrates the manager's dashboard view.
3.6 Data Storage Mechanisms

In the integrated systems developed for this research project, data storage mechanisms are crucial for collecting and managing the information generated by both the AR Training System and the Digital Operational System. These mechanisms allow system administrators to efficiently analyze data through Power BI and PDF reports.

3.6.1 Data Storage for the AR Training System

The AR Training System, developed in Dynamics 365 Guides, is hosted in the Microsoft Power Platform Admin Center, which integrates with Microsoft Dataverse for data storage. This integration enables the collection and visualization of information directly from the admin center's analytics section, as depicted in Figure 3.28.

By storing data directly in Microsoft Dataverse, the system can manage multiple users and training sessions simultaneously in real time. This data storage mechanism provides insights into user activities, such as connection timing, duration spent on each step, and detailed analytics for each user and training session. This information is valuable for trainers, allowing them to evaluate the effectiveness of the training system, identify complex steps that require more user attention, and provide personalized guidance on difficult tasks.
3.6.2 Data Storage for the Operational Digital System

The Operational Digital System is developed using Microsoft Power Apps, designed for easy access across various devices, including computers, tablets, and mobile phones. This end-to-end system aims to capture all essential information during an operational shift and subsequently present this data as management reports for various departments within the company. Users must be assigned by the application owner or administrator to navigate through the app's resources. This system is secured by assigning roles within specific security groups, ensuring
that only authorized personnel can access relevant resources. For instance, this research created three security groups for operation, maintenance, and management departments, therefore, users assigned to the maintenance security group will not have access to operation resources.

During the development phase of this project, a SharePoint list was initially utilized as connector to Power Apps to store data. However, in the testing phase, the database was changed to a SQL server to address delegation and capacity limitations, as shown in Figure 3.29. Both SharePoint and SQL can serve the same initial purpose, which is collecting data in a database. While SharePoint is more versatile for editing and visualizing records and fields during the development phase, it presents limitations when managing extensive datasets. SQL, on the other hand, offers scalability and improved performance when handling larger volumes of data.

![Figure 3.29 SQL Data server](image)

*Figure 3.29 SQL Data server*
3.7 Data Management and Reporting

This research project adopted a standardized data management approach to categorize users into various roles, each with a specific permission level within both systems. Administrators and owners have the highest permission level, enabling them to manage the whole system. In the AR Training System, Microsoft Dataverse serves as both the back-end database service and the front-end visualization tool. The system categorizes training sessions by username, updating records every time an operator conducts training, ensuring record-keeping and providing historical data visualization, as shown in Figure 3.30.

Figure 3.30 Historical data visualization of training sessions
One remarkable advantage of the AR Training System is its scalability. The QR code technology used to contain each Augmented Reality Training session can be utilized across multiple mines, just by using the QR code and HoloLens 2 device. This centralized approach makes it very efficient to manage employees’ training information, even across different locations or countries, as illustrated in Figure 3.31.

![Figure 3.31 Training information across different locations or countries](image)

On the other hand, the Operational Digital System addresses common issues in the mining industry, such as ensuring pre-operation inspection, sharing information across departments, keeping record of operational data, and visualization of operational information in real time, retarding equipment defect awareness and maintenance work order scheduling. To overcome these challenges, the application provides user-friendly interfaces designed for easy navigation, even for operators with limited technology experience.
One of the primary issues resolved by the Digital System is sharing information of pre-operation inspections across operation and maintenance. The traditional paper-based process involved supervisors travelling around the mine to collect paper checklists and other cards from operators, and then, traveling back to maintenance workshops to hang out those inspections. The traditional process is time-consuming, leads to misunderstanding, and inspections might get lost in that process. In contrast, the Operational Digital System allows operators to conduct pre-operation inspections within minutes, supervisors to receive inspections from the cellphone app and approve those in need of maintenance, streamlining the process.

Additionally, employees can easily access equipment status reports by clicking on the image or text directly from the home page of the application. This quick access takes users to equipment status list, where all the inspections are display as well as the most relevant information of each pre-op, such as employee name, equipment number, unit number, date, employee comments and the equipment status, as illustrated in Figure 3.32.
Filters allow users to find and open specific inspections, as illustrated in Figure 3.32. Once an inspection is opened, users can view equipment status, details, photos, operator information, and supervisor approvals, as shown in Figure 3.33.

In situations where an MSHA inspector requires a specific and physical pre-operational inspection, a PDF button converter is available at the end of the digital inspection report displayed in the application. This button generates a PDF inspection report that can be downloaded, printed, or shared, as demonstrated in Figure 3.34.
The information related to delays, loaded tons, and work timing is displayed within the application and is automatically stored on OneDrive as PDF reports or Excel documents, depending on...
department requirements. Users can access this information in real-time through various folders, as illustrated in Figure 3.35.

Figure 3.35 OneDrive Storage as PDF reports

3.8 Discussion

In the mining industry, safety, efficiency, and effective training are essential to ensure a successful operation. This research proposed two innovative business solutions through the integration of different technologies and software under the Microsoft Power Platform. This academic discussion focused on two primary solutions that this project presents: Augmented Reality Training System and Operational Digital System. These systems represent a holistic approach to
enhance both employee training and operational efficiency within a mining context, offering the potential to drive down costs, improve safety, and streamline processes. While the examples discussed here pertain to a specific case study, the underlying principles and process can be adapted and scaled to meet unique needs of mining companies across multiple locations.

Augmented Reality technology has emerged as a disruptive and innovative solution to address critical challenges within manufacturing, training, or production industries. This project explored the integration of AR technology in mining training, which facilitates a safe learning environment and shows a notable empowerment of operators with practical knowledge and experience. On the other hand, the Operational Digital System enhances operational efficiency and departmental information sharing, significantly reducing the time required for defected equipment awareness, maintenance scheduling, supervisor walk-arounds, employee timing for payroll, and more. These innovative technology-driven solutions are reshaping the mining industry for the better, offering end-to-end solutions from data collection, visualization, and business analytics.

### 3.8.1 Augmented Reality Training System

The Augmented Reality Training System has the potential to revolutionize training procedures for heavy equipment operators in the mining sector. It leverages Microsoft's Dynamics 365 Guides and HoloLens 2 devices to provide a comprehensive training experience. This system allows operators to learn through immersive experiences, bridging the gap between theory and practical knowledge.

One of the innovative features of this system is the use of step-by-step instructions, interactive elements, photos, videos, and 3D models. These components are integrated to provide precise
visual guidance in the real-world environment while interacting with the training resources. This dynamic approach enables new hires to comprehend the complexities of mining heavy equipment and provides experienced employees with refresher training to avoid skipping steps in the inspection or forgetting previous knowledge. Furthermore, the ability to overlay digital information onto physical equipment simplifies the learning process, as operators can replicate their actions and procedures in a safe, step by step.

The system proposes standardized and flexible training modules for the most common heavy equipment used in the mining operations where this research took place. Each training also incorporates a dynamic evaluation and quizzes components. At the end of each training task, operators must pass a quiz to demonstrate their understanding of the procedures, and the last step of AR training guides is to complete an inspection evaluation, in which the system will record their performance. This feature ensures that operators are thoroughly trained and competent in their roles before operating mining equipment.

Additionally, this system centralizes the management of training data, offering detailed insights into individual operator performance. In this system, administrators can monitor users’ progress, analyze the duration spent on each task, and identify potential weaknesses. This data-driven approach empowers trainers to personalize guidance, focusing on areas where operators may require additional support. Furthermore, the QR code technology employed in the system makes it scalable across multiple mine sites, creating a centralized hub for training data. The ability to manage training data across various locations or countries enhances the overall efficiency and consistency of the training process.
3.8.2 Operational Digital System

The Operational Digital System addresses critical challenges related to pre-operation inspection, record-keeping, operational efficiency, and information sharing. The main interface of this system is an application that can be displayed on smartphones, tablets, or computers, streamlining the process of collecting, sharing, and analyzing multi-source data, providing real-time information to all relevant departments.

One of the central issues resolved by this application is the labor-intensive process of collecting paper checklists from operators. Traditional paper-based systems required supervisors to travel long distances to collect, record, and deliver these inspections to maintenance. The Digital Application accelerates this process by allowing operators to conduct pre-inspections digitally in the field, and a couple of minutes after, supervisors receive notifications to approve maintenance requests or store inspections in the cloud, significantly expediting the mine workflow.

The application offers comprehensive record-keeping and visualization of equipment inspections, making it easier for mining companies to meet regulatory compliance requirements demanded by the Mine Safety and Health Administration (MSHA). Thus, this system can compile historical information and generate reports more efficiently, simplifying MSHA audits. Furthermore, the application is equipped with features to capture operational data, including information about delays, loaded tons, and work timing. This data is stored automatically on OneDrive, streamlining the recording, and sharing of information across departments. In this way, the Digital System optimizes the interaction between operators, supervisors, maintenance teams, and the payroll department.
Chapter IV
Conclusions and Recommendations for Future Research

4.1 Conclusions

The mining industry is committed to addressing all challenges related to safety and efficiency. This thesis has explored the transformative potential of augmented reality and digital applications in addressing these challenges. The adoption of AR technology and digital solutions offers a promising future for the mining sector by fundamentally changing how mining operations are conducted and how employees are trained. This concluding chapter summarizes the key takeaways and insights from the research presented throughout this thesis.

The Augmented Reality Training System developed through Microsoft's Dynamics 365 Guides and HoloLens 2 device represents a significant improvement in employee training within the mining industry. This system offers a holistic approach to training heavy equipment operators and ensures they are well-equipped and proficient in their roles prior to operating mining equipment. Moreover, the integration of step-by-step instructions, photos, videos, 3D models and interactive elements provides a dynamic and immersive hands-on learning experience, allowing operators to understand complex machinery and procedures within the real-world mining environment.

The training system proposed provides mining companies with the flexibility and scalability to centralize training guides and data management across different mines. System administrators can track and analyze operator performance, identify areas that may require additional support,
and optimize training processes thanks to Power BI visualization tools. The scalability of the system, aided by QR code technology, enables users to access training guides in different locations, fostering consistency and efficiency in training.

In conclusion, the incorporation of Augmented Reality and digital applications marks a significant opportunity for the mining industry, directly impacting this sector in two key areas: employee training and operational efficiency. While the examples discussed throughout this thesis are drawn from a specific case study, the principles and applications of AR technology and digital solutions are applicable across the mining sector. The research findings presented in this thesis emphasize that technology holds the key to a safer, more efficient, and cost-effective future for mining operations.

4.2 Future Research

This thesis has delved into the potential of Augmented Reality and digital applications in the mining industry, several areas remain open for further research and exploration. These potential future studies may expand upon the findings and concepts discussed in this thesis, driving innovation in the mining sector:

✓ While this thesis presents a case study from one mine facility, future research should further analyze the testing and production phases, incorporating operator feedback on ease of use and perceived usefulness. Furthermore, other studies should expand the scope to encompass multiple mining companies and various types of mining operations, including underground
mining, considering the specific requirements and challenges faced by different mining sectors.

✓ The inclusion of artificial intelligence in augmented reality and digital applications represents a promising avenue for future research. AI can be employed to enhance operator training by offering real-time guidance and decision support. For instance, AI algorithms can detect operator errors and provide immediate feedback or suggest alternative actions. Additionally, AI can facilitate predictive maintenance by analyzing equipment data to predict potential failures, thereby preventing costly downtime.

✓ While HoloLens 2 has been at the forefront of AR technology, future studies may focus on developing and testing wearable devices designed explicitly for mining environments. These devices could incorporate ruggedized features, improved battery life, brightness adjustment for outdoor environments, and better ergonomics.

✓ Research focusing on user experience and design aspects is essential for the wider adoption of AR and digital applications in mining. Understanding how to create more intuitive interfaces and improve the ease of use for individuals unfamiliar with technology is a crucial area of exploration.

✓ As the mining industry becomes more digitally connected, there is an increased need for robust cybersecurity and data privacy solutions. Future research should investigate cybersecurity measures to safeguard critical mining operations and data, addressing potential vulnerabilities in both systems.
Bibliography


Technology.


