Int. j. adv. multidisc. res. stud. 2026; 6(1):1188-1199

Received: 02-12-2025
Accepted: 12-01-2026

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Examining the Effectiveness of Project Software in Project Completion: A Case Study of Ventsim Simulation Software in Designing Ventilation System in Underground Mines

[1] **Gabriel Disashi Kalwisha,** [2] **Dr. Chibomba Kelvin**
[1] Department of School of Humanities and Social Sciences, Information and Communications University, Lusaka, Zambia
[2] Advisor, Department of Social Sciences, Information and Communications University (ICU), and Zambia Research and Development Center, Lusaka, Zambia

Corresponding Author: **Gabriel Disashi Kalwisha**

Abstract
Mining operations at great depth face persistent challenges in maintaining safe and efficient airflow systems due to complex geological structures and fluctuating underground conditions. Traditional ventilation planning methods are often slow or prone to errors and unable to predict dynamic airflow changes accurately. This study is titled "Examining the Effectiveness of Project Software in Project Completion: A Case Study of Ventsim Simulation Software in Designing Ventilation System in Underground Mines." The study is guided by four specific objectives: to establish the existing ventilation system and airflow dynamics at Mindola Sub Vertical (Mopani Copper Mine), to ascertain the effectiveness of Ventsim simulation software in optimizing ventilation design, to evaluate the precision of Ventsim in modeling underground ventilation systems, and to identify potential limitations in the adoption and use of Ventsim for project completion. The research purpose is to assess the role of Ventsim in addressing ventilation challenges faced in deep underground mining while contributing to safer and more efficient project delivery. A mixed-methods approach was employed. Quantitative data were collected from seventy-five (75) respondents through structured questionnaires while qualitative data were obtained through interviews and focus group discussions with mine engineers and ventilation officers. The results showed that 57.3% of respondents identified mechanical ventilation as the dominant system at the mine, while 70.7% reported using Ventsim in some phase of ventilation planning. 72% rated the software as accurate or highly accurate in modeling airflow and pressure variations, though precision declined in simulating gas dispersion and sudden ventilation failures. The study concluded that Ventsim was an underutilized simulation tool that improved project planning and safety but faced challenges such as steep learning curves, limited real-time data integration and occasional software instability.

Keywords: Ventsim, Ventilation Systems, Project Software, Underground Mining, Project Completion, Simulation Modelling

1. Introduction

This chapter will focus on the, background of the study, problem identification, purpose, rationale, objectives identification and stating the significance of the study.

1.1 Background

Simulation software is becoming more and more important in the engineering and resource extraction fields especially in underground mining where planning and execution must be very precise in environments that are constantly changing and high-risk. Globally, Kurniawan *et al*. (2020) [9] say that the use of digital tools in mining has grown a lot in the last ten years, and that simulation platforms have been very important in making decisions better. These platforms not only simulate complicated systems, but they also let engineers try out different situations, improve operational plans and lower risks before putting them into action.

Several researchers Regionally have stressed that mine ventilation is not just a safety feature, but also a key factor in how well the mine works and how much energy it uses. McPherson (2009) [12] found that good ventilation can make people more productive, lower health risks, and lower operating costs. But designing ventilation systems is still hard because geological structures change, work zones change, and environmental conditions change. In this kind of situation, simulation tools like Ventsim let users model these changes in real time, change the paths of air flow, and practise emergency situations without having to try things out in real life.

In Zambia, the mining industry remains the backbone of the economy, and underground operations like those at Mopani Copper Mine have intensified the demand for advanced ventilation management systems. The human factor in the use of digital technologies in mining is still very important. Rogers and Dearing (2017) [19] said that the successful use of software tools in mining operations is often stopped not by technological problems, but by the culture of the organisation, resistance to change, and lack of technical training. When it comes to Ventsim, the software's ability to help with project completion depends on how well users can set up simulations, understand the results, and turn the outputs into steps that can be taken to finish the project. This shows how important it is for engineering teams to have structured training and knowledge transfer. Sunkpal and Mishra (2022) [20] also made this point when they found that mines with high digital literacy got much more out of simulation software.

This study aims to examine the effectiveness of Ventsim simulation software in project completion, focusing on its role in ventilation design at Mindola Sub Vertical, Mopani Copper Mine. Kumar and Singh (2019) [10] say that mines need to use real-time monitoring and predictive modelling techniques more and more to meet occupational health standards and emission controls. Engineers can use simulation software to predict conditions and make changes ahead of time which helps them follow the rules.

1.2 Statement of the Problem

Mine ventilation continues to be one of the most important issues facing underground mining operations worldwide. Over 30% of mining-related occupational illnesses and fatalities worldwide are caused by inadequate underground ventilation, according to the International Labour Organisation (ILO, 2021). This is made worse by the fact that contemporary underground mines are getting deeper and more intricate, which raises the energy consumption and ventilation system operating costs. Up to 50% of a mine's energy expenses can be attributed to ventilation according to McPherson (2009) [12], highlighting the necessity of effective design and monitoring systems. Despite the availability of sophisticated simulation tools such as Ventsim for modelling and optimising ventilation networks, little is known about how well these tools work in practice and how well they can enhance project outcomes.

Due to technical and infrastructure constraints, these difficulties are even more noticeable in the African context. According to a 2015 study by Musingwini and Minnitt, many African mines, especially those in Sub-Saharan areas, continue to use antiquated ventilation techniques, which lowers operational effectiveness and raises safety concerns. Some of the deepest underground mines on the continent are run by Southern African nations like South Africa, Zimbabwe, and Zambia. These mines are also some of the most dangerous in terms of heat and gas emissions. In Zambia, between 2010 and 2017, 22% of underground mining accidents were attributed to inadequate ventilation (Muwowo and Chanda, 2019) [16].

1.3 General Objective

The general objective of this study is to examine the effectiveness of Ventsim simulation software in supporting the successful completion of underground mine ventilation projects.

1.4 Specific Objectives

1. To establish the existing ventilation system and airflow dynamics at Mindola Sub vertical (Mopani copper mine).
2. To ascertain the effectiveness of ventsim simulation software in optimizing ventilation design.
3. To evaluate the precision of ventsim simulation software in modeling ventilation systems in underground mines.
4. To identify potential limitation in adoption and use of ventsim simulation software for project completion.

1.5 Research Questions

1. What are the characteristics of the current ventilation system and airflow patterns at the Mindola Sub-Vertical Shaft?
2. How effective is Ventsim simulation software in optimizing underground mine ventilation design?
3. How accurately does Ventsim simulate real-world ventilation systems in underground mining environments?
4. What are the challenges and limitations associated with implementing Ventsim in underground mine projects?

1.6 Significance of the Study

This study is significant because it adds new knowledge to the growing field of digital transformation in mining focusing on how simulation tools like Ventsim improve underground ventilation design. While the software is widely promoted, little research has assessed its real-world performance in specific contexts. This study bridges that gap by evaluating Ventsim not only as a technical tool but also as a factor that influences project efficiency, safety and timely completion. It provides insights that can guide better decisions on using, customizing and integrating simulation software in mining operations. The research also helps engineers connect theoretical models with on-site realities, offering evidence on how well Ventsim reflects actual airflow conditions and emphasizing the importance of calibration and validation in achieving accurate results.

Beyond engineering the study has broader implications for project management and industry practice. It highlights how improved ventilation design can reduce delays, enhance safety and streamline project delivery. The findings can help managers and policymakers strengthen planning, training and system optimization to overcome software-related challenges. At a national and global level the study contributes to developing standards for digital mining tools, providing context-specific data from Zambia and similar regions in Sub-Saharan Africa. By grounding global innovations in local realities, the research supports safer, more efficient, and more sustainable mining while enriching academic and professional understanding of simulation use in developing contexts.

1.7 Theoretical Framework

This study was guided by the Technology Acceptance Model (TAM) and Project Management Theory, which together explain how engineers adopt and use simulation software like Ventsim in mine ventilation design. TAM, developed by Davis (1989), focuses on two key factors: perceived usefulness and perceived ease of use. It suggests that people are more likely to use a technology if they find it helpful and easy to operate. Later extensions of TAM, such as UTAUT2 (Venkatesh *et al*., 2016) [22], added factors like behavioural intention and organisational support, which are crucial in understanding adoption in engineering contexts. This framework helps the study assess how user perceptions, system quality and training influence the acceptance of Ventsim in real mining operations.

Recent studies show that TAM remains relevant in the mining sector. Research in Ghana and South Africa found that training, organisational support and user experience strongly influence long-term adoption of digital tools (Bado & Korb, 2021; Mkhize & Sibanda, 2023) [1, 13]. These findings highlight that successful software implementation depends on both the technology's functionality and the context in which it is used. While TAM focuses on user acceptance, Project Management Theory provides a broader view of how tools contribute to achieving project goals like cost, quality, and time efficiency (Kerzner, 2017; PMI, 2021) [6, 17].

2. Literature Review

2.1 Overview

According to McPherson (2009) [12], a frequently cited expert on mine ventilation, mine ventilation is the regulated flow of fresh air to every area of an underground mine, guaranteeing the removal and dilution of dust, heat, and harmful gases. This fundamental knowledge emphasises the intricacy and significance of carefully planned ventilation systems, especially in hot, deep and geologically complex mines like those in Zambia's Copperbelt. Mopani Copper Mines' Mindola Sub-vertical Shaft is an established operation that needs a highly coordinated airflow network to satisfy operational and regulatory requirements. A dynamic and frequently unpredictable subterranean environment is created by deep-level heat load, diesel emissions from mobile equipment and gas concentrations linked to sulphide ore bodies all of which must be accommodated by the ventilation system.

Because the Mindola Sub-vertical Shaft operates at a considerable depth, it is subject to geothermal gradients and rising air temperatures, which increase by about 1°C for every 100 meters of depth (Banda and Phiri, 2021) [2]. Natural ventilation is therefore inadequate, necessitating the use of surface fans, booster fans, and regulators for forced ventilation. In order to regulate the direction and pressure of airflow, the mine currently uses a hybrid ventilation system that consists of primary fans at the surface and secondary fans placed strategically throughout the workings. Although this arrangement offers sufficient coverage in the majority of production zones, shifting work areas and fluctuating air demand present ongoing difficulties., as new tunnels are dug, old workings are sealed, and production schedules change, the airflow dynamics in such a system are not static.

According to Cheng *et al*. (2016) [4], the airflow system in deep underground mines needs to support emergency preparation for situations like fires or gas leaks in addition to providing enough oxygen and cooling. This necessitates a system that is both flexible and robust, qualities that static ventilation designs find difficult to accomplish. According to operational data, airflow at Mindola is frequently redirected when production priorities change. This calls for variable-speed control of booster fans and regulator reconfiguration, but the lack of an updated airflow model limits the efficacy of these measures. Ventilation engineers frequently rely on manual calculations and periodic measurements due to the lack of real-time data integration. Although this method is conventional, it can cause a delay in reacting to dangerous situations.

Qureshi *et al*. (2021) [18], who emphasise Ventsim's use in designing ventilation for emergency situations, such as fires or toxic gas leaks, further support the tool's value in assisting scenario planning. Users can model the worst-case airflow behaviours under system disruptions, such as obstructions, fan failures, or dangerous gas leaks, using Ventsim's modelling environment. By giving engineers vital information on oxygen depletion zones and smoke propagation rates, these simulations help them plan safer escape routes and place refuge chambers in strategic locations. By establishing a foundation in actual, testable airflow behaviour, Ventsim revolutionises emergency ventilation planning, which is often reactive or predicated on antiquated assumptions in mines. This supports the claim that optimisation includes worker safety and adherence to health regulations in addition to economic considerations.

Ventsim's optimisation features also extend to the life-of-mine planning process, which sets it apart from static design tools. Long-term ventilation design needs to account for future shaft systems, expansions, and declines, claim Matsumoto and Thiel (2022) [11]. Their comparative analysis of several Australian mines showed that Ventsim made it easier to integrate short-term and long-term airflow needs. Planners could test the effects of expansions on airflow resistance, fan requirements, and regulator configurations using time-lapse simulations and the software's ability to "build" future mine development layers. By ensuring that current designs are not only ideal for the layout of the mine today but also scalable and adaptable for future operations, these forward-looking capabilities help mine expansion projects minimise ventilation-related disruptions and avoid redesign costs.

According to Khan and Murthy (2021) [7], ventilation engineers, especially those with little software experience, prefer Ventsim because of its user-friendly interface. Users can easily locate hotspots or airflow bottlenecks thanks to the user-friendly 3D visualisations. Pressure readings, colour-coded pathways, and real-time flow direction arrows make it easier to understand complicated models and lessen cognitive load.

2.2 Personal critique of the literature review

Technical problems with interoperability also make it harder for Ventsim to fit into larger project workflows. Chileshe and Nkomo (2021) [5] say that project management systems, CAD platforms and GIS databases often use different data standards. Ventsim can import and export common file types, but when you move data from one format to another, it can sometimes get messed up. For example if the coordinates or attributes in the 3D tunnel geometry don't match up, it can cause airway representations to be cut off or junctions to be in the wrong place.

2.3 Establishment of research gaps

New research is starting to look into how AI and automation could help Ventsim become more popular. Kimathi and Mwila (2023) [8] suggest using machine learning algorithms to automatically find ventilation problems or suggest regulator settings based on how the system has been used in the past. These systems could make it easier for junior staff to use advanced simulation by taking some of the mental and technical load off of human users. Moyo and Ssenyonjo (2022) [14] say that people who live in remote areas often have to wait a long time for technical support especially during local business hours that don't match vendor time zones. Teams are less likely to try out new features or customise their models when they can't get help with problems right away. For project teams with tight deadlines, delayed support can stop simulation workflows and slow down the process of getting design approvals or safety clearances.

3. Research Methodology

The study used a descriptive survey design, which allowed data to be collected from a defined group in a structured way. This approach helped describe current practices and user experiences without manipulating variables. Structured questionnaires were used to gather consistent and comparable information about software usability, accuracy, and impact on project delivery. The design ensured that the results were reliable and could represent broader patterns among mining professionals involved in underground ventilation projects.

Purposive sampling was used to select 75 participants with direct experience in ventilation design or simulation software. This included mining engineers, ventilation officers and project managers at Mopani Copper Mines particularly within the Mindola Sub-vertical Shaft operations. Data were gathered using structured questionnaires made up of closed-ended and Likert-scale items to collect measurable responses. The results were coded and analyzed using Microsoft Excel and SPSS to generate descriptive statistics such as frequencies, percentages and mean scores. Triangulation strengthened validity by comparing questionnaire findings with expert opinions and field observations. Ethical standards guided every stage of the study. Participation was voluntary, consent was obtained, and confidentiality was maintained. Ethical approval was also secured from relevant institutions to ensure integrity and protect participants' rights throughout the research process.

4. Research Findings and Discussions

4.1 Presentation of Results on Based on Demographics

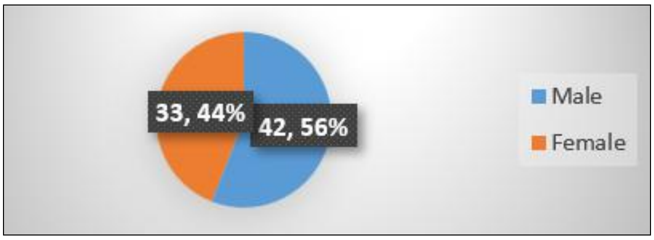


Table 4.1: Sex of Respondents

Table 4.1 presents the distribution of respondents by sex. Out of the 75 participants, 33 (44.0%) were female while 42 (56.0%) were male. This indicates a slightly higher participation of males compared to females in the study sample.

Table 4.2: Age

Variable	Observation	Mean	Sstandard deviation	Min	Max
age	75	38.0533	10.2376	25	62

Table 4.2 presents the descriptive statistics for the age distribution of respondents. The analysis shows that the mean age was 38.05 years with a standard deviation of 10.24 years, indicating moderate variation within the sample. The youngest respondent was 25 years old, while the oldest was 62 years old.

Table 4.3: Marital Status

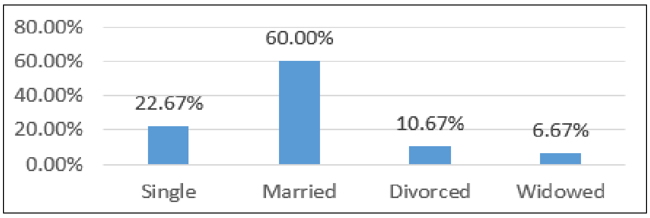


Table 4.3 presents the distribution of respondents according to marital status. The majority of participants, 45 respondents (60.0%), reported being married. This was followed by 17 respondents (22.7%) who were single, 8 respondents (10.7%) who were divorced, and 5 respondents (6.7%) who were widowed.

Table 4.4: Highest Level of Education

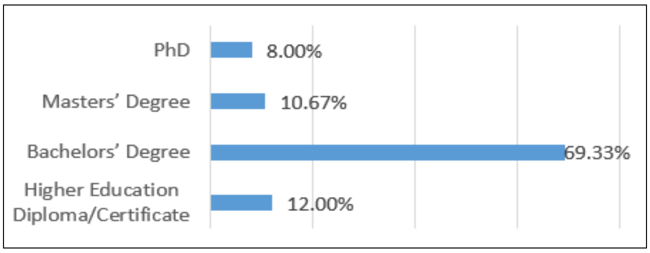
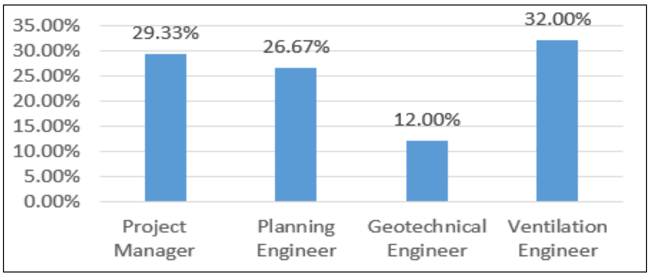


Table 4.4 shows the distribution of respondents according to their highest level of education. A majority of the respondents, 52 (69.3%), had attained a Bachelor's degree. This was followed by 9 respondents (12.0%) with a Higher Education Diploma or Certificate, 8 respondents (10.7%) with a Master's degree, and 6 respondents (8.0%) who held a PhD qualification.

Table 4.5: Current Role



As shown in Table 4.5, respondents were drawn from a variety of professional roles. Ventilation Engineers formed the largest group with 24 respondents (32.0%), followed by

Project Managers with 22 respondents (29.3%). Planning Engineers accounted for 20 respondents (26.7%), while Geotechnical Engineers represented 9 respondents (12.0%).

Table 4.6: Years of Experience

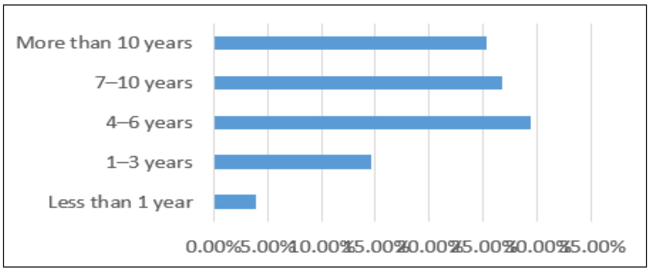


Table 4.6 presents the respondents' years of experience in project procurement. The largest group consisted of 22 respondents (29.3%) with 4–6 years of experience, closely followed by 20 respondents (26.7%) with 7–10 years of experience. Another 19 respondents (25.3%) reported having more than 10 years of experience. Smaller groups included 11 respondents (14.7%) with 1–3 years of experience, and 3 respondents (4.0%) with less than 1 year of experience.

4.2 Presentation of results based on the existing ventilation system and airflow dynamics at Mindola Sub Vertical (Mopani Copper Mine)

Table 4.7: Type of Ventilation System

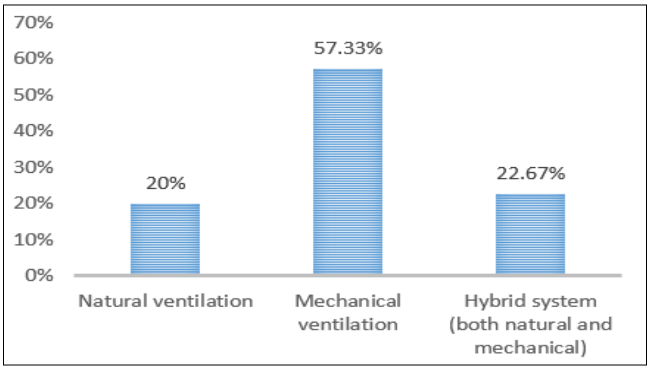


Table 4.7 shows the distribution of responses regarding the type of ventilation system currently in use at Mindola Sub Vertical. A majority of respondents, 43 (57.3%), indicated that the mine relies on a mechanical ventilation system. A further 17 respondents (22.7%) reported the use of a hybrid system, combining both natural and mechanical methods, while 15 respondents (20.0%) noted the use of natural ventilation alone.

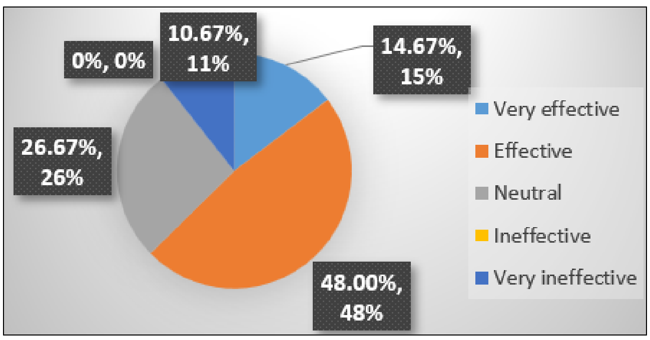


Table 4.8: Effectiveness of the Current Ventilation System

As presented in Table 4.8, nearly half of the respondents, 36 (48.0%), considered the current ventilation system effective in maintaining air quality. Another 11 respondents (14.7%) rated it as very effective, while 20 respondents (26.7%) remained neutral. 8 respondents (10.7%) perceived the system as very ineffective.

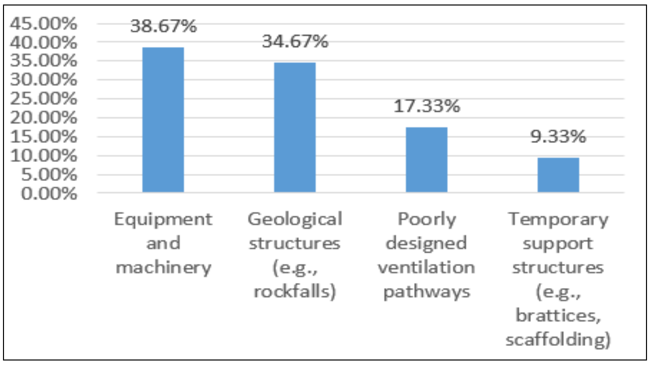


Table 4.9: Main Sources of Airflow

Table 4.9 summarizes the main sources of airflow obstructions within the mine. Equipment and machinery were the most frequently cited factor (29 respondents, 38.7%), followed closely by geological structures such as rockfalls (26 respondents, 34.7%). Other notable contributors included poorly designed ventilation pathways (13 respondents, 17.3%), and temporary support structures such as brattices or scaffolding (7 respondents, 9.3%).

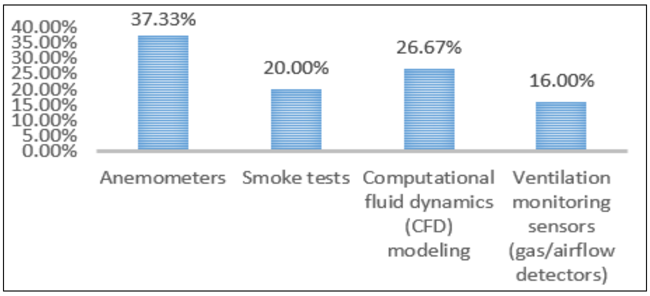


Table 4.10: Methods Used to Monitor Airflow

Table 4.10 presents the methods reported by respondents as being used to monitor airflow dynamics within the mine. The most frequently cited method was the use of anemometers (28 respondents, 37.3%), reflecting their practicality and ease of application in measuring airflow velocity. Computational fluid dynamics (CFD) modeling was also identified by 20 respondents (26.7%), showing the growing role of simulation in ventilation planning. Traditional smoke tests were reported by 15 respondents (20.0%), mainly for visualizing air movement in specific sections.

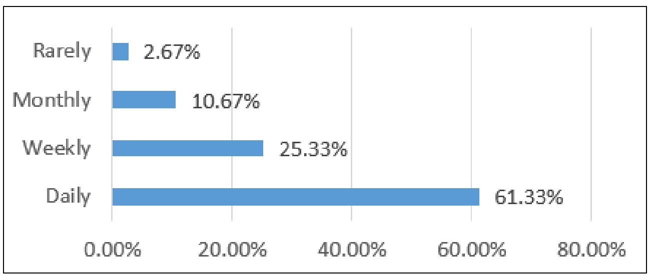


Table 4.11: Frequency of Ventilation System Inspection

Table 4.11 shows how frequently the ventilation system at Mindola Sub Vertical is inspected and maintained. The majority of respondents, 46 (61.3%), reported that inspections are conducted daily, reflecting the critical importance of ventilation in underground mining operations. A further 19 respondents (25.3%) stated that inspections occur weekly, while 8 respondents (10.7%) indicated a monthly schedule. Only 2 respondents (2.7%) reported that inspections are carried out rarely.

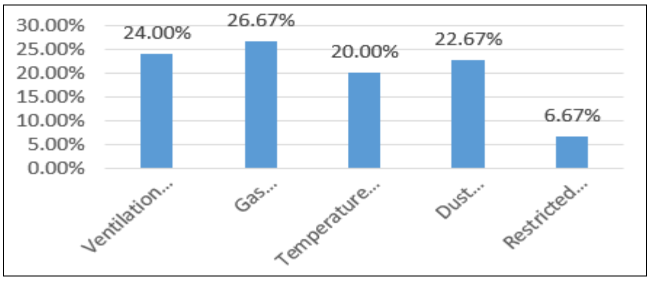


Table 4.12: Common Challenges in Maintaining Effective Airflow

Table 4.12 presents the challenges commonly encountered in maintaining effective airflow within the mine. The most cited issue was gas accumulation (20 respondents, 26.7%), particularly involving hazardous gases such as NOx, CO, and CO_2.

4.2.1 What emergency ventilation measures are available in case of system failure at Mindola Sub Vertical?

Emergency Ventilation Measure	Frequency	Percent	Cumulative (%)
Backup fans and auxiliary ventilation units	18	24.0%	24.0
Emergency air doors and refuge bays	12	16.0%	40.0
Manual airflow redirection procedures	9	12.0%	52.0
Automatic alarm and shutdown systems	8	10.7%	62.7
Designated escape routes with fresh-air bases	7	9.3%	72.0
None in place	14	18.7%	90.7
Not sure	7	9.3%	100.0
Total	**75**	**100.0%**	

As shown in Table 4.13, several types of emergency ventilation measures were identified by respondents as being in place at Mindola Sub Vertical in the event of system failure. The most common were backup fans and auxiliary ventilation units, cited by 24.0% of participants, followed by emergency air doors and refuge bays (16.0%) and manual airflow redirection procedures (12.0%).

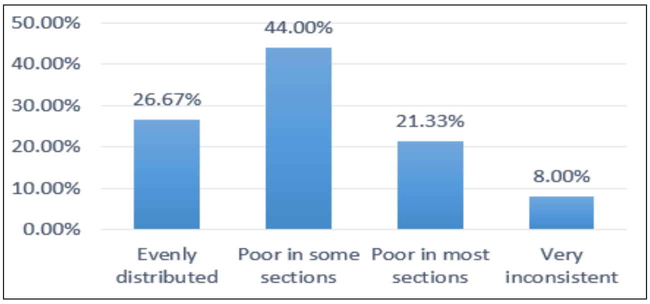


Table 4.13: Air Distribution Across

Table 4.14 reflects respondents' perceptions of air distribution throughout various sections of the mine. The largest group, 33 respondents (44.0%), described it as poor in some sections, while 16 respondents (21.3%) rated it as poor in most sections. Only 20 respondents (26.7%) found air distribution to be evenly distributed, and 6 respondents (8.0%) described it as very inconsistent.

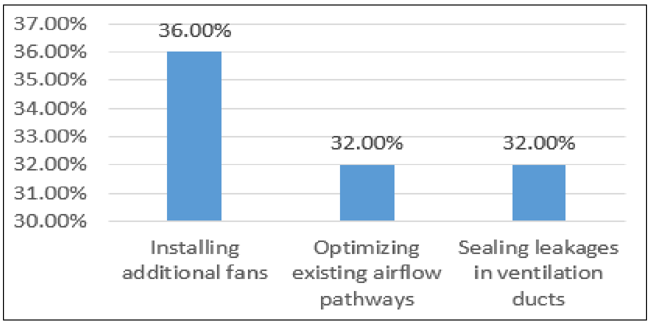


Table 4.14: Strategies to Improve Ventilation Efficiency

Table 4.15 outlines the strategies reported to enhance ventilation efficiency and reduce airflow losses. The most frequently mentioned approach was installing additional fans (27 respondents, 36.0%), followed by optimizing existing airflow pathways (24 respondents, 32.0%). Sealing leakages in ventilation ducts was also reported by a combined total of 24 respondents (1 + 23 = 32.0%), reflecting a key priority for minimizing leakage-related losses.

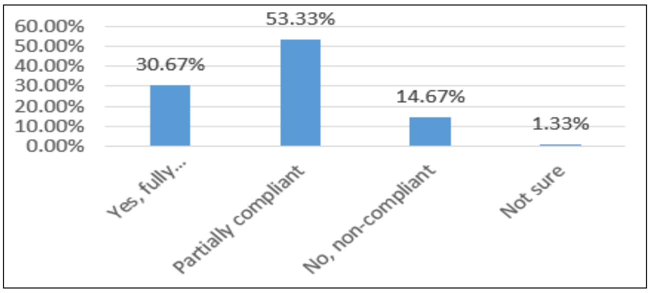


Table 4.15: Compliance with Industry Safety Standards

Table 4.16 shows that 40 respondents (53.3%) rated the current ventilation system as partially compliant with industry safety standards. 23 respondents (30.7%) believed it was fully compliant, while 11 respondents (14.7%) indicated it was non-compliant, and 1 respondent (1.3%) was not sure.

4.3 Presentation of results based on the effectiveness of Ventsim simulation software in optimizing ventilation design

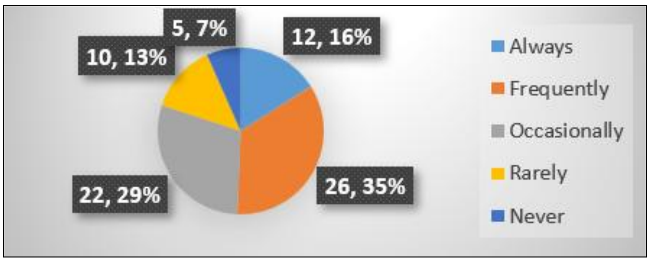


Table 4.16: Usage of Ventsim Simulation Software

Table 4.17 shows how often Ventsim simulation software is used for ventilation design at Mindola Sub Vertical. A considerable proportion of respondents, 26 (34.7%), indicated that they frequently use the software while 12 respondents (16.0%) reported using it always as part of their ventilation planning tasks. Another 22 respondents (29.3%) stated that they use it occasionally, suggesting partial integration of the software into specific project phases rather than daily operations.

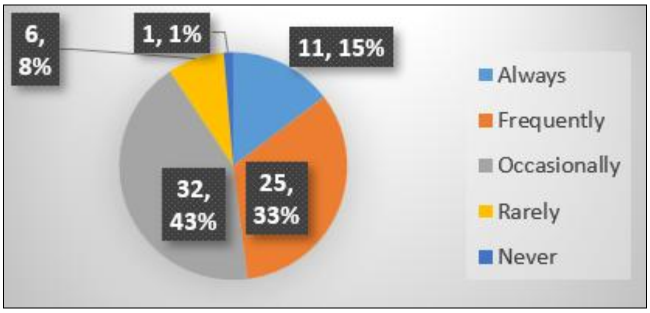


Table 4.17: Frequency of Use in Ventilation Planning

As shown in Table 4.18, the frequency of Ventsim usage varied among respondents. 32 respondents (42.7%) reported using it occasionally, while 25 respondents (33.3%) indicated that they used it frequently. Smaller groups included those who used it always (11 respondents, 14.7%), rarely (6 respondents, 8.0%), and only 1 respondent (1.3%) who reported never using it.

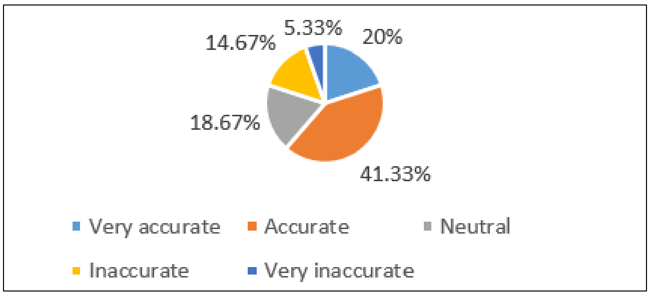


Table 4.18: Accuracy of Ventsim in Predicting Airflow and Efficiency

Table 4.19 illustrates respondents' views on the software's accuracy. The largest group, 31 respondents (41.3%), rated it as accurate, while 15 respondents (20.0%) considered it very accurate. Conversely, 14 respondents (18.7%) were neutral, 11 respondents (14.7%) rated it as inaccurate, and 4 respondents (5.3%) viewed it as very inaccurate. the findings indicate strong confidence in the software's predictive capability, with more than 60% of respondents considering it accurate or very accurate.

Table 4.19: Ventsim in Identifying Ventilation Inefficiencies

Method of Identifying Inefficiencies	Frequency	Percent
Detects poor airflow distribution and recirculation zones	20	26.7%
Highlights pressure drops and resistance points in the system	17	22.7%
Simulates gas buildup and temperature variations under load	14	18.7%
Compares alternative ventilation layouts to improve system design	12	16.0%
Identifies energy inefficiencies and fan performance limitations	7	9.3%
Provides early visual feedback for corrective decision-making	5	6.7%
Total	**75**	**100.0%**

Table 4.20 shows that respondents identified several ways in which Ventsim helps detect ventilation inefficiencies before implementation. The most cited response from 26.7% was that it detects poor airflow distribution and recirculation zones, while 22.7% noted it highlights pressure drops and resistance points in the system. 18.7% stated that it simulates gas buildup and temperature variations improving anticipation of problem areas. Smaller groups mentioned that it compares alternative layouts (16.0%), identifies fan performance limitations (9.3%), and provides early visual feedback (6.7%).

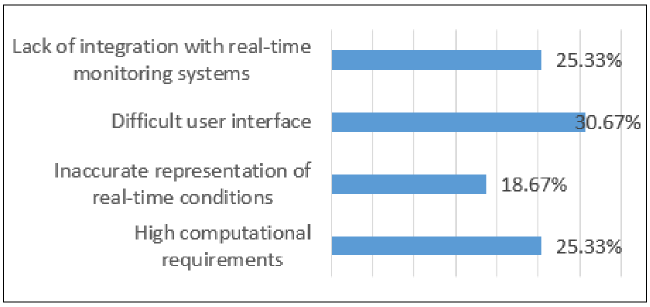


Table 4.20: Limitations of Ventsim

Table 4.21 highlights the main limitations observed in the use of Ventsim for ventilation optimization. The most frequently cited challenge was a difficult user interface (23 respondents, 30.7%), followed by high computational requirements (19 respondents, 25.3%), and lack of integration with real-time monitoring systems (19 respondents, 25.3%). Another 14 respondents (18.7%) noted issues related to inaccurate representation of real-time conditions.

Table 4.21: Other Ventilation Simulation Tools

Comparison Criteria	Frequency	Percent
Provides higher accuracy in airflow and pressure modelling	19	25.3%
Offers better 3D visualization and user interface	15	20.0%
Easier to learn and integrate with mine systems	14	18.7%
Requires less computational time and data input	10	13.3%
Produces more reliable scenario testing results	8	10.7%
Performs similarly to other tools	9	12.0%
Total	**75**	**100.0%**

Table 4.22 illustrates how respondents compared Ventsim with other ventilation simulation tools based on specific functional attributes. The largest group, 25.3%, stated that Ventsim provides higher accuracy in airflow and pressure modeling, while 20.0% highlighted its superior 3D visualization and user interface. 18.7% viewed it as easier to learn and integrate into mine systems, reflecting appreciation for its usability.

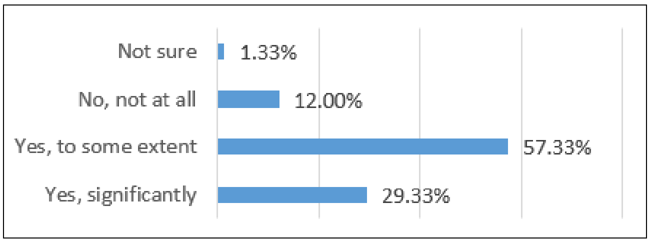


Table 4.22: Contribution of Ventsim to Cost Savings

Table 4.23 shows that 43 respondents (57.3%) believed Ventsim contributes to cost savings to some extent, while 22 respondents (29.3%) stated it does so significantly. In contrast, 9 respondents (12.0%) felt it was not effective in achieving cost savings, and 1 respondent (1.3%) was not sure.

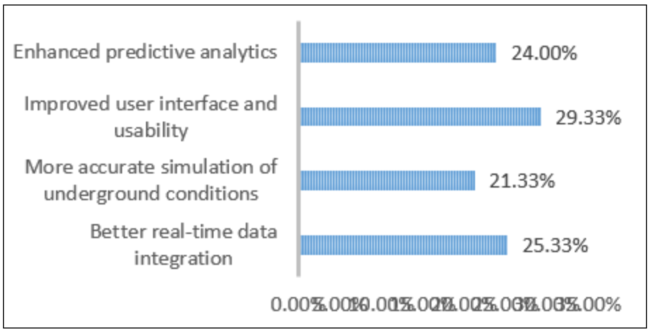


Table 4.23: Improvements to Enhance Effectiveness

Table 4.24 presents respondents' recommendations for improving Ventsim. The most frequently cited improvement was the need for an improved user interface and usability (22 respondents, 29.3%), followed by better real-time data integration (19 respondents, 25.3%), and enhanced predictive analytics (18 respondents, 24.0%). 16 respondents (21.3%) suggested more accurate simulation of underground conditions.

4.4 Presentation of results based on the precision of Ventsim simulation software in modeling ventilation systems in underground mines

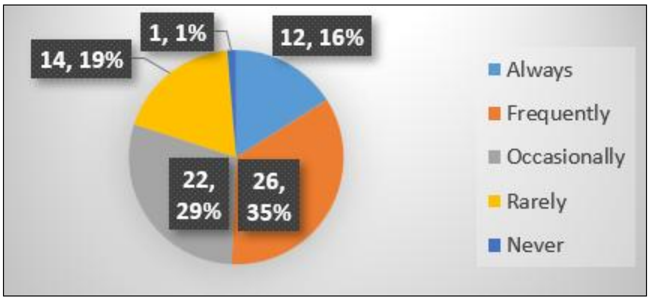


Table 4.24: Frequency of Use

Table 4.26 presents responses on how often Ventsim is used for modeling ventilation systems at Mopani Copper Mine. The largest group, 26 respondents (34.7%), reported using it frequently, followed by 22 respondents (29.3%) who use it occasionally. A smaller proportion, 14 respondents (18.7%), indicated that it is used rarely, while 12 respondents (16.0%) stated it is used always. Only 1 respondent (1.3%) reported that it is never used.

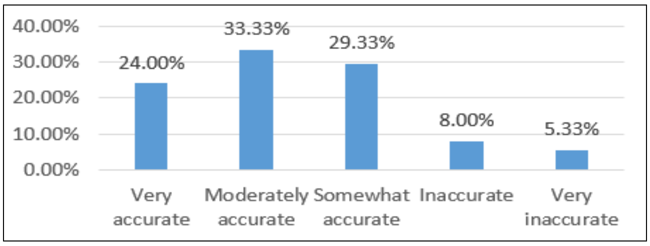


Table 4.25: Accuracy of Ventsim Airflow Modeling

As shown in Table 4.27, perceptions of Ventsim's accuracy varied. 25 respondents (33.3%) rated it as moderately accurate, 22 respondents (29.3%) as somewhat accurate, and 18 respondents (24.0%) as very accurate. Conversely, 6 respondents (8.0%) considered it inaccurate, and 4 respondents (5.3%) rated it as very inaccurate.

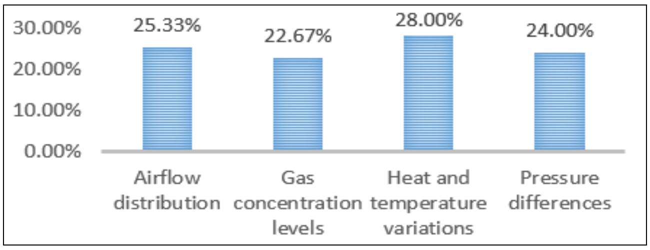


Table 4.26: Most Accurately Modeled

Table 4.28 identifies the ventilation parameters that respondents believe Ventsim models most accurately. The highest number of responses were for heat and temperature variations (21 respondents, 28.0%), followed by airflow distribution (19 respondents, 25.3%), pressure differences (18 respondents, 24.0%), and gas concentration levels (17 respondents, 22.7%).

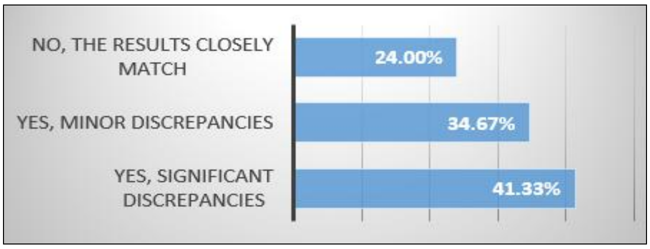


Table 4.27: Simulations and Real-Time Measurements

Table 4.29 presents data on observed discrepancies between Ventsim simulations and real-time ventilation measurements. The majority of respondents, 31 (41.3%), reported significant discrepancies, while 26 respondents (34.7%) noted minor discrepancies. Only 18 respondents (24.0%) stated that simulation results closely matched real-time conditions.

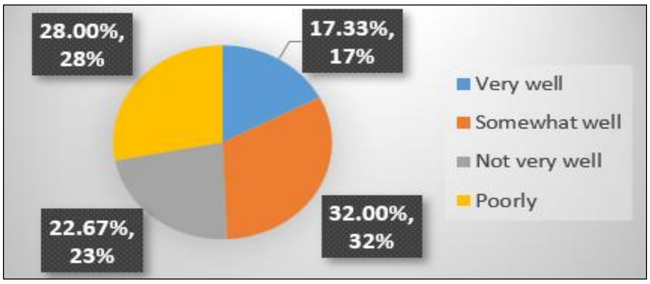


Table 4.28: Simulation of Unexpected Ventilation Failures

Table 4.30 presents responses on how well Ventsim simulates the impact of unexpected ventilation failures such as fan breakdowns or blockages. The largest group, 24 respondents (32.0%), reported that it does so somewhat well, while 21 respondents (28.0%) felt it performs poorly, and 17 respondents (22.7%) stated it simulates such failures not very well. Only 13 respondents (17.3%) indicated that Ventsim simulates failures very well.

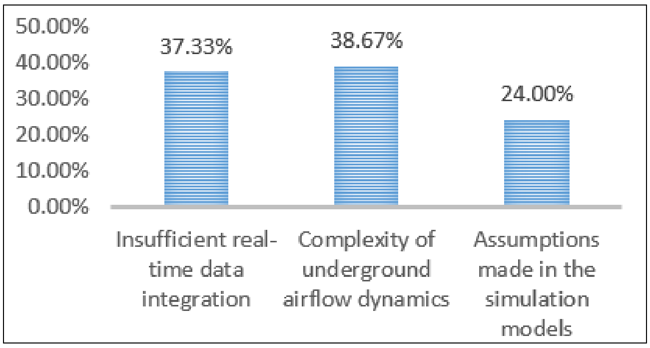


Table 4.29: Factors Contributing to Inaccuracies

As shown in Table 4.31, the most frequently cited factor contributing to inaccuracies in Ventsim modeling was the complexity of underground airflow dynamics (29 respondents, 38.7%). This was closely followed by insufficient real-time data integration (28 respondents, 37.3%), while 18 respondents (24.0%) identified assumptions made in simulation models as a key factor.

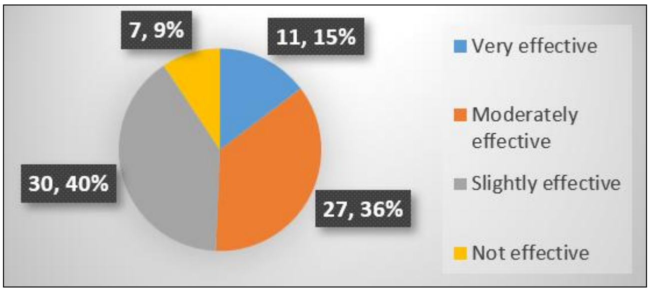


Table 4.30: Prediction of Hazardous Gas Buildup

Table 4.32 shows mixed views regarding Ventsim's effectiveness in predicting hazardous gas accumulation. The largest group, 30 respondents (40.0%), rated it as slightly effective, while 27 respondents (36.0%) considered it moderately effective. Only 11 respondents (14.7%) rated it as very effective, and 7 respondents (9.3%) deemed it not effective.

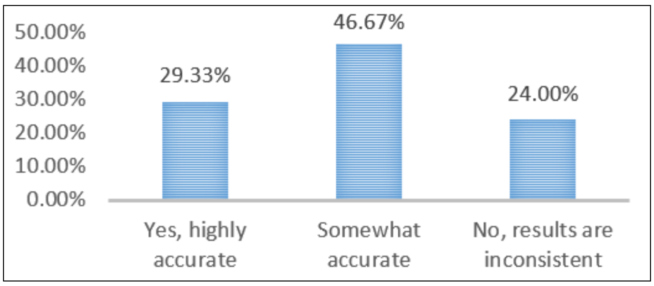


Table 4.31: Accuracy in Scenario Testing

Table 4.33 presents respondents' views on whether Ventsim allows for accurate scenario testing of ventilation design modifications. The majority, 35 respondents (46.7%), stated that it is somewhat accurate, while 22 respondents (29.3%) considered it highly accurate. In contrast, 18 respondents (24.0%) found the results inconsistent.

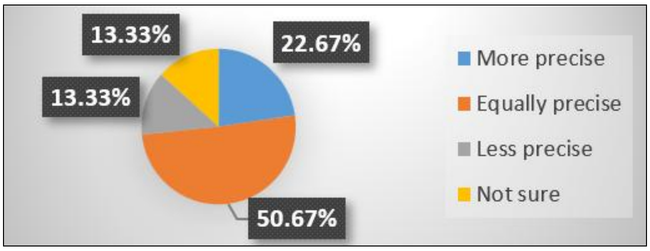


Table 4.32: Manual Calculations and Other Tools

Table 4.34 illustrates how respondents compared Ventsim to manual calculations and other simulation tools in terms of precision. Half of the respondents, 38 (50.7%), considered it equally precise, while 17 respondents (22.7%) viewed it as more precise. In contrast, 10 respondents (13.3%) rated it as less precise, and another 10 respondents (13.3%) were not sure.

Table 4.33: Suggested Improvements to Enhance Precision

Table 4.35 presents the improvements suggested by respondents to enhance Ventsim's precision. The most frequently cited was better real-time data integration (34 respondents, 45.3%), followed by more user-friendly calibration options (21 respondents, 28.0%), and more advanced algorithms for airflow simulation (20 respondents, 26.7%).

4.5 Presentation of results based on the potential limitations in adoption and use of Ventsim simulation software for project completion

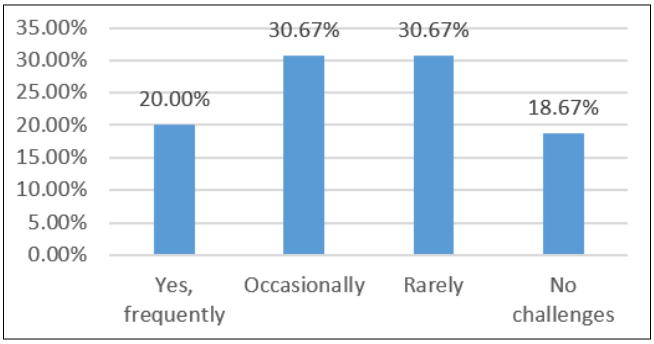


Table 4.34: Challenges in Using Ventsim

Table 4.36 shows whether respondents had encountered challenges when using Ventsim for project completion. The largest groups, 23 respondents each (30.7%), reported experiencing challenges occasionally or rarely. A further 15 respondents (20.0%) indicated they faced challenges frequently, while 14 respondents (18.7%) stated that they had experienced no challenges.

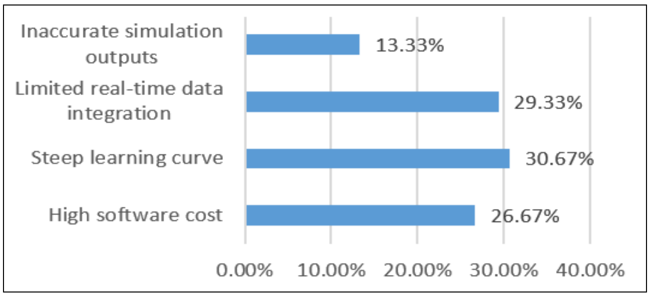


Table 4.35: Main Limitations in Adoption

As presented in Table 4.37, respondents identified several limitations in adopting Ventsim. The most cited was the steep learning curve (23 respondents, 30.7%), followed by limited real-time data integration (22 respondents, 29.3%), and high software cost (20 respondents, 26.7%). A smaller group, 10 respondents (13.3%), highlighted inaccurate simulation outputs as a limitation.

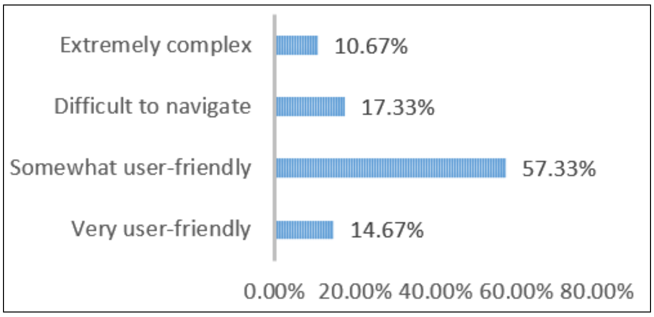


Table 4.36: User-Friendliness of the Interface

Table 4.38 summarizes respondents' views on Ventsim's user-friendliness. The majority, 43 respondents (57.3%), rated it as somewhat user-friendly, while 11 respondents (14.7%) described it as very user-friendly. 13 respondents (17.3%) found it difficult to navigate, and 8 respondents (10.7%) considered it extremely complex.

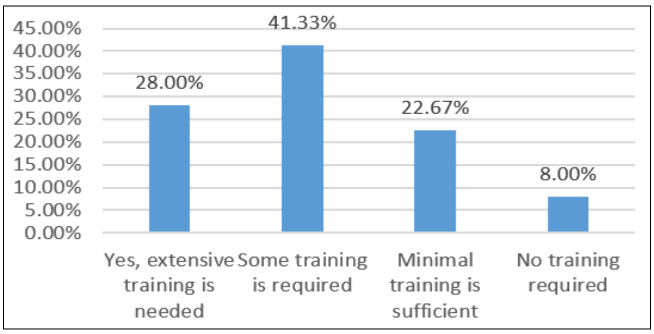


Table 4.37: Training Requirements

Table 4.39 shows that most respondents believe training is necessary for effective Ventsim use. 31 respondents (41.3%) stated that some training is required, while 21 respondents (28.0%) indicated that extensive training is needed. On the other hand, 17 respondents (22.7%) felt that minimal training is sufficient, and 6 respondents (8.0%) believed no training is required.

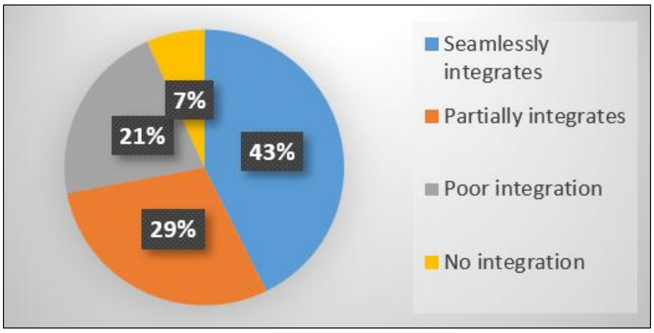


Table 4.38: Integration with Other Monitoring Systems

Table 4.40 presents findings on Ventsim's integration with other mine ventilation monitoring systems. 32 respondents (42.7%) stated that the software seamlessly integrates, while 22 respondents (29.3%) indicated it partially integrates. Another 16 respondents (21.3%) rated the integration as poor, and 5 respondents (6.7%) reported no integration at all.

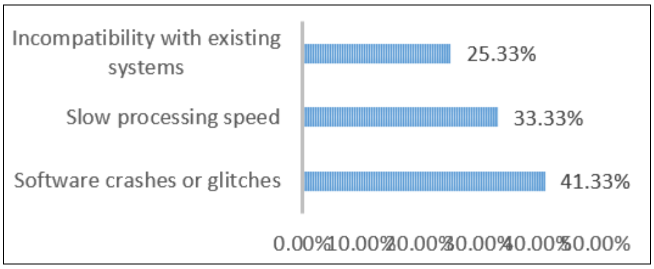


Table 4.39: Technical Difficulties Affecting Ventsim Performance

Table 4.41 presents responses on technical difficulties that hinder Ventsim performance in project execution. The most frequently cited issue was software crashes or glitches (31 respondents, 41.3%), followed by slow processing speed (25 respondents, 33.3%), and incompatibility with existing systems (19 respondents, 25.3%).

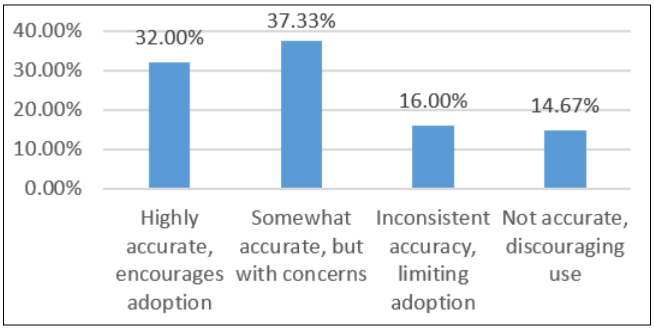


Table 4.40: Impact of Accuracy on Adoption

As shown in Table 4.42, respondents expressed varied perspectives on how Ventsim's accuracy influences its adoption. 28 respondents (37.3%) stated that it is somewhat accurate but with concerns, while 24 respondents (32.0%) reported that its high accuracy encourages adoption. Conversely, 12 respondents (16.0%) noted that inconsistent accuracy limits adoption, and 11 respondents (14.7%) said that inaccuracy discourages its use altogether.

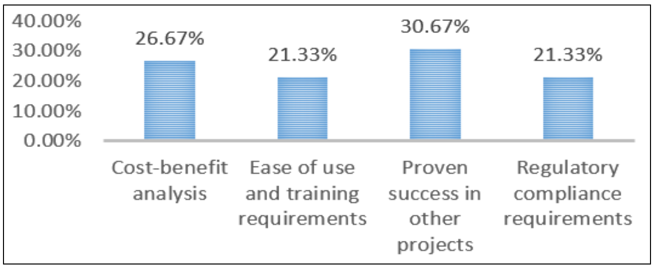


Table 4.41: Factors Influencing Management

Table 4.43 identifies the main factors influencing management's decision to invest in Ventsim. The most common factor was proven success in other projects (23 respondents, 30.7%), followed by cost-benefit analysis (20 respondents, 26.7%). Ease of use and training requirements (16 respondents, 21.3%) and regulatory compliance requirements (16 respondents, 21.3%) were also considered important.

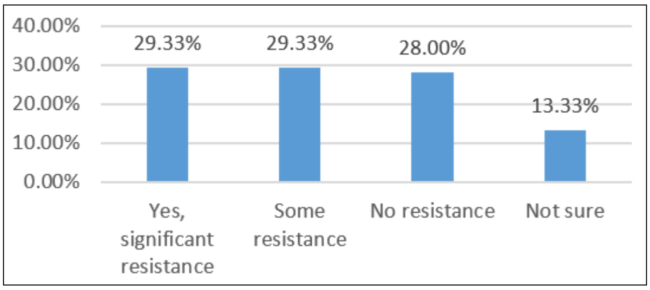


Table 4.42: Staff Resistance to Implementation

Table 4.44 shows the extent of staff resistance when implementing Ventsim. 22 respondents (29.3%) reported some resistance, while another 22 respondents (29.3%) indicated significant resistance. In contrast, 21 respondents (28.0%) reported no resistance, and 10 respondents (13.3%) were not sure.

Table 4.45 presents random responses from participants on the improvements that would encourage wider adoption of Ventsim for project completion. The responses reflect several recurring themes. these responses indicate that while Ventsim is already valued, its wider adoption would depend on addressing cost, usability, accuracy and training support.

Table 4. 43: Suggested Improvements to Encourage Wider Adoption

Respondent	Response
R12	"Reduce the licensing fees so smaller mining operations can afford to adopt the software."
R27	"Provide better training modules and user manuals to help new users understand the system quickly."
R8	"Improve the speed of simulations, especially when running large and complex models."
R34	"Ensure seamless integration with existing mine monitoring systems and data loggers."
R19	"Develop a more user-friendly interface with simplified navigation."
R41	"Enhance accuracy in modeling gas dispersion and unexpected system failures."
R6	"Offer stronger technical support and after-sales service for troubleshooting."
R23	"Introduce cloud-based or mobile-compatible versions to allow remote access and collaboration."

5. Conclusion and Recommendation

5.1 Conclusion

The study assessed how well Ventsim simulation software improved ventilation design and project completion at Mindola Sub Vertical, Mopani Copper Mine. Most respondents confirmed that mechanical ventilation systems were used with a few hybrid and natural setups. the system was considered functional, many pointed out problems such as uneven airflow, frequent blockages, and limited emergency preparedness. These issues showed that even with an established ventilation system, safety and productivity were still affected by poor maintenance and inconsistent operation. Ventsim was widely known and used especially for analysing airflow, gas levels, pressure and temperature, and for identifying potential design problems. usage varied with most people applying it only occasionally. The research also revealed that users valued Ventsim as a planning and risk prevention tool rather than a fully integrated system. Some trusted its accuracy while others saw clear gaps between simulations and real-world conditions due to weak data integration and the complexity of underground airflow. Barriers to adoption included high software costs, slow processing, system errors and limited training opportunities. Staff resistance to new technology also slowed wider use. Despite these challenges participants believed that with better accuracy, user support and affordability, Ventsim could be used more effectively. Overall the study concluded that Ventsim is a valuable but underutilized tool. Strengthening training, integration and reliability would help transform it from a supporting aid into a central system for safer and more efficient underground mining.

5.2 Recommendation

The study recommended that Mopani Copper Mine strengthen Ventsim's connection with real-time ventilation monitoring systems. The differences between simulated and actual readings showed that ongoing calibration and data validation were essential. Linking Ventsim to live sensors and monitoring devices would make predictions of airflow, gas levels and temperature more accurate and responsive to underground changes. This integration would enhance safety and allow for quicker, data-driven decisions. The study also emphasized the need for full staff training and technical support. The steep learning curve and limited user confidence highlighted the importance of structured programs, refresher courses and accessible support channels to help staff use the software effectively and reduce downtime caused by errors or crashes.The mine was also advised to explore cost management and accessibility measures to encourage broader use of the software. High licensing fees limited adoption, especially in smaller departments, so flexible pricing or subscription-based options could make it more affordable. Management should evaluate the long-term safety and efficiency gains rather than focusing only on upfront costs.

6. References

1. Bado K, Korb K. Technology acceptance in Ghana's small-scale mining: A TAM study. Resources Policy. 2021; 70:101-113.
2. Banda L, Phiri M. Ventilation design delays and safety incidents in Zambian mines. Zambia Engineering Journal. 2021; 14(2):99-115.

3. Belle B, Du Plessis S. User expertise and data requirements in ventilation simulation tools. Mining Technology. 2018; 127(1):48-60.
4. Cheng X, Wu Y, Zhang W. Digital simulation in mine ventilation design: A review. International Journal of Mining Science. 2016; 50(3):200-215.
5. Chileshe P, Nkomo S. Interoperability challenges in mining project management systems. Journal of Mining Information Management. 2021; 12(3):141-155.
6. Kerzner H. Project management: A systems approach to planning, scheduling, and controlling (12th ed.). Wiley, 2017.
7. Khan S, Murthy C. Usability and accessibility in ventilation simulation tools. International Journal of Human-Computer Studies. 2021; 151:1026-1040.
8. Kimathi N, Mwila C. AI-driven recommendations for mine ventilation optimization. Journal of Intelligent Mining Systems. 2023; 1(1):14-28.
9. Kurniawan R, *et al*. Trends in digital tool adoption in mining. Resources Policy. 2020; 28(4):405-419.
10. Kumar R, Singh A. Heat load and ventilation in deep mines: Challenges and strategies. Mining Engineering Review. 2019; 38(6):234-247.
11. Matsumoto K, Thiel M. Integrating short- and long-term ventilation planning using Ventsim. Mining Technology and Innovation. 2022; 14(4):221-239.
12. McPherson MJ. Subsurface ventilation and environmental engineering (3rd ed.). Society for Mining, Metallurgy & Exploration, 2009.
13. Mkhize S, Sibanda T. Impact of training on simulation software precision. African Journal of Mining Technology. 2023; 15(1):35-51.
14. Moyo R, Ssenyonjo S. Vendor support challenges in remote mining regions. Mining Software Support Quarterly. 2022; 4(2):90-105.
15. Mousing P, Minnitt R. Ventilation practices in Sub-Saharan African mines. Journal of African Mining. 2015; 11(2):123-139.
16. Muwowo M, Chanda J. Accident factors and ventilation inadequacies in Zambian mines. Zambia Mining Safety Journal. 2019; 5(3):150-163.
17. PMI (Project Management Institute). A Guide to the Project Management Body of Knowledge (PMBOK® Guide) (7th ed.). Project Management Institute, 2021.
18. Qureshi A, *et al*. Emergency scenario planning with simulation software. Journal of Safety Engineering. 2021; 16(4):233-249.
19. Rogers EM, Dearing JW. Diffusion of innovations in mining organizations. Mining Management Review. 2017; 8(1):12-29.
20. Sunkpal P, Mishra K. Organizational culture and simulation software uptake. Journal of Mining Technology. 2022; 128(1):60-73.
21. Venkatesh V, Davis FD. A theoretical extension of the Technology Acceptance Model. Management Science. 2000; 46(2):186-204.
22. Venkatesh V, Thong JYL, Xu X. UTAUT2: Extending the Technology Acceptance Model for consumer contexts. MIS Quarterly. 2016; 36(1):157-178.