# CURRENT THEMES IN MECHANISED MINING

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| **AUTHOR(S)** | LD VAN EYK, PS HEYNS |
| **PROJECT TEAM** | LD VAN EYK, J WANNENBURG, DF MALAN, PS HEYNS |

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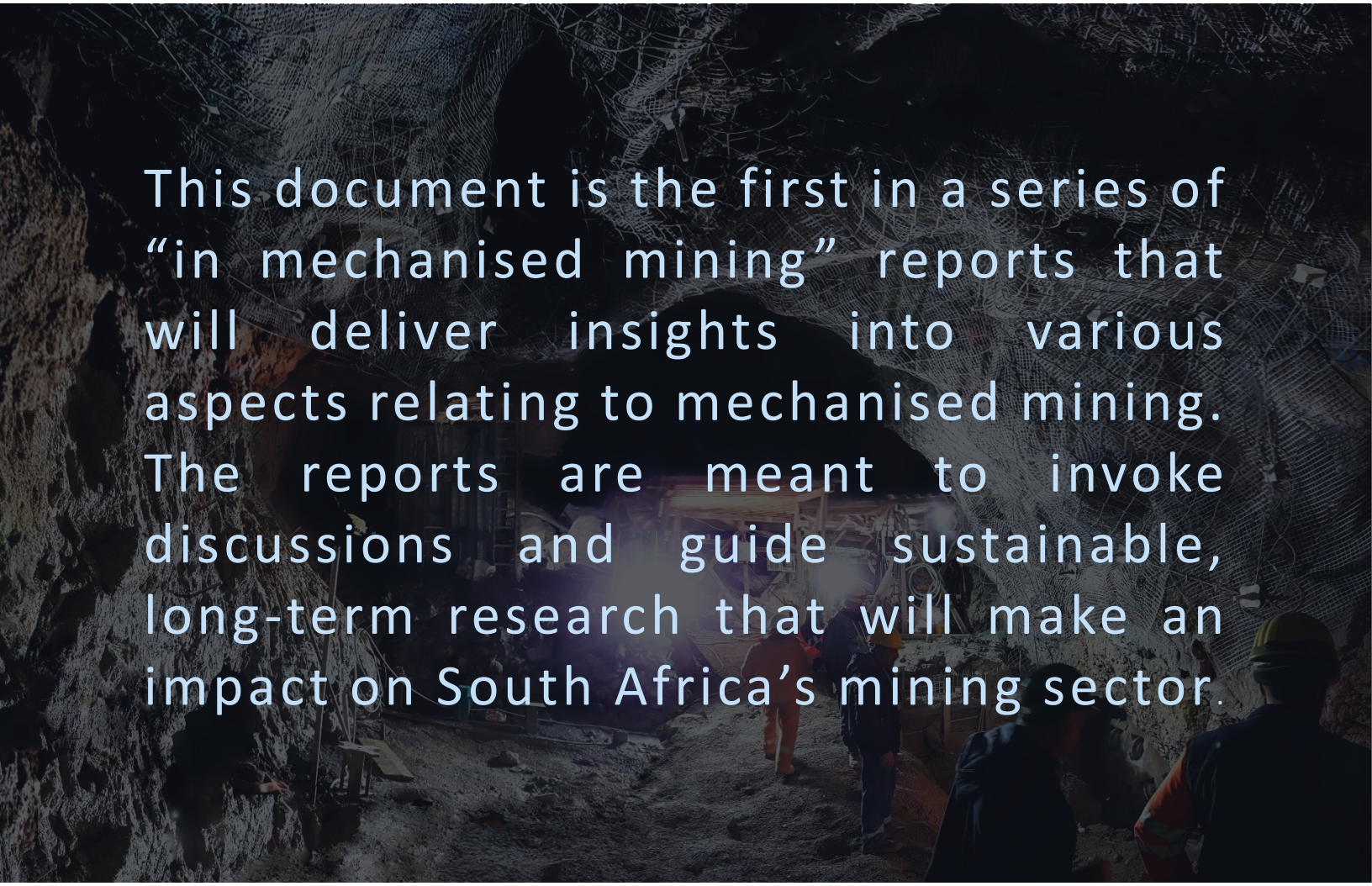


# 1 INTRODUCTION

## 1.1 BACKGROUND

The mining landscape is dynamic with new challenges arising every day. This report identifies themes that are relevant within mechanised mining, with specific focus given to underground applications. These themes are identified by analysing recent academic literature reviews, recent industrial documents on mining, mining conference opinions and interactions with various players in the mining field.

Although the focus of RAMMS is predominantly underground, narrow reef, hard rock mining, this report allows for a wider view of the mining industry, leading to the potential for cross-pollination of ideas.

## 1.2 SCOPE OF REPORT

This report starts with identifying some themes that are currently important to mining research. Following from this, important themes from industry are identified. These themes are specifically relevant to South African mining. In the final section, we summarise the key themes and discuss the interplay of the themes between mining research and industry. This summary can serve as a springboard to guide future research within RAMMs.

# 2 THEMES FROM MINING RESEARCH

To understand the direction of ongoing research within the underground mining field, several review articles relevant to the field were examined. These pieces spanned topics including rock engineering, rockburst prediction, tunnelling, advancements in ground penetrating radar, and the current state of machine learning and artificial intelligence in underground mining.

A recurring theme across these articles is the mention of machine learning algorithms. This is unsurprising given the potency of these data-driven models, especially in situations where data is plentiful. As mining becomes increasingly mechanized, and hence data-rich, the relevance of these methods is coming to light. This will be discussed in greater detail in section 3.

Sifting through the wealth of topics, six overarching themes were identified that, if addressed, could spark innovative research. While these themes are derived from a variety of subjects, their applicability is universal across underground mining operations in South Africa.

## 2.1 INTEGRATION OF MACHINE LEARNING AND PHYSICAL MODELS FOR ADDED INSIGHTS:

Both Morgenroth et al. (2019) and Pu et al. (2019) discuss the interplay between physical and machine learning models within their research. Morgenroth et al. (2019) point out the potential of integrating machine learning techniques with physical models as a new trajectory for future research in rock engineering. Pu et al. (2019) underscore the value of machine learning in predicting the timing of rockburst failures. Although current state-of-the-art methods are adept at anomaly detection, they do not always provide insights into when these detected anomalies will translate into failures. Hence, they suggest the need to bridge this gap, from merely detecting an anomaly to accurately predicting when this anomaly will result in a failure.

In summary, both articles highlight the potential of marrying machine learning with physical models, concluding that this fusion could give birth to novel strategies in a variety of fields.

## 2.2 CREATING ACTIONABLE INSIGHTS:

A key consensus among the review articles by Pu et al. (2019) and Ali and Frimpong (2020) is the emphasis on generating actionable insights. Pu (2019) identifies a shortcoming in current machine learning models used for rockburst prediction: they primarily focus on anomaly detection, which, while useful, is not actionable due to the absence of an associated time frame for when the anomaly may result in a failure. Echoing a similar sentiment, Ali and Frimpong (2020) highlight the need for decision-making automation in haul truck object detection systems. It is not enough to just detect an object; to enable automation, the system must also be capable of identifying the object type and determining an appropriate response.

This convergence in viewpoints underscores an opportunity for advancing mining research: focussing on the generation of actionable insights. Such insights are especially useful to an environment in the process of automation.

## 2.3 VALIDATION AND STANDARDISATION ARE NECESSARY FOR ADOPTABLE MACHINE LEARNING MODELS:

Both Morgenroth et al. (2019) and Shreyas and Dey (2019) identify the need for validation and standardisation of machine learning models. Both review articles are quite general, focussing on rock engineering and underground excavations, hence this theme seems to be quite widespread.

In terms of validation, machine learning methods often demonstrate high competence in fitting data, but the performance can be unpredictable when dealing with changes in input data. Most existing research fails to address this uncertainty, which can contribute to scepticism among potential users.

As for standardisation, it is desirable to have consistent best practices for training machine learning models. A standardised approach to model selection, architecture optimisation, and hyperparameter tuning could greatly enhance the overall effectiveness and adoption of these methods.

Overall, the sentiment is that we need to build models that are standardised for certain applications whilst clearly defining their domain of applicability.

## 2.4 MACHINE LEARNING MODELS ARE NOT INTERPRETABLE:

While only Shreyas and Dey (2019) specifically mention the interpretability issue, it is widely recognized in the machine learning field that some models operate as "black boxes", offering little to no interpretability. Shreyas and Dey (2019) concluded that Random Forest and Decision Trees were more interpretable than their neural network counterparts. The requirement for interpretability is paramount in the mining sector because their scope of practical use may be limited if they cannot be interpreted and hence trusted. This point ties into the theme in section 2.3, reinforcing that models need to be developed that are trusted and understood.

## 2.5 LEVERAGING PRETRAINED MODELS THROUGH TRANSFER LEARNING HOLDS POTENTIAL:

Amaral et al. (2022) reviewed different techniques for automatic detection of underground objects using ground penetrating radar. Although this review seems quite specific, the key finding may be extrapolated. Amaral et al. (2022) concluded that pre-trained models, fine-tuned on the specific domain of ground penetrating radar, were able to outperform experts in the field. The pretrained model in question, Alexnet, was initially trained for general object-detection tasks. Despite the model's different original scope, it proved to be efficient in identifying objects from ground-penetrating radar scans due to the transferability of certain features like edge detection and contrasting regions.

This approach, called transfer learning, can be applied in numerous ways, and holds significant potential for the mining sector, providing a means to leverage powerful pretrained AI models for specific applications.

## 2.6 GENERAL ARTIFICIAL INTELLIGENCE CAN BENEFIT FROM RELATED KNOWLEDGE:

Ali and Frimpong (2020) propose the creation of a general artificial intelligence that can scale to multiple domains, rather than developing a new model for each problem. This idea complements the theme in section 2.3, as such a model would, by default, be a standard solution for a variety of problems.

The implementation of a truly general artificial intelligence, however, is not without its challenges, requiring significant technical, financial, and time investments. Existing examples such as Google's AlphaGo and the more recent GPT offer encouraging prospects but are the result of extensive resources.

The key insight here is that these general models can capture commonalities between different domains and leverage them to address unseen tasks, aligning with the theme of knowledge transfer raised in section 2.5.

## 2.7 CONCLUDING REMARKS:

The identified themes are not mutually exclusive and have overlapping implications. For instance, the integration of physical and machine learning models (theme 1) may yield more actionable insights (theme 2). Moreover, the use of interpretable models (theme 4) could help standardise the selection of models in the mining industry (theme 3), as these models facilitate more straightforward conclusions.

There is significant potential in recognizing commonalities across different domains in engineering, learning from these, and applying the insights to the target domain (theme 5 and 6) - mining. This could be achieved by building a generalized model or, more feasibly, through transfer learning.

In summary, the interrelated nature of these themes presents opportunities for their combined exploration, enhancing the application of machine learning methods in the mining industry.

# 3 THEMES FROM INDUSTRY:

Although various sources were used to inform this section, one report particularly stood out for its invaluable insights. This was the collaborative report between the Minerals Council South Africa (MCSA), PricewaterhouseCoopers (PwC), and the Mandela Mining Precinct (MMP). The MCSA board mandated PwC's smart mining team and MMP's Real-Time Information Management Systems (RTIMS) program to conduct this study biennially. The referenced report is the second in the series, titled "Ten insights into 4IR," which was published on April 11, 2023. This report will hereafter be referred to as the 4IR report.

Additionally, two SAIMM conferences stood out for their invaluable insights. The first is the Digital Transformation in Mining 2023 conference, held on the 28th and 29th of June 2023. This conference will be referred to as DTM2023. The second is the GM-SAIMM forum, held on the 12th and 13th of July and will be referred to as GMG2023.

DTM2023 focussed on the digitisation of the mining industry, presenting success stories and new technologies but also highlighting current challenges. GMG2023 had three main themes, namely safety, energy management and security and finally cyber security. This conference had multiple break-out sessions and panel discussions which served as a great resource for identifying current issues miners are facing.

Below are seven themes that became apparent from the 4IR report, DTM2023, GMG2023 and talks with industry players. These themes are by no means exhaustive, with topics such as cyber-security and energy management not being addressed. They were purposefully not included, as they do not necessarily align with RAMMS's goals.

## 3.1 MINES ARE MOSTLY DIGITIZED AND CONNECTED:

A common theme from both DTM2023 and the 4IR report was that mines are predominantly digitized, with 100% of miners having integrated digital technology into their operations. None of the mines consider themselves as newcomers to the digital world anymore (4IR, p.10). Although the mines are beginning to accumulate large quantities of data, the pressing question from DTM2023 was, "what do we do with this data?" Mines are still uncertain about how to best utilize the data, suggesting that a significant impact can be made in the mining industry through data-driven methods. Some mines have already begun processing their data, but the insights derived may not always deliver the expected value. This issue was specifically discussed at DMT2023 and is alluded to in the 4IR report (p. 16). The anticipated improvements in throughput and efficiency were only half of what was expected. The report indicates that mining companies are deriving these values from actual information systems (quantitative) rather than estimations (qualitative). This clearly indicates that the potential value from digitization has not been fully realized. The following theme provides an insight into a potential reason why.

## 3.2 CREATING ACTIONABLE INSIGHTS FOR BOTH MANAGERS AND OPERATORS:

As mines become digitized, they are faced with an overwhelming amount of data that they may not know how to effectively use. Moreover, the insights drawn from the data do not always translate into actionable steps. For instance, reporting on excessive fuel usage is informative but does not provide the manager with a course of action to reduce fuel consumption. The information lacks an associated action. A more insightful report could measure multiple sensors, identify an anomaly (such as unusual wheel bearing vibrations), and correlate this data with excessive fuel usage, thereby guiding the manager on the necessary action to take e.g., repairing the bearing.

Another related concern, raised during a discussion with a mine manager at DTM2023 and highlighted in the 4IR report, is that current technology does not furnish operators with essential actionable insights. The manager expressed frustration about receiving KPI targets and shortfalls without any guidance on how to address the issues. Simply informing a miner

that they are behind schedule does not resolve the problem. Hence, there is a clear need for conveying meaningful information directly to the miners, enabling them to enhance productivity through actionable insights.

An example of such actionable insights can be found in Nerospec's dashboard on a Load Haul Dump (LHD) that they instrumented: drivers are provided with a load gauge on their LHD dashboard. This gauge displays the estimated maximum load they can scoop versus the load they have currently scooped. This type of indicator can assist miners to improve their productivity in real-time with actionable insights. Contrast this with a manager informing them after the shift that they only hauled 90% of their target load.

Therefore, two clear shortcomings have been identified:

1. Actionable insights must be developed.
2. Insights that enable operators to enhance their productivity in real time must be developed.

Supporting these points, the 4IR report mentions that unions are in favour of digitizing mines, provided that the digitization aids the operator's decision-making in real time rather than being used solely for accountability (4IR, p.13, p.19). The information provided to the operator must be context-based, such that it adapts according to the operator's actions and empowers them to enhance productivity in real-time (p.23). The idea is not to take away autonomy from the thinking human, but rather enhance it.

## 3.3 ASSET MANAGEMENT HOLDS SIGNIFICANT VALUE:

The 4IR report underscores the importance of asset management, pinpointing it as a major source of value to be gained from digital programs (4IR, p. 22). While predictive maintenance is still in the early stages of adoption, 25% of respondents reported having implemented predictive maintenance practices, and another 50% are in the process of testing new programs (4IR, p. 26). The mining sector seems to be approaching the threshold necessary for integration into the condition monitoring domain. This was previously hindered by a lack of:

- Sensor availability on machinery
- Data infrastructure
- Real-time data acquisition
- Partnerships and collaborations with Original Equipment Manufacturers (OEMs)

One could argue that Level 9 collision prevention regulations have incentivized mining companies to digitalize their operations to the point where condition monitoring is now possible on a vast array of assets. The 4IR report reveals that 50% of mining operations have adopted some form of Industrial Internet of Things (IIoT), with another 50% in the process of piloting new programs around IIoT. Moreover, the report concludes that one of the main drivers for environmental, social, and governance (ESG) improvements is the transition from planned to predictive maintenance via an array of sensors and monitors.

Consequently, mines are now equipped to measure the condition of their assets in real-time. Whether they have the technical abilities to do so is another question that will be addressed shortly. The next theme that is a recurring issue to researchers and seemingly the mining industry alike: Access to data.

## 3.4 DATA AVAILABILITY VERSUS ACCESSIBILITY:

The 4IR report emphasizes the critical role of collaborations with OEMs in overcoming barriers to data accessibility (4IR, p. 26), with respondents expressing uncertainty regarding whether OEMs are reluctant to embrace new technologies or are intentionally withholding cooperation. This sentiment was echoed in discussions with Nerospec, who suggested that OEMs may be protective of their data to avoid exposing underperforming machinery. As such, OEMs might not be motivated to share their data. A presentation by Sandvik at the DTM2023 conference showcased the insights gleaned from their digital monitoring centres, demonstrating the potential value of operational data. However, it also highlighted the central issue – OEMs maintain control of the data, while mining operations are essentially purchasing data

interpretation services. The 4IR report reaffirms this, stating that “At the heart of the problem is access to data – and it will require a different level of engagement with OEMs to make more progress or the rise of ecosystems of service businesses outside of mining that can deliver turnkey solutions on OEM equipment.”

In summary, as mining operations grapple with data access challenges, external parties, including researchers, face similar difficulties and may need to become more self-reliant in data gathering.

## 3.5 TECHNICAL CAPABILITIES OF MINING OPERATIONS:

The question of whether mining operations have the technical expertise to handle the vast volumes of data was raised at the end of section 3.3. Several mentions during DTM2023, GMG2023 and the 4IR report suggest that the mining sector lacks appeal in attracting talent, with the phrase “mining is not sexy” being used multiple times throughout DTM2023. The 4IR report mentions that only 2 out of the 10 most favoured employers among engineering and technology students are mining companies (4IR, p. 31).

This shortage of talent means that mining operations lack the resources needed to fully exploit the potential of their data. This presents an opportunity for external research entities to contribute, provided they have adequate access to the necessary data.

## 3.6 FOCUS ON SAFETY IN SOUTH AFRICAN MINING OPERATIONS:

Safety emerged as a persistent theme in the 4IR report. It was noted that South African mines have 50% more fatalities annually compared to the global average (4IR, p. 25). Furthermore, mining CEOs indicated that 4IR technologies were predominantly being employed in three key areas, one of which is safety (4IR, p. 26). The focus on safety was further amplified at the GMG2023 conference, where a full day was spent on safety-related topics, with collision prevention systems being a topic that received quite a bit of engagement.

These insights reveal that South African mines are striving to align with global safety standards by utilizing data to enhance safety measures. This opens avenues for research that can substantially contribute to improving safety standards in mines through data-driven methods.

## 3.7 COLLISION PREVENTION SYSTEMS ARE REDUCING PRODUCTIVITY:

As mentioned above, a recurring topic at GMG2023 was the issue of the recent collision prevention level 9 legislation. The MCSA presented their recent work in the field, having provided clear measures to determine whether a system is at level 9. Previously, mines had to rely on vague legislation which caused major headaches amongst miners, due to its wording.

Another issue that was raised during a breakout session was that the existing solutions are too sensitive. This can be attributed to two major factors:

Firstly, many mine layouts today were designed close to a decade ago, before the issue of TMM-related fatalities had gained traction. Therefore, the space between vehicles and pedestrians is limited, with no scope to expand the width of roads. This means that whenever a pedestrian passes a vehicle, the CPS system intervenes and stops the TMM until the pedestrian has passed. Cubbies were also indicated as being ineffective due to the second factor: Immature technology. The current solutions predominantly rely on radio-based solutions to detect when two objects are close to one another. This technology is chosen due to the poor visibility underground. The drawback, however, is that these technologies work on signal strength, and hence have no sense of the relative location between two objects. Therefore, even if a pedestrian stands in a cubby, out of harms’ way, the system cannot determine where the pedestrian is and intervenes regardless of both driver and pedestrian being aware that it would have been safe to proceed.

These issues are causing an increase in CPS interventions, leading to increased wear on system component as well as a reduction in productivity. Because mines cannot change their mine layout, the solution needs to come from the technology side.

## 3.8 CONCLUDING REMARKS:

When following the identified themes, a general thread of the state of underground mining in South Africa emerges: Mines have mostly digitised themselves, which is leading to a plethora of data being captured. They are generating insights from this data, but these insights are not always actionable. Despite the limited insights, mines remain convinced that their data holds significant value, with asset management being believed to be the biggest area where value can be derived.

Mines are, however, not yet sure how to best use their newfound data. Thus, they know where they are heading, but may not know how to get there. This is due to multiple factors. Firstly, they may not have full access to their data. Secondly, they may not have the in-house expertise to process the data. The first point is a source of frustration for miners and researchers alike and may take time to resolve. The second point, however, is exactly the type of challenge that researchers can address.

# 4 THE INTER-PLAY BETWEEN KEY THEMES:

Before concluding with the interplay of themes between mining literature and industry, a summary of the key themes is given to serve as a quick reference aid:

## 4.1 KEY THEMES FROM LITERATURE:

1. The integration of machine learning methods with physical models offers new potential for research.
2. Machine learning models need to move beyond anomaly detection to provide actionable insights that enable automatic decision-making.
3. Focus needs to be directed to validating and standardising machine learning models to ensure their reliable performance across varying input data and use-cases.
4. Machine learning models are difficult if not impossible to interpret, thus, more research is required to increase model interpretability.
5. Pretrained models fine-tuned to specific domains can provide superior performance, offering opportunities to unlock further value in the mining sector.
6. The development of general artificial intelligence models, capable of functioning across multiple domains, could serve as a standard solution for various problems, although their creation is resource-intensive and challenging.

## 4.2 KEY THEMES FROM INDUSTRY:

1. Mines are now at a point where they are starting to gather large volumes of data. They are not yet sure what the best way is to extract value from this data.
2. Insights from data are not good enough. The insights need to be actionable, and preferentially, directly actionable to an operator.
3. Miners expect the largest value return from asset management, with predictive maintenance mentioned as a new drive.
4. Obtaining data from mines may be difficult because they themselves don’t always have access to the data or may be concerned over the security of their data.
5. Mines have a shortage of skills and hence their ability to draw meaningful insights from their data is limited. Researchers can aid mines by developing useful tools to find insights in their data.
6. Mining safety has been identified as an issue and is being tackled through mines’ newfound data.
7. Collision prevention systems are impacting productivity due to infancy in the technology.

## 4.3 CONCLUDING REMARKS – AN INTERPLAY OF THEMES:

A theme consistently emerging in both mining research and industry is the concept of actionable insights (theme 2 from both fields). Existing literature acknowledges the ability of current models to deliver insights, but that these insights are not necessarily actionable. In a similar vein, industry recognises that despite digitisation and the adoption of existing technologies, they are occasionally left with information they can't convert into actions. Therefore, future work should concentrate on addressing this issue.

The path to more actionable insights isn't entirely unexplored. Other academic themes hint at potential solutions. By building on existing knowledge, the creation of hybrid systems — where physical and machine learning models are combined — may pave the way for richer insights from data (academic theme 1). Moreover, the transfer of insights from related fields through transfer learning is another promising avenue (academic themes 5 and 6).

Two themes plaguing not only mining, but the wider field of machine learning are those of interpretability and standardisation of machine learning models (academic themes 3 and 4) and go largely unaddressed in underground mining literature. Despite mines generating vast quantities of data (industry theme 1), they may lack the necessary expertise to extract value from this data (industry theme 5). Consequently, it is vital that researchers develop standard, interpretable models instead of expecting each mine to develop custom solutions without the requisite skillset.

Finally, the prevailing sentiment in the industry identifies safety and asset management as key areas for data utilisation (industry themes 3, 6 and 7). This observation contrasts what is found within the literature from the SAIMM journal over the past three years, with no entries directly addressing safety or condition monitoring in the underground mining context. Hence, significant research value could be added in these domains.

In conclusion, although mining research and industry may focus on different areas, there is ample scope for mutually beneficial cooperation and knowledge exchange. The similarities and inter-play between mining research and industry above illustrate sensible areas where researchers may focus to derive optimal value from their work.

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