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Lia DiBello, David Lehmann, Edmund Sterling Chamberlain and Daniel Rohrlick

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Lia A. DiBello M.A., Ph.D, David Max Lehmann Ph.D. PE, MBA CRM, E.S. Chamberlain III and Daniel Rohrlick B.S.
Workplace Technologies Research Inc. and Applied Cognitive Sciences Labs Inc.

For decades, our team has explored accelerating expertise through a specific kind of "gamification", which emphasizes unstructured tasks with high stakes "non-negotiable" goals and opportunities for rapid trial and error iteration. This results in the development of deep domain expertise.
Recent work incorporating the use of Massive Multi-player virtual worlds with advanced behaviour tracking as a way of increasing the power of this method and scaling it has yielded some unexpected benefits. This paper describes an application in the mining portfolio business and explores how the extension of powerful tools can introduce or transform traditional business by changing the cognitive potential of people using them. Implications for NDM research are discussed.

OVERVIEW

For decades, our team has explored accelerating expertise through a specific kind of "gamification", which emphasizes unstructured tasks with high stakes "non-negotiable" goals and opportunities for rapid trial and error iteration. This results in the development of deep domain expertise. This approach – although new – has deep roots in long standing research on expertise (e.g., Chi, Glaser and Farr, 1988) and the cognitive mechanisms involved, which we have discussed in other work (DiBello 2011; DiBello 2019; Hoffman et. al 2014). In 2007, we incorporated the use of Massive Multi-player virtual worlds with advanced behaviour tracking and instant feedback as a way of increasing the power of this method and scaling it. The differences between these applications and our previous attempts were size and complexity. The number of people in the environment and the number of moving parts that could be in play (such as technologies and impacts) were much greater. Over time, two uses of these environments emerged:

1. Developing expertise more rapidly in what would be considered relatively "bounded" domains. Examples of these include project management, IT deployment for supply chain efficiency, understanding and managing risks in changing insurance markets with globalization, maximizing returns in mining, and even issues such as psychologically safe leadership, inclusion, and leadership approaches that promote innovative team practices, to name a few.
2. Solving problems in corporations which are very complex and which are solved more efficiently by exploring options in 3D, through iterative trial and error, usually in a collaborative team. These approaches go beyond "digital" twins which are models that users can observe, but which are not immersive. Rather, our models are immersive; people can log in as avatars allowing reality analogous models to be tested against contact with human actors trying out a new approach or a change in a workplace. Specifically, the *immersive participation of actual workers, customers or stakeholders executing proposed strategies or even company designs "inworld" allows all to see if the proposed plan will survive reality – and more to the point – contact with human actors.* The 3D platform, if rich enough, can both serve as places to "rehearse" what-if ideas, and as ways to cognitive extend the team's ability to think about complex options

Why is this important? Managers and workers have their own notions of the goal and how to get there. Until they "enter" the model, both the model and the thinking and acting of users are not reality tested. Further, sometimes the interactions between human actors trying a model and the model reveal a better approach, which can then, in turn, be iteratively tested. Most important, all this can happen without the risk or cost of doing this in real life.

Iterative rehearsal has sometimes resulted in the discovery of an entirely new approach to business, or a whole different business model that is not possible without using the virtual world platform itself. A third usage has therefore emerged, related to the two above; *making possible new approaches to business*. Specially, massive 3D environments that are connected to outside data sources make possible business models that are too complex to manage without the assistance of 3D environments.

MANAGING A PORTFOLIO OF MINES VIRTUALLY:

In this paper, a specific case study will be described where our virtual world enabled a new business model; managing a portfolio of small mines as if they were one large mega deposit. A little background will put this case study in context.

A little background about mining as a business (skip this if you don't need the background)

Unlike most businesses which compete for customers, there is always a market for most minerals, such as gold, silver, or copper, but the price fluctuates with market conditions. Mining is profitable by spending less to get the valuable minerals out of the ground than it can be sold for on the open market. Therefore, mining companies are always concerned with the balancing act of cost per ounce. That can vary by the location and type of mine.

Normally a mining company mitigates a lot of long tail risk by going after "mega deposits", which can take up to 20 years to discover and qualify and which can cost over $2-3 Billion to develop before any gain is realized. The eventual yield from the deposit, which can last 40 years or more, pays for the upfront cost. On the other hand, the company must still continually offset the cost of mining itself with fluctuating mineral prices and cost of fuel, labor and other refining. They do this by changing what parts of the ore body are mined when (low grade ore vs high grade ore) or even which mines are mined when if the company owns several. When new technologies for processing waste become available, they may re-process waste for valuable minerals left behind. In summary, it has always best to own a large deposit for a long time.

Further, at high level, there are key factors considered:

1. Exploration costs are considerable. This involves finding the deposit through geological surveys, securing the land involved, and then verifying the existence of a valuable deposit with drilling and analyzing "core" samples. These "cores" are kept and stored as proof the quality and depth of the deposit and to determine its approximate boundaries. In order to establish the value of the deposit for sale or to raise funds to develop a mining operation, a report – often called a 43-101 – is used as proof of its value. In general, depending on the depth and irregularity of the deposit's shape, drilling alone can cost up to $1.5 Billion. Once the mine is built and extraction begins, it may continue at the edges of the deposit to see if there is more value. This is called "brown-field exploration".
2. The Block model; this is an abstract characterization of the ore body, divided into the 10 meter cubes, showing the value of each cube (how much gold, copper, silver or other mineral it contains) and the type of "overburden" or waste it has. This allows the company to plan the mining operation, e.g., is the overburden soft or hard rock, and will special treatment, such as crushing and or cyanide leaching, or other chemical processing be required to separate the valuable minerals from the rock?
3. The block model helps the mining company make two things: The life of mine plan; (how long can the mine last) and the weekly or daily mining plans, or the extraction sequence. Which blocks will be extracted when? Mineral prices on the open market, the cost of fuel and labor can affect the mining plan – it can change even on a daily basis. Bottom line, mining operators need to keep the cost of extracting each ounce lower than the price that will be paid on the open market.

In general, given the upfront costs to develop mines, large deposits are preferred, which last at least 40-50 years. Depending on the country and type of location, these can take anywhere from 6-20 years to find and qualify before any mining is done. Further, some types of mines, such as deep block cave mines, use modern methods of using elaborate infrastructure located below the orebody which functions somewhat like an automated factory to use the earth's gravity to "cave" the ore body into collection "draw points" and robotic loaders which can run 24 hours a day. Although safer and more efficient, they can take years and several $Billion to build before any ore is collected. These are reserved for large orebodies where several decades of mining is expected to occur.

The problem is large deposits are becoming scarce. Companies are looking for ways to make money from smaller deposits and speed up the discovery and start up process. There is plenty of gold, silver, copper and other minerals of interest, especially rare earths used in electronics, but most of these minerals are not in large deposits. Finding a way to efficiently make money with smaller deposits would be tremendously valuable.

The U.S. mining project

This project involves using two technologies to greatly reduce the time and cost of discovery while our technology reduces the cost and risk of the actual mining operation design. MFT (Mineral Finder Technology is an A.I. discovery system, owned by CTAC, which eliminates much of the upfront discovery normally done through drilling. CTAC's MFT technology is a proprietary spectrographic and magnetic resonance technology that maps the underground orebody and any underground water. They have a specific analytic algorithm that develops a 3D mapping from the data they collect. This acts like much like an MRI would for a human patient in planning surgery. The mining company still has to drill to obtain cores as proof of the deposit, but they have a much better idea of where to drill, and need many fewer cores. This reduces the cost of discovery to a few $Million from up to over $1Billion and reduces the time to profitable operation < one year.

For mining customers, FutureView has a history of making immersive 3D models of mines in virtual worlds so that mining companies can "rehearse" future design options, including operational strategies, the use of enterprise technologies such as predictive maintenance systems, driverless fleet dispatch, and ore extraction planning. Being able to rehearse strategies with actual workers executing in compressed time allows the company to see if their assumptions have blind spots, if the mine itself has unforeseen issues or if the plan itself has problems (e.g., some preventive maintenance strategies don't factor in how much equipment is required for production plans). We have usually gotten involved when the mines are built, and need modification or a change in technology deployment.

As indicated, unlike other "digital twins" our mines are immersive and multi-player. Teams could log in as avatars and do a normal shift in compressed time to see if the mine itself, planned technologies, equipment and other planned features would work with actual requirements for mining workers and managers to make their numbers. It was a good way to test a scheduled maintenance plan, a mine plan, and evaluate fleet and equipment requirements and work flow. At times, we have modelled portions of a mine that did not yet exist for single mining operations which were expanding. Part of the virtual mine was an exact replica of the mine as it was in real life, and part of it was as it would be five-seven years in the future. The idea was to test the design with human beings working in it. Was the new design efficient? Safe if there was an emergency such as an underground fire? Could scheduled maintenance be implemented effectively. Were teams able to navigate the larger design?

Our worlds have two built in advantages: 1. Our worlds have the ability to track users' behavior, and if desired, compare it to a model of "goodness" and 2. They give users feedback as to how they are doing on working standards. Are they driving a truck that they failed to inspect before starting their shift and which has a tire near the end of its duty cycle? Did they enter a specific work area not wearing the PPE required for that area? Are they driving so fast (in an open pit mine) that they would not be able to stop if a person stepped in front of their equipment? Are they operating equipment too close to other people to be safe? Are supervisors who are tracking teams in large mines using a radio aware of where their crew members are? We found that giving each user a heads up display that they could pull up on their screen with a click and see how they were doing on behavioral goals was a powerful tool for remodelling behaviour. It also helped workers prepare for changes in the mine's features and helped the mining company tweak the design to be safer, more efficient and compatible with the goals of both workers and the mine company.

Because CTAC gets involved typically before there is a mine at all; the customer's goal with CTAC's technology is ask if there is a deposit to justify building a mine. However, it does not help answer the question of how the mine should be designed, especially if problematic underground features are found, such as underground water bodies In partnership with CTAC, we have been able to use the 3D models of the ore body that CTAC makes, LIDAR representations of the terrain and surrounding community, and the engineer's wireframe or Spline graph of the mine that a mining company is thinking of building around the orebody to render the whole operation in a virtual world before the mines are actually built in real life. Building a virtual mine around an accurate depiction of the ore body in an accurate rendition of the terrain and nearby communities does a number of things:

1. It shows you what kind of mine will work.
2. It allows an actual workforce to practice with it and design the technologies and equipment that will make it profitable
3. It will socialize and educate the surrounding community about mining, and how having a mine nearby might affect them, or not affect them at all.
4. It will help plan the environmental impact, the reclamation process and minimize any harm by rehearsing any unforeseen events.

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We wondered if the all the features collectively could be used to make it possible for companies to more efficiently manage a collection of small mines as one large mine, through a central virtual control room which tracks all the financial performance of each mine, and the portfolio as a whole, while immersive digital twins allowed for strategy formation and experimentation in each mine, as each one is acquired and integrated into the portfolio for maximum performance. The behavioral tracking and feedback could "onboard" each worker not only to the centralized technologies running the managing the mines, *but also the portfolio's business goals,* so that everyone would understand how they fit into the larger picture.

In late 2020, the opportunity materialized. The project involves 11 smaller mines and deposits that would not be possible to develop in a cost-effective way using older methods. In a virtual world platform, they will be managed as one mega deposit, managed with one business strategy, even though not co-located in real life. Operational options are being "rehearsed" in digital twins of the actual mines while workforces for each mine are trained together on technologies shared across mines in a multi-player, cloud-resident virtual world. The financial and operational "control room" for whole portfolio is virtual and shared by all the properties.

At this point in the project, we are still onboarding the mines and not all are fully operational in the virtual world or in real life. We onboard them virtually as they are acquired and onboarded in real life. The idea being that this is when we need to rehearse how they are integrated into the portfolio for best return on investment.

The infrastructure to support the project is shown in the functional diagram in figure 1. At a high level, the elements in the gold box are components of the FutureView "mothership" and are generic to all our applications (we also work in other industries besides mining). The part that people interact with resides in a Unity client, in this case on an Amazon Virtual Cloud Server. We use Smart Fox pro to manage the multi-player avatar experience and Signal R and Smart Fox as relay mechanisms for linking data and elements in the 3D world with each other and to external softwares and data sources we need to stream in and manipulate. Examples include softwares that run the real mines and stock market data used to evaluate the mine's financial performance or set goals. Figure 2 shows the control room which streams live data from each mine and from outside financial sources. Figure 3 shows some workers logged in as avatars in one of the 11 mines, 2 miles beneath the surface, inspecting ventilation pumps. Figures 4 and 5 show how the mines are constructed into 3D underground spaces that workers can enter and work in using the CTAC ore body and the engineer's Spline graph.

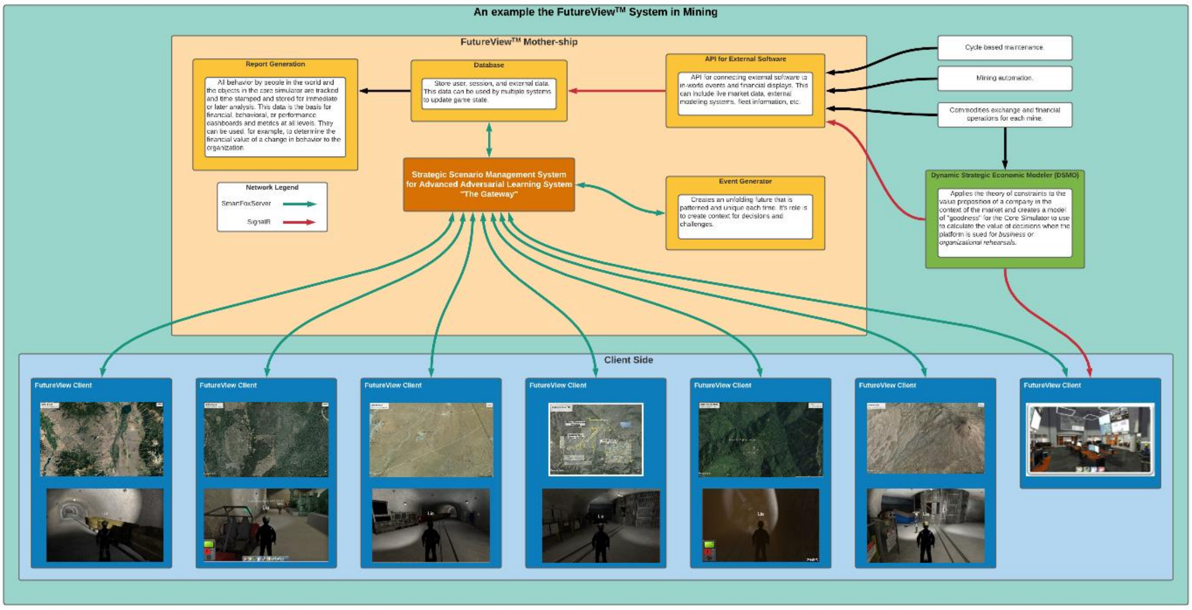

Figure 1. Diagram of the platform architecture with six mines and control room

Figure 2. Closeup of Control Room

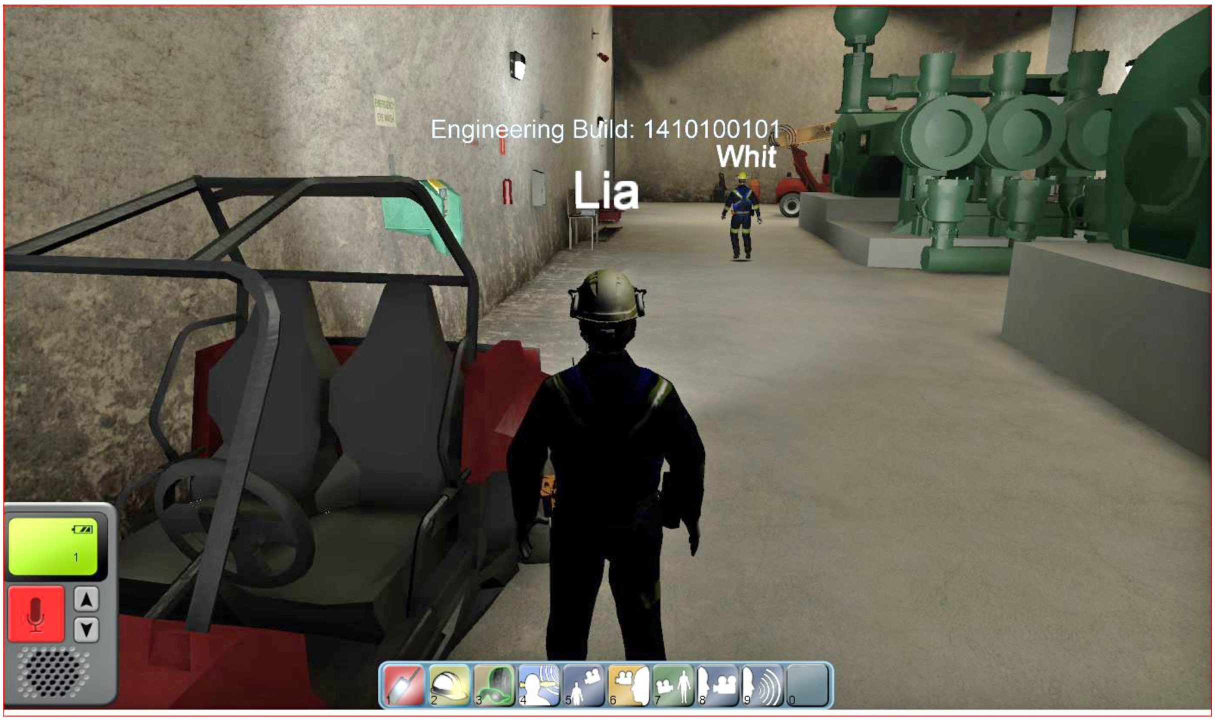

Figure 3. Closeup of Avatars inside one of the many mines

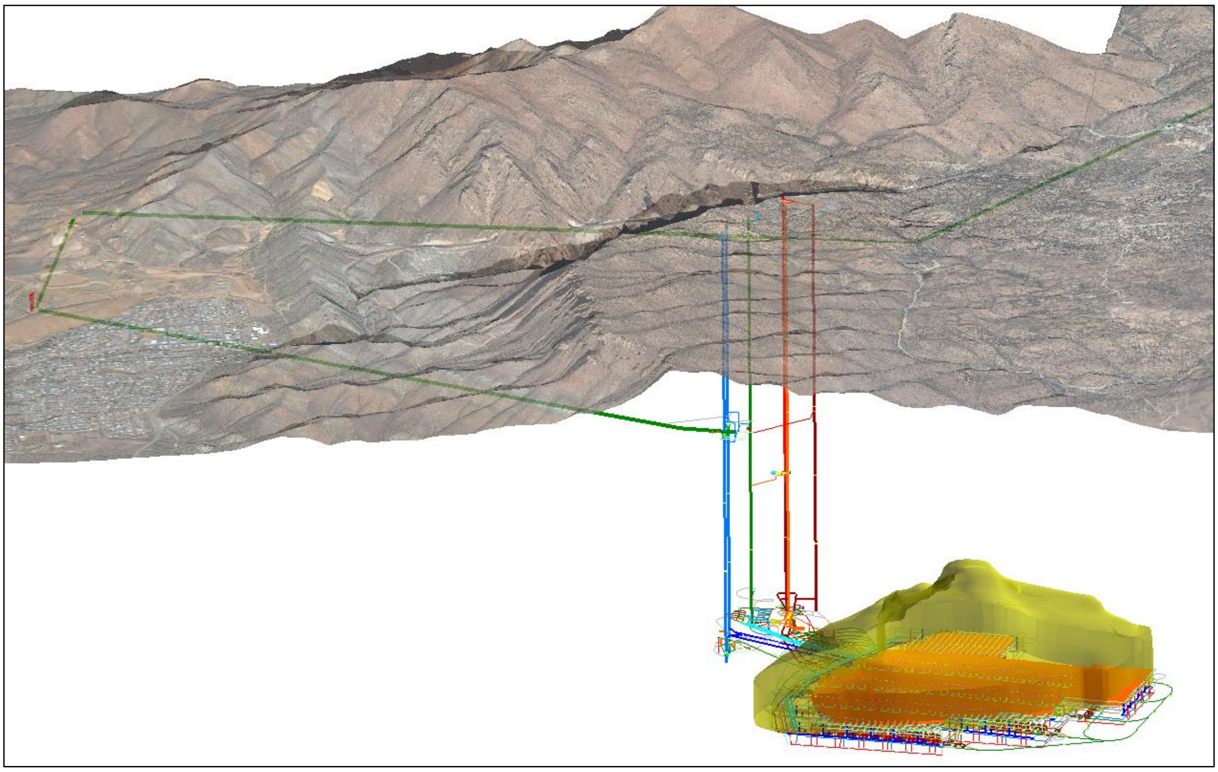

Figure 4. CTAC orebody model in Unity editor with wireframe of underground tunnelling

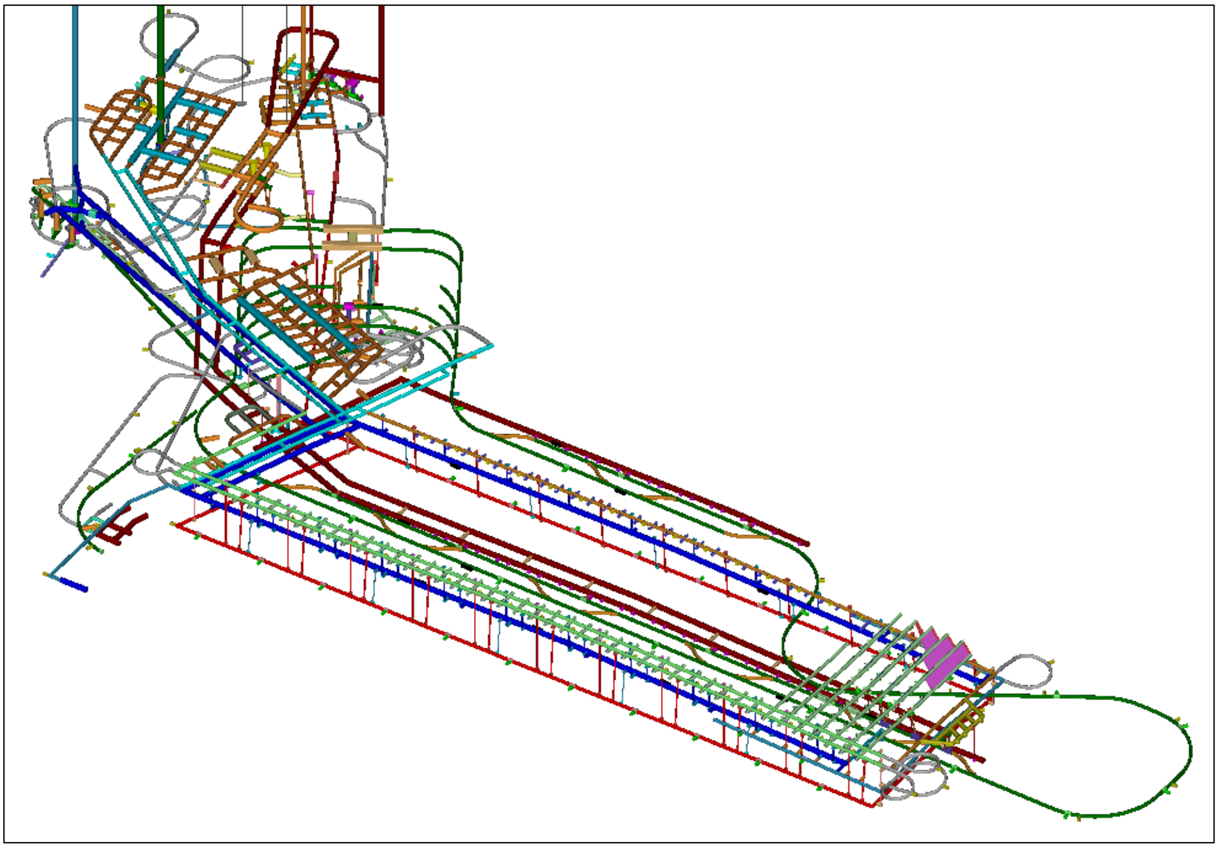

Figure 5. closeup of wireframe of tunnelling.

FINDINGS

We are in early days with this project, but so far, we are finding that some important decisions have been enabled by the platform's ability to clarify the relationships between the mines and their value to the portfolio's goals. In fact, some mines have been repositioned in the portfolio as their value becomes more clear when viewed in the context of the whole portfolio with simulated future financials against actual market data. We are also able to evaluate what kind of investment in equipment, technology and infrastructure improvement makes sense for each location in the context of the whole by "rehearsing" the impact of these changes and examining the total effect in context.

Most important, the employees at all locations can experience the relevance of their locations in the whole picture and see how their mine and their role contributes the larger goals. Further, supervisory training, safety training and even onboarding to the company's mission and vision can be accomplished in work-oriented rehearsals across all mines in a virtual world. We are able to communicate a single vision, mission and set of corporate values across the whole workforce and bring them together in the mega world. Micro and Macro feedback, delivered together helps participants "connect the dots" between individual behaviours and their own impact on larger events, increasing their capability to mentally simulate eventualities.

Given the speed of CTAC's exploratory technology and the ability to develop "what if" strategy exploration, more mines are being considered for addition. Since we started this project, two other mining companies are considering the platform and the model for similar projects. At present, this portfolio contains an estimated $130Billion in assets, although all the mines are relatively small.

SUMMARY

A number of additional benefits have emerged as the study project unfolds. The project is bringing together a widely inter-disciplinary team and introducing NDM methods of research to these teams. These include: Gold investors, mining companies in far reaching places, refineries, other NDM researchers, Geophysicists and business people interested in new portfolio management models not profitable without advanced expertise and the technology to support them. It is also drawing the attention of those interested in the Future of work and workforce development.

A potential study that could emerge as this project continues is the ways that technology expands the cognitive capability of individuals and teams by allowing them to externalize problem solving in an immersive reality-analogous virtual environment of a problem space that they can control and manipulate. The role of immediate feedback, problem space exploration, and compressed time can be examined to explore the various impacts on cognitive capability in a number of decision-making domains.

This project is one of many where we are deploying a "mega world" to manage a complex set of problems to achieve complex goals. There are many other settings under consideration, such as "circular economies" in Africa, responsible forestry and mining of the Amazon, leadership models for colleges, and new agricultural models. Currently, we also have ongoing projects in mental health, and DOD applications for military officers who must make decisions under uncertainty. The opportunity to rehearse the future in complex domains is the common theme here.

Anyone who wishes to know how human thinking is affected by using technology to extend decision making capability, collaboration or the role of "rehearsal" in complex cognition would benefit from following this work. The project also shows how advanced technology that extends our cognitive capability can enable new business models. Pointing to the ways in which it happens has implications for NDM research.

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