Mining Gold from a New Mountain of Data

How to Combat Combinatorial Explosion

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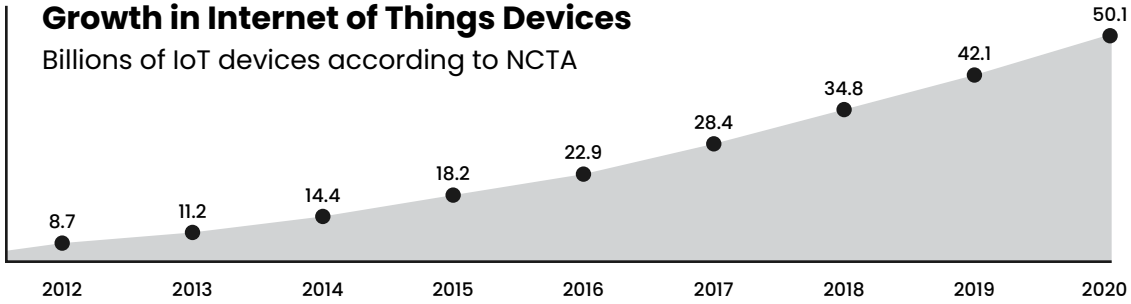
Introduction

The rapid increase in sensors and sensor data gathered from small devices (e.g., the accelerometers and GPS location sensors in most smartphones) networked into an Internet of Things (IoT) is a thoroughly studied and recognized phenomenon of modern life. Even so, the sheer scale of sensor proliferation is staggering. The trade association for broadband and television providers (NCTA) estimates that between the years of 2012 to 2020, consumer-connected IoT sensors increased nearly 500% from 8.7 billion to 50.1 billion (see graph below). This is projected to rise to 75 billion by 2025.



With the exponential rise in consumer devices, the same trend is being seen within many other industries, including mining. Since the introduction of IoT sensor monitoring, mine owners and operators have understood its inherent value. Their assets are often located in challenging distributed environments that lack access to power, high-speed internet, and protection from the elements. This situation has required mine owners, managers, engineers, consultants, and crews to remotely access insights into important information around the health and status of their assets. With the increase in both the total number of sensors and the different types of sensors, there is now an enormous new data resource that many mine managers are struggling to exploit.

More data and more varieties of data are good, but this rapid increase is not subject simply to exponential growth but to combinatorial growth, and even to combinatorial explosion.

> In the last 10 years, we have experienced exponential growth in the number of sensor observations posted to our platform. It speaks to the ever-accelerating number of devices being deployed as part of highly automated real-time monitoring workflows each year. The benefits that the mining industry has experienced in terms of efficiency gains and more insightful decision-making has been tremendous.
>
> *Alex Pienaar, Senior Sales Director of Infrastructure IoT, Bentley Systems*

The Promise and Peril of Combinatorial Explosion

Combinatorial explosion is a mathematical effect that occurs when combinations of variables or nodes within a system are each connected to another, or when the random arrangement of nodes creates new patterns.

A simple example occurs whenever a standard deck of playing cards is shuffled. The number of possible outcomes is $8x10^{67}$, a 68-digit number that is much larger than the number of all the atoms on and in the Earth. One consequence is that no randomly shuffled deck of cards, in the entire history of shuffled decks, has ever been exactly like any other shuffled deck of cards—and never will be.

Data derived from a single mine's sensor network is subject to combinatorial explosion because the data derived from discrete network nodes (sensors) can be combined to create new information. For example, a mine that measures earth movement with seismic monitors, robotic total stations, and strain gauges—and considers the resulting data in combined reports—has more information about earth movement than mines deploying a more limited set of sensors (for example: radar only). This information can be used to increase operational efficiency and mine site profits, as well as sometimes to save lives. When a mine deploys thousands of sensors with many discrete types, the quantity of new information available is so great that it is hard even to estimate the amount with ordinary methods.

The promise of this data growth is in the sheer amount of new, useful information now available to mine operators. The peril is in the staggering amount of useless information that must be analyzed to extract truly useful insights. This analysis cannot be performed efficiently with spreadsheets and manual compilation of reports, even by the best engineering talent. But it can be performed by engineers making use of intelligently designed data analysis and reporting.

Powerful sensor data monitoring, management, analysis, and automation creates a new type of "data story" to help make sense of the data. When these solutions are implemented in a mining ecosystem, these data stories result in dramatic, positive improvement in several areas of operation:

Dramatically Improve Operations with Powerful Sensor Data Monitoring, Management, Analysis, and Automation

1 Focus on Data Analysis, Not Data Gathering

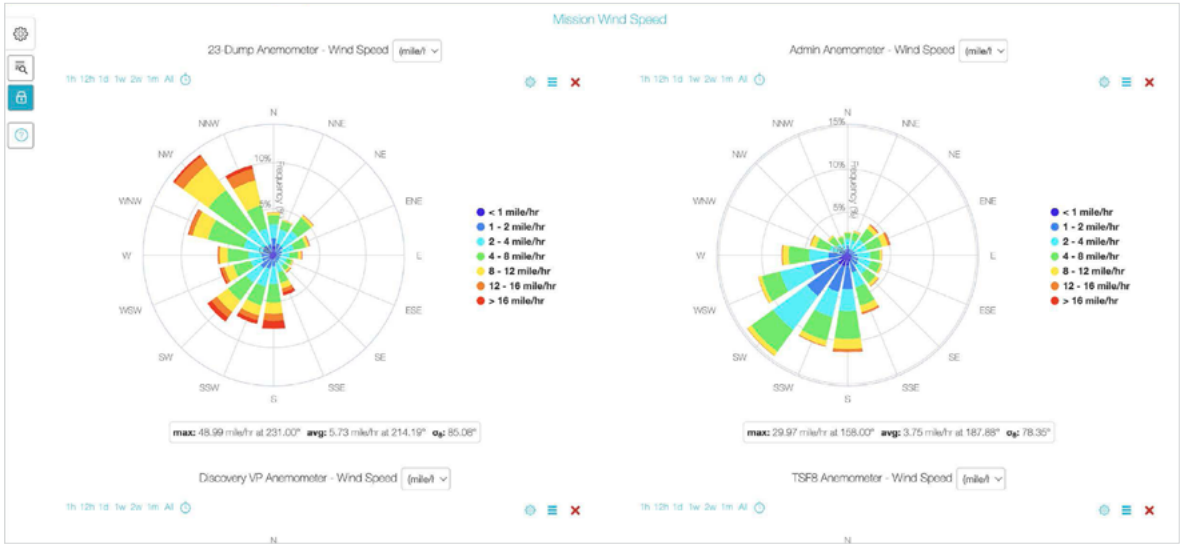
It is important to use engineer time and labor efficiently, ensuring that talented technical staff are spending most of their time on the high-level analysis and problem-solving that they are uniquely qualified to perform.

Unfortunately, the typical current practice in mining operations, when monitoring and reporting on sensor data streams, is directly counter to this prime organizational directive. Talented technical staff spend much of their time manually compiling the data from discrete groups of sensor types, as well as comparing and analyzing this data with existing systems that are looking to extract useful and relevant information. Reports are compiled manually and then shared with on-site mine staff and external stakeholders through email and other communication channels. Fairly often, they also end up performing the laborious IT work of installing, checking, repairing, and attending to remote-connected sensors and their data streams.

It is tedious and detailed work, and it cannot be assigned to non-technical staff. "This work has to be done by engineers, and it's very much a scrape and sever approach, where you're literally scraping the data and then severing the connection," says Alex Pienaar, senior director of Infrastructure IoT sales at Bentley Systems. "The data is so disparate and fractured as it arrives from many different types of sensors that it requires an expert eye to 'decode' it, understand it, and make sure everything makes sense from a consolidated timeline perspective. If you require additional metrics or data, the whole data wrangling process starts from scratch."

Infrastructure IoT solutions build an “internet of mine sensors” and can immediately reduce or eliminate engineer time spent on these tedious tasks. They do this in several ways, including by:

- Providing a single interface to all sensor data streams and all data reporting. This interface must be intuitive and highly visual with all the expected features of modern applications, including easily customized user profiles, dashboards, smartphone applications, secure access and distribution, and cloud implementation.
- Automating data compilation. This is an important one, according to Pienaar. “Instead of wrangling data from disparate sensor clusters, manufactured in different eras and doing different things, it’s huge to have a single application to gather all these data points into a cohesive view,” he said. “In one stroke, it saves engineers hours and hours of finicky monitoring work.”
- Automating and customizing reporting. “A lot of time is spent just in reporting,” said Pienaar. “We have documented, specific use cases where a client was spending a full week putting together their monthly report—leaving them just three weeks to do their actual monthly work!” With Infrastructure IoT solutions, after setup and customization of desired reports, all that week of work and meetings is easily reduced to an hour or so of button clicking, review, and automated publication to relevant staff and consultants.



A comprehensive Infrastructure IoT solution eliminates the engineer-intensive time currently spent cleaning up datasets and databases, compiling spreadsheets and exporting CSV files, updating subsidiary software, reporting and presenting, and monitoring. Even when only considered in staff time saved, these automated solutions are an investment offering immediate and substantial value.

By reducing engineer time spent on tedious tasks, time is freed up for more meaningful and valuable data analysis, and an Infrastructure IoT solution enables powerful ways to do that analysis. Technical staff can, for example, quickly develop custom reports that explore the new wealth of data available, analyze that data more deeply than previously possible for relevant findings that make a real difference in mine operations, and distribute those findings clearly and securely. Dashboards can be created to automatically monitor and report on sensor clusters that were previously checked rarely and reactively, while proactive alerting protocols can be implemented in a morning to automatically propagate important information to remote sites and smartphones. Powerful sensor monitoring, management, analysis, and automation are mining operation management capabilities that leverage sensor data to greatly extend the reach and knowledge of engineering staff.

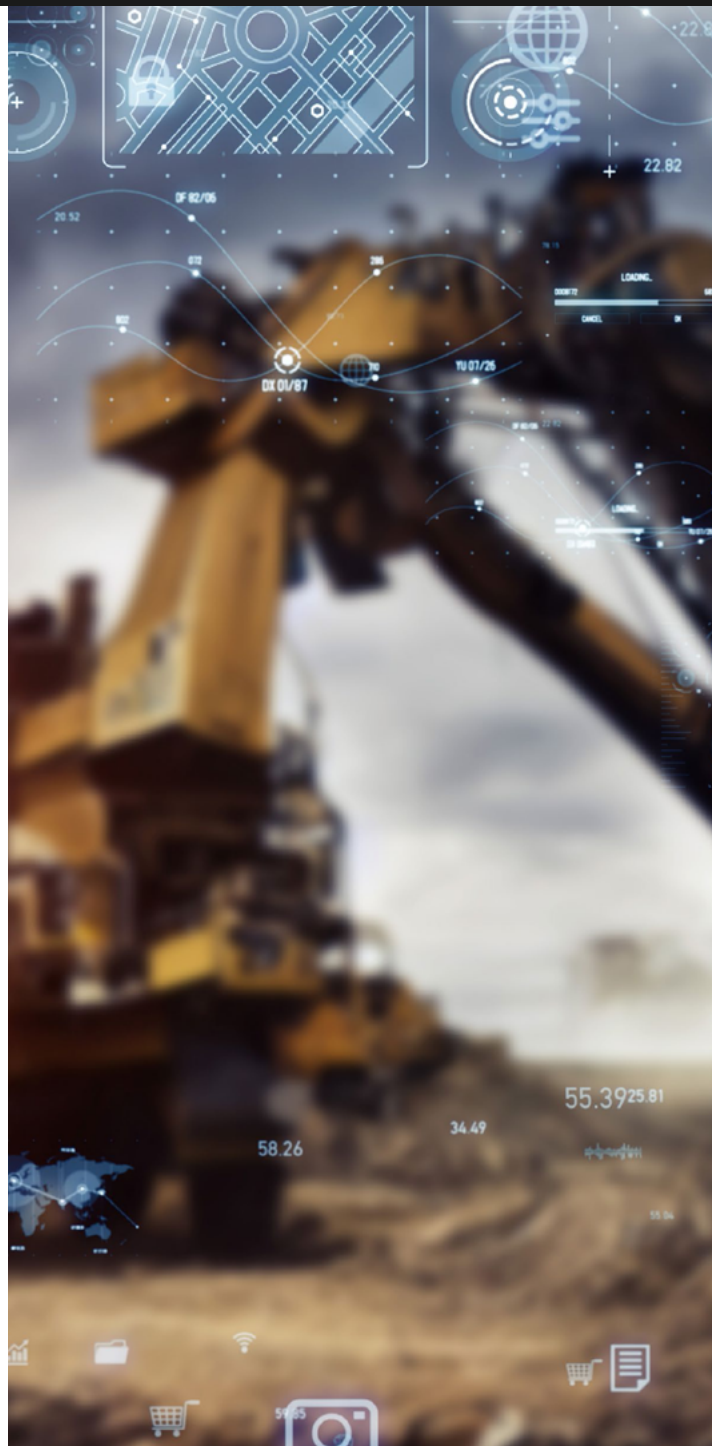


Image courtesy of Schnabel Engineering

2 Make Crucial Data Visible

Schnabel Engineering is a large consulting firm with a specialty in geotechnical, dam, mine, and tunnel engineering services. Leveraging and monitoring sensor installations in mine sites has been a focus in recent years, and many lessons have been learned by Schnabel designers and mine site operators. "For one thing, we're all realizing the value in real-time data," said Senior Engineer Johanna Simon, an instrumentation specialist at Schnabel Engineering. "And since it's easier to collect, access, and visualize the real-time data now, mines are willing to install more sensors."

Simon said that the newly available real-time data visibility is attractive to mine operators because "It allows them to make decisions as things are happening rather than reactive decisions once they collect and process quarterly readings," he said. "Historically, sensor data is typically gathered quarterly, even if it's via a data logger with hourly readings, because the data logger is only downloaded once a quarter, or less often. With a monitoring platform implemented, mine staff and Schnabel, as their engineering support, can log in whenever they feel like it from the safety of their internet-connected location. When needed, they can make system changes, such as increasing the frequency of readings to track critical conditions. This might include a forecasted rainstorm or a hurricane when the mine owner might say, 'You know what? It's raining really hard right now, and it's very windy. I want readings every five minutes instead of once an hour.' And with the Bentley monitoring platform, they have the flexibility to do that easily, while the storm is happening, allowing them to make risk-informed real-time decisions based on the most current data."

The key is implementation of a solid Infrastructure IoT solution that wirelessly connects, gathers, and analyzes clusters of discrete sensor data streams, as well as automatically makes data trends visible in real time with alerts, dashboards, and reports.

"In mines, and even beyond mines, we've reached the point where cloud-based sensor data access and near real-time measurement are so reliable that now, people are saying that there is a large variety of robust measurement devices available, and web-based platforms are reliable and bring huge value," said Allen Cadden, principal at Schnabel Engineering. "Further, automated systems also allow us to capture data in remote locations without exposing our field personnel to difficult conditions, thus making our safety managers happier. So, it's time to support our field and office staff with data to help them make better data-driven decisions and be more successful.

"We love the fact that with the great platforms like Bentley—sensors can just be plugged in, and everything works easily," he said. "It's true that sensors themselves have gotten more reliable but, crucially, the platforms are also easier to use and much more reliable."

One Schnabel project involved the installation of a Bentley Infrastructure IoT platform at a legacy mineral mine. "It's closed now, and being managed with a skeleton crew," said Cadden. "Not a lot of people, and not constantly, but they still have serious environmental concerns and criteria to measure." The initial sensor installation was basic. "They started with a weather station because they were really interested in how much rainfall they were seeing at the site," said Simon. "And then, from the weather station, they expanded to add vibrating wire piezometers in what had previously been open standpipe piezometers. The installation replaced the need to make regular trips around the site to obtain manual water level readings at all of these open standpipe locations."

Image courtesy of Schnabel Engineering

Image courtesy of Schnabel Engineering

Manual data collection was useful, but it was also tedious to gather and analyze. After a sensor monitoring platform was implemented, mine staff learned that they could gather and correlate the weather station and piezometer data continuously and this newly visible, real-time data stream proved to be enormously helpful for day-to-day decision-making. Therefore, the mine decided to install more sensors and get more data. "They were impressed with how they could correlate the existing data streams, and the data told a story," said Cadden. "From there, they added additional piezometers. They've also added flow meters on some of their pipes, as well as flow detectors in their weirs, which helps them monitor outflow and maintain water levels to meet environmental requirements.

> We're starting to think of monitoring platforms as asset management tools. Being able to understand how assets are performing in real time allows us to continually optimize their performance, manage risks, and avoid downtime or challenges.
>
> *Allen Cadden, Principal, Schnabel Engineering*

3 Adapt to a Changing Workforce

Mine managers and mining industry executives understand that the mining industry workforce is under pressure from three trends.

Steady Growth in Mine Employment

384+ **new mines** need built globally to meet demand by 2035[2]

80–120K **Canadian mine workers** must enter the workforce by 2030[5]

11–13K **jobs per year** expected to be added to mining over the next 20 years[1]

36K **job vacancies** in the U.S. mining sector in April 2023, up from 27,000 in 2022[1]

4% **growth** in mining and geological engineering employment from 2019-2029[3]

Aging Mining Workforce

50%+ **of the U.S. mining workforce** is expected to retire by 2029[1]

221K **U.S. mine workers** are expected to retire in the next 10 years[1]

46 **the average age** of U.S. mine workers[5]

20% **of workers** in the mining, oil and gas industry are over 55+ years old[3]

[1] *Society for Mining, Metallurgy & Exploration*
[2] *Benchmark Mineral Intelligence*
[3] *U.S. Bureau of Labor Statistics*
[4] *McKinsey Survey of Mining Senior Leaders and Executives, 2022*
[5] *Deloitte, "Tracking the trends 2023: The indispensable role of mining and metals"*

Difficulty Attracting Workers

71% **of mining leaders** say they are experiencing a talent shortage[4]

86% **of mining executives** say it's more difficult to recruit and retain talent than it was 2 years ago[4]

42% **of 15 to 30 year-olds** said they "definitely wouldn't" work in mining[4]

39% **decline in mining graduations** in the U.S. since 2016[4]

63% **decline in mining engineering** enrollment in Australia since 2014[4]

We see strong projected growth in the need for skilled mine workers alongside these two worrisome workforce trends: skilled workers aging out and leaving the industry, and far fewer younger workers, particularly mining engineers, entering the industry.

Fortunately, comprehensive Infrastructure IoT solutions can help mitigate these worrisome trends in a few important ways.

The skills of experienced technical staff are significantly leveraged when digital applications enhance their abilities to extract and analyze sensor data. It provides opportunities to learn new skills and reduces the time spent performing tedious and repetitive tasks, allowing for a more gratifying work experience.

This situation applies to younger workers as well, especially as they are of a generation conditioned to expect intuitive interfaces and powerful, automated data-analysis solutions. The new generation of mining engineers and technical staff grew up with combinatorial explosion. With phones, movies, TV, games, and music around them, they are conditioned to life in an ocean of analyzed data remaking their lives in real time—why not take advantage of that?

One consequence of this very different upbringing is that younger workers expect to work in different ways. A Mining International article said, "To be brutally honest, many of today's [...] up-and-coming generation of professionals have been brought up in a world where most things can be provided at the touch of a few buttons and a bit of technological wizardry. The world of remote locations, long hours, and the ever-present knowledge that you could lose your job when the next bust comes along is not a welcoming one."

As the world learned during the pandemic, working from home is becoming commonplace. Organizations that allow and enable more remote activities will be more appealing to a broader applicant audience.

Infrastructure IoT solutions, whether implemented on-premises or through cloud services, that enable remote monitoring, managing, and analysis of sensor data are an important part of the enterprise solutions of companies as they adapt to workforce changes. By enabling remote monitoring of sensor clusters and networks, as well as in-depth analysis and reporting by skilled specialists included in globally distributed teams, Infrastructure IoT makes skilled mining jobs more attractive to the younger generations of the mining workforce.

Bentley Infrastructure IoT

Exponential growth and combinatorial explosion are consequences of the computer revolution and the Information Age. They affect all industries, not just the mining sector. Nevertheless, mine operators face unusual challenges when dealing with the vast new data and information resources resulting from the Internet of Mine Sensors. The mining industry has a responsibility to mine this intangible new resource and extract operational insights that will improve the mining and extraction of all the tangible assets that sustain civilization itself.

Bentley Systems' Infrastructure IoT solutions use matched data transparency and state-of-the-art visualization and analytical capabilities that turn sensor data from any mine into gold. These powerful and valuable insights can streamline operations, make risk-informed decisions, and improve critical infrastructure.

About Bentley Systems

Bentley Systems (Nasdaq: BSY) is the *infrastructure engineering software* company. We provide innovative software to advance the world's infrastructure – sustaining both the global economy and environment. Our industry-leading software solutions are used by professionals, and organizations of every size, for the design, construction, and operations of roads and bridges, rail and transit, water and wastewater, public works and utilities, buildings and campuses, mining, and industrial facilities. Our offerings, powered by the *iTwin*® Platform for infrastructure digital twins, include *MicroStation*® and *Bentley Open*™ applications for modeling and simulation, *Seequent*®'s software for geoprofessionals, and *Bentley Infrastructure Cloud*™ encompassing *ProjectWise*® for project delivery, *SYNCHRO*™ for construction management, and *AssetWise*® for asset operations. Bentley Systems' 5,200 colleagues generate annual revenues of more than $1 billion in 194 countries.

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