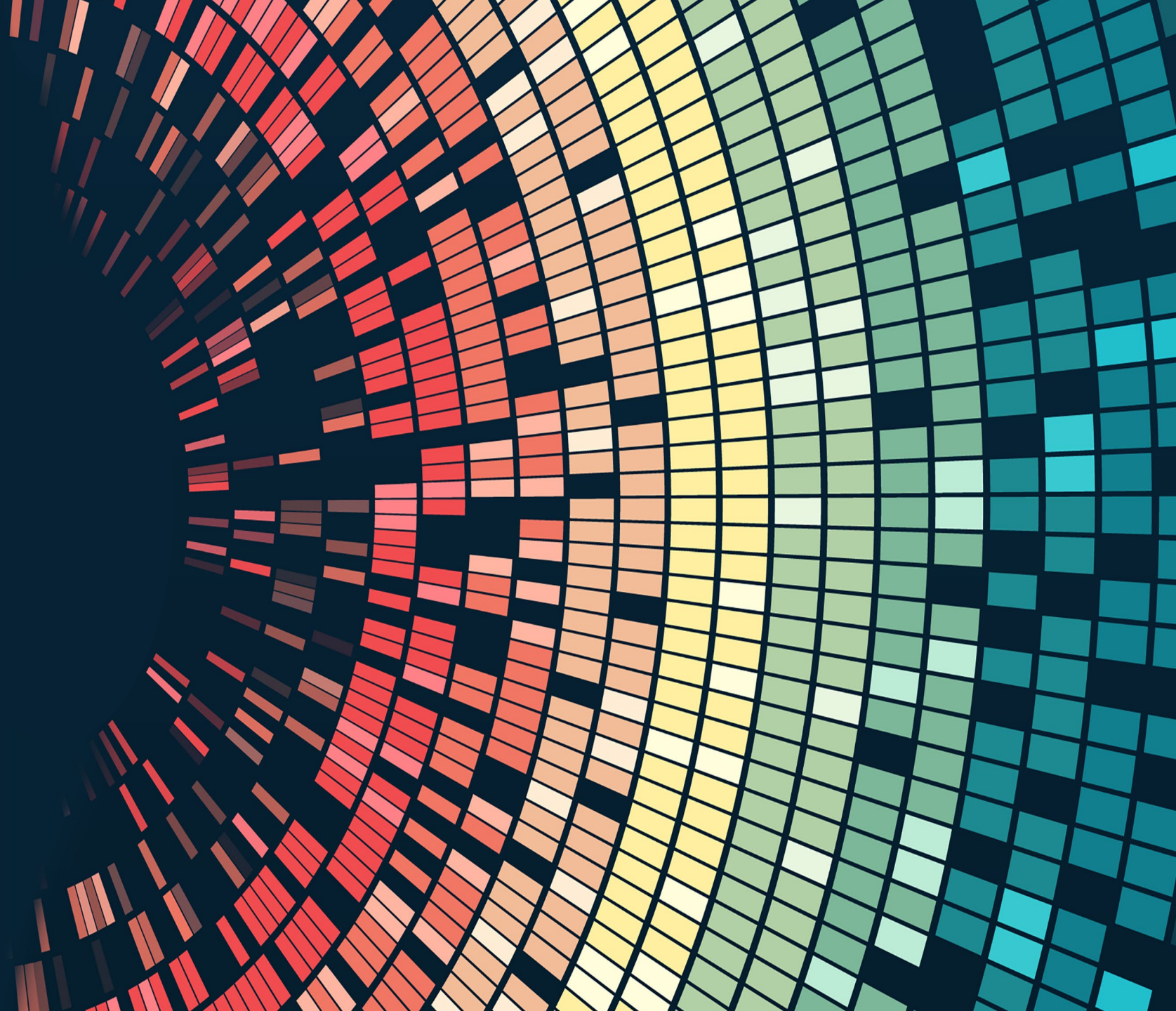
2023

Condition Monitoring Report

Trends in monitoring technology for built and natural environments



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Introduction

This report provides a global snapshot of condition monitoring and how organizations drive value through automation and digitization, along with the challenges they face. This timely analysis provides actionable insights to help both end users and service providers identify opportunities in 2023 and beyond.

Companies that build or service large infrastructure installations such as dams, mines, and transportation facilities must monitor the conditions within—and surrounding—those installations to look for signs of possible structural failure or environmental degradation. In today's world, where both regulators and the public are paying closer attention to safety and the environment, automated, real-time measurement and management are critical.

To understand current and future condition monitoring trends and practices among both service providers and asset owners, Bentley Systems commissioned ThoughtLab to conduct a **global survey of 500 companies** in the first quarter of 2023. Survey respondents included a mix of **C-suite executives** and other senior managers, as well as technical managers and technical staff knowledgeable about condition monitoring in their organizations. These executives worked in **six sectors across five countries**. Company sizes ranged from under 100 employees to over 1,000.

The study found that automation of condition monitoring is growing as companies embrace connected sensor technology that reduces the need for frequent manual sampling. By moving to automated monitoring, organizations can increase the scope of their monitoring activities, track more parameters, integrate data with other sources, build transparency, and monitor trends in real time. However, some organizations may see challenges in implementation around a lack of skills and knowledge, as well as technology limitations.

For companies that overcome these challenges, the rewards can be high, with some organizations citing returns of over USD 1 million.

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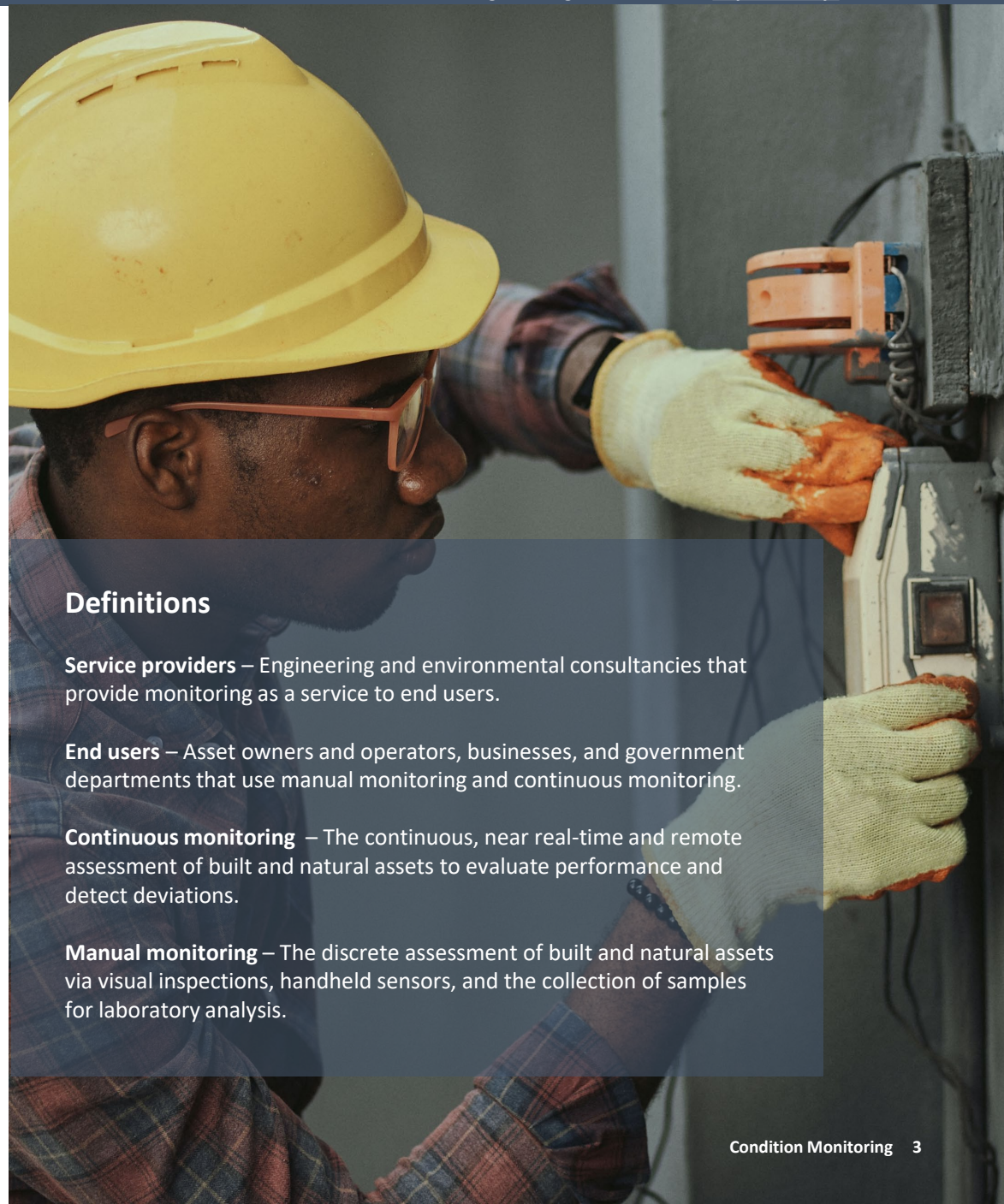


Definitions

Service providers – Engineering and environmental consultancies that provide monitoring as a service to end users.

End users – Asset owners and operators, businesses, and government departments that use manual monitoring and continuous monitoring.

Continuous monitoring – The continuous, near real-time and remote assessment of built and natural assets to evaluate performance and detect deviations.

Manual monitoring – The discrete assessment of built and natural assets via visual inspections, handheld sensors, and the collection of samples for laboratory analysis.

Condition monitoring techniques in this report

Discrete monitoring

Visual Inspections

Handheld Sensors

Sampling and Lab Analysis

Time-based monitoring (Delayed real-time)

Local sensors and data with periodic manual download

Disparately located sensors, time-based program

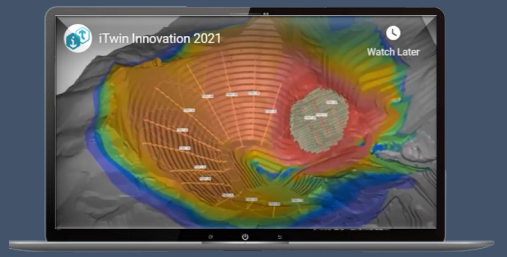
Must physically visit the device for batch upload of readings

Real-time continuous monitoring (using IoT)

Condition-based, continuously active, real-time cloud connected (geo-referenced) surveillance and early identification

Image Courtesy of Yuba Water Agency

Remote sensing



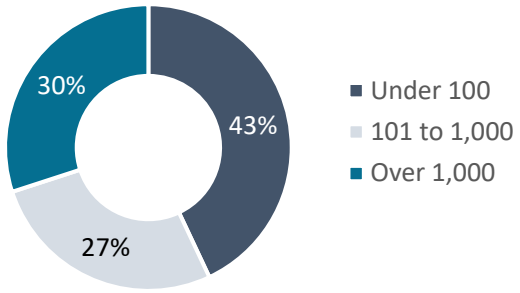
Snapshot in time comparisons from high fidelity reality mesh (from drones, satellite, point clouds, terrestrial sources)

Research background

Survey sample profile

The 500 survey respondents represent a cross section of titles, industries, countries, and employee size. Executives were divided into three groups: C-suite/general senior management, technical management, and technical staff.

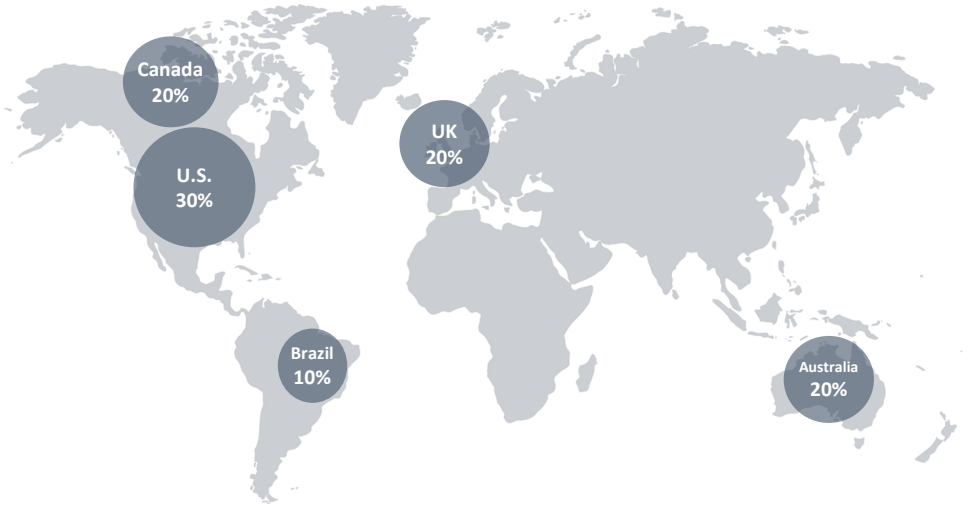
Respondents by number of employees



1,213

Average number of employees

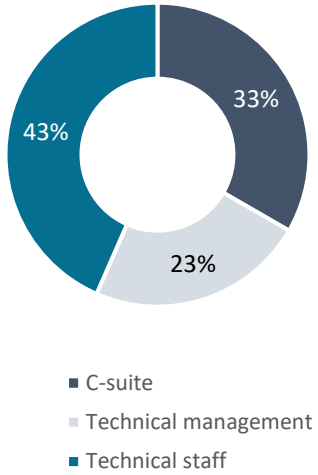
Respondents by country



Respondents by industry

End users				Service providers	
Mines 13%	Private/public development 13%	Transport. 13%	Dams 12%	Environmental services 25%	Infrastructure engineering/design 25%

Respondents by title



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Defining maturity in condition monitoring

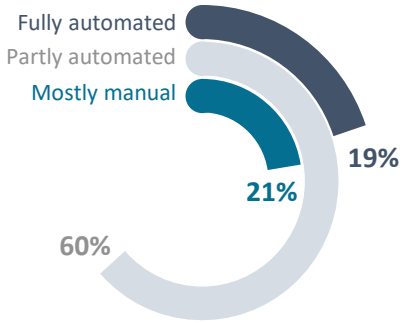
To analyze organizations' progress in automating condition monitoring, we created a maturity framework based on the question:

What percentage of your organization's monitoring is manual?

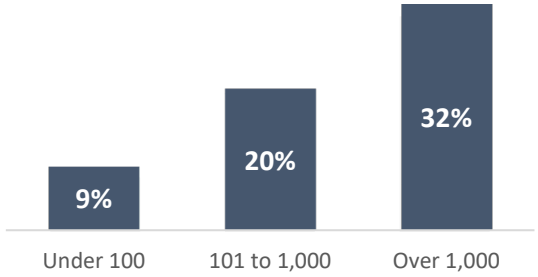
- **Fully automated:** Organizations that fully automate their condition monitoring
- **Partly automated:** Organizations that are 50% or more automated
- **Mostly manual:** Organizations with over 50% manual condition monitoring

Fully automated firms are more likely to be those with over 1,000 employees, while mostly manual businesses tend to have fewer than 100 employees. Dam operators have the largest percentage of fully automated companies and environmental services firms have the smallest percentage.

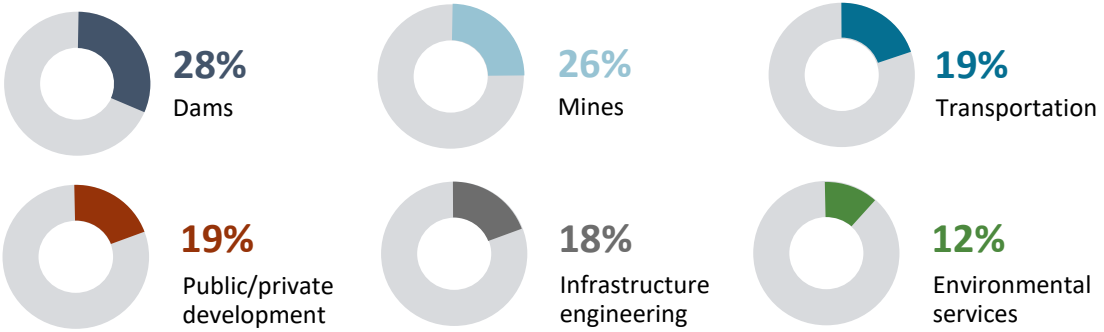
Automation maturity



Fully automated organizations by employee size



Fully automated organizations by industry



Current data practices

Organizations monitor a wide range of data…

Organizations most often monitor air quality, vibration, ground and surface water, and structural data. Environmental services firms, mining firms, and dam operators monitor the most types of data, while transportation and private/public development organizations monitor the least.

The factors that industries monitor vary. Dam operators are more apt to monitor groundwater, vibrations, and geotechnical elements than others, but few monitor air quality or noise. Similarly, private/public organizations are more likely to monitor structural data and soil than others, as they are mindful of public safety and pollution. Environmental services and transportation groups are more likely to track noise.

Sensor data monitored by all organizations

Air quality	70%	Noise	52%
Vibration	69%	Geotechnical	45%
Groundwater	64%	Soil	41%
Structural	63%	Geospatial	36%
Meteorological	59%	Metocean	19%
Surface water	59%		

Q7. What are you monitoring?

Sensor data monitored by industry

	Service providers		End users			
	Environ. services	Infrastructure engineering	Dams	Mines	Private/ public	Transport
Air quality	94%	86%	10%	92%	52%	40%
Vibration	78%	64%	86%	76%	56%	48%
Groundwater	85%	33%	93%	82%	59%	48%
Structural	14%	86%	67%	76%	81%	76%
Meteorological	60%	63%	81%	62%	41%	44%
Surface water	86%	33%	91%	39%	59%	48%
Noise	85%	45%	12%	50%	30%	60%
Geotechnical	45%	43%	86%	47%	32%	24%
Soil	21%	38%	22%	58%	70%	59%
Geospatial	34%	33%	53%	55%	27%	21%
Metocean	26%	11%	24%	23%	11%	16%

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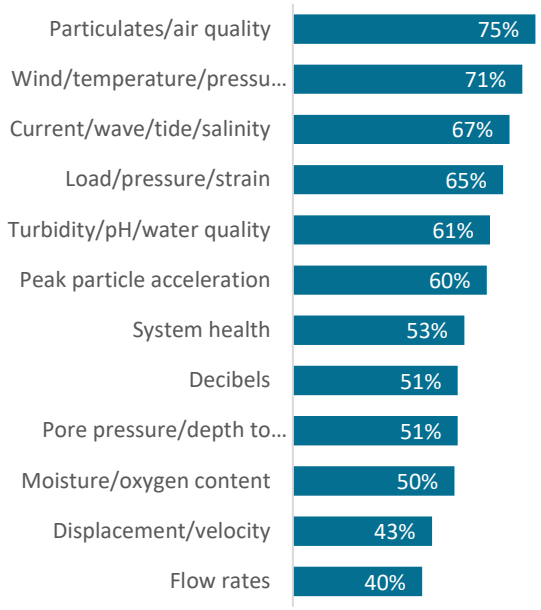
…and a growing number of parameters

Over the last two years, 34% of companies have upped the number of parameters they monitor. The top parameters that organizations now track are particulates and air quality (75%), closely followed by wind, temperature, and pressure (71%). But there are wide variations by industry.

For dam operators, water-related parameters are paramount, especially turbidity, pH, and water quality, which 100% measure. Nearly all measure pore pressure and flow rates. Conversely, very few dam operators monitor particulates and air quality (12%), the top parameter for mines (98%) and environmental services firms (97%).

Because of the wide range of infrastructure areas that they cover—from water and energy to buildings and construction—environmental services firms monitor the most parameters overall. Dam and mines are close behind. Transportation and private/public organizations monitor the fewest number of parameters.

Main parameters monitored by all



Number of parameters over last 2 years

Main parameters monitored by industry

	Service providers		End users			
	Environ. services	Infrastructure engineering	Dams	Mines	Private/ public	Transport
Particulates/air quality	97%	86%	12%	98%	59%	56%
Wind/temperature	84%	69%	76%	76%	54%	57%
Current/wave/tide/salinity	86%	43%	95%*	67%	62%	59%
Load/pressure/strain	68%	60%	79%	77%	56%	54%
Turbidity/pH	82%	45%	100%	70%	41%	24%
Peak particle acceleration	76%	49%	79%	76%	40%	35%
System health	47%	68%	38%	61%	54%	41%
Noise level	80%	46%	12%	50%	30%	60%
Pore pressure/depth	45%	38%	98%	64%	49%	35%
Moisture/oxygen	76%	40%	59%	50%	27%	30%
Displacement/velocity	31%	46%	62%	53%	37%	41%
Flow rates	48%	22%	91%	30%	37%	29%
Average number tracked	8.2	6.1	8.0	7.7	5.5	5.2

* 95% of dam operators monitor at least one of these four parameters: current, wave, tide, or salinity.

Q: What are the main parameters that your organization currently monitor?

Organizations integrate other data into their analyses…

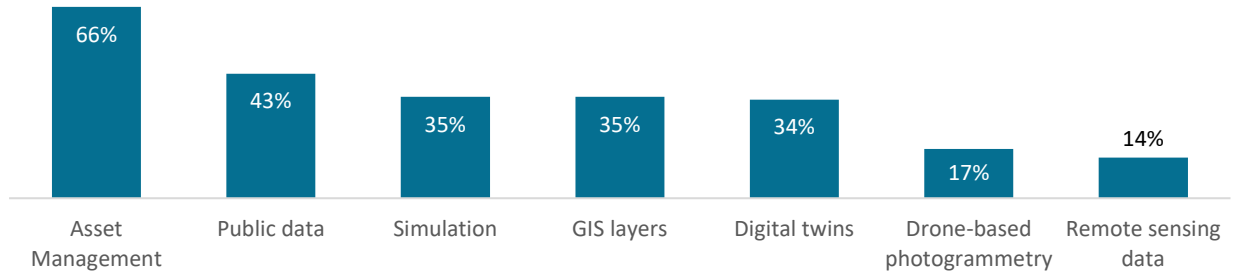
Organizations not only monitor a growing range of parameters, but they also combine that data with information from other sources to gain deeper insights. For example, two-thirds of companies integrate sensor data with input from their asset management systems. Four out of 10 combine collected data with information from public sources. Slightly fewer integrate it with geographic data from GIS layers.

The mix of external and internal data varies by industry. Environmental services and private/public development organizations, for example, are more likely to draw on data from asset management systems, while dams are most apt to include public and government data (60%).

Increasingly, organizations will incorporate these data sets into digital twins to take condition monitoring to a higher level. Digital twins provide organizations with a more sophisticated and holistic view of conditions and trends, with the ability to conduct forecasting and what-if scenario analysis.

Currently, dam and mine operators integrate the greatest variety of outside information sources, and they—along with private-public development organizations—are also more apt to integrate their data into digital twins.

Additional information sources integrated with sensor data, all organizations



By industry

	Service Providers		End Users			
	Environmental services	Infrastructure engineering	Dams	Mines	Private/ public	Transport
Asset management systems	72%	67%	62%	55%	71%	65%
Public or government data	42%	34%	60%	42%	35%	51%
GIS layers	26%	39%	48%	50%	32%	22%
Simulation or predictive models	40%	26%	38%	30%	38%	40%
Digital twins	22%	25%	45%	44%	49%	37%
Drone-based photogrammetry	4%	22%	16%	26%	24%	16%
Remote sensing data	10%	13%	16%	23%	13%	16%
Average number integrated	2.16	2.26	2.85	2.7	2.62	2.47

Q: Are you currently integrating sensor data with additional information sources to increase insights for your organization? If so, which apply?

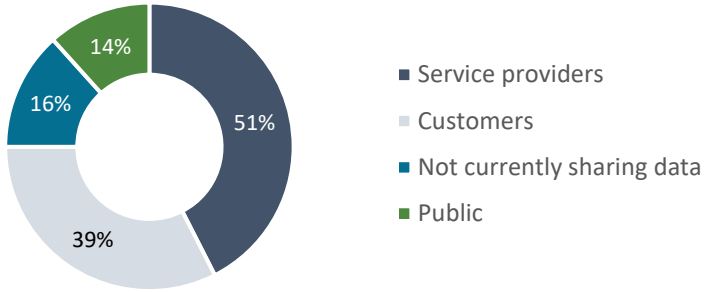
...and share data with different stakeholders

Half of the organizations surveyed share data with service providers, more than with any other stakeholder. By sharing their data with providers, they can benefit from providers' knowledge and experience in identifying potential equipment, structural, or environmental issues before they cause problems. They can also make sense of large amounts of condition monitoring data and provide improved performance.

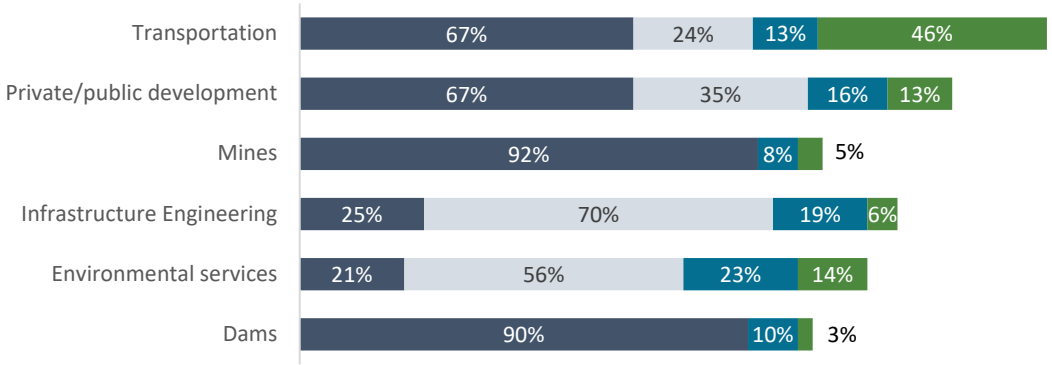
Some organizations are also sharing their data with customers (39%) and the public (14%). Sixteen percent of companies do not currently share their data.

Industries show different profiles for their data sharing. Dam and mine operators almost exclusively share their data with service providers, and they do not share data with customers at all. A relatively large number of organizations in environmental services and infrastructure engineering do not share data at all. Transportation organizations are the most likely to share their data with the public.

Percent that share condition monitoring data with different recipients



Percent that share condition monitoring data by industry



Q: Are you currently sharing your monitoring data? If so, with whom?

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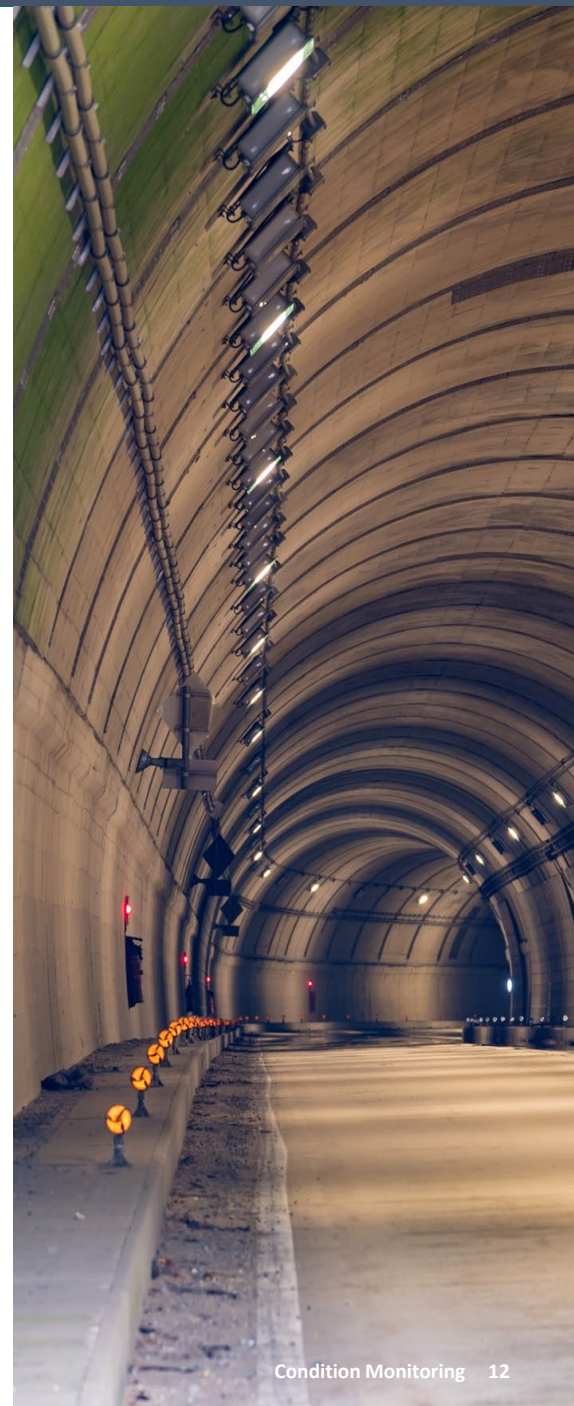


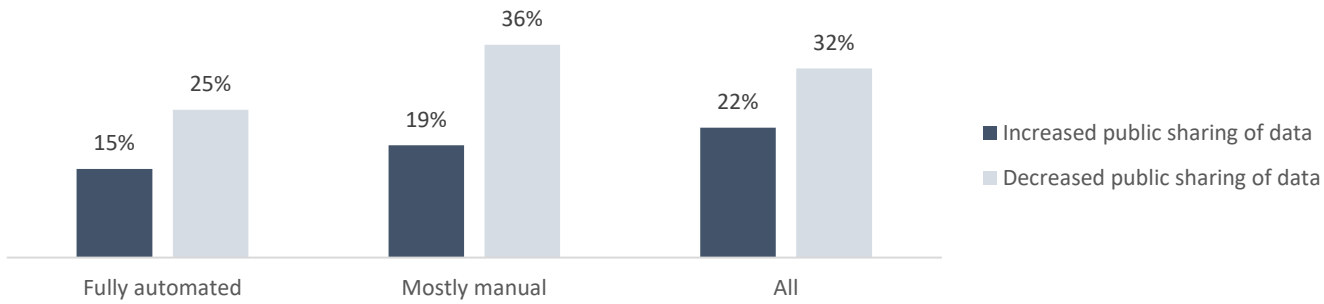
But sharing data with the public is falling. Why?

Our research uncovered a surprising finding: over the last two years, organizations have reduced the amount of data they share with the public—regardless of their degree of automation. One-quarter of fully automated firms decreased the amount of data shared with the public, and only 15% increased it. Similarly, 36% of mostly manual companies decreased the data shared with the public, while only 19% increased it.

This raises the question: why is the public sharing of data falling when data management is improving?

There could be several reasons: confidentiality of information, privacy concerns, legal obligations, worries about quality of data, and resource limitations. But as regulators, investors, customers, and communities push for greater disclosure of environmental data, organizations will want to take steps to ensure the quality of the condition monitoring data that will need to be reported publicly.

Percent increasing or decreasing public sharing of data by maturity



Q: How have the following monitoring practices at your organization changed over the last two years?

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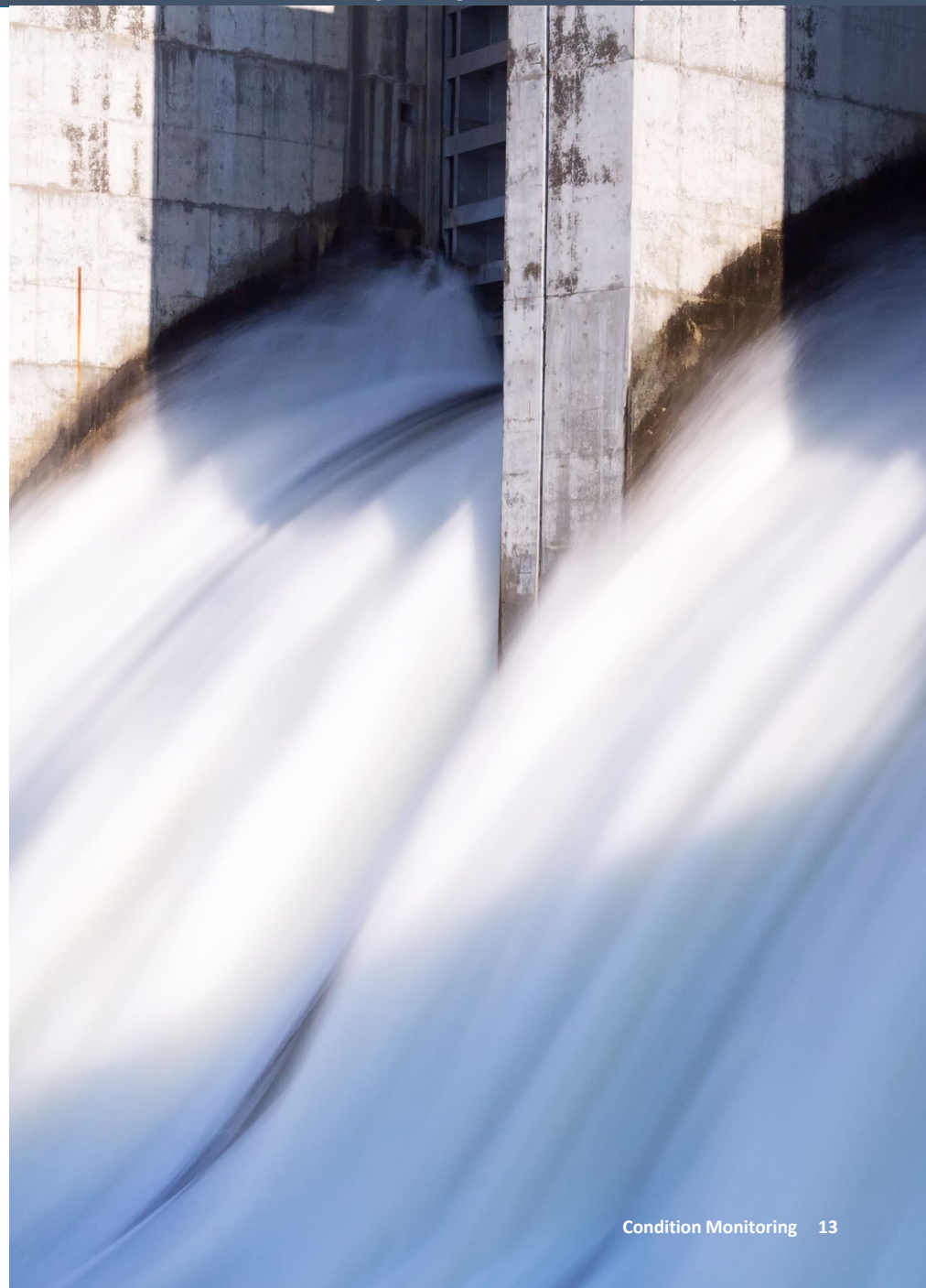


Condition monitoring methods

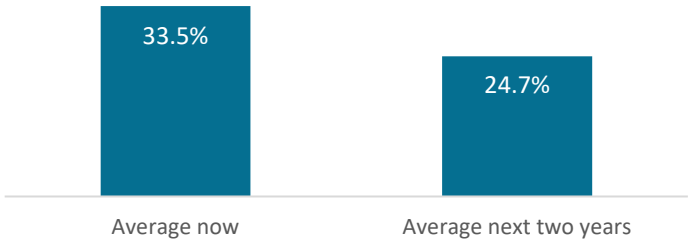
Organizations are reducing manual monitoring

More than two out of 10 organizations reduced manual monitoring over the last two years. Currently, about one-third of total monitoring is manual, and by 2025, that percentage will fall to just under a quarter.

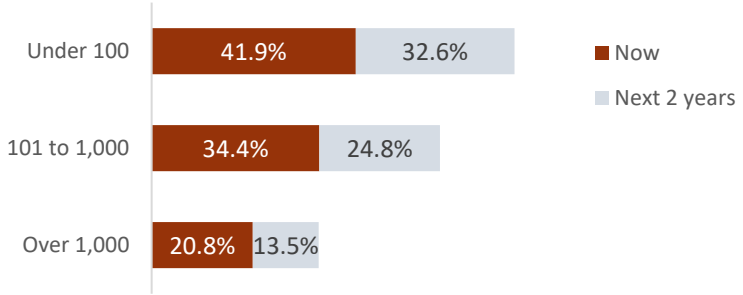
This trend is consistent across industries. In fact, nearly all sectors are shrinking the percentage of manual monitoring by a similar proportion. The standouts are dam operators, which have already reduced the share of manual monitoring they do to 26% and plan to cut it to just over 19% over the next two years.

Organizations with fewer than 100 employees depend more on manual methods now and will continue to do so in the future. Organizations with more than 1,000 employees will be conducting only 13.5% of their monitoring manually by 2025.

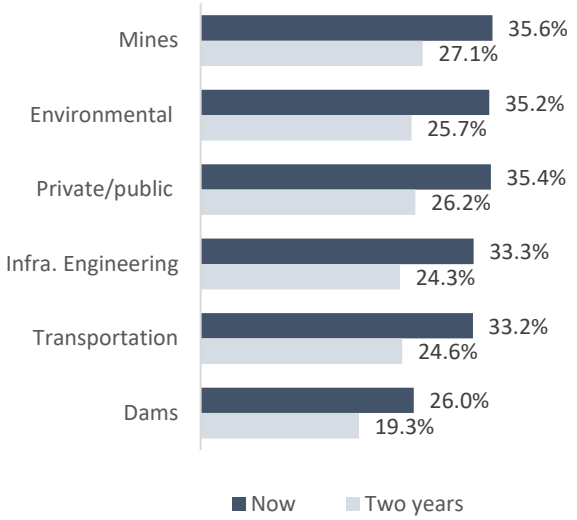
Percent of monitoring that is manual, all organizations



Percent of monitoring that is manual by employee size



Percent of monitoring that is manual by industry



How use of manual monitoring changed over last two years

Q: What percentage of your organization's monitoring is manual? Q12. What percentage of your organization's monitoring do you expect to still be manual in two years?

Real-time monitoring is on the rise

Over the last two years, companies have not only reduced the percentage of monitoring done manually, but 25% also have expanded their use of real-time monitoring.

While 81% of organizations still rely at least partly on manual sample collection, many are now using other more digitally advanced techniques to monitor conditions. Indeed, 68% now use in-situ measurement with hand-held sensors, and 67% do continuous monitoring with sensors for manual download. Additionally, 48% continuously monitor with sensors and near-real-time transmission via telemetry, and 27% use automated sample collection for lab analysis.

The shift to digital measurement methods presents an opportunity for both service providers and end users. Service providers can bridge skills gaps by providing new high-value service offerings to their customers. Similarly, end users stand to realize operational efficiencies, reduce downtime, and avoid catastrophic asset failure.

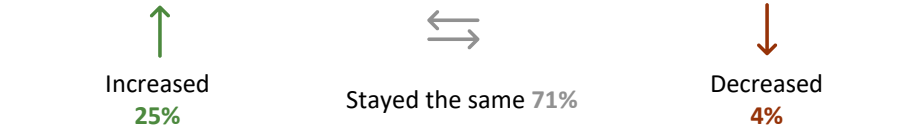
The transition to digital monitoring is occurring at different speeds depending on the sector. Dam operators lead now with 38% automated sampling (vs. 27% for all sectors). They also outpace other sectors in continuous sensor monitoring with near-real-time transmission (67% vs. 48% of all sectors). However, the environmental services sector lags, with 18% using automated sample collection (vs. 27% of all sectors) and 88% still doing some form of manual sampling (vs. 81% of all sectors).

Q: What type of monitoring do you do?

Type of monitoring done by all and by industry

		Service providers		End users			
	All	Environmental services	Infra. eng.	Dams	Mines	Private /public	Transp.
Manual sample collection for laboratory analysis	81%	88%	82%	72%	74%	81%	81%
In-situ measurement with hand-held sensors	68%	62%	67%	86%	61%	67%	75%
Continuous monitoring with sensors for manual download from site	67%	62%	66%	78%	61%	67%	78%
Continuous monitoring with sensors with near-real-time telemetry	48%	42%	46%	67%	44%	37%	57%
Automated sample collection for laboratory analysis	27%	18%	25%	38%	33%	29%	29%

How use of real-time monitoring changed over last two years



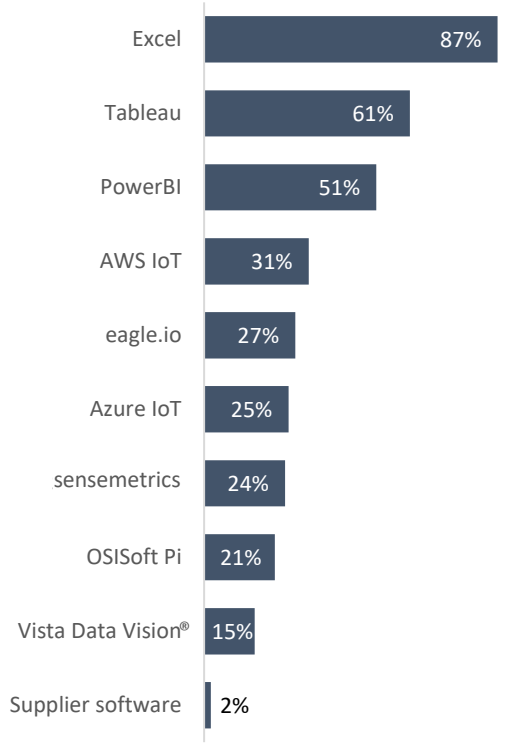
A minority of firms use specialized monitoring software

Most organizations use general purpose programs, such as Excel, Tableau, and PowerBI, to support their condition monitoring activities. These applications are best suited for collating and analyzing static data collected through manual monitoring.

Organizations have added specialized monitoring software to their repertoire. For example, about a quarter of organizations use eagle.io™ and a similar percentage use sensemetrics®. For some sectors, such as dams, the percentages are higher.

Organizations that do continuous monitoring use either generic IoT applications (which require significant customization and development) or specialized condition monitoring software (like eagle.io and sensemetrics). The market share of software tailored to continuous monitoring techniques is expected to grow over the next five to 10 years, in line with the mounting adoption of continuous monitoring.

Organizations' current monitoring software



Organizations' current monitoring software by industry

Service Providers

Environmental services

Excel	90%
Tableau	66%
PowerBI	52%
Vista Data Vision	34%
AWS IoT	31%

Infrastructure engineering

Excel	85%
Tableau	66%
PowerBI	54%
eagle.io	32%
AWS IoT	30%

End Users

Dams

Excel	79%
PowerBI	64%
Tableau	59%
sensemetrics	43%
eagle.io	36%

Mines

Excel	92%
Tableau	55%
PowerBI	44%
AWS IoT	35%
eagle.io	32%

Private/public

Excel	89%
Tableau	60%
PowerBI	49%
sensemetrics	46%
OSISoft Pi	33%

Transportation

Excel	84%
Tableau	54%
eagle.io	51%
PowerBI	41%
AWS IoT	31%

Q: What is your current monitoring software?

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Monitoring capabilities, parameters, and transparency are growing

Over the past two years, more than two-thirds of companies have widened the scope of their monitoring capabilities.

This increase in scope includes monitoring more types of data, adding more advanced sensors, and storing more and bigger datasets in the cloud. It also can involve enhancing analysis with artificial intelligence (AI) and machine learning to enable predictive maintenance.

As part of this overall widening of scope, just over one-third of respondents increased the number of parameters they measure. This increase is no surprise, since a similar number of organizations are boosting their use of real-time monitoring—and commensurately reducing their use of manual methods.

Almost one-quarter of organizations are also widening monitoring transparency to enable better decision-making, collaboration, and accountability. Accordingly, they are taking steps such as utilizing data sharing platforms, providing more frequent reporting, and building open communication channels.

Changes in monitoring practices over the last two years

Scope of monitoring capabilities

Increased	Stayed the same	Decreased
67%	30%	3%

Numbers of parameters measured

Increased	Stayed the same	Decreased
34%	60%	6%

Monitoring transparency

Increased	Stayed the same	Decreased
23%	74%	3%

Q: How have the following monitoring practices at your organization changed over the last two years?

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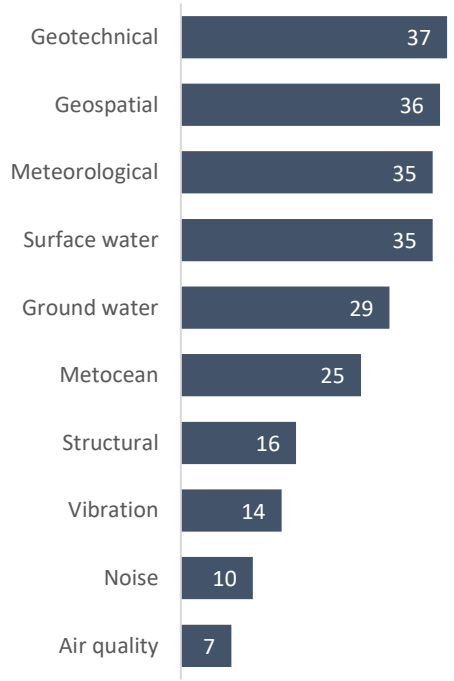
How automated organizations drive value

Track more built and natural systems

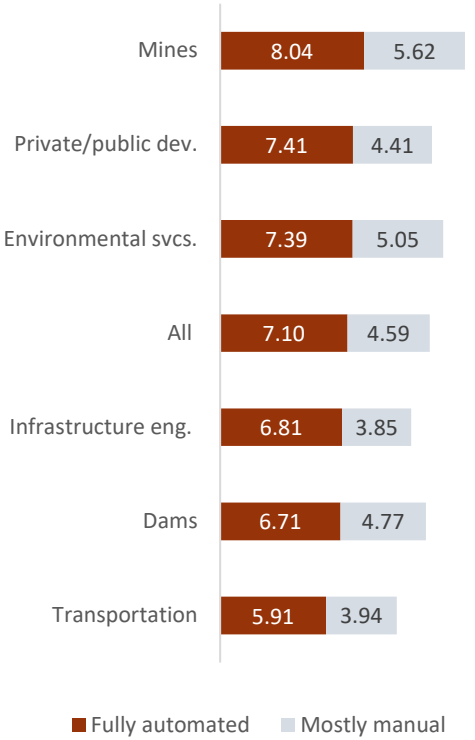
In an era of greater environmental scrutiny, organizations need to monitor a wider spectrum of data. **Companies that fully automate their condition monitoring are already jumping ahead.** On average, they track more than seven factors vs. fewer than five for companies relying on manual processes. Companies that fully automate are much more likely to track geotechnical, geospatial, meteorological, and surface water.

Automation enables organizations in each industry to monitor a broad set of critical factors, including those that are more difficult to track manually, such as vibration. On average, companies that fully automate condition monitoring track two to three more variables than those doing manual analysis.

Percentage point difference in monitoring, fully automated vs. mostly manual



Average number of factors monitored by industry and maturity



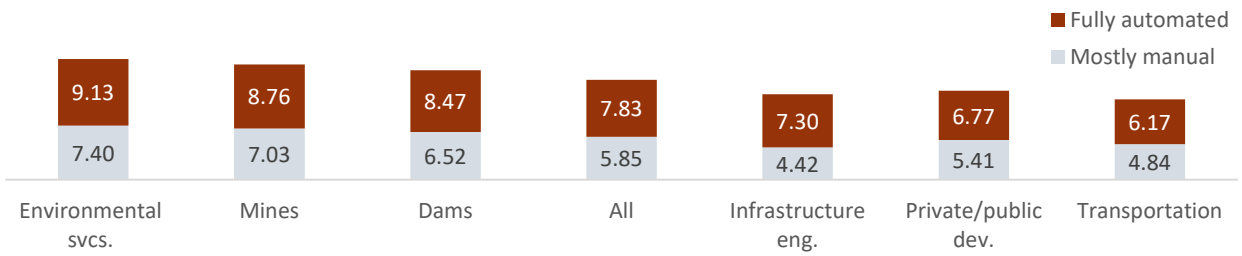
Q: What are you monitoring?

Monitor a richer set of parameters

Thanks to their adoption of digital applications, **fully automated organizations monitor about eight parameters**, while other businesses follow about six. Organizations that fully automate their condition monitoring are far ahead in tracking many key parameters. For example, 77% of fully automated firms monitor turbidity and water quality compared with 49% of mostly manual businesses. Other major gaps between leaders and mostly manual businesses include current/wave/tide/salinity, peak particle acceleration, pore pressure/depth to water, moisture/oxygen content, flow rates, and wind/temperature/pressure/rain/solar coverage.

This more comprehensive coverage of environmental parameters provides fully automated companies with expanded capabilities to meet tightening requirements of regulators and conduct more rigorous analysis. Environmental services firms—which work with clients in varying industries—monitor the most parameters, with fully automated organizations tracking more than nine. Transportation firms monitor the fewest, with fully automated companies covering only about six, while mostly manual businesses track fewer than five.

Average number of parameters monitored by industry and maturity



Q: What are the main parameters that your organization currently monitors?

Parameters monitored by fully automated organizations vs. others

	Fully automated	Mostly manual	Percent point difference
Wind/temperature/pressure/rain	81%	64%	+ 17
Current/wave/tide/salinity	81%	55%	+ 26
Turbidity/pH/water quality	77%	49%	+ 28
Particulates/air quality	77%	71%	+ 6
Peak particle acceleration	68%	56%	+ 12
Load/pressure/depth to water	68%	58%	+ 10
Pore pressure/depth to water	66%	38%	+ 28
Moisture/oxygen content/conductivity	58%	38%	+ 20
System health	57%	48%	+ 9
Flow rates	51%	31%	+ 20
Noise level	51%	42%	+ 9
Displacement/velocity/acceleration/tilt	47%	35%	+ 12

Improve analysis by integrating sensor data with other information

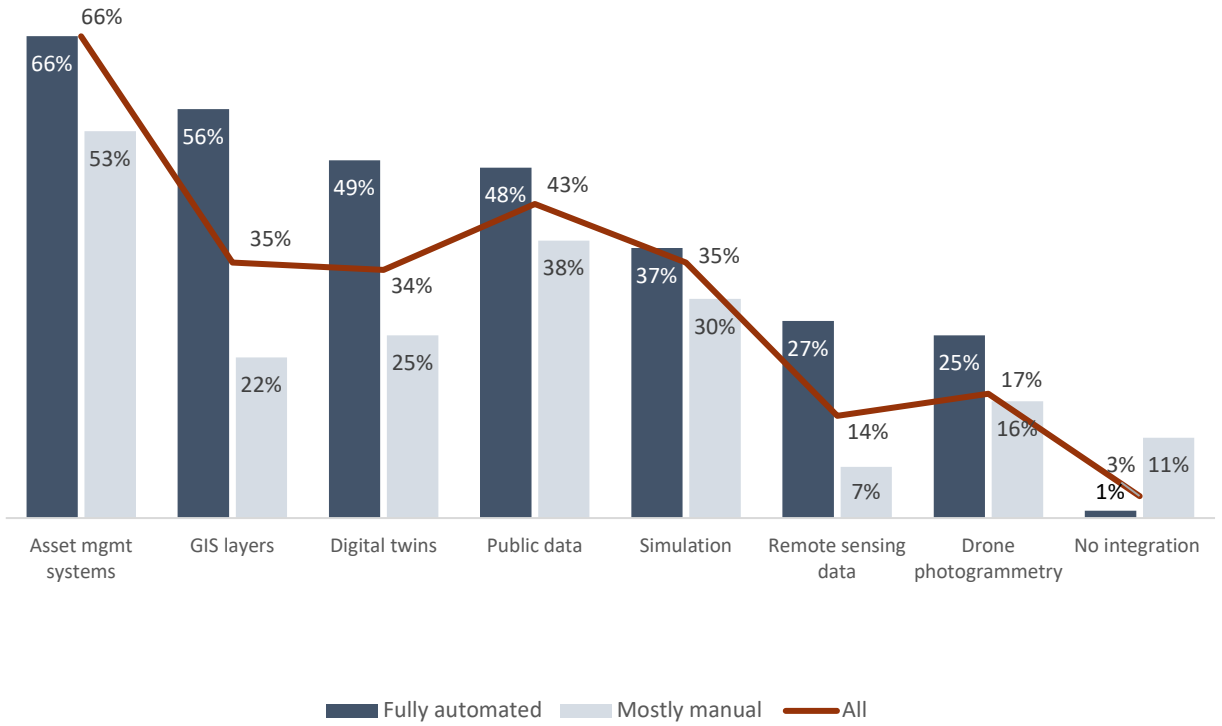
Because their sensor data is digitized, companies with fully automated monitoring methods can more easily integrate it with other information sources. That integration enables companies to get the maximum value from their condition monitoring programs. Here are examples of add-on analytics:

Asset management systems. Two-thirds of fully automated organizations integrate sensor data with information from their asset management systems. As a result, they can analyze their performance with greater accuracy and optimize asset management costs and decisions. Integrated sensor data can help companies manage day-to-day operations more effectively and analyze data in a historical context for scientific purposes.

GIS layers. Organizations with fully automated condition monitoring—particularly those working with dams and mines—are far ahead of others in integrating data from GIS layers. As a result, they have greater access to critical geographic and environmental data in multidimensional, visual formats. This data helps them understand underlying conditions and spot unusual patterns.

Drone-based photogrammetry. Fully automated companies are ahead in integrating data from drone-based photogrammetry. Such information can provide measurements and other data documenting on-the-ground conditions or remote sensing derived from reflected and emitted radiation at a distance. Both can help companies see the big picture or to monitor hard-to-reach areas.

Additional information sources integrated with sensor data by maturity



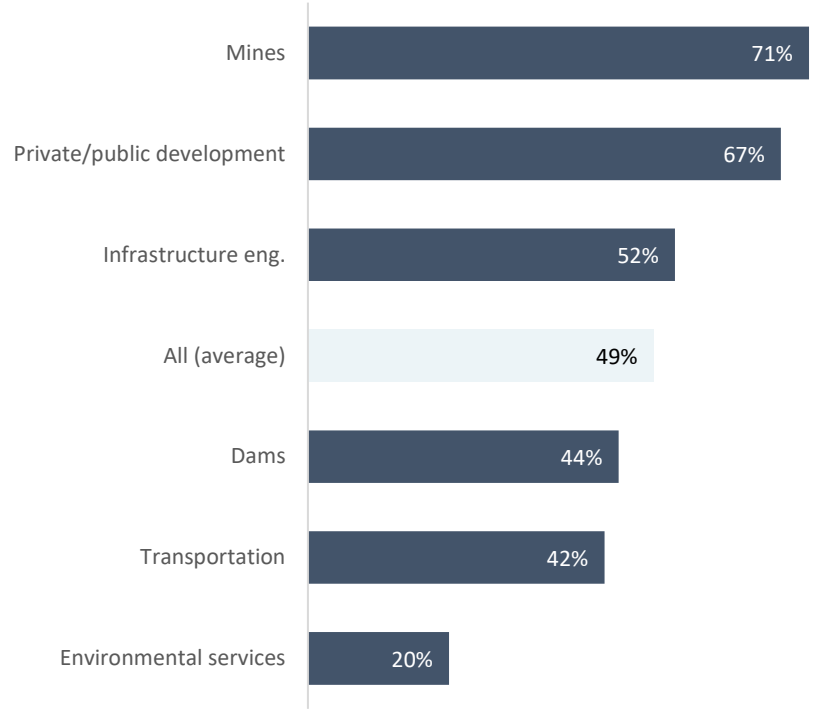
Q: Are you currently integrating sensor data with additional information sources to increase insights for your organization? If so, which apply?

Gain insights from data through digital twins

Companies with fully automated condition monitoring methods are twice as likely as mostly manual businesses to integrate condition monitoring data with digital twins. These advanced capabilities provide virtual models of an asset and set of processes built from real-world data received from sensors or network-connected equipment.

Digital twins are becoming ubiquitous among companies that have adopted fully automated condition monitoring in the mining industry - seven out of 10 report using it. For these firms, digital twins can yield many benefits. They improve mining machinery productivity, bolster employee engagement and development, drive better day-to-day decisions, and test new processes cost effectively. Use of digital twins is also common among fully automated organizations in private/public development for similar reasons.

Percentage of fully automated organizations that integrate digital twins by industry



Q: Are you currently integrating sensor data with additional information sources to increase insights for your organization? If so, which apply?

Draw on specialized software, rather than general capabilities

Organizations that have fully adopted automated condition monitoring use a wider combination of general and specialized software to monitor and analyze data on conditions. On average, these organizations combine about four types of software vs. about 2.5 for mostly manual organizations.

What separates fully automated organizations from others is their greater use of specialized monitoring applications. Fully automated organizations tend to rely on up to two specialized applications, while their more manual counterparts typically use just one. Fully automated organizations are much more likely to use eagle.io, Azure IoT, sensemetrics, and Vista Data Vision than other firms.

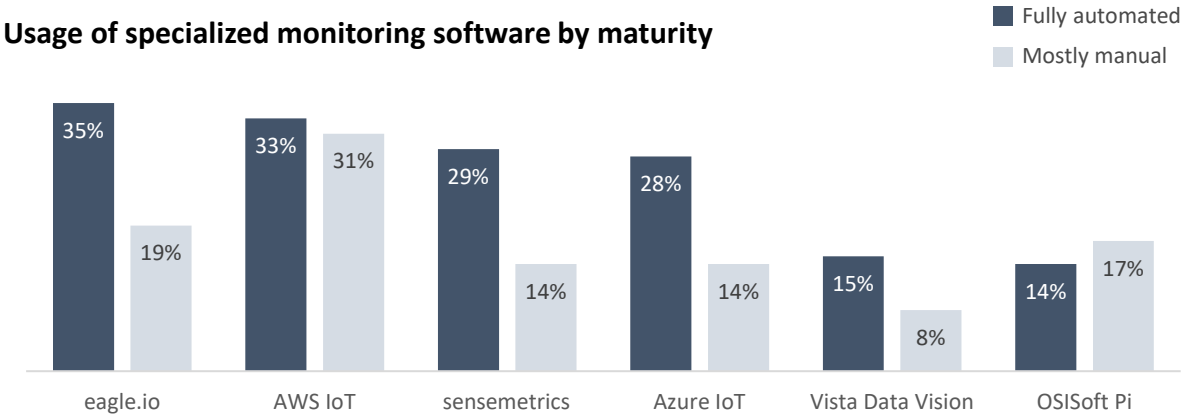
The limitations of general software

Even when using general software, automated organizations opt for the more graphically rich alternatives, such as Tableau or PowerBI. Organizations that are mostly manual tend to use Excel.

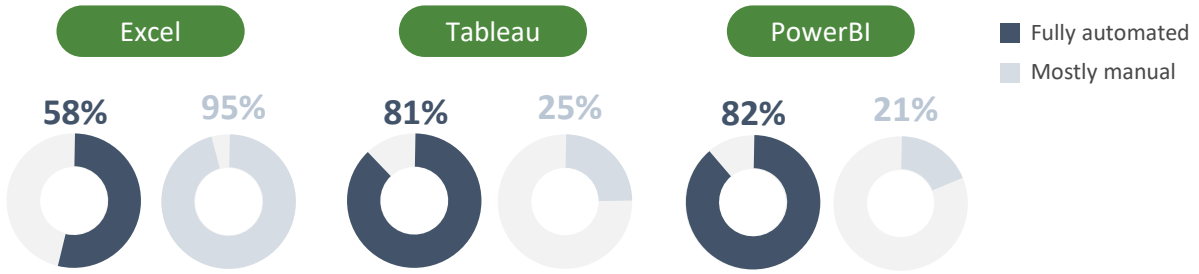
Fully automated organizations know the limitations of general software. Unlike specialized monitoring services, these generic applications cannot manage data acquisition from devices and provide real-time alerts. They also rely heavily on manual data entry and processing, which can be time-intensive, costly, and more prone to errors.

But their choice of applications will depend on circumstances. For instance, those whose operations rely on critical, real-time data may not want a cloud-based application if they are in a location without reliable power and internet access.

Usage of specialized monitoring software by maturity



Usage of general software by maturity



Q: What is your current monitoring software?

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Share data more widely with key stakeholders

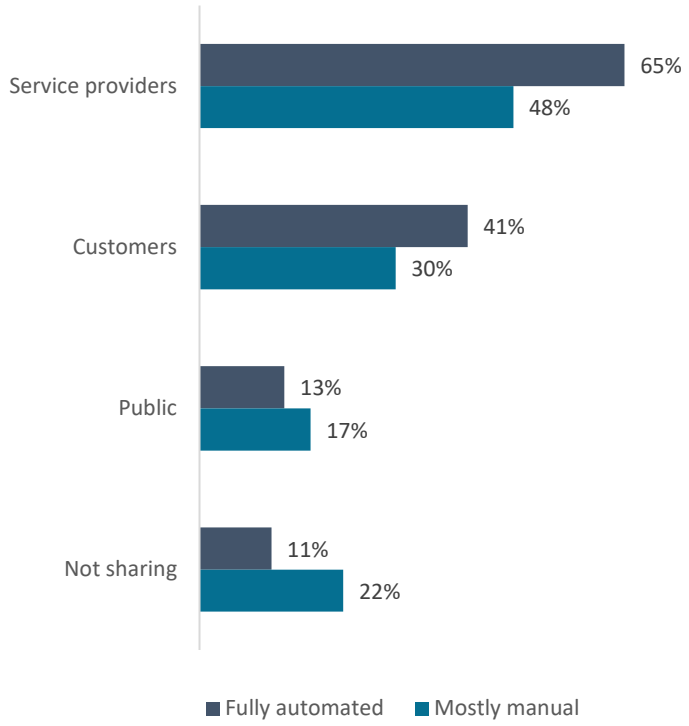
Companies that fully automate their condition monitoring have another edge. Since they are more digitally advanced, they are in a better position to share their data with service providers and customers. In fact, 22% of mostly manual businesses do not share data at all, compared with just 11% of automated organizations.

Almost two-thirds of fully automated organizations share data with service providers vs. only 48% of mostly manual businesses. Sharing data enables them to draw on the specialized knowledge of their service providers and tap into their often-greater analytical capabilities.

Fully automated firms are also more likely to share data with customers: more than four in 10 do so vs. less than a third of mostly manual businesses. This can include service providers sharing data with end users that own the assets, or asset owners sharing data with customers to build trust and transparency.

41% of fully automated organizations **share data with their customers**.

Data sharing by maturity



Q: Are you currently sharing your monitoring data? If so, with whom?

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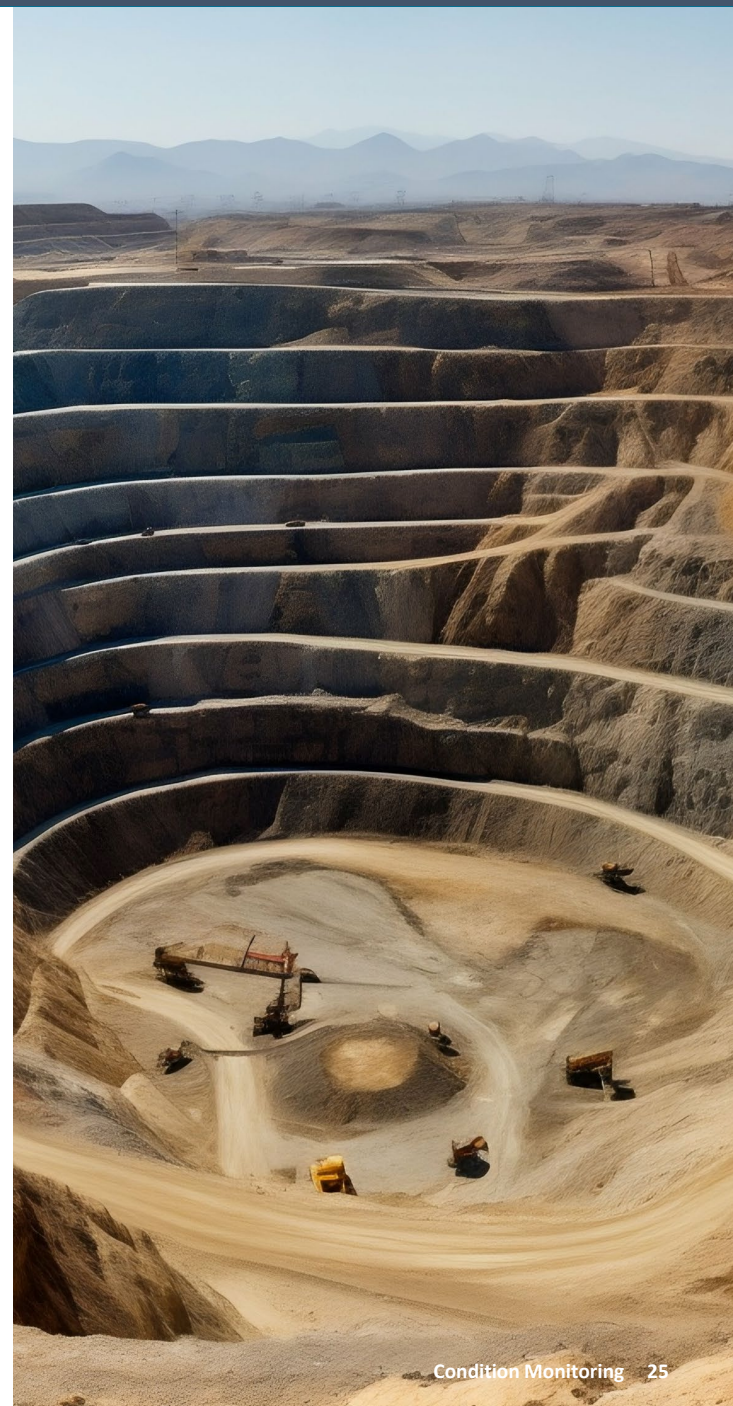
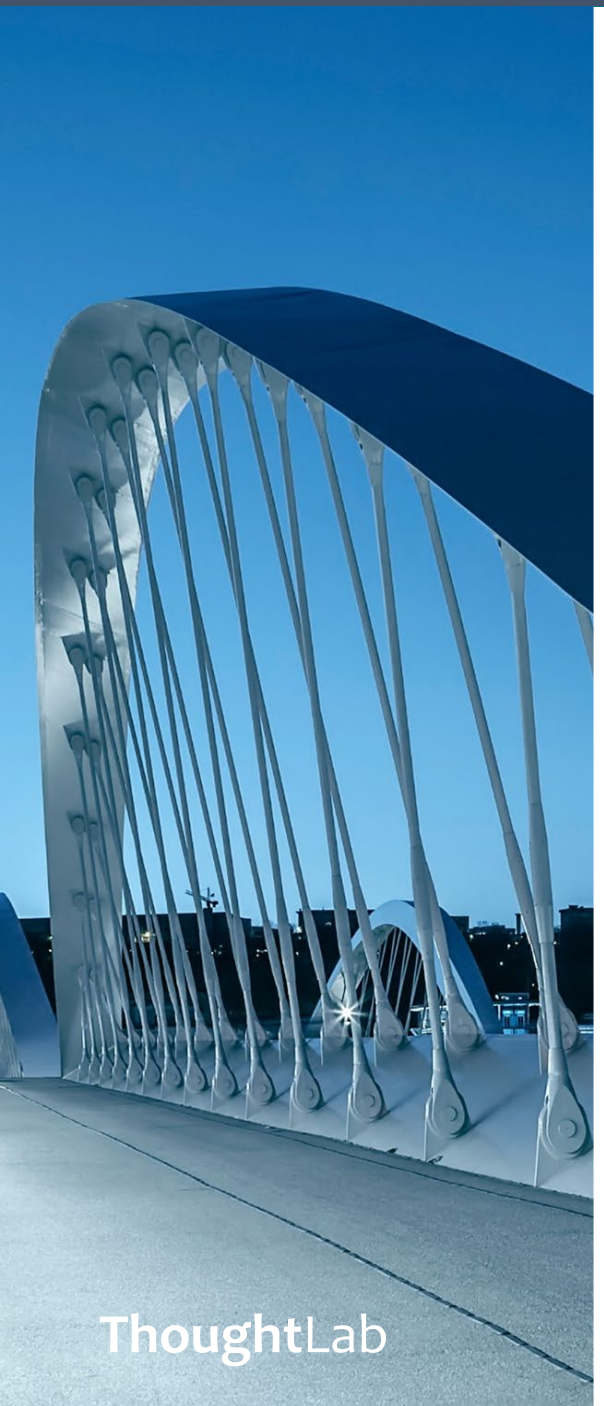




Show the art of the possible in monitoring

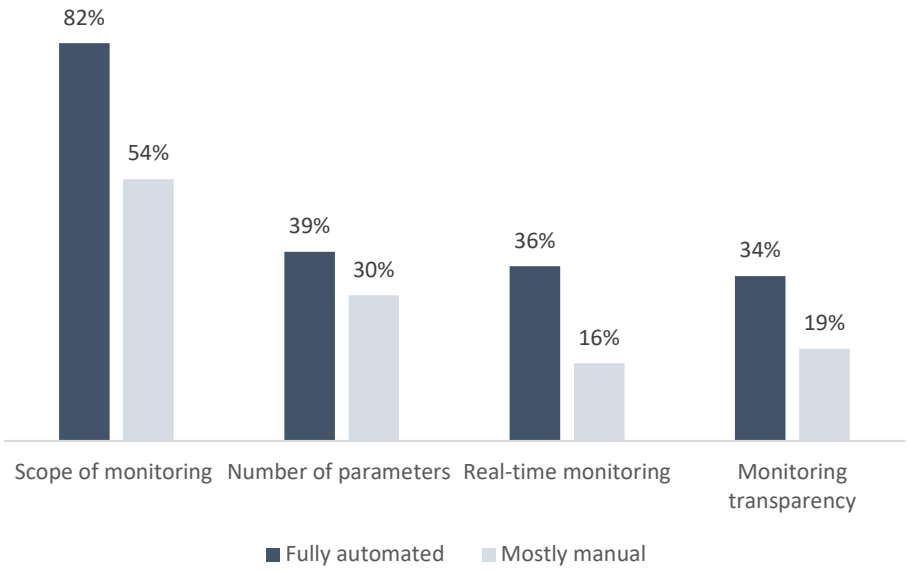
Fully automated organizations are moving much faster than others to improve their condition monitoring practices, widening the gap with those that have not yet adopted fully automated condition monitoring.

Over the past two years, 82% of fully automated organizations have broadened the scope of their monitoring capabilities and services, compared with 54% of those that are mostly manual. Fully automated organizations have also done more to increase the number of parameters they measure, adopt real-time monitoring, and monitor transparency.

Companies that fully automate their condition monitoring can do more advanced analysis and correlations across larger sets of data. They can also gain a 360-degree view of performance, which helps them meet the demands of stakeholders and regulators for more transparency.

As a result, fully automated firms have a greater ability to ensure environmental and structural safety, reduce risk, and address problems quickly.

Increases in monitoring practices over the last two years, by maturity



Q: How have the following monitoring practices at your organization changed over the last two years?

Deliver a higher ROI on condition monitoring

The switch to automated condition monitoring is a means to gain cost benefits and improve return on investment.

There is little total difference in cost between the two methods. Only 16% of organizations that predominantly use manual monitoring believe automated monitoring is more expensive.

The percentage is even lower (6%) among those organizations that have made the switch (which are in a better position to gauge the costs). In fact, after the initial cost of investing in automated systems is recovered, the running costs are typically lower than for the time-consuming manual approach.

Percent that believe remote monitoring costs more than manual

Q: What are the biggest barriers for your firm in converting manual monitoring programs to remote monitoring?

Examples of ROI across industries

Groundwater management

A 108-square-mile groundwater monitoring project improved its economics by implementing an automated monitoring solution. With an investment of about USD 180,000, the project reduced overall costs by 78% within 21 days, which translated into a USD 698,000 savings.

Tailings storage facility

Automated remote condition monitoring improved operating costs at the largest tailings storage facility in North America. The solution took five days to implement and saved USD 218,000 on upfront engineering time. It increased data availability to real time, providing a current annual cost reduction of USD 143,000.

Dam safety

A dam operator installed an automated monitoring system that paid for itself in just four months while simultaneously providing an opportunity to reduce risk and increase safety. The new now achieves a 90% increase in probability of detecting a change in condition within six hours of onset. The result has been an ongoing savings in excess of USD 1.2 million over a five-year period.

Another dam owner connected in-place inclinometers (IPIs) to an automatic monitoring platform instead of manually collecting data. The resulting immediate access to results and response to alerts resulted in USD 1 million in savings over a three-year period.

Overcoming challenges

Addressing pain points experienced in monitoring programs

For over half the companies surveyed, time delays are the largest challenge in their current monitoring programs. Delays can result from manual data collection, laboratory analysis time, complex data processing and analysis, equipment downtime, and lack of automation.

More than half of organizations also report sampling errors. These can occur due to inadequate sample sizes, poor sampling techniques, or human error. Indeed, companies tend to see more hurdles overall when they conduct mostly manual condition monitoring.

Automated remote continuous monitoring addresses these and other pain points cited by respondents.. For example, organizations that conduct remote, continuous monitoring struggle less with sample time/cost/safety issues (23% vs. 36% for mostly manual) and infrequent samples (27% vs. 37% for mostly manual).

Challenges experienced with monitoring

1. **59%** Time delays from sample collection to receiving analytical lab reports
2. **57%** Time delays from sample to lab data receipt
3. **54%** Sampling errors
4. **43%** Maintaining visualizations and charts
5. **31%** Infrequent samples don't capture events
6. **27%** Sample time/cost/safety issues
7. **15%** Sharing data with stakeholders

Top challenges for monitoring programs by industry

Service Providers		End Users			
Environmental services	**Infrastructure engineering**	**Dams**	**Mines**	**Private/ public**	**Transportation**
Time delay from sample to lab reports 64%	Time delay from sample to lab data 62%	Maintaining visual and charts 59%	Time delay from sample to lab reports 58%	Time delay from sample to lab reports 63%	Sampling errors 59%
Time delay from sample to lab data 62%	Time delay from sample to lab reports 57%	Time delay from sample to lab reports 57%	Sampling errors 55%	Sampling errors 62%	Maintaining visual and charts 51%
Sampling errors 54%	Sampling errors 45%	Sampling errors 55%	Time delay from sample to lab data 53%	Time delay from sample to lab data 60%	Time delay from sample to lab reports 49%

Q: What are the biggest challenges that your firm experiences with its current monitoring programs?

Surmounting barriers to automation of condition monitoring

Lack of knowledge around telemetry to transmit data

The lack of knowledge around telemetry is cited by a main obstacle by **78%** of respondents.

Solution: Work closely and synergistically with your ecosystem

Remote monitoring sensors and equipment often use different standards for transmitting data to monitoring systems. They use a variety of definitions, vocabulary, data storage, and exchange formats, which may not be compatible with software that companies use to process and analyze sensor data. Those responsible for environmental monitoring often don't have the needed skill sets needed to ensure that everything works seamlessly together.

One of the best solutions is for companies to work closely with their ecosystem partners. They will be able to put together a range of equipment from different manufacturers and ensure that the telemetry from these disparate sensors can be transmitted to—and correctly interpreted by—a company's monitoring systems and software.

Lack of knowledge around hardware installation

70% of firms do not have the expertise to install specialized hardware, such as sensors, and telemetry equipment.

Solution: Partner with a specialist consultant or provider

While complete plug-and-play hardware solutions exist for some specific uses, they are not available for many types of monitoring, particularly when a company needs hardware to work in a range of challenging environments. For each use case, companies need to source a variety of components that are not necessarily designed for their purposes. That can require extensive solution engineering, including custom enclosures and protection measures, power systems, and communication infrastructure.

Organizations should consider partnering with specialist consultants or providers with the needed expertise to find, modify, and install the right components. These partners will also have the skills to integrate different technologies and sensors for disparate environments—such as water or air temperature—into the monitoring system.

Lack of commercially viable sensors for parameters

Sensors must be accurate, durable, and compatible. Lack of viable sensors is an obstacle for **72%** of respondents.

Solution: Use available sensors for parameters that correlate with hard-to-sense parameters

Many parameters like pesticides, herbicides, nutrients, and metals lack viable remote sensing solutions. One fix is to use low-cost sensors that will correlate with—or predict—increases in concentration from harder-to-sense parameters.

For example, sewage treatment plants often have a requirement for continuous measurement of turbidity of water, with triggers for manual monitoring when turbidity exceeds a certain level (e.g., 5 NTU). Turbidity is the canary in the coal mine. If the water is cloudy, it's likely due to a process failure. An increase in turbidity will be correlated with a rise in other contaminants.

In this way, operators can quickly react to problems, flagged by this lead indicator of turbidity, and trigger the more expensive and slow manual monitoring of other pollutants when required.

Key takeaways

Key takeaways

State of the industry

1. **Organizations monitor a wide range of data and parameters, which have increased for 34% of companies over the last two years.** The top parameters now tracked are particulates and air quality (75%), closely followed by wind, temperature, and pressure (71%). But there are wide variations by industry.
2. **To gain greater insights, organizations integrate sensor data with information from other sources.** The external sources include asset management systems (66%), public data (43%), simulations (35%), GIS layers (35%), and digital twins (34%). They also share data with stakeholders, such as service providers (51%) and customers (39%).
3. **Organizations are reducing their use of manual monitoring.** Over the last two years, 21% of organizations cut their use of manual monitoring. Currently, about one-third of total monitoring is manual, and by 2025, the percentage will fall to just under a quarter.
4. **Organizations are moving to real-time continuous monitoring.** Over the past two years, 25% of organizations increased their use of real-time monitoring. About two-thirds of organizations continuously monitor with manual download, and 48% continuously monitor with near real-time transmission.
5. **A minority of firms use specialized monitoring software.** About quarter of organizations use eagle.io and a similar percentage use sensemetrics. For some sectors, such as dams, the percentages are higher. The market share of continuous monitoring software is expected to grow over the next five to 10 years.

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Key takeaways

What automated organizations do differently

1. **Track more built and natural systems.** Companies that fully automate their condition monitoring on average track more than seven systems vs. less than five for companies relying on manual processes. Companies that fully automate are much more likely to track geotechnical, geospatial, meteorological, and surface water.
2. **Do more to integrate sensor data with other information.** Companies with fully automated monitoring can more easily integrate data with other information sources. That enables them to maximize the value from their condition monitoring programs.
3. **Gain insights from data through digital twins.** Companies with fully automated condition monitoring are twice as likely as mostly manual businesses to integrate data with digital twins. These companies gain a holistic view of conditions and the ability to conduct forecasting and what-if scenario analysis.
4. **Draw on specialized software, rather than general applications.** Organizations with fully automated condition monitoring combine about four types of software vs. about 2.5 for mostly manual organizations. Of those software solutions used by automated organizations, 1-2 are typically specialized solutions.
5. **Move faster to improve condition monitoring.** Over the last two years, 82% of fully automated organizations have increased the scope of monitoring vs. 54% of mostly manual companies. Similarly, they have done more to increase the number of parameters, monitor in real time, and build transparency.
6. **Overcome the challenges of moving to automated condition monitoring**. These challenges include limitations in technology, such as the lack of commercially viable sensors for parameters and deficiencies in knowledge around telemetry or hardware installation. To vault these hurdles, firms often work closely with ecosystem partners and consultants, and use available sensors that correlate with hard-to-sense parameters.

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