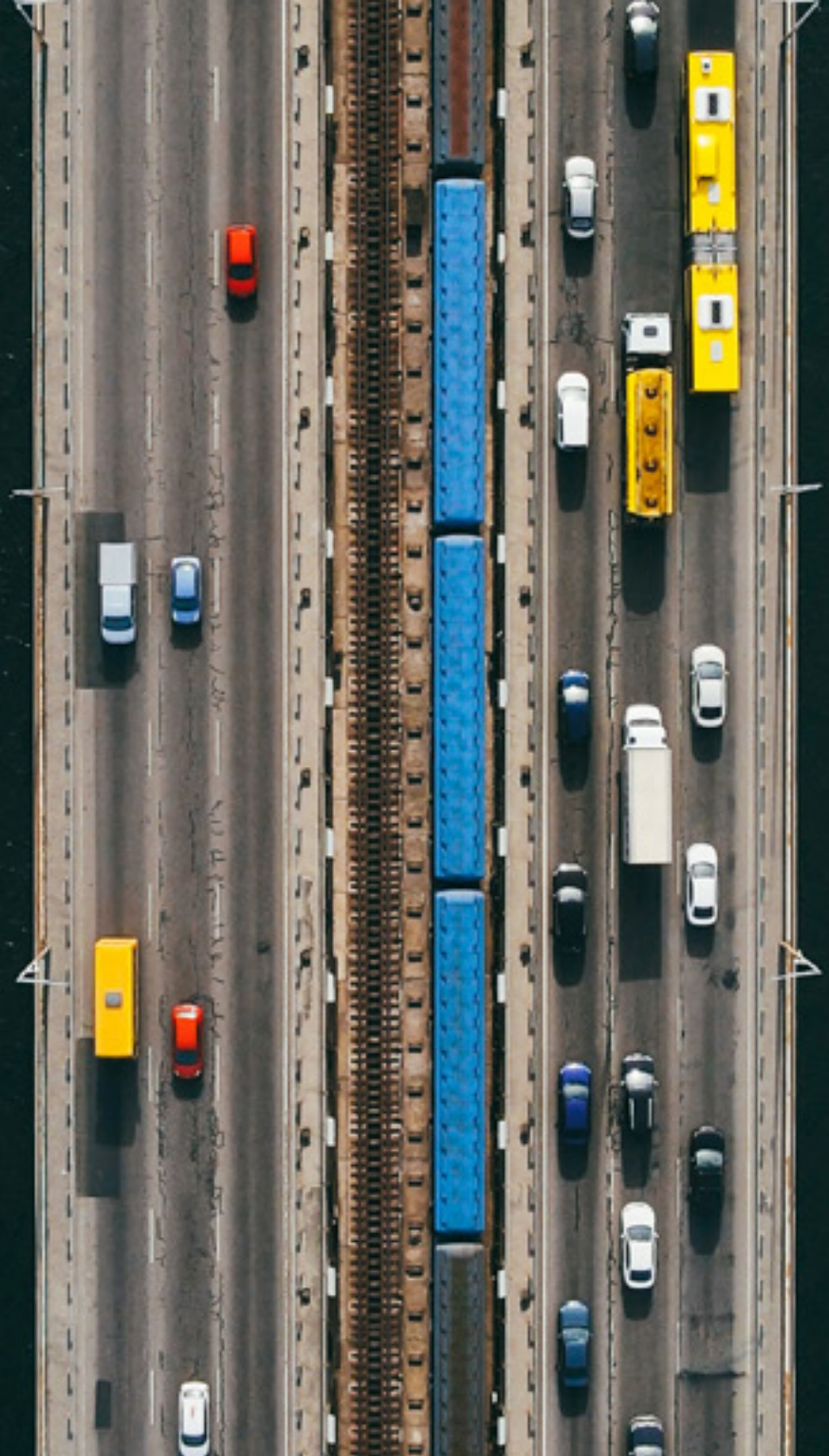
Condition monitoring in transportation

- Roads and railways
- Bridges and tunnels

2024 Report



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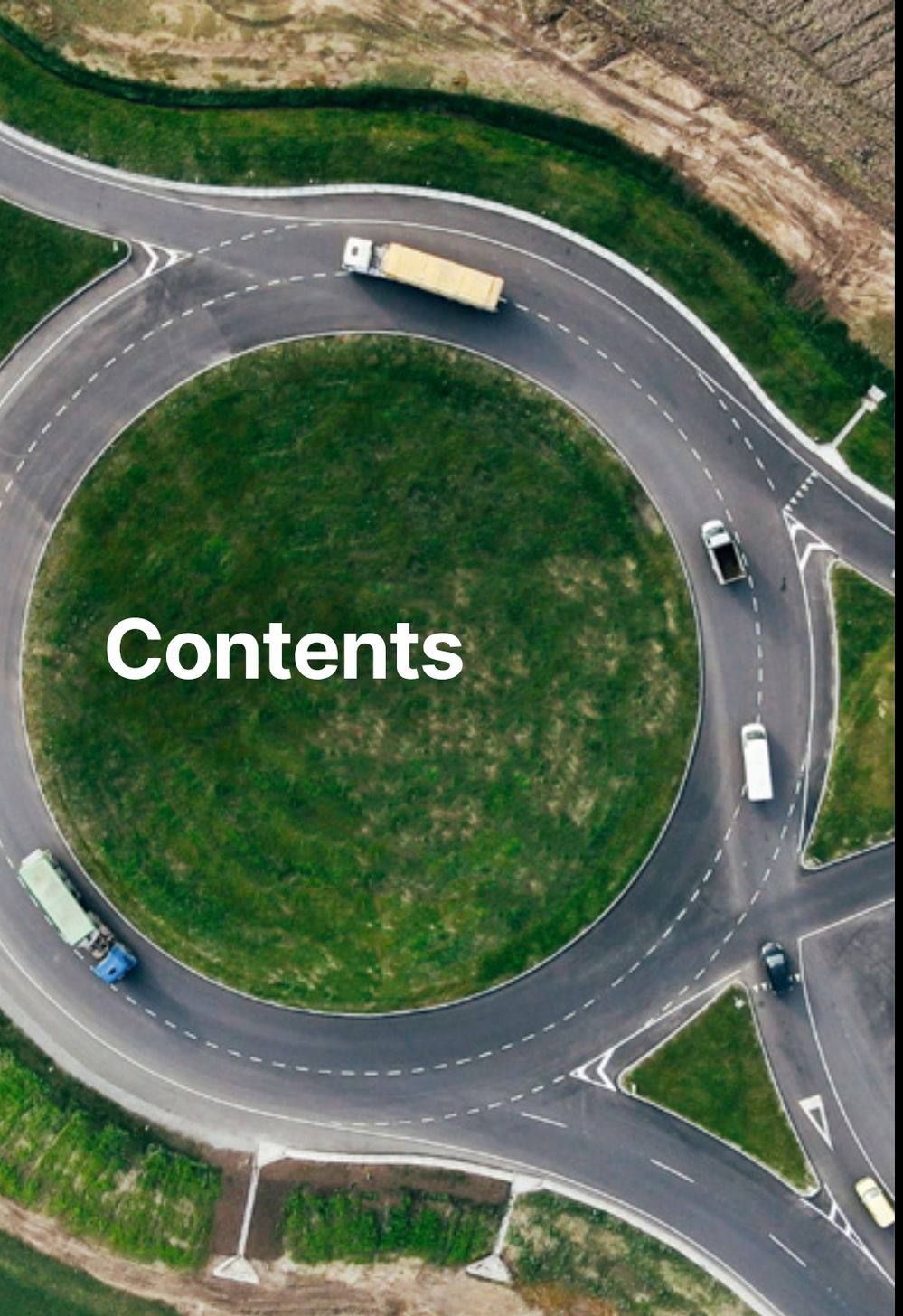
Advancing Infrastructure



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Introduction

Transportation is a significant driver of any country's economy, with impacts on trade and commerce, employment, urban and regional development, energy consumption, and the environment. As such, ensuring the condition, efficiency, and safety of transportation infrastructure is central to competitiveness, productivity, and the quality of life of citizens around the world.

Yet the transportation sector faces large pain points, including aging infrastructure, concerns about climate change, limited data for improving decision-making, a relative lack of technology resources and expertise, and cybersecurity. Indeed, transportation is typically behind other industries in its adoption of the latest technologies to improve efficiency and performance of its condition monitoring practices.

To understand condition monitoring trends and practices globally, Bentley Systems commissioned ThoughtLab to conduct a survey of 400 industry experts from North America, Europe, and Australia. Experts included a mix of C-suite executives, technical managers, and technical staff working for companies ranging in size from under 100 employees to over 1,000.

The survey included 71 road and railway owners and their service providers, as well as 65 bridge and tunnel owners and their service providers. These organizations are covered in this report.

The results show the progress that transportation owners and service providers are making in automation and other condition monitoring practices—including a shift to automated monitoring—to achieve their goals around enhanced safety, reduced risks, sustainable operations, and heightened efficiencies over the longer term.

Part 1: Roads and railways

Current landscape

Condition monitoring is largely automated

Automated data collection is the most common collection method in the road and railway sector. It accounts for an average of around three-fourths of data collected by owners and service providers. While providers automate slightly more of their data collection, both groups equally employ the most advanced method—automated collection with sensors for transmission via telemetry.

More owners fully automate their data collection

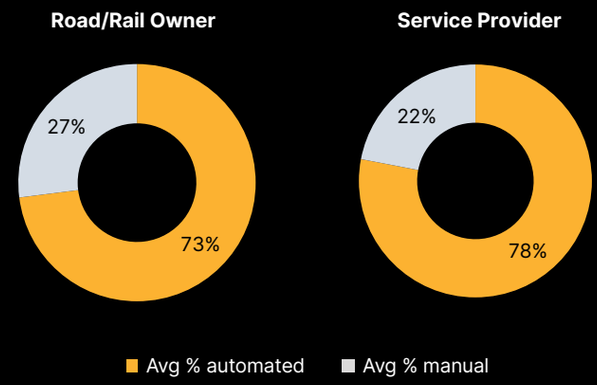
A larger share of owners (30%) than providers (21%) no longer manually collect any data at all. Some providers are likely supporting owners with on-site visual assessments of critical components such as pavement quality, track conditions, and structural integrity to identify signs of deterioration or damage.

Given the safety and economic risks surrounding potential failures of transportation infrastructure, owners and providers increasingly recognize the benefits of automation to improve performance, reduce costs and risks, and ensure regulatory compliance.

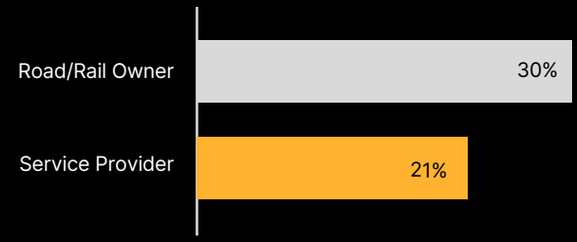
> Automation not only improves efficiency and productivity, but also cost reduction.
>
> – Technical manager, Canadian road/rail owner

Q. What percentage of your organization's monitoring utilizes manual data collection?
Q. How does your organization collect data for its monitoring programs?

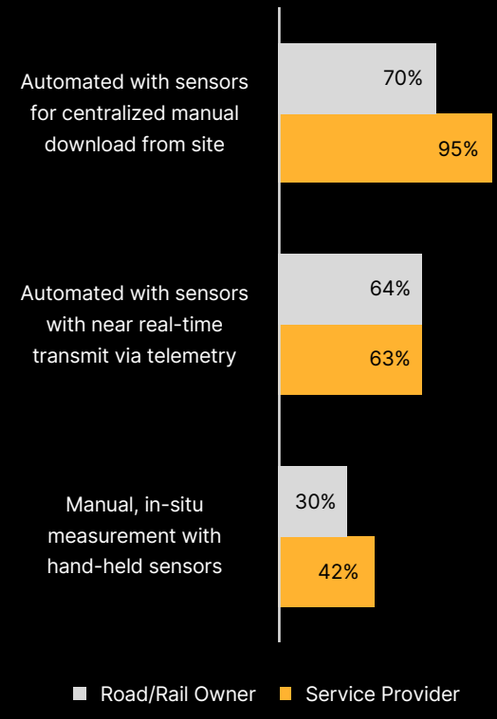
Average % automated vs. manual collection of data



% that fully automate their data collection



Monitoring data collection methods



Data integration improves results

Data is critical for effective condition monitoring. Selecting software to analyze that data can be challenging, given the range of choices available. Among owners and service providers, Excel is the most widely used software (by over 80% of both groups). This is followed by Tableau, another general-purpose application, and, for service providers, Power BI. On average, owners employ 3.4 applications (out of nine), while providers use 4.1.

Far fewer owners and providers employ specialized software designed to analyze sensor data. Of this software, they prefer eagle.io and AWS IoT. As owners and providers make progress in automation, they may move more towards specialized apps, which enable real-time monitoring of data, advanced visualizations, and customized reporting.

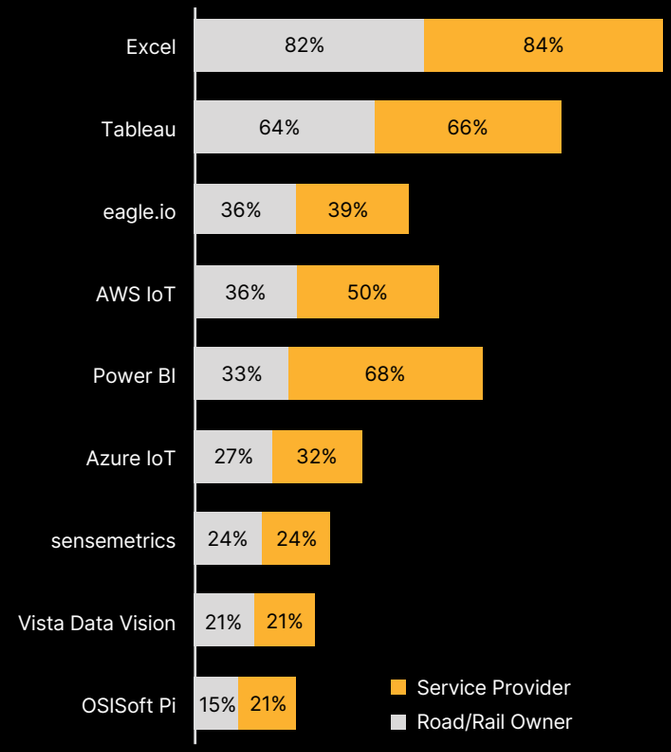
Providers tap into other data sources a bit more

Both groups enhance insights from sensor data by integrating it with data from some outside information sources. Service providers do so a bit more, accessing 2.8 (out of 7) outside data sources on average versus 2.6 for owners.

Asset management systems are the most popular external data source, used by more than 70% of owners and providers. These systems can provide a comprehensive view of infrastructure performance and maintenance history. Road and railway owners are more likely to integrate their data with public data, while service providers are far more likely to tap into drone-based photogrammetry, a much more advanced data source.

Q. What software do you leverage for sensor monitoring activities?
Q. Is your organization currently integrating sensor data with additional information sources to increase insights? If so, which of the following apply?

Software used for analysis



Integrating sensor data with other sources

	Road/Rail Owner	Service Provider
Asset management systems	73%	79%
Public data	55%	42%
Digital twins	39%	39%
GIS layers	36%	42%
Predictive models	24%	32%
Remote sensing data	18%	11%
Drone-based photogrammetry	9%	34%

Automation reduces monitoring challenges

As part of our research, we compared the performance of organizations that utilize fully automated monitoring with those that use some degree of manual monitoring. We labeled the first group as “fully automated” and the second group as “any manual.”

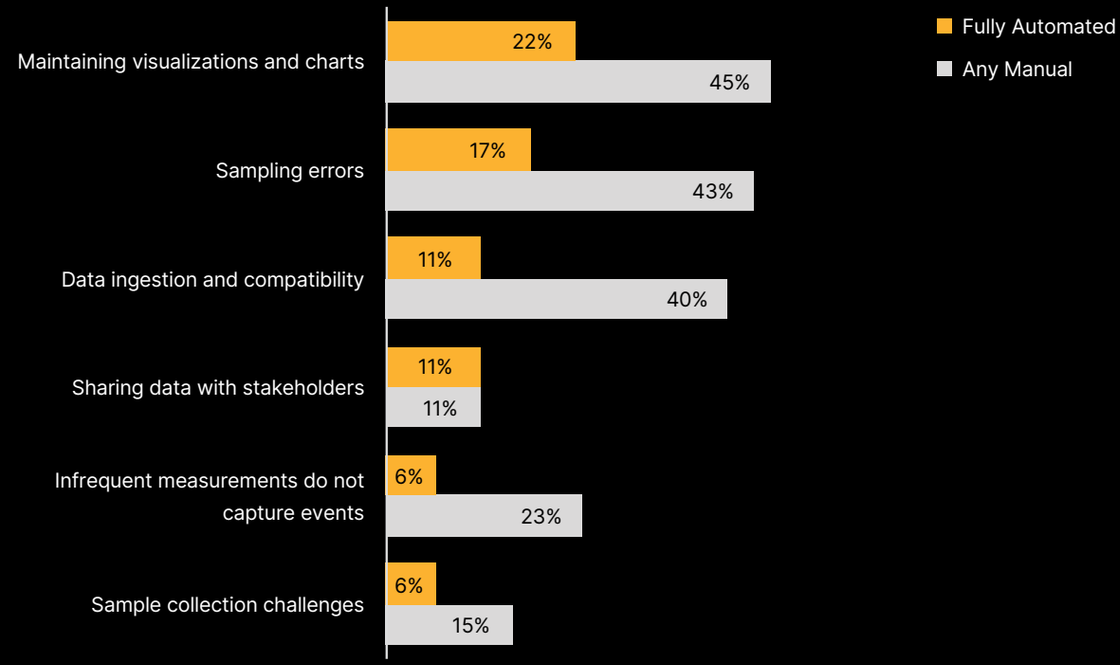
On average, organizations in the road and rail sector that are fully automated report fewer challenges to their condition monitoring: 1.9 (out of 8 covered in the study) versus 2.7 among those doing some manual monitoring. And 28% of fully automated organizations report no major issues at all, versus just 6% of manual organizations.

Across all challenges cited, those that use some manual data collection are far more likely to experience difficulties, particularly in maintaining visualizations, sampling errors, and data ingestion and compatibility—challenges that burden at least four out of 10 organizations that do any amount of manual monitoring.

> It’s critical to fully grasp existing procedures in order to identify which ones can be automated to get the desired results.
>
> – Project manager, Australian road/rail owner

Q. What are the largest challenges that your organization experiences with its current monitoring programs?

Condition monitoring challenges



Trends: the shift to automation

Monitoring practices continue to evolve

Over the last two years, road and railway owners and their service providers have demonstrated a clear trend towards automation. Some 27% of owners and 16% of providers increased their use of automated real-time collection.

Owners and providers also expanded other monitoring practices. They boosted the number of parameters they measure (33% of owners and 42% of providers), widened the scope of their monitoring capabilities (33% and 34%, respectively), and increased its transparency (36% and 32%). Much of this was facilitated by automation.

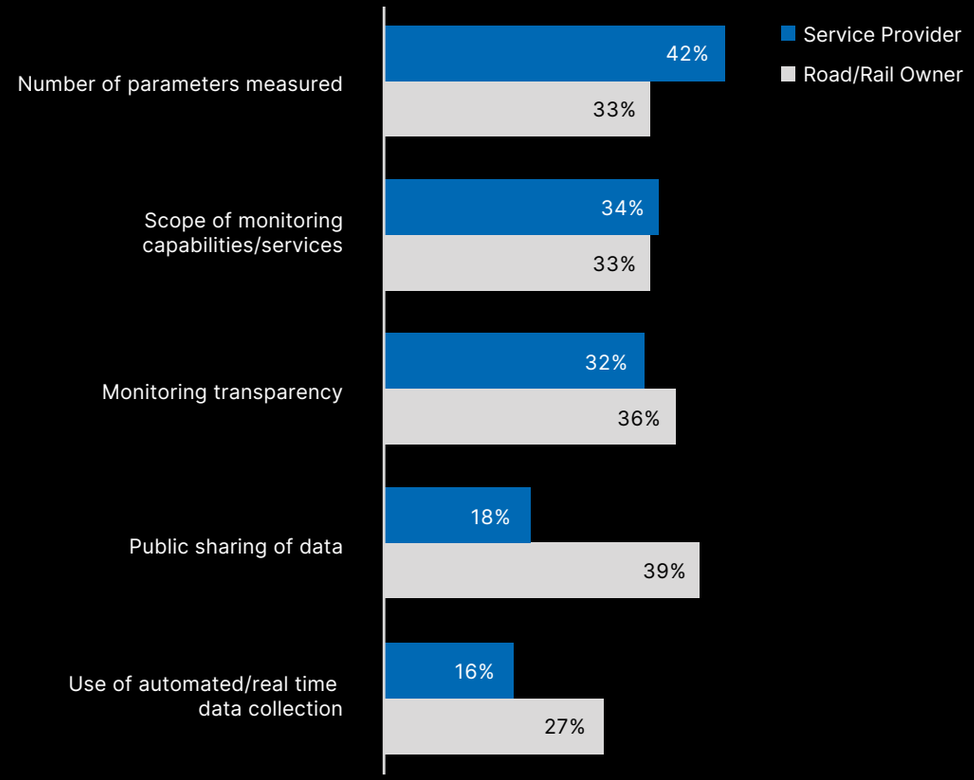
Public disclosure builds trust with the community

Owners also shared more information publicly: 39% did so, likely to address growing regulatory and environmental pressures and to build trust among the public regarding the safety of transportation infrastructure.

On the other hand, whereas 18% of providers also increased public sharing of data over the last two years, a larger share (34%) did the opposite, reducing public disclosures. This was likely out of concerns to protect client confidentiality and comply with privacy and security protocols.

> Automation leads to organization growth.”
>
> – Technical manager, Canadian service provider for road/rail

Organizations reporting increases in monitoring practices



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

Various forces drive automation trend

Social license—the need to communicate strong condition performance to stakeholders—is the biggest external driver for automation among road and rail owners and their service providers. Both groups face growing environmental pressures and safety concerns as transportation infrastructure ages. Hence, 58% of owners and 79% of providers say social license is very influential.

Other factors also motivate their decisions, although to a lesser, moderate extent. Nearly 70% of owners and 61% of providers cite technology trends as moderately influential. Similarly, 64% of owners and 71% of providers see operational demands as moderately influential. The figures for economic factors are 67% and 68%, respectively.

Increasing governmental regulations play a role in adoption

While specific regulations are viewed as very influential by only a quarter of owners and providers, they do play a role. Most road and rail owners (67%) and their providers (68%) see them as moderately influential.

In the U.S., for example, they are subject to various regulations around safety, carrier rates, hazard materials, worker training, and other areas issued by entities such as the National Highway Traffic Safety Administration, the Federal Highway Administration, the Federal Railroad Administration, and the Occupational Safety and Health Administration, among others.

Q. How influential are the following external market forces in driving adoption of automated monitoring?

Forces driving adoption of automated monitoring

		Road/Rail Owner	Service Provider
Social license - Need to communicate strong condition performance to stakeholders	Very influential	58%	79%
	Moderately influential	39%	11%
Technology - The advent of more accurate, lower cost sensors, gateways, telemetry, and cloud processing	Very influential	27%	37%
	Moderately influential	67%	61%
Operational demands - Requirement to measure and respond to conditions that might impact my business in real time	Very influential	21%	26%
	Moderately influential	64%	71%
Regulatory - Increasing governmental requirements to implement real-time monitoring to detect or avoid harm	Very influential	24%	24%
	Moderately influential	55%	76%
Economic - e.g., the cost of labor and manual monitoring is increasing over time, automated data collection is becoming more economically feasible	Very influential	24%	24%
	Moderately influential	67%	68%

Adopting automation provides benefits

On average, road and rail owners and their service providers reap the same number of benefits from their shift to automation (2.4 out of the five benefits we asked about). A similar share report seeing the ability to execute projects more cost effectively (76% each) and to execute more projects in a year (30% of owners and 34% of providers).

Other benefits vary. More providers than owners (71% versus 61%) say automation has helped them move into new markets, likely because it is easier for providers than owners to add new clients across geographies. Similarly, providers are more likely than owners to say automation helped them operate with leaner teams (21% versus 15%).

Revenue is a key benefit for owners

On the other hand, far more owners (61%) than providers (37%) report generating greater recurring revenue from their automation efforts. This is a critical benefit, especially for many road owners or operators, which face significant funding challenges and investment needs as their infrastructure ages.

> Businesses can utilize data insights produced by automated processes to make well-informed decisions."
>
> – Technician, Canadian service provider for road/rail

> Automated monitoring can easily result in a higher return on investment."
>
> – CAD designer, U.K. service provider for road/rail

Benefits of shifting to automated monitoring

	Road/Rail Owner	Service Provider
We can execute projects more cost effectively.	76%	76%
We have more capability to move into new markets.	61%	71%
We are able to unlock recurring revenue.	61%	37%
We can execute more projects in a year.	30%	34%
We can operate with leaner teams/staff.	15%	21%

Q. How has the shift to automated monitoring affected your business?

A look to the future

Roads and railways lead in automated monitoring

Both road and railway owners and their service providers will continue to increase their automated monitoring over the next two years, reaching 80% of data collected among owners and 86% among providers. That will put them slightly ahead of the average for all industries in our study (which also includes mines, dams, utilities, and water distribution/ wastewater infrastructure).

The misconceptions of full automation

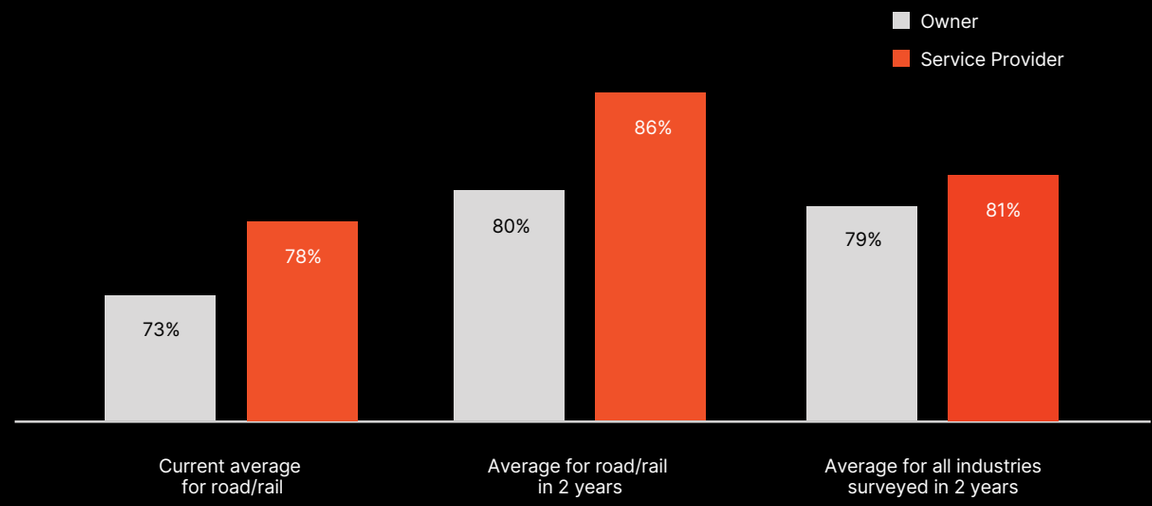
Most organizations will continue to do some manual monitoring, perhaps because of the need to make visual inspections of their infrastructure. Some firms believe that manual data collection has advantages, such as lower cost. However, 76% of both providers and road and railway owners say that automation has allowed them to execute projects more cost effectively.

Others believe humans are better at detecting subtle changes and patterns. A technician with a French provider for roads and railways said: “Decisions involving nuance, ethics, or common sense are most effectively handled by human intuition.” Despite such concerns, automating data collection does not eliminate human judgment or oversight. Rather, it frees up staff from mundane data collection tasks, allowing them to offer valuable insights elsewhere when needed.

> The utilization of automated systems enables the collection of data in real time, thereby improving process monitoring and control.”
>
> – Project coordinator, U.K. service provider for road/rail

Q. What percentage of your organization’s monitoring utilizes manual data collection? What percentage of your organization’s monitoring data do you expect to still be manually collected in two years?

Average percentage of automated data collection



Automation supports long-term viability

The message is clear for both road and railway owners and their service providers: in the long term, automated data collection is crucial for meeting the needs of stakeholders.

Automation will drive the future readiness of owners...

For road and railway owners, stakeholder demands for accurate, real-time data, along with the need to drive cost efficiencies while extracting more insights from data, will make automation a necessity rather than a choice. That is why 39% of owners that currently collect some data manually do not expect their current practices to enable them to meet stakeholder demands in 10 years.

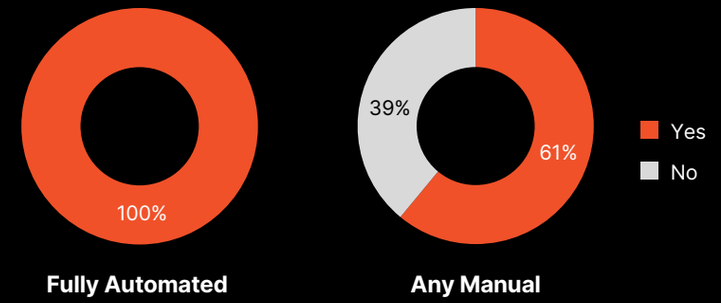
By contrast, all fully automated road and railway owners believe that their condition monitoring practices will meet these demands in 10 years.

...and the economic viability of service providers

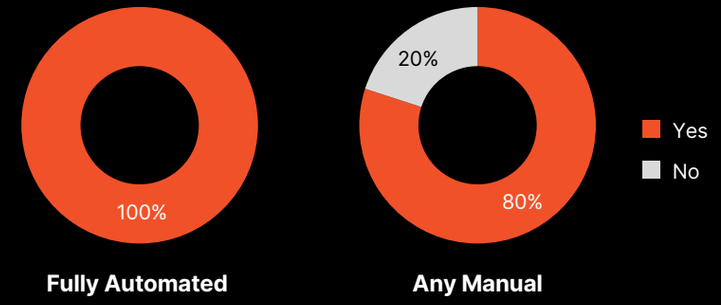
The story is similar for service providers, who also recognize the importance of automation for their future business success. All fully automated providers surveyed are confident that their approach will be economically viable in 10 years. By contrast, 20% of those that do some manual collection do not expect their monitoring practices to stay viable over the long term. The other 80% may be underestimating the growing need to automate.

Q. Road/railway owners: Do you think your organization can continue to meet the demands of various stakeholders in 10 years if it continues with its current data collection approach?
Q. Service providers: Do you think your organization's condition monitoring practices will be economically viable in 10 years if you continue with your current data collection approach?

Meeting stakeholder demands through data collection practices



Economic viability of condition monitoring practices



Key takeaways

How automation is improving condition monitoring for roads and railways

The survey found that condition monitoring practices are advancing in the road and railway sector, with 73% of data collection now automated among owners and a higher 78% among their service providers. Over the next two years, owners and providers alike will further increase their automated monitoring of all data collected to 80% and 86%, respectively. Our analysis reveals that the move to automation generates several key benefits for road and railway owners and their providers:

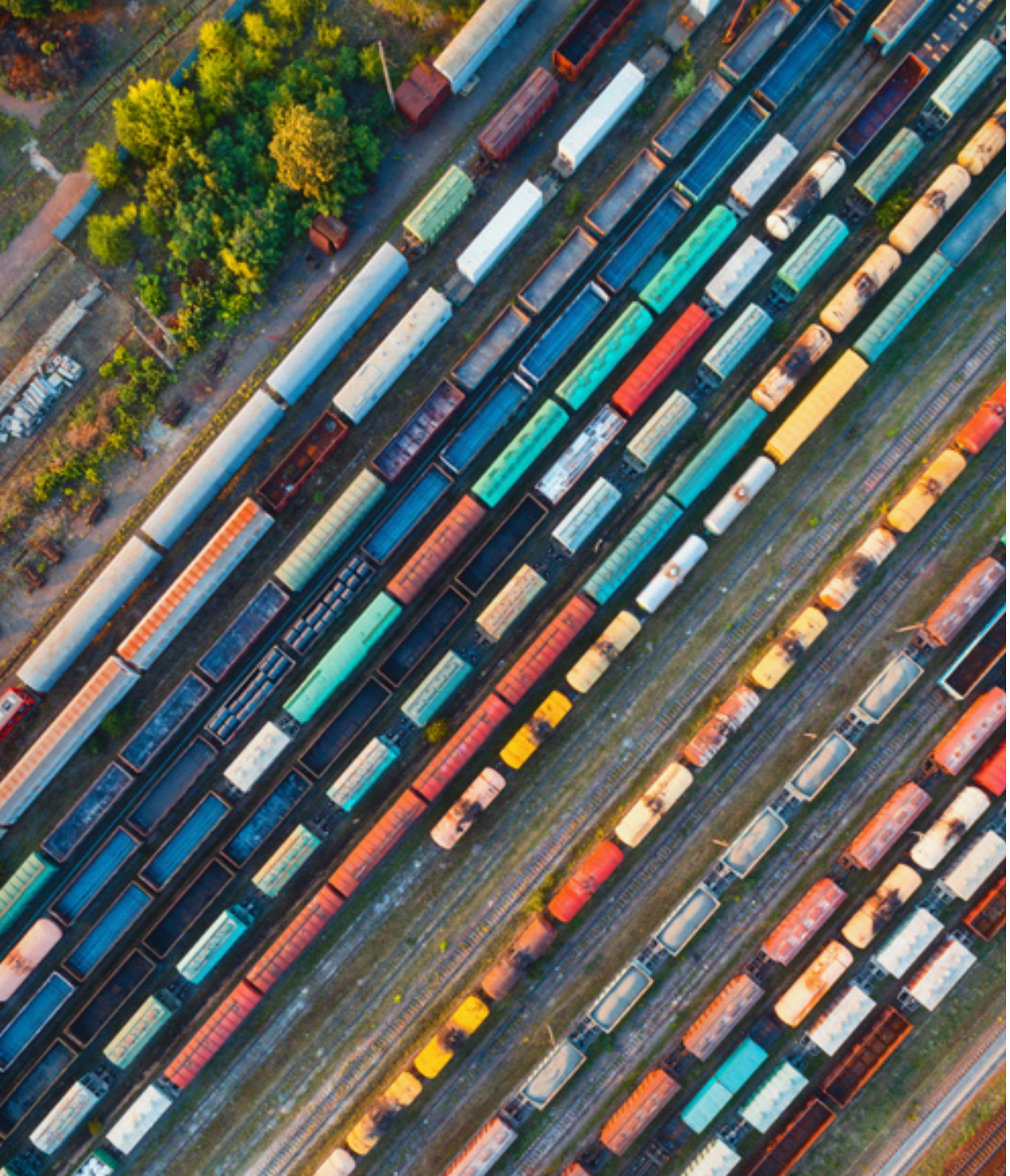
1. **Greater ability to integrate sensor data with other information sources.** Organizations that are fully automated find it easier to integrate data from multiple sources, such as asset management systems, public sources, GIS layers, and digital twins. This integration enables them to maximize the value from their monitoring programs.

2. **Fewer challenges in condition monitoring.** Fully automated organizations encounter fewer hurdles in condition monitoring than manual ones: 1.9 versus 2.7, respectively (of the six challenges covered in this report). Maintaining visualizations and charts, sampling errors, and data ingestion and compatibility are among the pain points that are largely relieved through automation.

3. **Ability to monitor more parameters and expand other practices**. Over the last two years, 50% of fully automated road and railway owners and their service providers boosted the number of parameters they measure, such as temperature, particulates, and system health. In addition, 44% broadened the scope of their monitoring capabilities, and 28% increased monitoring transparency.

4. **Greater efficiencies and ability to execute more projects.** Providers and road and railway owners generate significant cost efficiencies and other business benefits by embracing automation. Over three-quarters (76%) in both groups say they can execute projects more cost effectively and 30% of owners and 34% of providers can execute more projects in a year.

5. **Increased market penetration and growth.** Some 61% of owners and 71% of providers report that the shift to automation has enabled them to move into new markets. At the same time, automation has allowed 61% of owners and 37% of providers to unlock recurring value.



Lessons learned on the road to automation

We asked road and railway owners and their service provides for advice on shifting to automation in condition monitoring. Here are five lessons learned.

1. **Develop a unique and detailed plan for your business.** Organizations that have a thorough understanding of their needs and establish a well-defined implementation plan can achieve better results. “Thoroughly researching the organization’s unique needs is essential, with a focus on features such as real-time tracking, predictive analytics, and automating reporting,” said a COO with a U.S. road and railway owner.

2. **Ensure good data quality and accuracy.** Organizations should routinely assess the performance of automated processes and install rigorous data quality assurance procedures. “Automation relies heavily on data, so maintaining data quality and accuracy is crucial for optimal performance,” said a project coordinator with an Australian road and railway operator.

3. **Install robust data security protection and governance.** In addition to data accuracy, protecting data is critical, so the right tools and processes need to be put in place to do so. “Establish clear data governance policies and procedures to ensure data integrity, security, and compliance,” said a design engineer with a Spanish road and railway operator.

4. **Foster a culture of continuous innovation.** Implementing automation is not a one-and-done step, but a process, as technology continues to change. Organizations need to be flexible and keep abreast of technological advances. “Embrace continuous improvement and innovation, as automation technologies are constantly evolving, and staying updated with advancements can lead to better outcomes,” said a CTO with a U.K. service provider.

5. **Educate and engage employees.** Companies should ensure their technical staff know they are not being replaced by automation. Automated condition monitoring will simply reduce or eliminate the mundane, time-consuming work of manual data collection so they can focus on more important tasks. One CTO with a Canadian service provider said, “Gaining employee support and understanding of the benefits of automated condition monitoring is crucial for successful implementation.”

The future of condition monitoring for roads and railways

The future of condition monitoring for roads and railways is set to be revolutionized by the integration of advanced technologies and data-driven approaches. Additionally, the insights provided by advanced monitoring can inform future infrastructure design and make roads and railways more efficient, reliable, and sustainable. Here are some key trends and innovations expected to shape the industry:

1. **Accessible, integrated data will improve safety.** Linking data sources such as work records, satellite data, and drone data will enable comprehensive monitoring of road and railway conditions. Artificial intelligence will identify early indicators of risk changes, allowing for timely intervention. Engineers will access real-time and historical data on site, improving safety of the inspection and maintenance processes.

2. **Advanced road and railway monitoring will increase reliability.** Advanced condition monitoring will detect performance outliers early, enabling proactive maintenance and reducing unexpected downtime. Integrating a variety of data sources, including visual inspections, historical records, vehicle-mounted measurements, and satellite and drone data, will support thorough root cause analyses, sustainability simulations, and predictions of asset lifespans. Real-time traffic reporting will improve congestion management and travel reliability.

3. **Environmental impact monitoring will enhance resilience.** Continuous monitoring of environmental changes, both natural and built, will allow for real-time assessment of their impact on the infrastructure's risk profile. Extrapolation of these impacts will provide predictive insights into future risks, enabling preemptive measures to improve resilience.

4. **Advanced technology will provide better security.** Advanced monitoring systems will detect and report unauthorized access, use, work, and theft, safeguarding road and railway infrastructure from potential threats and ensuring operational integrity.

5. **Future spending forecasts will be more accurate.** By using condition data, deterioration rates, and failure rates, predictive models will forecast future financial requirements, including the need for spare inventory and their geographic distribution. This will enable more accurate budgeting and resource allocation, ensuring that road and railway maintenance and upgrades are adequately funded and efficiently executed.

Part 2: Bridges and tunnels

Current landscape

Data collection is largely automated

On average, the percentage of automated data collection is the same for both bridge and tunnel owners and their service providers. However, a larger share of owners than providers are fully automated (30% versus 22%).

Service providers use more advanced automation methods

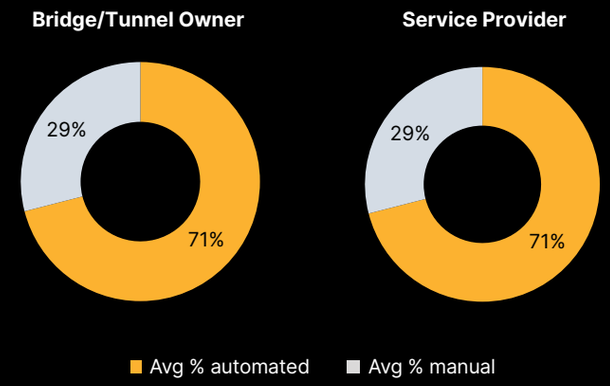
More owners make use of manual, in situ measurement. One reason is that owners commonly do routine visual inspections, basic measurements, and manual monitoring tasks internally, leveraging their on-site staff and expertise for these activities.

Many owners likely are outsourcing more advanced automated monitoring to engineering firms and other providers with the necessary capabilities, technology, and experience. Indeed, more providers than owners (44% versus 39%) use the most advanced method—sensors with near real-time transmission via telemetry.

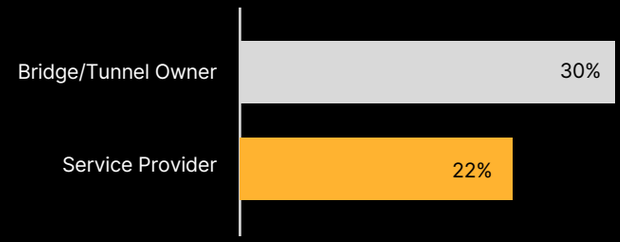
> People are inclined to make errors, whereas automation carries out tasks with unwavering accuracy.
>
> – Project engineer, U.S. bridge/tunnel owner

Q. How does your organization collect data for its monitoring programs?
Q. What percentage of your organization's monitoring utilizes manual data collection?

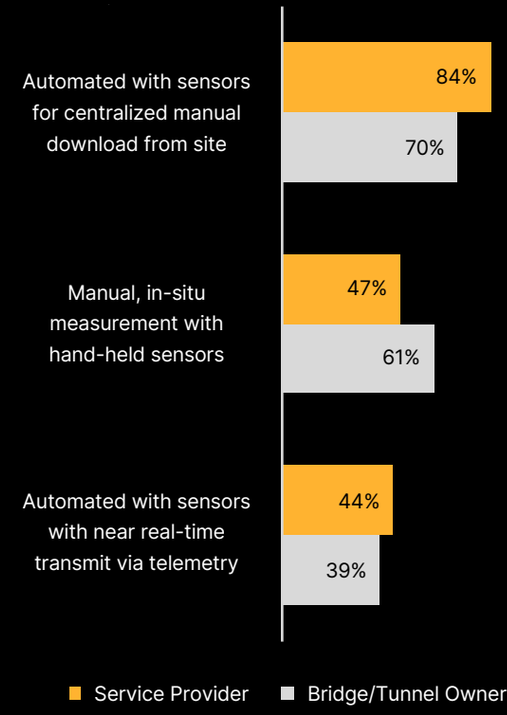
Average % automated vs. manual data collection



% that fully automate their data collection



Monitoring data collection methods



Specialized software simplifies monitoring

On average, bridge and tunnel service providers use more software applications (4.2 out of nine covered in the study) than owners (3.7) for their sensor monitoring activities. Both types of organizations rely on Excel and Tableau heavily, but service providers are more likely to use Power BI.

Both also use cloud IoT solutions like Azure IoT and AWS IoT at about equal rates, but they use different specialized software. Providers more often use eagle.io, while owners favor Vista Data Vision and sensemetrics.

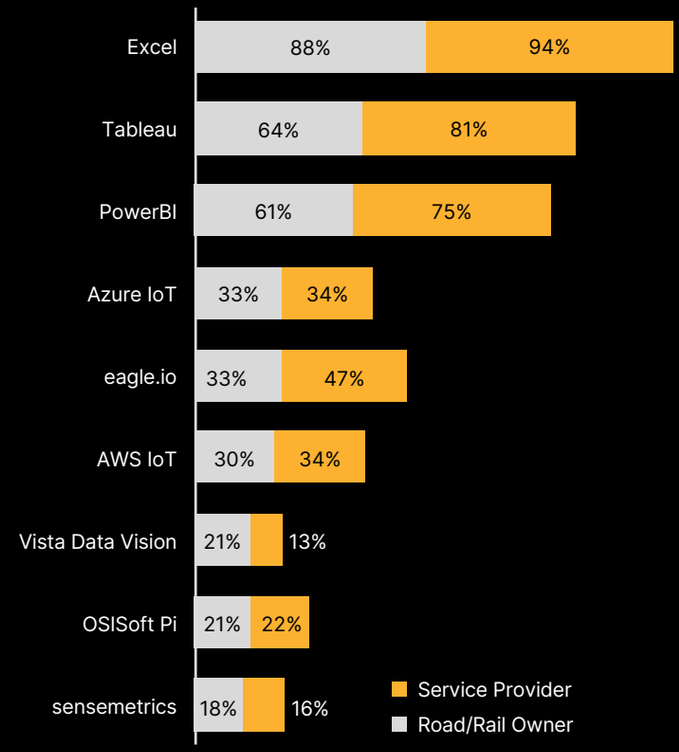
These specialized systems can simplify and enhance condition monitoring in many ways. They enable real-time monitoring of data, quick deployment without extensive hardware configuration, data consolidation and integration, and advanced visualization and customized reporting. Hence, both owners and providers are likely to increase their use of specialized systems as they shift more towards automated monitoring.

Integration with other data sources is key

Organizations can enhance the value of condition monitoring data if they integrate it with data from other information sources. Asset management systems are the most common external source of data utilized by both bridge and tunnel owners and their service providers to increase insights from their sensor data. Such systems offer real-time and historic data that operators and providers can use to support decision-making. Service providers integrate slightly more types of external data than owners (2.9 versus 2.4).

Q. What software do you leverage for sensor monitoring activities?
Q. Is your organization currently integrating sensor data with additional information sources to increase insights? If so, which of the following apply?

Software used for analysis



Integrating sensor data with other sources

	Bridge/ Tunnel Owner	Service Provider
Asset management systems	76%	72%
Public data	48%	47%
GIS layers	39%	50%
Digital twins	39%	31%
Predictive models	15%	56%
Remote sensing data	15%	16%
Drone-based photogrammetry	9%	22%

Pain points diminish with automation

Automation alleviates many of the pain points experienced by bridge and tunnel organizations in their condition monitoring programs. Those using any degree of manual data collection report 1.9 challenges on average (out of six covered here), while fully automated organizations report only 0.5.

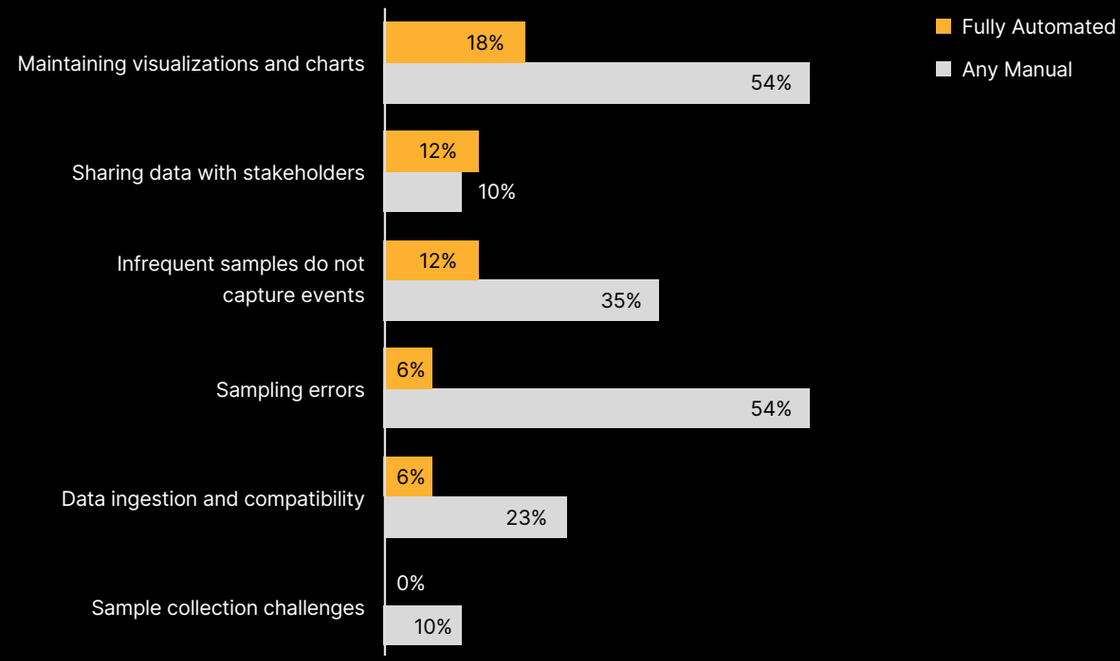
Digitized processes deliver higher data integrity

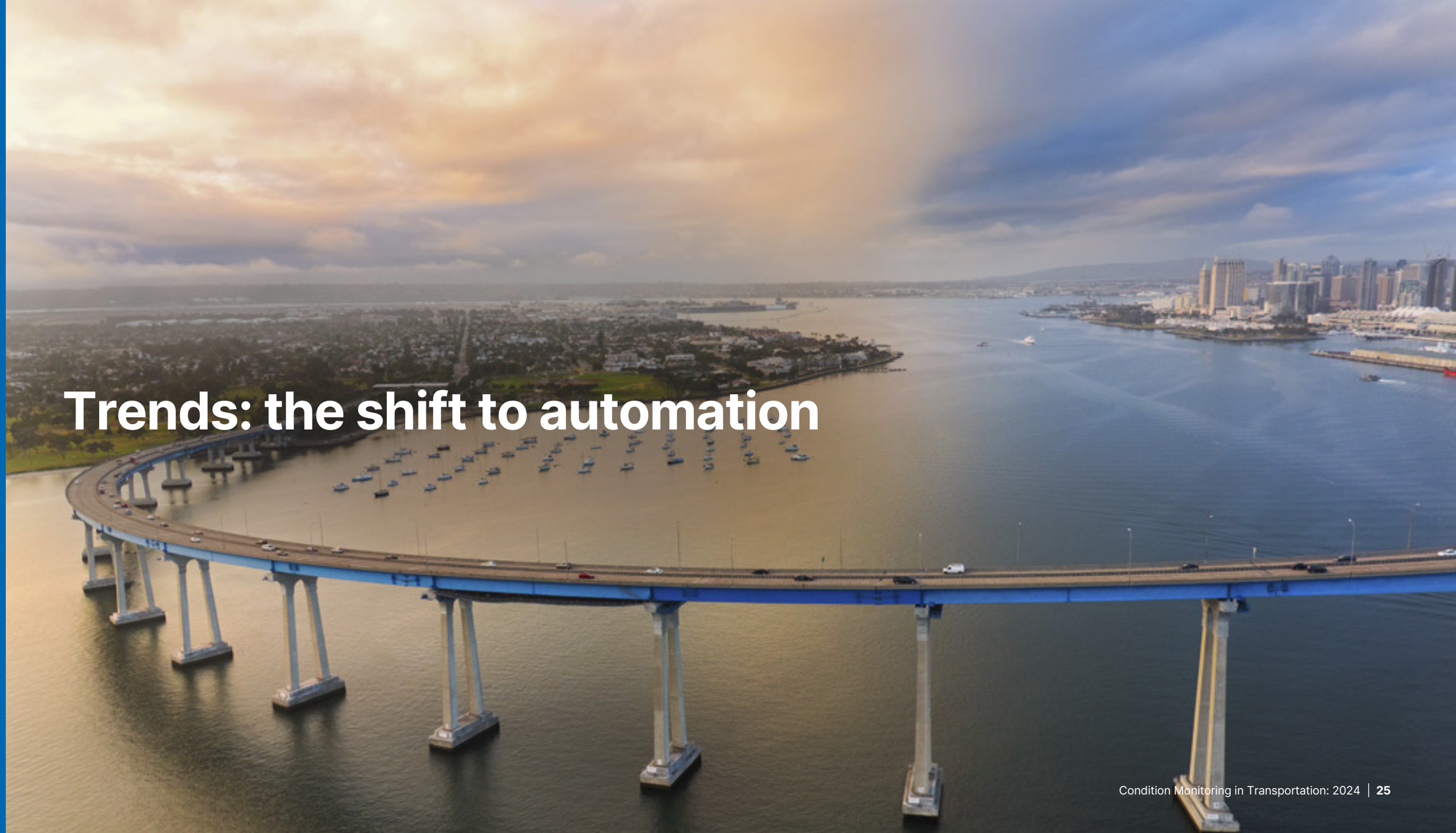
There are other stark differences in the challenges cited, particularly in sampling errors, by 54% of organizations doing any manual monitoring versus 6% of fully automated ones. More than half (54%) of any manual organizations face problems with maintaining visualizations versus just 18% of fully automated ones. Infrequency of measurements is a challenge for 35% of any manual organizations versus 12% of fully automated entities. No fully automated organization reported a problem with sample collection versus 10% of those doing any amount of manual monitoring.

> People are inclined to make errors, whereas automation carries out tasks with unwavering accuracy.”
>
> – Project engineer, U.S. bridge/tunnel owner

Q. What are the largest challenges that your organization experiences with its current monitoring programs?

Condition monitoring challenges





Trends: the shift to automation

Monitoring scope and parameters are increasing

Over the past two years, many bridge and tunnel operators and their service providers took steps to further automate condition monitoring, increasing their use of automated, real-time data collection (cited by 18% of owners and 22% of service providers).

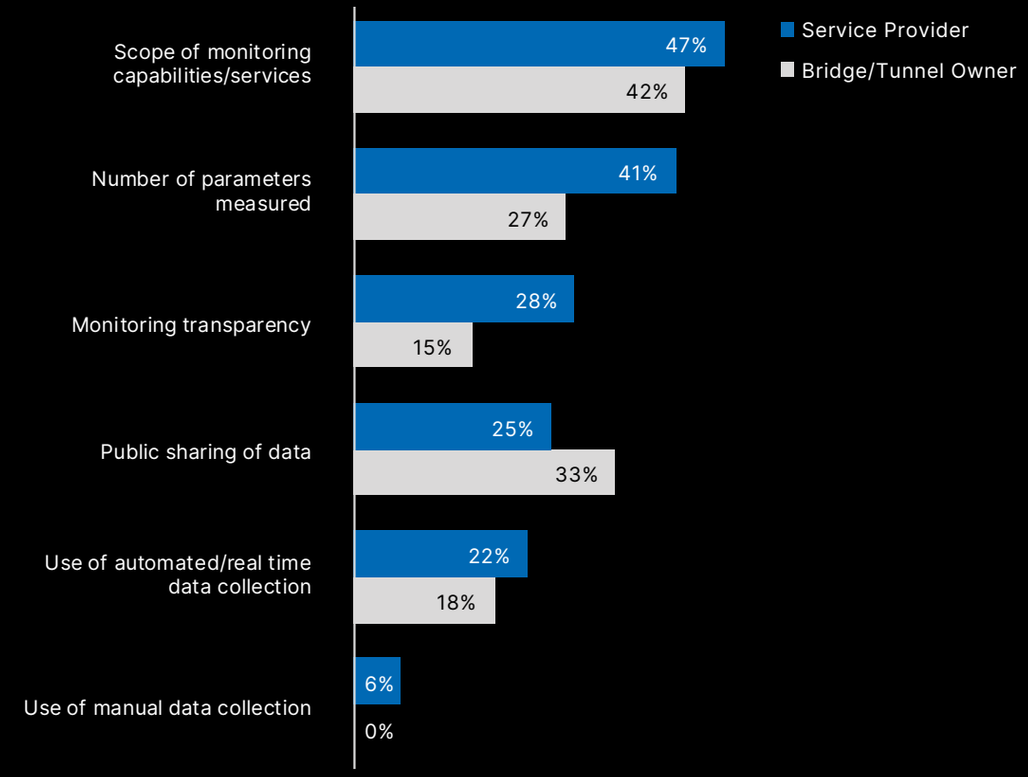
This trend has been accompanied by other developments. More than 40% of both types of organizations boosted the scope of their monitoring capabilities. More than 40% of providers and 27% of owners increased the number of parameters they measure. Nearly 30% of providers and 15% of owners increased monitoring transparency.

Sharing data builds trust with the community

At the same time, one-quarter of providers and one-third of owners boosted their public data sharing. Bridge and tunnel owners may be under more pressure by stakeholders to share information about the condition of such critical infrastructure. On the other hand, providers may be more cautious out of concern to protect the privacy and security of sensitive information about their clients.

> As organizations expand, manual procedures become progressively more time consuming and ineffective."
>
> – Senior engineer, Australian bridge/tunnel owner

Organizations reporting increases in monitoring practices



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

Social license is key driver of automation

With aging infrastructure causing safety and environmental concerns among the public, both service providers and bridge and tunnel owners see social license as a prime driver of automated monitoring. Automation allows owners and providers to communicate performance information swiftly and more accurately by enabling monitoring of more parameters and providing real-time data on the integrity of their infrastructure.

Other factors motivating automation, such as technology, operational demands, economics, and regulations, also influence their decisions, albeit typically more moderately.

Bridge and tunnel owners see technology and operational demands as somewhat more important than service providers, while the latter are more influenced by economic drivers as they look to cut costs.

Growing impact of governmental regulations

Government regulations are not viewed as very influential by most owners and providers, but they are still a moderate factor for more than 60% of organizations surveyed. Regulators such as the U.S. Federal Highway Administration, for example, impose requirements on the design, construction, maintenance, and inspection of bridges and tunnels. Similar standards apply in Europe and elsewhere. Recent bridge collapses, such as the Fern Hollow Bridge in Pittsburgh in 2022, could heighten regulatory scrutiny in the future.

Q. How influential are the following external market forces in driving adoption of automated monitoring?

Forces driving adoption of automated monitoring

		Bridge/Tunnel Owner	Service Provider
Social license - Need to communicate strong condition performance to stakeholders	Very influential	64%	72%
	Moderately influential	18%	19%
Technology - The advent of more accurate, lower cost sensors, gateways, telemetry, and cloud processing	Very influential	39%	31%
	Moderately influential	61%	66%
Operational demands - Requirement to measure and respond to conditions that might impact my business in real time	Very influential	33%	25%
	Moderately influential	58%	69%
Regulatory - Increasing governmental requirements to implement real-time monitoring to detect or avoid harm	Very influential	21%	25%
	Moderately influential	67%	63%
Economic - e.g., the cost of labor and manual monitoring is increasing over time, automated data collection is becoming more economically feasible	Very influential	21%	31%
	Moderately influential	76%	63%

Owners and service providers see benefits from automation

The greatest benefit of automated monitoring for bridge and tunnel owners and their service providers is reducing project costs. More than eight out of 10 organizations in both groups cite cost reduction as a benefit. Automated monitoring helps to trim costs by reducing the frequency of manual inspections and enabling targeted maintenance efforts.

Overall, owners see slightly more benefits from automation than service providers. They report 2.8 benefits (out of five) on average versus 2.5 reported by providers.

Automated monitoring boosts productivity and revenue

Over three-quarters of bridge and tunnel owners report a greater capability to move into new markets, while only 38% of providers say the same. Nearly 40% of owners and 25% of providers say they can execute more projects in a year.

However, more service providers than owners report the ability to unlock recurring revenue (56% versus 48% of owners) and operate with leaner teams (44% versus 30%).

> By improving our data-gathering process, we've reduced mistakes and discrepancies, ensuring greater accuracy."
>
> – Technician, Australian service provider for bridges and tunnels

> By improving response times and eliminating process bottlenecks, we can enhance customer service and satisfaction."
>
> – Senior manager, Canadian service provider for bridges and tunnels

Q. How has the shift to automated monitoring affected your business?

Benefits of shifting to automated monitoring

	Bridge/Tunnel Owner	Service Provider
We can execute projects more cost effectively.	82%	88%
We have more capability to move into new markets.	26%	38%
We are able to unlock recurring revenue.	48%	56%
We can execute more projects in a year.	39%	25%
We can operate with leaner teams/staff.	30%	44%

A look to the future

The industry will continue to automate

Bridge and tunnel operators and their service providers will make strides in automating their data collection over the next two years. While on average the share now is 71% for both groups, it will rise to 79% for owners and 80% for providers. This will put them essentially on par with the averages for all industries in the study, which includes roads and railways, dams, utilities, and water distribution/wastewater.

80% say automation lowers project costs

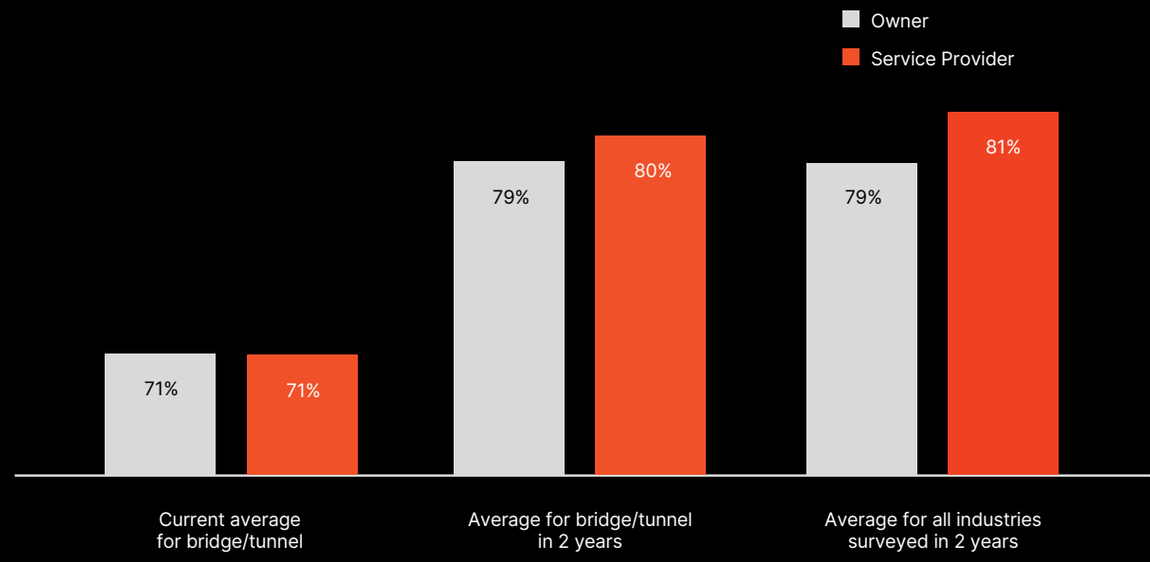
Owners and providers expect to keep some monitoring manual because of the need for human oversight, values, and judgment. Some may not yet fully trust automated methods.

Yet advanced organizations realize that automation will enable staff to spend less time on mundane tasks and more on using the personal skills and insights that separate them from machines.

One misconception is that manual processes are less expensive. Our study shows the opposite: more than 80% of owners and service providers say that automation enables them to run projects more cost effectively.

> By enabling human agents to concentrate on other intricate tasks, automation enhances the overall performance of the company."
>
> – Architect, Dutch service provider for bridges and tunnels

Average percentage of automated data collection



Q. What percentage of your organization's monitoring utilizes manual data collection? What percentage of your organization's monitoring data do you expect to still be manually collected in two years?

Automation is needed to future proof the industry

The message is clear for both bridge and tunnel owners and service providers: in the long term, automated data collection is crucial for meeting the needs of stakeholders.

Automation will drive the future readiness of owners...

Many bridge and tunnel owners that perform any manual data collection may need to reevaluate their practices—driven by factors that include social license, operational needs, and regulations. Thirty percent believe they will not be able to meet the demands of their stakeholders in 10 years with their current approach. Even those owners that believe their manual approach will remain effective may be underestimating growing pressures from businesses and citizens, as declining infrastructure raises environmental, safety, and other concerns.

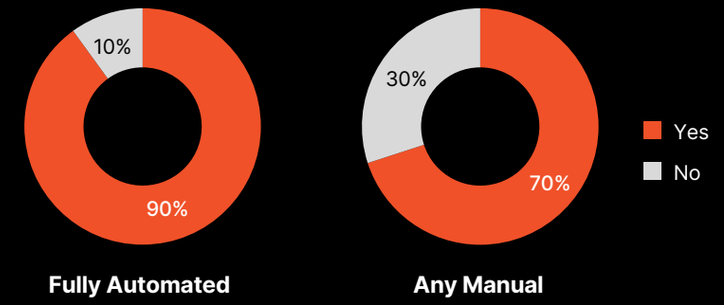
Tellingly, even 10% of fully automated owners believe they will not be able to meet the future stakeholder demands, reflecting just how stringent these stakeholder calls to action may become.

...and the economic viability of service providers

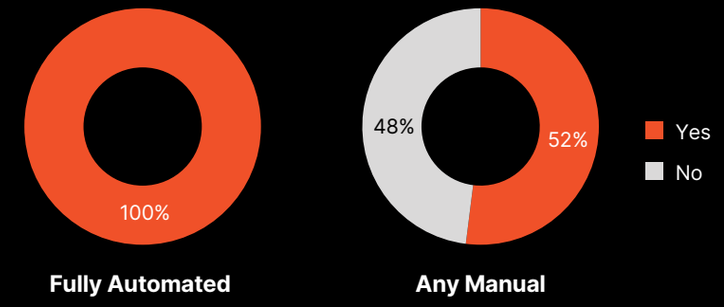
Similarly, many service providers will need to pick up the pace on automation to ensure the future economic viability of their monitoring practices. While every fully automated service provider believes that its data collection approach will be economically viable in 10 years, 48% of those doing any manual collection believe their practices will not.

Q. Bridge/tunnel owner: Do you think your organization can continue to meet the demands of various stakeholders in 10 years if it continues with its current data collection approach?
Q. Service provider: Do you think your organization's condition monitoring practices will be economically viable in 10 years if you continue with your current data collection approach?

Meeting stakeholder demands through data collection practices



Economic viability of condition monitoring practices



Key takeaways

How automation is improving condition monitoring for bridges and tunnels

As is the case with roads and railways, owners and their service providers in the bridge and tunnel sector are advancing in automating their data collection for condition monitoring. At present, 71% of data is collected using automated methods by both owners and providers, and over the next two years, this will go up to 79% and 80%, respectively. Our research shows that the move to automation generates several key benefits for bridge and tunnel owners and providers:

1. **Fewer hurdles in their condition monitoring practices.** Fully automated bridge and tunnel organizations report fewer problems on average: 0.5 versus 1.9 (out of six challenges reviewed in this report) for those doing any manual data collection. Issues with maintaining visualizations and charts, infrequent measurements, and sampling errors are largely relieved for bridge and tunnel organizations through automation.

2. **Ability to increase their scope of monitoring and number of parameters measured.** While 42% of owners and 47% of providers have increased the scope of their monitoring, the figures are higher for fully automated entities: 70% and 57%, respectively. And while 27% of owners and 41% of providers have increased the number of parameters measured, for fully automated organizations, the percentages are 60% and 57%.

3. **Ability to integrate sensor data with more external information sources.** Organizations that are fully automated can more easily integrate their data with other sources. They integrate data from 3.4 sources on average (out of 7 sources studied) versus 2.6 for those that are manual. The top sources are asset management systems, public or government data, and GIS layers.

4. **For owners, top benefits are cost effectiveness and ability to expand.** Both owners and providers report business benefits from their shift to automation. More than 80% of owners say they can execute projects more effectively, and 76% say they have more capability to move into new markets.

5. **For providers, the top benefits are cost effectiveness and revenue gains.** Nearly 90% say they can execute projects more effectively and 56% say that automation helps them to unlock recurring revenue.

Lessons learned on the road to automation

We asked bridge and tunnel owners and their service providers for advice on shifting to automation in condition monitoring. Here are five lessons learned.

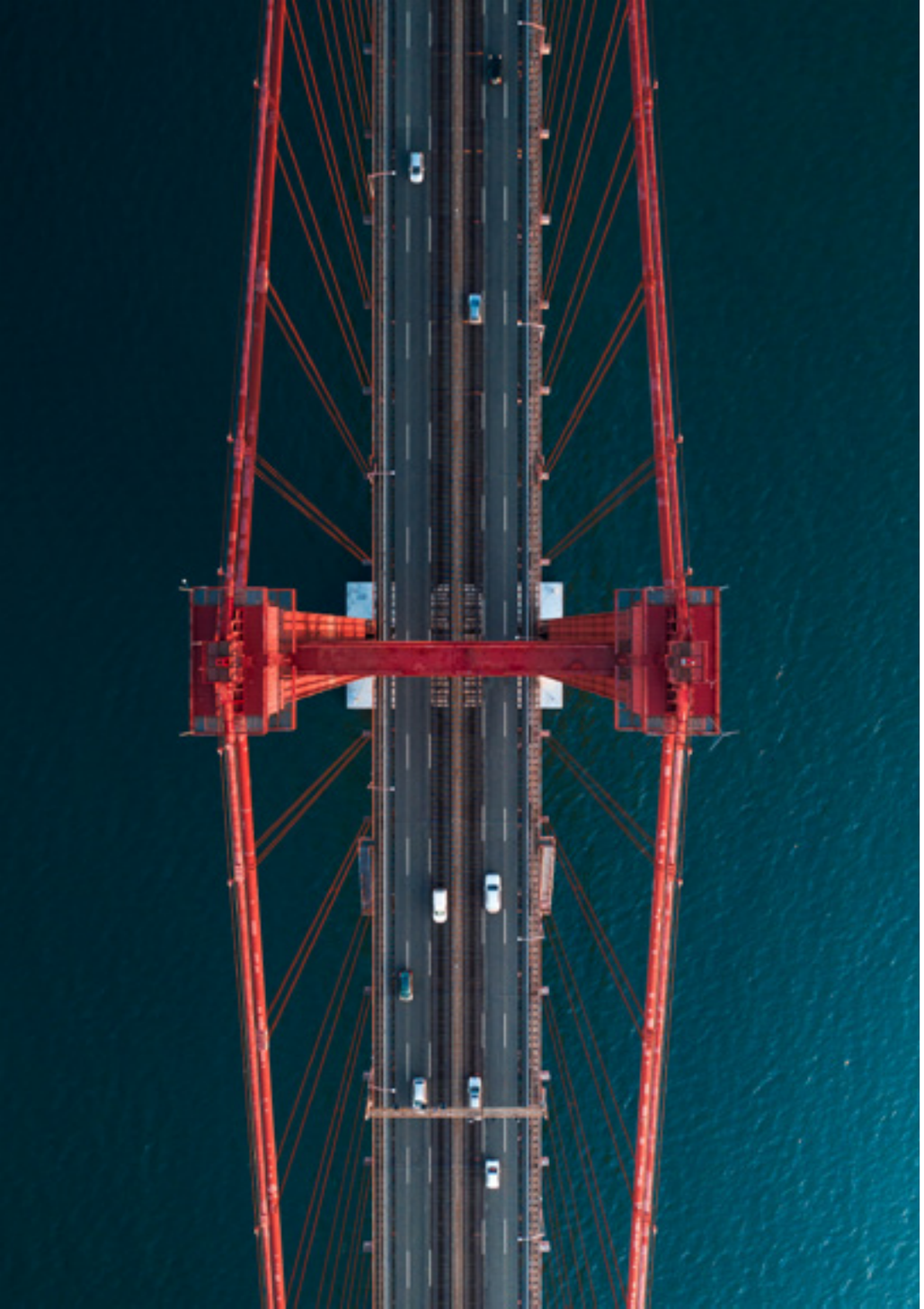
1. **Develop an effective implementation plan.** Organizations that establish detailed plans as they shift to automation can achieve better results. An IT manager with a Canadian bridge and tunnel owner said: “Proper planning is essential for successfully implementing automation.” A technical manager with another Canadian owner said: “Make sure to take into account all aspects of automation to enable a methodical approach to implementation.”

2. **Build robust data quality controls.** Successful automation depends on data quality. “Automation can improve quality control, but it’s essential to have robust quality assurance processes in place to monitor the performance of automated systems,” said a site supervisor with a German bridge and tunnel operator. A drafter with a U.S. owner said: “Creating standard rules for gathering, examining, and sharing information through automation guarantees consistency and accuracy.“

3. **Be willing to adapt and refine processes.** Organizations need to be flexible and keep on top of technological advances. A director of risk management with a Canadian owner said: “By adopting a culture of ongoing refinement, automation can be effectively tailored to meet the evolving demands of the business.”

4. **Find the right technology partner.** Bridge and tunnel organizations cannot do it all alone. A technical employee with a U.S. owner said: “Choose the right vendor based on experience, expertise, product offerings, and ability to support specific needs.”

5. **Educate, engage, and train employees.** Companies should reassure their technical staff that automation is not a replacement for their roles. Automated condition monitoring aims to reduce or eliminate the tedious, time-consuming tasks of manual data collection, allowing staff to focus on more important and engaging work. A manager with a bridge and tunnel owner in Europe said: “To balance the benefits of automation, the need for human oversight and decision-making is important.”



The future of condition monitoring for bridges and tunnels

The integration of advanced technologies and data-driven methods is expected to transform condition monitoring of bridges and tunnels. Additionally, the insights provided by advanced monitoring can inform future infrastructure design and make bridges and tunnels more efficient, reliable, and sustainable. Here are some key trends and innovations expected to shape the industry:

1. **Enhanced safety through accessible, integrated data.** Connecting data sources, such as work records, satellite, and drone data, will enable comprehensive condition monitoring of bridges and tunnels. Artificial intelligence will detect early signs of risk changes, making timely intervention possible. Engineers will be able to access both real-time and historical data on site, making inspection and maintenance procedures safer.

2. **Advanced bridge and tunnel monitoring will improve reliability.** By leveraging advanced condition monitoring, performance anomalies can be identified early, allowing for proactive maintenance and minimizing unexpected downtime. The integration of diverse data sources—such as visual inspections, historical records, vehicle-mounted measurements, and satellite and drone data—will enhance root cause analyses, sustainability simulations, and asset lifespan predictions. Additionally, real-time traffic reporting will aid in better congestion management and improve travel reliability.

3. **Environmental impact monitoring will increase resilience.** Continuous monitoring of environmental changes, both natural and built, will enable real-time evaluation of their effects on the risk profile of bridges and tunnels. Extrapolating these impacts will provide predictive insights into future risks, allowing for preemptive actions to increase resilience.

4. **Better security is made possible with advanced technology.** Advanced monitoring systems will identify and report unauthorized access, usage, activities, and theft, protecting bridge and tunnel infrastructure from potential threats and maintaining operational integrity.

5. **More accurate future spending forecasts.** Predictive models will use condition data, deterioration rates, and failure rates to forecast future financial requirements—such as the need for spare inventory and their geographic distribution. These forecasts will allow for more precise budgeting and allocation of resources, helping to make sure bridge and tunnel maintenance and upgrades are properly funded and carried out.

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