

Quantum Sensing in Transport & Logistics

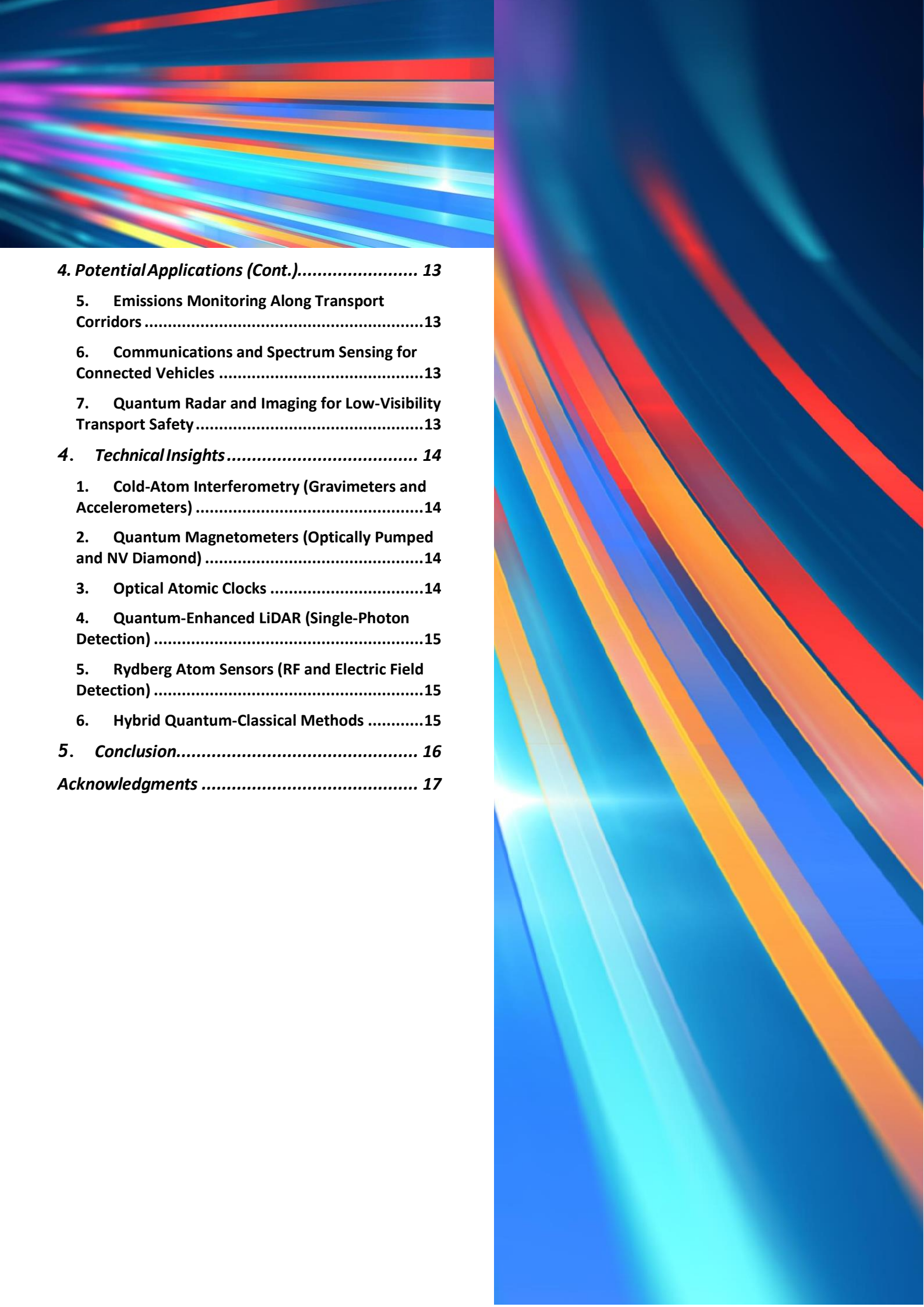
Market Research Update

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1. Overview

Quantum sensing is emerging as a transformative technology for the transport and logistics industry, addressing critical challenges that conventional sensors cannot solve. Quantum computing, also called processing, is underway. Quantum sensing, exploiting proven physics principles, is already delivering measurable results in the field across aviation, maritime, rail, and road transport.

At its core, quantum sensing harnesses three properties of quantum mechanics: superposition (atoms existing in multiple states simultaneously), entanglement (correlated quantum states between particles), and quantum interference (which amplifies tiny physical signals into measurable patterns). In a typical quantum sensor, atoms are cooled to near absolute zero using lasers, placed into quantum superposition, and then allowed to interact with the physical quantity being measured, such as a gravitational or magnetic field. When the atoms' quantum states are read out, tiny differences caused by external forces appear as measurable interference patterns. Because these measurements are tied to immutable atomic properties rather than manufactured components, quantum sensors are inherently self-calibrating and drift-free.

For non-technical readers, the key insight is this: classical sensors (accelerometers in smartphones, gravity meters used in construction, magnetometers in compasses) all accumulate errors over time because their mechanical or electronic components gradually shift. A high-end military inertial navigation system drifts by roughly 1.8 kilometres per hour without GPS corrections. Quantum sensors, by contrast, reference the unchanging properties of atoms themselves, so their measurements remain accurate for far longer periods.

The transport sector faces several urgent problems that quantum sensing can address. GPS spoofing and jamming affected over 1,000 commercial flights daily in 2024, creating safety risks for aviation and shipping. Underground utility mislocations cost the UK an estimated £319 billion over two decades, disrupting road and rail construction. Ageing infrastructure (bridges, tunnels, rail tracks) requires inspection methods that go beyond visual assessment. Precision timing for logistics networks becomes critical as autonomous systems proliferate.

Government investment in quantum sensing now exceeds \$10 billion globally. The UK committed £2.5 billion through its National Quantum Strategy. The US National Quantum Initiative Reauthorization Act (December 2024) authorizes \$2.7 billion for FY2025--2029. The EU Quantum Europe Strategy includes dedicated funding for quantum inertial navigation sensors. Industry analysts project the quantum sensing market will grow to \$3--10 billion by 2035, with transport and defence as the primary early adopters.

Belgium's contribution to this field is currently concentrated upstream, in enabling components and secure infrastructure rather than fielded transport sensors. imec (Leuven) is developing chip-scale control electronics for NV-diamond quantum sensors under the EU-funded ACDC_Q project, while Hasselt University's IMO-IMOMEC institute conducts complementary diamond quantum sensing research. Belnet, imec, UGent and partners have built Belgium's first quantum key distribution links under BeQCI, now extending cross-border through BENELUX-QCI with the Netherlands and Luxembourg --- infrastructure that would ultimately secure the sensor data and manifests moving through Belgian ports and rail corridors. KU Leuven's new Proximus Chair in Quantum Science and Technology, and the cross-sector Quantum Circle Belgium network, aim to translate this research base into commercial applications, positioning Belgium as a likely fast-follower once sensing hardware matures rather than a first mover in fielded transport trials.

The following sections present verified, publicly documented use cases across seven quantum sensing technology categories, followed by an analysis of potential future applications, the underlying sensing technologies, and a realistic adoption timeline.



2 Case Studies (extraction)

Multiple organizations have completed field trials, pilot projects, or early commercial deployments of quantum sensing technologies in the transport and logistics sector.

The table below summarises these use cases, followed by detailed descriptions of each.

Project / Organisation	Technology	Application	Country	Status	Sector
Q-CTRL Ironstone Opal	Quantum magnetometer	GPS-free airborne and maritime navigation	Australia / USA	DO-160 airworthiness qualified; Airbus/Lockheed Martin deployment; DARPA contract	Defense / Aviation / Maritime
SandboxAQ AQNav	Magnetic anomaly navigation	GPS-free aircraft navigation (C-17, multi-type)	USA	200+ flight hours; USAF SBIR Phase II	Defense / Aviation
Boeing / AOSense multi-sensor flight test	Quantum inertial measurement unit	Multi-sensor GPS-free flight navigation	USA	Completed 2024; X-37B test pending	Defense / Space / Aviation
University of Birmingham / Delta g	Cold-atom quantum gravimeter	Underground infrastructure mapping for roads	UK	Published in Nature (2022); spinout funded	Infrastructure / Civil Engineering
Network Rail / QT-PRI project	Quantum gravity sensor	Buried culvert detection beneath railway tracks	UK	Research completed	Rail / Infrastructure
Exail (ex-Muquans / iXblue)	Absolute Quantum Gravimeter	Seabed mapping; gravity-aided navigation	France	Commercial product (AQG); French Navy delivery 2024	Maritime / Defense / Geospatial
Imperial College London / Royal Navy	Cold-atom quantum accelerometer	Maritime and Arctic GPS-free navigation	UK	Sea trials 2023–2025; London Underground test	Maritime / Defense / Urban Transport
High-BIAS 2 / Infleqion / BAE / QinetiQ	Quantum optical clock + cold-atom gyroscope	Airborne quantum PNT system	UK	World-first flight test May 2024	Defense / Aviation
Vector Atomic / RIMPAC 2022	Optical atomic clock	Maritime precision timing (20+ days)	USA / NZ	Published in Nature (2024)	Maritime / Defense
SBQuantum / ESA / CSA	NV diamond magnetometer	Space-based magnetic field mapping for navigation	Canada	MagQuest finalist; ESA €800k contract	Space / Navigation
Bosch Quantum Sensing / Element Six	NV-centre diamond sensor	Automotive navigation and EV battery monitoring	Germany	Joint venture est. 2025; prototype stage	Automotive / Energy
QLM Technology	Quantum Gas LiDAR	Methane leak detection along gas transport infrastructure	UK	Commercial product launched 2023	Energy / Utilities
Infleqion Tiqker / Royal Navy XCal	Quantum optical clock	Autonomous submarine GPS-free timing	UK / USA	Deployed October 2025	Defense / Maritime
MoniRail / Network Rail RQINS	Quantum inertial navigation system	GPS-free mainline rail positioning	UK	Mainline trial 3 Mar 2026 (Great Northern); Innovate UK/DSIT funded	Rail / Infrastructure



CPI TMD Harlequin	Quantum-classical hybrid INS (gMOT cold-atom accelerometer)	Maritime GNSS holdover extension	UK	Sea trial completed Dec 2025 (THV Galatea); second trial planned end 2026	Maritime / Defense / Navigation
Inflection Quantum Spectrum (RIQER / QuDiFi / QOBRA)	Rydberg atom RF receiver	Full-spectrum RF sensing for GPS-denied navigation and comms	USA / UK / Australia	Category launched May 2026; field programmes in 3 nations	Defense / Communications / Navigation

3 Case Studies (detail)

1. Magnetic Navigation for Aircraft (Q-CTRL)

Q-CTRL (Sydney, Australia) developed **Ironstone Opal**, named one of TIME's Best Inventions of 2025. Using optically pumped quantum magnetometers combined with AI-powered signal processing, it detects magnetic "landmarks" in Earth's crust and matches them to preloaded anomaly maps. In airborne trials, it achieved up to 111× better positioning accuracy than strategic-grade inertial navigation systems, with best-case accuracy of 22 metres (0.01% of flight distance). In July 2025, it completed 144 hours of continuous maritime operation aboard the Royal Australian Navy vessel MV Sycamore. Q-CTRL holds two DARPA Robust Quantum Sensors (RoQS) contracts totalling A\$38 million (with Lockheed Martin as subcontractor) and a U.S. Defence Innovation Unit contract for the QuINS prototype. In July 2026, Ironstone Opal became the first quantum navigation system to achieve safety-of-flight qualification under the RTCA DO-160 airworthiness standard, and is now deployed commercially with Airbus, in defence with Lockheed Martin, and in a new sub-1kg variant for NATO Class II+ surveillance UAVs.

2. Magnetic Navigation for Military Aircraft (SandboxAQ)

SandboxAQ's AQNav (spun out of Alphabet in 2022, named TIME's Best Inventions of 2024) is a real-time magnetic anomaly navigation system that has accumulated over 200 flight hours across 40+ sorties on four aircraft types, including the U.S. Air Force's C-17 GlobeMaster III. It met FAA en-route RNP 2 accuracy 100% of the time and RNP 0.3 (550-metre accuracy) 64% of the time. SandboxAQ holds contracts with the U.S. Air Force (SBIR Phase II), Airbus subsidiary Acubed, and was accepted into the NATO DIANA 2025 cohort.

3. Multi-Sensor Quantum Navigation Flight (Boeing / AOSense)

Boeing completed the world's first multi-sensor quantum navigation flight test in 2024: a four-hour GPS-free flight on a Beechcraft 1900D from St. Louis. The test simultaneously operated a six-axis quantum inertial measurement unit built with **AOSense**, SandboxAQ's AQNav, and an HRL Laboratories star tracker. The quantum IMU reduced navigation errors from tens of kilometres to potentially tens of metres over long flights. AOSense, a Stanford spin-off founded in 2004, has since had its quantum inertial sensor selected for testing aboard the X-37B spaceplane (launched August 2025).

4. Underground Infrastructure Mapping (University of Birmingham)

The University of Birmingham's **Gravity Pioneer project** achieved a world first in February 2022: detection of a 2×2-metre utility tunnel buried beneath a road surface, published in Nature. The device uses two clouds of laser-cooled rubidium atoms, achieving a signal-to-noise ratio of 8 with 0.5-metre spatial resolution. The £6-million UKRI-funded consortium included RSK Group, Teledyne e2v, Dstl, and Fraunhofer UK. The technology was spun out as **Delta g**, which raised £1.5 million in 2023 to create "Google Maps for the underground."

5. Railway Culvert Detection (Network Rail / QT-PRI)

Network Rail partnered with the University of Birmingham, RSK, and Atkins on the **QT-PRI project** (Quantum Technology - Potential for Railway Infrastructure), which evaluated quantum gravity sensors for detecting buried culverts beneath railway tracks. Blocked culverts cause saturated trackbeds, speed restrictions, and delays across Network Rail's inventory of over 190,000 earthworks and more than 6,000 km of buried assets with incomplete records. The gravity sensors demonstrated superior performance to ground-penetrating radar for locating deep structures.

3 Case Studies (detail)(cont.)

6. Commercial Quantum Gravimetry (Exail, France)

Exail (formerly iXblue/Muquans) offers the **Absolute Quantum Gravimeter (AQG)**, the only commercially available industrial-grade quantum gravity meter, achieving 1 μGal precision through cold-detection and positioning. Exail also demonstrated the world's first three-axis quantum accelerometer (QuAT) in 2022, published in *Science Advances*, achieving 50 $\times$ better accuracy than classical sensors alone.

7. Maritime and Arctic Navigation (Imperial College London)

Imperial College London demonstrated the UK's first cold-atom quantum accelerometer in 2018 and has since conducted sea trials aboard the Royal Navy research ship XV Patrick Blackett (2023) and an Arctic field trial aboard MV Anvil Point (2025), integrated in a QinetiQ NavyPOD. The sensor has also been deployed on the London Underground for rail signalling research, representing a rare example of quantum sensing applied directly to urban rail transport.

8. Airborne Quantum PNT System (High-BIAS 2)

The **High-BIAS 2 project** achieved a landmark in May 2024: the world's first publicly acknowledged flight test of quantum position, navigation, and timing (PNT) systems on an aircraft. Conducted at MoD Boscombe Down aboard QinetiQ's RJ100 demonstrator, the test integrated **Infleqtion's Ticker optical atomic clock** and a cold-atom quantum gyroscope. The consortium (Infleqtion, BAE Systems, QinetiQ, Fraunhofer Centre for Applied Photonics, and others) was funded by nearly £8 million from UKRI as part of the UK's £2.5 billion National Quantum Strategy.

9. Optical Clocks at Sea (Vector Atomic)

Vector Atomic demonstrated the reliability of quantum timing technology during the multinational RIMPAC 2022 maritime exercise by operating optical atomic clocks continuously for more than 20 days aboard the New Zealand naval support vessel *HMNZS Aotearoa*. The trial showed that these next-generation clocks can provide extremely accurate and stable timing in demanding operational environments, helping ships maintain navigation and communications when GPS signals are unavailable or disrupted. The results were published in *Nature* in 2024. The company has also achieved another important milestone by delivering the first space-qualified quantum atomic gyroscope, highlighting the growing maturity of quantum navigation technologies for both maritime and space applications.

10. Space-Based Magnetic Mapping (SBQuantum)

SBQuantum (Sherbrooke, Canada) uses nitrogen-vacancy diamond magnetometers that operate at room temperature without cooling. As one of three finalists in the U.S. National Geospatial-Intelligence Agency's MagQuest Challenge, SBQuantum is preparing space-based sensor tests with Spire Global. The European Space Agency awarded SBQuantum approximately €800,000 under its FutureEO Programme, and the Canadian Space Agency has tested the sensor at an altitude of 40 km in conditions reaching -60°C.

3 Case Studies (detail)(cont.)

11. Automotive Quantum Sensing (Bosch / Element Six)

Bosch Quantum Sensing (Germany), a 75/25 joint venture between Robert Bosch and Element Six (De Beers Group), is developing NV-centre diamond magnetometers for navigation and automotive applications. The prototype has shrunk from lab-scale to approximately smartphone-sized, with a target of matchbox-scale integration. Bosch estimates a global market potential of ~\$6 billion annually by mid-2030s for medical and mobility applications, including GPS-free vehicle navigation and EV battery monitoring.

12. Quantum Gas LiDAR for Pipeline Safety (QLM Technology)

QLM Technology (Bristol, UK) commercially launched its Quantum Gas LiDAR in July 2023: a single-photon detection system for *continuous methane and CO₂ leak monitoring* along gas pipelines and distribution infrastructure. Tested at Colorado State University's METEC facility, it detected 264 individual methane leaks over 81 days, achieving a 75% detection rate and 2.4-metre location accuracy. Partners include SLB (Schlumberger), TotalEnergies, and National Grid.

13. Autonomous Submarine Timing (Infleqtion Ticker / Royal Navy)

Infleqtion's Ticker optical atomic clock was deployed in October 2025 on the Royal Navy's Excalibur (XCal) extra-large uncrewed underwater vehicle --- the first-ever deployment of a quantum optical atomic clock on an autonomous submarine. *It supports sonar, fire control, and secure communications in GPS-denied underwater environments.* In December 2025, Safran Electronics & Defence and Infleqtion announced a strategic collaboration integrating Ticker with Safran's White Rabbit timing protocol, with commercial availability targeted for Q1 2026.

14. Rail Quantum Inertial Navigation (Network Rail / MoniRail)

A Rail Quantum Inertial Navigation System (RQINS) was trialled for the first time on any mainline railway in the world aboard a Govia Thameslink Railway Great Northern service between London and Welwyn Garden City on 3 March 2026. The system uses ultra-sensitive sensors to detect minute changes in motion and rotation, requiring *no external satellite signal and remaining resilient in tunnels, dense infrastructure, and jammed environments.* The development programme is led by a consortium headed by MoniRail with Imperial College London, the University of Sussex, QinetiQ, PA Consulting, and the National Physical Laboratory, backed by Innovate UK and the Department for Science, Innovation and Technology, and convened by GBRX, the strategic innovation body for Great British Railways. It builds on earlier quantum positioning trials run by the Ministry of Defence and on the London Underground, and aims to eventually reduce reliance on costly trackside positioning infrastructure while improving signalling, network planning, and condition monitoring.



15. Maritime Quantum-Hybrid Navigation (CPI TMD Harlequin)

In late 2025, CPI's TMD Technologies Division successfully completed sea trials of *Harlequin*, a next-generation navigation system that combines conventional navigation technology with quantum sensing. Tested aboard the operational Trinity House vessel *THV Galatea* during normal lighthouse service, the system demonstrated that quantum sensors can continuously correct the small navigation errors that gradually build up in traditional inertial navigation systems. This significantly extends the time a vessel can navigate accurately when GPS or other GNSS signals are unavailable, degraded, or deliberately jammed. Developed through an Innovate UK programme in collaboration with the University of Strathclyde, Imperial College London, and Kelvin Nanotechnology, the project represents an important step towards more resilient navigation for maritime applications. A second round of sea trials is planned for late 2026 to further improve the system before commercial deployment.

16. Quantum RF Spectrum Sensing (Inflection Quantum Spectrum)

In May 2026, Inflection introduced *Quantum Spectrum*, a new generation of quantum radio-frequency (RF) sensing technology designed to detect and analyze wireless signals with exceptional sensitivity and accuracy. Unlike conventional systems that often require multiple specialized antennas, the technology can monitor a very wide range of radio frequencies using a single compact sensor. Inflection is currently demonstrating the technology through government-funded programmes in the United States, the United Kingdom, and Australia, in collaboration with major defence and technology partners. While initially developed for defence applications such as navigation in GPS-denied environments and electronic warfare, the technology also has significant commercial potential. Future applications include improving aviation spectrum management, strengthening transport and critical infrastructure communications, detecting drones, and making wireless networks more resilient against jamming and spoofing.

Key Takeaways from These Case Studies

Quantum sensing has already been applied to a wide variety of transport and logistics problems, from airborne navigation to underground utility detection. In each case, a specific physical measurement (gravity, magnetic field, acceleration, timing) was performed with quantum-level precision, yielding results that classical sensors could not achieve. Magnetic navigation systems (Q-CTRL, SandboxAQ) have demonstrated 100× improvements over conventional inertial systems. Quantum gravimeters (Birmingham, Exail) have detected buried structures invisible to traditional survey methods. Optical atomic clocks (Vector Atomic, Inflection) have maintained sub-nanosecond accuracy for weeks at sea without GPS. Many of these projects were funded by defence agencies, but the transition to commercial transport is accelerating. The organizations that invest now in understanding these capabilities will be best positioned when quantum sensors transition from defence prototypes to commercial products.

4. Potential Applications (Cont.)

Beyond the demonstrated use cases, quantum sensing opens up several high-impact application areas in transport and logistics. Most revolve around navigation resilience, infrastructure safety, and operational efficiency. The following subsections describe the areas where quantum sensing is expected to have the greatest impact.

1. GPS-Free Navigation Across All Transport Modes

GPS vulnerability is the single largest driver of quantum sensing adoption in the transport sector. GPS signals can be jammed, spoofed, or simply unavailable (indoors, underwater, in urban canyons). Quantum inertial navigation systems (using cold-atom accelerometers and gyroscopes) and magnetic anomaly navigation (using quantum magnetometers) offer passive, unjammable alternatives. These systems emit no signals, cannot be detected, and work in any electromagnetic environment. Near-term applications include backup navigation for commercial aviation, autonomous vessel guidance in contested maritime zones, and positioning for autonomous vehicles in GPS-denied urban areas. The UK Department for Transport projects that quantum navigation could generate £8 billion in economic value for UK transport alone by 2035.

2. Underground Utility and Void Detection for Road and Rail

Three out of every five excavations for UK roadworks hit the wrong location, causing costly delays and safety incidents. Quantum gravimeters can map buried pipes, tunnels, sinkholes, and voids without excavation, detecting structures at depths unreachable by ground-penetrating radar. For rail operators, quantum gravity sensors can locate forgotten culverts, identify waterlogged embankments, and monitor subsidence beneath tracks. This application is among the nearest to widespread commercial deployment, with companies such as Delta g (University of Birmingham spin-out) and Exail already offering or developing portable systems suitable for field use.

3. Structural Health Monitoring of Transport Infrastructure

Ageing bridges, overpasses, tunnels, and rail structures require continuous monitoring for structural integrity. Nitrogen-vacancy (NV) centre diamond quantum sensors can detect fractures in prestressed concrete by non-destructively measuring magnetic flux leakage. This technique, demonstrated by researchers at the University of Stuttgart (2025), addresses a critical safety need for transport infrastructure across Europe and North America. Bosch Quantum Sensing is working to miniaturize NV sensors to chip scale, enabling their direct embedding in bridge decks and rail sleepers for permanent, automated monitoring.

4. Precision Timing for Logistics Networks and Autonomous Systems

Modern logistics depends on precise time synchronization: container tracking systems, port scheduling, fleet management platforms, and railway signalling all require accurate timestamps. Quantum optical atomic clocks (such as Inflektion's Tiqker and Vector Atomic's portable clocks) can maintain nanosecond-level accuracy for weeks without GPS updates, far surpassing conventional quartz or rubidium oscillators.

4. Potential Applications (Cont.)

As autonomous vehicles, drones, and robotic warehouse systems become more prevalent, the demand for GPS-independent precision timing will grow. Chip-scale atomic clocks (Microchip Technology's SA.45s CSAC, with over 100,000 units sold) already provide holdover timing for military and critical infrastructure applications and are expected to penetrate civilian transport within this decade.

5. Emissions Monitoring Along Transport Corridors

Quantum-enhanced LiDAR systems (such as QLM Technology's Quantum Gas LiDAR) enable continuous, remote monitoring of methane and CO₂ emissions along pipelines, port facilities, and transport corridors. With increasingly stringent environmental regulations (particularly the U.S. EPA's Methane Emissions Reduction Program and EU methane regulation), transport and logistics operators face growing obligations to detect and report emissions. Quantum LiDAR offers single-photon sensitivity, enabling detection of small leaks over large areas from fixed installations or vehicle-mounted platforms.

6. Communications and Spectrum Sensing for Connected Vehicles

Rydberg atom electric field sensors represent a frontier technology for transport communications. Infleqion's SqyWire quantum RF receiver, funded under DARPA's Quantum Apertures programme, uses Rydberg atoms to detect radio signals across an ultra-broad frequency range (HF through SHF). Future applications could include vehicle-to-everything (V2X) communications, spectrum management in dense transport environments, and electronic warfare protection for military logistics convoys. Thales demonstrated a related quantum interference filter at the 2025 Paris Air Show, replacing large RF antennas with a shoebox-sized quantum device.

7. Quantum Radar and Imaging for Low-Visibility Transport Safety

Quantum radar and quantum imaging remain largely at the research stage but hold significant potential for transport safety. The University of Waterloo demonstrated a 10× improvement over classical radar using quantum illumination at microwave frequencies under a \$2.7 million Canadian Department of National Defence contract. Fraunhofer IOSB's QUILT project is working on quantum ghost imaging to see through fog, smoke, and adverse atmospheric conditions. Practical quantum radar for transport applications is estimated to be at least a decade away, but early work in quantum-enhanced detection for autonomous vehicles and airfield operations is underway.

4. Technical Insights

To understand how quantum sensing delivers these capabilities, it is useful to know the key sensing technologies being deployed. Each exploits a different quantum-mechanical property to measure a specific physical quantity with extreme precision. Below are the primary technologies relevant to transport and logistics.

1. Cold-Atom Interferometry (Gravimeters and Accelerometers)

Cold-atom interferometers use laser-cooled atoms (typically rubidium or caesium) as test masses in a quantum superposition. An atom cloud is split, allowed to evolve under the influence of gravity or acceleration, and recombined. The resulting interference pattern reveals the gravitational or inertial force with extraordinary precision. This is the technology behind quantum gravimeters (University of Birmingham, Exail) and quantum accelerometers (Imperial College London, AOSense). Key advantages include absolute measurement capability (no need for external calibration), drift-free operation over extended periods, and sensitivity to gravity variations caused by underground voids, tunnels, or geological features. The primary technical challenge is size, weight, and power (SWaP): laboratory cold-atom systems fill optical tables, while field-deployable units currently occupy server-rack-sized enclosures. Miniaturisation is the critical engineering challenge.

2. Quantum Magnetometers (Optically Pumped and NV Diamond)

Quantum magnetometers measure Earth's magnetic field with sufficient precision to detect crustal anomalies (variations caused by geological formations, ore bodies, and human-made structures). Two main types are in use for transport. Optically pumped magnetometers (OPMs), used by Q-CTRL and SandboxAQ, exploit alkali-metal vapour cells where laser light polarises atomic spins, and changes in the magnetic field alter light transmission. NV (nitrogen-vacancy) centre diamond magnetometers, used by SBQuantum and Bosch, exploit a crystal defect in synthetic diamond that acts as a quantum sensor at room temperature without requiring cryogenic cooling. The key advantage for navigation is that the Earth's crustal magnetic field provides a unique, location-specific "fingerprint" that cannot be jammed or spoofed, enabling passive position fixing by matching sensor readings to preloaded maps. The primary limitation is the quality and resolution of available crustal magnetic maps, which vary significantly by region.

3. Optical Atomic Clocks

Optical atomic clocks trap individual atoms or ions and probe them with laser light at optical frequencies (hundreds of terahertz), achieving timing stability that exceeds microwave-based atomic clocks by orders of magnitude. Inflektion's Ticker and Vector Atomic's portable optical clocks have demonstrated sub-300-picosecond-per-day stability at sea. For transport, optical clocks enable extended holdover timing (maintaining accurate time for weeks without GPS), which is critical for submarine navigation, maritime synchronization, and resilient logistics network timing. Chip-scale atomic clocks (CSACs) offer a simpler, more mature alternative at lower performance levels (microsecond-per-day stability) in a package the size of a postage stamp.

4. Quantum-Enhanced LiDAR (Single-Photon Detection)

Quantum-enhanced LiDAR systems use single-photon detection based on the quantum properties of light to achieve superior sensitivity compared to classical LiDAR. QLM Technology's Quantum Gas LiDAR uses infrared laser pulses tuned to specific gas absorption wavelengths, detecting returning photons individually. This enables remote, continuous monitoring of gas leaks at concentrations and distances impossible for conventional optical gas imaging. The technology is directly applicable to gas transport infrastructure, port terminal safety, and environmental compliance monitoring along logistics corridors.

5. Rydberg Atom Sensors (RF and Electric Field Detection)

Rydberg atom sensors exploit atoms excited to very high energy states, where they become extremely sensitive to electric fields. By placing these atoms in a vapour cell and probing with laser light, researchers can detect radio-frequency signals across an ultra-wide bandwidth (from kHz to hundreds of GHz) with a single, compact device. This technology, demonstrated by Inflektion (SquWire) under DARPA's Quantum Apertures programme, could replace arrays of conventional antennas with a single quantum receiver. Transport applications include spectrum sensing for V2X communications, electronic warfare protection for military logistics, and communications in RF-congested environments such as ports and airports.

6. Hybrid Quantum-Classical Methods

Virtually all deployed quantum sensing systems use hybrid approaches that combine quantum measurements with classical signal processing, AI-based filtering, and traditional inertial navigation. Q-CTRL's Ironstone Opal pairs quantum magnetometers with proprietary AI to achieve real-time position fixes. SandboxAQ's AQNav uses machine-learning algorithms to match magnetic signatures to crustal maps. Boeing's multi-sensor test integrated quantum inertial, magnetic, and celestial navigation. This hybrid approach is essential because quantum sensors alone do not provide complete navigation solutions --- they must be fused with complementary data sources. The classical AI and signal processing layer is often as important as the quantum hardware in determining overall system performance.

5. Conclusion

Quantum sensing has crossed the threshold from physics experiment to transport technology. The field's most compelling near-term applications, GPS-free navigation via magnetic anomaly matching (Q-CTRL, SandboxAQ), underground infrastructure mapping via gravity gradiometry (University of Birmingham / Delta g, Exail), and precision timing via optical atomic clocks (Infleqtion, Vector Atomic), are all in active field trials or early commercial availability.

The convergence of rising GPS vulnerability, massive government investment, and successful real-world demonstrations has created genuine momentum. What distinguishes quantum sensing from quantum computing is that it does not require fault-tolerant qubits or error correction at scale. The physics works today, and the engineering challenge is miniaturization and ruggedization rather than fundamental breakthroughs.

The timeline for adoption runs as follows:

Timeframe	Transport Application	Status
2024–2026	Defence and aerospace navigation; maritime trials	Active field trials with early operational deployment
2027–2030	Commercial aviation backup navigation; rail infrastructure monitoring	Commercial gravimeter availability
2028–2032	Autonomous vehicles; fleet management; port operations	Contingent on continued miniaturisation and cost reduction
2032–2035	Full integration into civilian transport infrastructure	Mass-produced quantum sensors manufactured using semiconductor production techniques, enabling costs comparable to today's conventional sensors.

Three barriers dominate the path to mainstream adoption.

- 1) Size, Weight, and Power (SWaP) remain the primary constraint, with Q-CTRL's software-based ruggedization and Bosch's miniaturization roadmap representing two complementary solutions.
- 2) Cost is the second barrier: current systems are priced for defence budgets, though wafer-scale fabrication could reduce component costs by approximately 40%.
- 3) Magnetic map quality is the third constraint specific to magnetic navigation, with SBQuantum's MagQuest work aiming to improve the World Magnetic Model that underpins all magnetic navigation.

The organizations that invest now in understanding quantum sensing capabilities, particularly in rail infrastructure monitoring, maritime navigation, and aviation resilience, will be best positioned when quantum sensors transition from defence-funded prototypes to commercial products over the next three to ten years.

***Sources:** The information and use cases in this document are based on publicly available company announcements, government press releases, peer-reviewed publications (Nature, Science Advances, Nature Communications), industry reports (McKinsey, BCG), and government workshop reports (U.S. DOT Quantum Technologies in Transportation Workshop, November 2024; UK Department for Transport quantum impact assessment, 2024). Each use case has been cross-referenced against primary sources.

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Disclaimer

This research paper represents a **snapshot in time**. The field it addresses is evolving at lightning speed, and insights, data, and interpretations may shift rapidly as new developments emerge. Readers are therefore encouraged to view this paper as a contribution to an ongoing conversation, rather than a final statement.

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(Applications in Transport & Logistics)

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