Private Networks for Transportation & Logistics

An overview of the challenges, market drivers, use-cases and trends for private networks in the transportation & logistics industry.

Disruptive Analysis

iBwave

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Summary

The transportation and logistics sector is one of the most promising industries for emerging private LTE and 5G networks, as well as adjacent technologies such as edge computing and new Wi-Fi6E/7 versions.

Ports, airports and warehouses/fulfilment centres are among the most advanced adopters so far, while railway stations, large aviation/marine manufacturers and others are starting to exhibit interest as well. Highway agencies, railway networks and municipal transit systems are lagging, although they are showing more interest in neutral-host infrastructure, as well as future specialised versions of 5G aimed at vehicle-to-vehicle or next-generation rail connectivity.

Companies and public agencies in this (broad and diverse) sector are deploying many applications with demanding requirements for wireless connectivity in terms of bandwidth, predictable latency, security and uptime. Video-based uses such as security cameras or remotely-driven vehicles can be major private 5G drivers, especially where outdoor settings are unsuited to Wi-Fi.

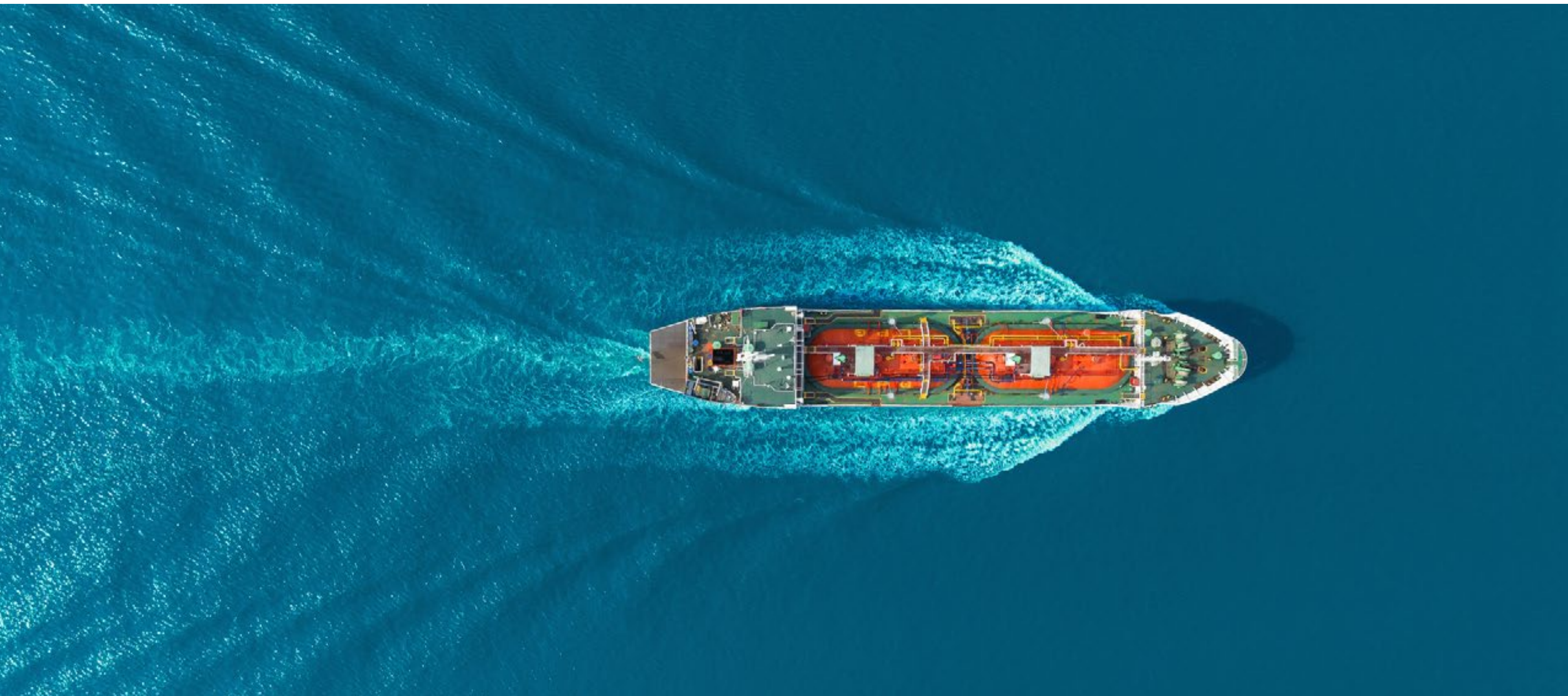
Given well-defined sites and a growing supplier ecosystem, transport hubs and logistics sites are rapidly becoming a key target for private wireless vendors and solution integrators.

Unlike many industries, transportation companies and organisations have long had sophisticated network infrastructure, often integrated with IoT and automation systems (“OT”, or “Operational Technology”), as well as more conventional IT and telecoms needs. As rail, ports and airports are parts of critical national infrastructure, they have often had highly resilient networks, and often dedicated technologies or spectrum for specific operational needs.

As all of these sectors become more automated and data-dependent, as well as facing growing challenges in both physical and cyber security domains. They also perform a central role in current shifts in global supply chains, as hubs for the distribution of containers, bulk products and smaller packages.

As 4G and 5G cellular matures, it is becoming “democratised” beyond traditional MNOs, by shifts in local spectrum and equipment availability. Private networks are now a growing reality.

Together, this is creating a match of supply and demand for private mobile networks, for onsite communications for staff, automation systems, vehicles, IoT sensors, cameras and infrastructure. This eBook outlines the main use-cases, deployment scenarios and paths to private 4G and 5G in transport and logistics industries. While this report focused mostly on the radio aspects, it is important to recognise that the broader ecosystem – from core networks to edge/cloud computing and planning / design / test systems – is evolving in tandem, along with a huge ecosystem of systems integrators and vertical specialists.



Definition of the transport and logistics sector

There are numerous transport and logistics sub-sectors and site types covered in this eBook. Although there are some common features and market drivers, there are also clear differences in locations' physical size and layout, as well as equipment and application platforms, legacy/alternative wireless technologies, regulatory oversight and technology conservatism.

The key domains covered in this eBook include:

- **Transportation hubs,** which refers to sites like ports, airports, stations and rail yards.
- **Logistics**, which relates to the centralised facilities for shipping, storage and sorting of containers and packages, such as warehouses and fulfilment / distribution centres.
- **Transport networks** including rail networks, metropolitan transit and light-rail systems, and road networks.

There are also often hybrid sites, such as FedEx's huge logistics "hub" sites next to Memphis and Indianapolis airports.

There is also some overlap with various other sectors, such as major manufacturing sites. For instance, aerospace manufacture and maintenance typically occur at combined factories/ airfields such as Boeing and Airbus' facilities. Similar combined operations occur in shipbuilding and train production. Mining, steel and cement companies may even have their own private rail-lines, from remote sites or industrial zones to multi-modal transit hubs at ports or cities.

For logistics sites, it should be noted that many facility owners also have large retail networks (such as Costco and Walmart), or other sites such as Amazon's AWS datacentres. Those ancillary operations and their specific applications are not directly included in this paper.

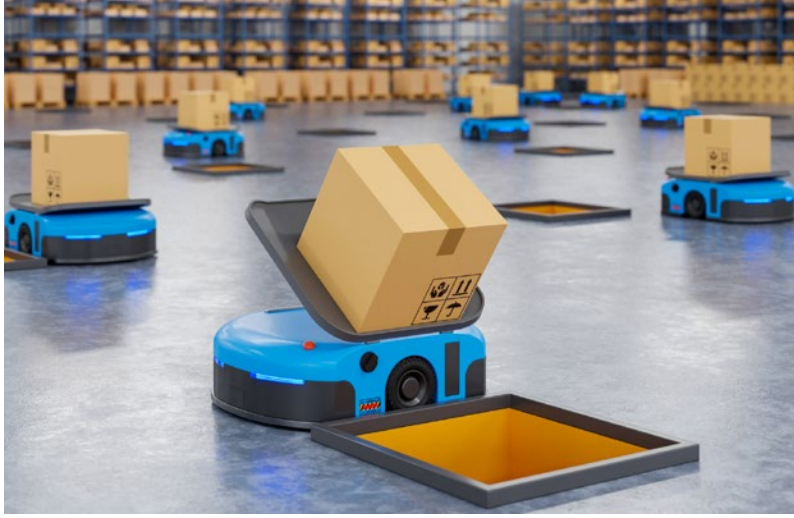
Key challenges and market drivers

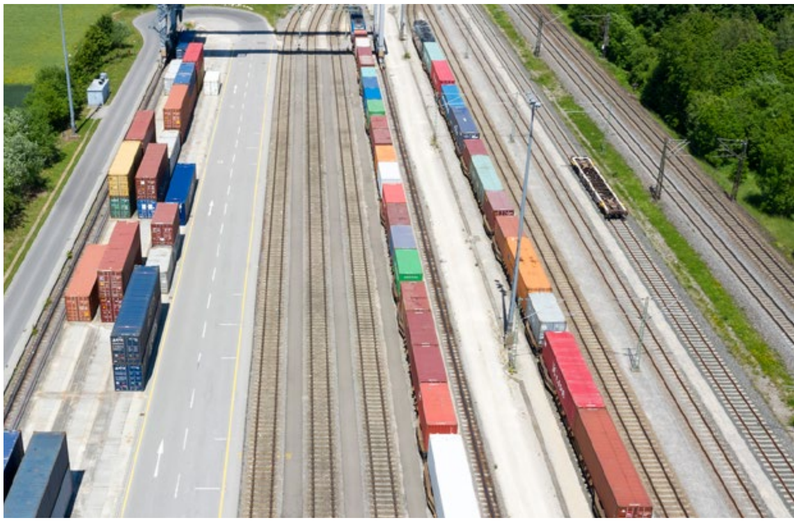
The demand for private networks for the transportation and logistics sector is ultimately driven by a number of top-level national and global changes, in addition to certain local factors such as political support for "free ports" or enterprise zones, or efforts to modernise railway networks.

Broadly speaking, these all create a greater requirement for connectivity, control and information flows – which then translates to more 4G and 5G networks, as well as Wi-Fi, fibre and wide-area network services.

Some of the key "megatrends" for logistics and transportation include:

- **Automation and robotics:** As discussed throughout this eBook, transport hubs and warehouses are becoming much more automated. Although port cranes, baggage-handling systems and automated guided vehicles are not new, they are being enhanced rapidly. In particular, robots and automated systems are using wireless video cameras for detecting packages, enabling remote-control and many other uses.
- **Data and analytics:** Transport and logistics companies are at the forefront of data-rich applications, from digital twins of jet engines and rail locomotives, to optimised scheduling and packaging of goods in fulfilment warehouses. Better-connected equipment, IoT sensors and video input can improve turnaround times, reduce shipment errors, reduce energy consumption and much more. Passenger-led transportation should face fewer delays, more dispersed crowds and improved customer service.
- **Predictive maintenance & asset management:** Transport systems are capital-intensive. The cost of downtime for a vehicle – or critical system in a





warehouse or airport terminal – can be huge. There is a huge opportunity for using networked information and sensors to enable "predictive maintenance" – fixing emergent problems before they become critical, or scheduling regular maintenance when it is needed rather than just based on a generic schedule. For instance, adding vibration and temperature sensors can give "early warnings" of issues, when anomalous readings are seen. There are also obvious safety benefits in areas such as aviation and maritime fault-diagnosis.

- **Improved employee safety and productivity:** There is far less tolerance of industrial accidents than in the past. Using automation and better information, transportation and logistics firms are looking to increase worker productivity at the same time as improving safety. This spans many aspects, from ensuring safe distances between workers and vehicles, to rapid reaction to any incident, plus improved recordkeeping and training. Reliable communication is essential, using both voice (often push-to-talk) and an increasing need for video communications and mobile access to enterprise application.
- **Climate change and decarbonisation:** Over the next decade, many transport and logistics businesses will face profound change as the planet heads towards Net Zero carbon emissions. Ports, airports, distribution centres and other sites are likely to need new electrical sources such as wind and solar, onsite battery storage, maybe hydrogen facilities and fleets of electric (often autonomous) site vehicles and machines. Connectivity will be needed for all of this, plus energy use monitoring, control, data-collection and reporting.
- **Geopolitics, re-shoring and supply-chain resilience:** Recent events such as the US-China trade war, the Covid Pandemic and the Russia/Ukraine war have highlighted the risks of global (and often fragile) supply chains to disruptive external events. As well as localised production, shipping and logistics will need to be much more efficient, automated and connected in order to re-route shipments, store inventory and deal with new paperwork and compliance requirements.
- **Cybersecurity:** Transport hubs and warehouses are part of national critical infrastructure. The rise of automation and cloud-based functions poses security challenges as well as gains from efficiency. Old IT, network and operational systems will be strengthened or retired if they have vulnerabilities, while networks will need extra resilience and redundancy. Wireless networks may be used as backups in case of failure of fibre or other links.

Combined, all of these broad factors, as well as company- or country-specific trends, are combining to mean that networks need to be:

- High-capacity and low-latency
- Wireless where possible, to enable mobility (e.g. AGVs) and access to locations where laying fibre is impractical.
- Standardised where possible, with a diverse supply chain and widely held skill sets
- Interoperable at the network layer and for protocols for messaging between different systems and partners.
- Available ubiquitously, either as-a-service, or on a privately-owned basis
- Secure and resilient, especially in sensitive "critical infrastructure" domains such as airports and railways
- Suitable both for large sites such as major ports, and smaller locations such as railway stations. In some cases they may need to scale up to national highway and rail networks.
- Lower (or at least predictable) costs per-site or per-device.

There is also a need for new network systems (such as 5G or Wi-Fi6/6E) to integrate with legacy connectivity types. This spans many different types of networking, both wired and wireless. Many of the more "Industry 4.0" features of 5G only become available in future, with later 3GPP Releases 16 / 17 / 18. This means that often multiple technologies will be used in combination, with a variety of integration or gateway approaches needed. Continual upgrades and refreshes are likely, as well as the addition of new use-cases.

(Also, outside the scope of this document, there is a huge amount of additional change occurring with network management and control, including cloud- and edge-based core networks and operational systems).

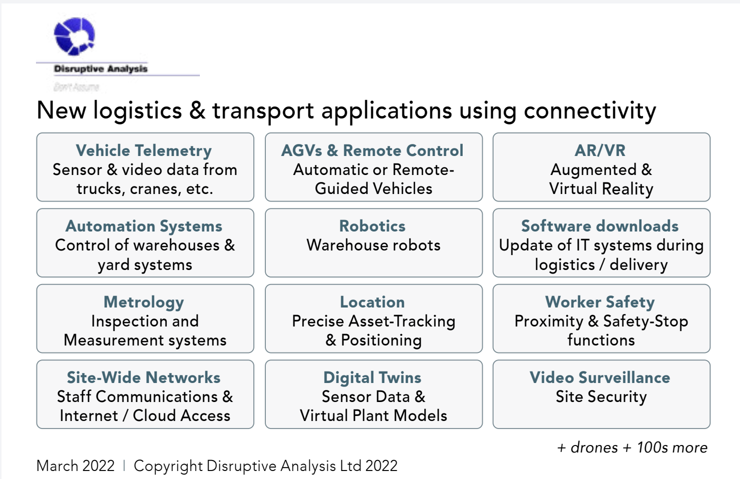
4G/5G use-cases in logistics and transportation

Given the industry structure and changes outlined above, there are two layers of questions to address in this report:

- What use-cases are suitable for cellular 4G and 5G connectivity?
- When is a private 4G/5G network more appropriate than a public network service from an MNO/carrier? [Note: some telcos are now offering fully "private" networks to their enterprise clients]

This section highlights some of the emerging use-cases that can benefit from cellular connectivity in the logistics and transportation sectors, especially for warehouses and fulfilment centres, ports and airports, which are probably the largest customers for private 4G/5G at the moment.

Other sectors such as rail networks and stations often have cellular coverage systems or neutral-host infrastructure for access to public mobile networks, but dedicated private systems are rare, beyond legacy GSM-R railway networks for critical operational communications.



(Future 5G variants like FRMCS will change that, but are years away).

While there are likely hundreds of applications overall – and some such as general office IT are omitted for conciseness – the following are typical of the aspirations of many companies in these sectors.

Vehicle telemetry & condition monitoring

Modern transport and logistics vehicles generate huge volumes of data, from motors, batteries, transmissions, wheels, hydraulic systems and external sensors for temperature, vibration and many other variables. This applies equally to dockside cranes, container and passenger ships, train locomotives, trucks and especially aircraft.

The data is used for multiple purposes, from preventative maintenance (by spotting incipient problems before damage occurs), to mandated record-keeping. Some data is used immediately for operational reasons, while other input is used to optimise performance, reduce energy consumption, improve maintenance practices and feed into "digital twins" (see later).

Trains and aircraft may need fast "batch" upload of telemetry data when they pull into a station, or come onto stand at an airport terminal, perhaps just for a few minutes at a time. Potentially gigabytes or terabytes may need to be transferred in a short period of time, uninterrupted by Wi-Fi congestion or contention for use of public cellular networks.

While some telemetry data will need to transit public 4G/5G mobile or satellite networks – for instance trucks on the road, or ships on the ocean – a large amount will be generated or sent "on campus" at ports, airports, logistics hubs and other privately-owned environments. The use of private 5G will be an important enabler for this type of application.

Automated or remote-guided vehicles (AGVs & tele-operation)

Various types of on-site and localised mobile vehicles and material-handling systems are used to move containers, packages or materials, either inside warehouse buildings or across larger sites such as ports. Inside buildings, automated guided vehicles or AGVs usually follow specific pathways and move quite slowly for safety reasons, separated from human workers. For larger outdoor areas such as container ports, much larger mobile units are used. Rail-mounted gantry (RMG) cranes move along the quayside on tracks, while straddle carriers or rubber tyred gantry (RTG) cranes have a greater range of movement around the container yards.

There is a significant shift towards remote-control or full automation of AGVs and cranes. This reduces risks of worker fatigue, removes safety hazards and eases recruitment challenges. They use connected cameras (sometimes ten or more) plus other sensors such as LiDAR, to analyse their surroundings, especially for safe use within the same spaces as human operators.

In future, airports are also likely to see more use of automated tugs, cargo tractors and baggage carts – with some already under remote control by human operators on the ramp. With high-definition cameras, plus sufficiently capable networks it should be possible to use a centralised control-tower for tele-operations for a large port or airport.

5G is an ideal connectivity option for this, supporting reliable and high-capacity upload of video, and low-latency downlink for control signals over wide areas, especially as the density of cameras and the height of some cranes is a challenge for Wi-Fi coverage. Future URLLC (Ultra Reliable Low Latency) capability will allow tighter edge-cloud integration and oversight, as well as interactions conducted accurately with other machines such as conveyor belts, lifting systems or docking/electrical charging points.

The critical importance and safety implications of such vehicles will likely mean that networks have to have overlapping, redundant coverage, with each unit having good connectivity to two or more cells.

AR / VR processes and training

Certain transport and logistics sites are early adopters of augmented and virtual reality technology – a field that is also starting to be included under the term "metaverse". AR headsets and glasses enable staff to work hands-free on complex tasks such as loading vehicles or select the right products from warehouse shelves. They can see shipment identification data, or see maintenance instructions displayed into their fields of view, or consulting remote experts.

As well as field operations, XR applications are useful for "back office" tasks such as product development and training. Designers can use VR to visualise new aircraft or train interiors. Simulations can identify the behaviour of passengers or staff in new airport terminals or rail stations. A wide variety of training tasks can benefit from AR/VR techniques.

Although Wi-Fi and wired connections tend to predominate for AR/VR today, 4G and 5G connectivity is becoming important for outdoor scenarios, or certain specialist applications. Cellular connectivity – as well as Wi-Fi6/6E – can also enable real-time AR streaming with some graphics tasks offloaded to edge-computing resource. This reduces the processing power required on the headset or tablet itself, extending battery-life or reducing the weight needed. Haptics (touch/sense) data transmission also needs low-latencies and high throughput speeds.

While few XR headsets integrate 5G chipsets today, they can be tethered to a cellular modem or mobile gateway. Future designs may include cellular options, especially for enterprise usage.

Automation Systems

As well as moving vehicles and robots, the core of many logistics facilities – especially for warehouses and fulfilment centres – is automation. They have hugely complex arrays of conveyor belts, sorting systems, collection bins and other elements. Similar automated systems work in airport baggage-handling zones, or some areas of ports and rail networks.

These systems require multiple layers of compute and communications here, from control of individual machines using PLCs (programmable logic controllers), through to cameras and weight-sensors for identifying particular shipments, or sorting them by type.

All of this requires connectivity, with extremely high reliability requirements, as well as low and often deterministic – that is, predictable - latency needs.

While fibre, Wi-Fi and various proprietary wireless solutions have been widely used in the past, 5G offers the potential for greater flexibility and/or lower costs in future. It may also may perform better in environments with miles of metalwork and electromechanical noise.

That said, "5G-only" warehouses or ports are highly unlikely. Most automation systems suppliers work with multiple network types, integrating the most appropriate for each machine and application.

Tenant and passenger connectivity

Businesses in transport and logistics can have up to three separate "audiences" for connectivity:

- Their own employees, systems and machinery.
- General public, especially as passengers.
- Other business tenants, such as retailers at train stations, trucking or insurance companies at ports, airlines and caterers at airports and so on.

The second two categories essentially turn the site owners into "semi-public" network operators. They either need to provide on-site access to national 4G/5G mobile carriers, or perhaps onboard these groups onto a private cellular network as some sort of managed service. Many will use Wi-Fi as well.

Some sites like warehouses may be simpler, without the need to deal with 3rd-party groups.

Use-cases for "tenant and passenger" 4G/5G will include typical consumer smartphone use, or business applications used in those related sectors such as retail or hospitality.

There is a broad set of technology options for on-campus/indoor coverage and "neutral host" wireless service provision to MNOs. Mobile coverage on ships and aircraft in international seas or airspace brings its own challenges for networking, which are outside the scope of this eBook.

Robotics

Robots – both fixed "arms" and mobile units – are being adopted across the transport and logistics sector. Depending on definitions, some of these overlap with other categories such as AGVs (automated guided vehicles). Trends include

- "Democratisation" of robots across more sectors of industry, as costs fall and the requirement for automation improves.
- Staffing shortages in many roles – especially those requiring repetitive and boring work, or operations in dangerous or dirty environments – is driving robot adoption.
- Industrial robots are becoming more interconnected and instrumented, with extra sensors, cameras and feedback systems, plus large data/telemetry feeds. This requires real-time connectivity.
- Growing relevance of "co-bots" or cooperative robots, that work in tandem with human operators.
- Ongoing development of "cloud robotics", to reduce the need for costly integrated sensing and compute in each robot.

Warehouses and fulfilment centres are becoming especially automated. For instance in consumer eCommerce and delivery, multiple items need to be "picked" and combined into mixed packages for shipment. Some sites use traditional shelves and aisles with stacked pallets or large boxes, while others have "bins" of smaller products which can picked out individually from above with a robot.

Shipments and deliveries must also be loaded and unloaded from trucks and containers – a complex task given the variation in sizes, weights and fragility, plus the need for final delivery drivers to be able to extract individual packages at each address stop.

Ports and airports are also adopting a wide range of robotic systems, both for interacting with passengers in terminals, and for dealing with operational functions. Use-cases include:

- Passenger-service robots which can interact in multiple languages, provide flight and gate information, guide people around the airport to service desks, assist with bag-drops and so on.
- Mobile check-in desks capable of automatically moving to congested areas, to reduce queuing times.
- Cleaning robots
- Baggage and cargo-container loading and unloading systems

All of this is driving the need for more (and better) wireless connectivity for robotics. Again, 5G is seen as an important enabler in many cases. Low latency and high reliability are essential to avoid collisions or enable remote control in case of problems. Individual warehouses may have 1000s of individual robots, ranging over very large facilities, including outdoor areas.

In addition, 5G's improving location/positioning capabilities are very important in warehouse settings, and also enable proximity-sensing between humans and mobile robots to be more accurate. Wi-Fi also remains important – and later versions such as Wi-Fi6E and the future Wi-Fi7 will help – but can suffer from congestion or interference in areas with lots of metalwork.

Bulk software downloads

A new 4G/5G use-case in logistics settings is management of software downloads to products in the supply chain. In particular, cars and other vehicles may receive custom software installations (or updates) relevant to particular countries on arrival. For example, it is common to have huge vehicle storage facilities alongside shipping ports, perhaps with 1000s of car awaiting onward delivery.

Modern vehicles – as well as other products such as industrial equipment and consumer electronics – may have many gigabytes of software embedded in their control systems. Being able to download updates "in the field" is hugely useful. However, this can require significant network capacity, often in outdoor areas with limited public network coverage. Cast-iron security is also important.

Private 4G/5G networks offer a mechanism for this type of application, especially as the vehicles will typically have embedded modems and a power source. Beyond cars, a similar approach could be used in other transport contexts, such as content uploads to aircraft entertainment systems or pilots' "digital briefcases".

Metrology

Metrology means "the study of measurement". It is a broad term covering a wide variety of activities and systems. However, in industrial settings such as transport, logistics and engineering it often represents the use of cameras or lasers to measure (or inspect) objects.

In the context of this eBook, the most important examples of metrology are in the production and maintenance operations for aircraft, trains and other vehicles requiring precision engineering for reliability and safety purposes.

For instance, aircraft and their engines regularly undertake inspections for tiny cracks or other signs of possible failure. This often takes place in the large hangars seen around major airports. Ships, locomotives, trucks, buses and other vehicles also have rigorous maintenance regimes.

Another area for metrology is in logistics and warehousing – whether that is for pre-shipping quality checks, measurement of package size for efficient loading, or specialist use-cases such as temperature-mapping for stored pharmaceuticals and food.

Some measurement devices can take millions of readings per second, generating terabytes of data per day. That is in addition to "normal" video feeds for similar purposes. This data may well exploit AI-enhanced approaches can analyse patterns, or detect flaws which may not be visible to the human eye. Machine-vision systems on-premise or in another edge-computing site can analyse such data, ideally in real-time.

While some metrology systems will be wired-in to other units, there is also a need for portability and mobility. Increasingly, such equipment uses wireless networks with high performance and throughput – especially where used in combination with robotics or drones. 5G is likely to play an important role in some settings, especially in locations which are tricky to connect with fibre.

Precise asset location and positioning

There are numerous purposes for asset-location and real-time positioning in logistics and transport environments. Robots and AGVs need to locate specific shelves or storage bins. They also need to dock accurately with charging stations, accurately record the location of any faults, and ensure safe distances from human workers.

As an example, airport assets like aluminium shipping crates, baggage carts and wheel-chocks need to be tracked and located, as well as other assets such as luggage trolleys which are frequently moved around.

Similar requirements occur in railway stations, ports, logistics hubs and other similar sites.

Accurate positioning can improve productivity and asset utilisation, as well as reducing the risks of theft by "geo-fencing" within specified boundaries. Tracking technologies also contribute to preventative maintenance, by ensuring items are stored in correct locations.

It is already possible to use a variety of wireless technologies (including private deployments of 4G NB-IoT) for asset-tracking, but real-time positioning, especially indoors, is hard.

Later versions of 5G, especially 3GPP Release 17 onwards, will permit highly accurate location tracking, down to centimeter-scale positioning. On a well-engineered private network, this would have multiple use-cases in aviation hangars and terminals, fulfilment centres and other locations. Linking private and public networks could also allow passengers to track their bags, or for individuals and businesses to locate package shipments and deliveries.

Worker safety systems

A key application for private networks in transport, logistics or other industrial settings is enabling companies to maintain worker safety more effectively. This is important for reputation, compliance, liability and other reasons. There are a number of elements here requiring good connectivity:

- Video cameras and analytics used to ensure compliance with safety rules (e.g. safety hats and high-visibility jackets being worn), or to actively observe for dangerous situations.
- Proximity awareness systems and virtual ring-fences, which can keep robots or autonomous vehicles away from human workers.
- Real-time monitoring of workers' health (heart rate monitoring, fall-detection etc), especially in the most dangerous parts of a site (e.g. rail yards or fuel depots), or for solo workers.
- Reliable, wireless-connected safety-stop buttons – used to bring automated systems to a halt if a worker is in danger.

Depending on the specific site, these functions may be needed both inside buildings such as warehouses, and outside on a dockside or airport ramp, and even in underground areas or inside vehicles.

"Smart work-wear" such as helmets or jackets can now be obtained with built-in cellular radios.

Private 4G/5G allows for reliable connectivity, with customised coverage and uptime guarantee that would be hard to obtain from public networks, and in locations that would be hard to reach with Wi-Fi.

Site-wide networks & workforce communications

Ports, airports and logistics hubs span areas that can be up to 10km across. Many have their own road networks, as well as open areas that can span long distances across runways or waterfront. Certain transport sectors such as railways and road networks obviously span even greater distances. Staff, assets and vehicles may be distant from the operations centre, and need to be contactable and controlled in real-time.

For such sites, it is essential to have site-wide (or "campus") networks, covering both outdoor and indoor areas. Often, some or all of the site is poorly covered by public mobile networks.

Reliable site-wide connectivity is needed for various applications and service functions, such as:

- Asset monitoring/location
- "Situational awareness" of environmental issues such as weather status
- Site-wide vehicle control
- Safety and security cameras, intrusion detection systems, alarms etc.
- General IT, Internet and cloud connectivity for on-site employees' handheld devices and smartphones.
- Workforce critical communications such as voice or video push-to-talk (PTT), alerting systems and various forms of collaboration and "unified communications".
- Gateways and hubs used to connect clusters of cameras, sensors and other devices.
- Localised coordination between multiple organisations, such as connecting crew, fuel companies, baggage handlers, caterers and cleaners that are "turning around" an aircraft in 20-30 minutes.

Cellular 4G/5G networks are more flexible than traditional site-wide VHF radios or PMR (private mobile radio) systems – and support data applications with far greater capacity. Wi-Fi can be used for small sites such as railway

stations, but is less viable for the larger facilities. The ability to issue private SIM cards to relevant staff – or contractors and suppliers – allows easy creation of "closed user groups".

Video surveillance systems

Transport and logistics sectors have significant needs for video surveillance, as well as video-based analytics for operational purposes. Locations such as ports, warehouses and airports have critical needs to monitor security and safety risks such as terrorism threats, fire, intrusion and theft or other illegal activities, potentially over large site area, both indoors and outdoors. Both perimeter surveillance and local video of the most-sensitive areas such as baggage-handling are essential.

Some sub-sectors such as aviation manufacturing and shipbuilding face additional risks from geopolitical actors or espionage.

Wireless connectivity with 4G and 5G allows extra capacity for high-resolution imaging, as well as reduced latency. Increasingly, cameras are attached to mobile assets such as vehicles, robots and drones, which obviously necessitates wireless access. While most cameras need cabling for power supply, even wired units may connect to a 5G-enabled hub or gateway.

Over time, edge-computing combined with machine vision will enable additional automation, as well as immediate alerting of anomalies

Other use-cases

There are numerous other use-cases for private networks and 5G emerging in transport and logistics. Some will be highly sector-specific. Some examples include:

- Drones used for various tasks, from delivering paperwork to ships waiting to come onto the dockside, to inspections of stockpiles of materials outside warehouses. Some will use 5G connections for video transmission or control.
- Fixed wireless access from central buildings to other remote locations on large sites, such as guardhouses, hangars or storage units.
- Private cellular networks deployed on ships or inside aircraft.
- Railway signalling and rail-yard marshalling tasks, including compliance with industry-specific safety and security needs.
- Highway management and maintenance (for instance, connecting ice- and fog sensors)
- Environmental monitoring sensors (e.g. for air or water contamination) around ports and airports.

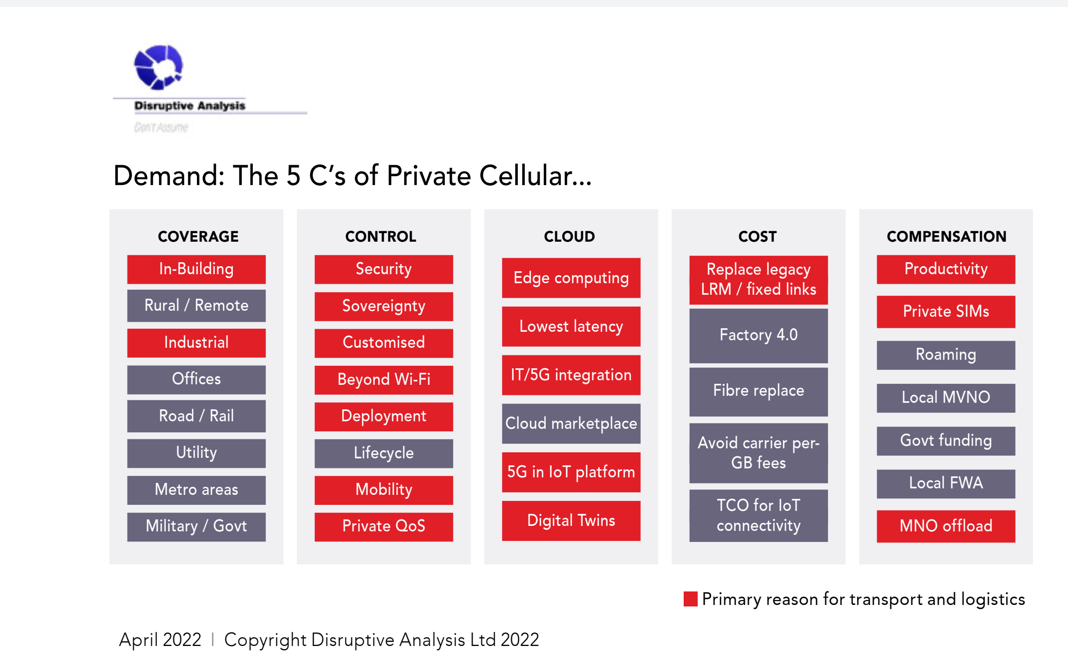
Why deploy private networks?

The second question mentioned above is at the core of this report. Why are these use-cases better suited to private 4G/5G rather than public network services from MNOs?

There are five top-level reasons that Disruptive Analysis uses to discuss Private 5G:

- Coverage
- Control
- Cost
- Cloud integration
- Compensation (or monetisation)

The following sections describe these in greater detail, as they apply to typical logistics and transportation sectors.



Coverage

A core reason for using private 4G/5G, rather than public MNO services, is the limitations of network coverage. MNOs tend to deploy network assets in areas with high population density, or along main roads. (Often, their spectrum license conditions stipulate coverage requirements in terms of resident population).

However, ports and warehouse hub sites tend to be located away from major population centres and normal residential / business districts. As a result, many transport and logistics companies' facilities often have relatively poor coverage. Even where public coverage is quite good – such as airports – most of the RAN planning will focus on the runway and terminals for passengers, rather than maintenance and other operational parts of the wider airfield area.

In addition, in-building coverage is especially poor for warehouses, given the common use of metal and concrete in construction, fewer windows compared to other sites, and various forms of screening and internal metalwork. At airports, baggage-handling and other service functions may be underground, while ports may need good wireless coverage to extend over expanses of water.

Control

Alongside coverage, this is the most important aspect of private networks for most transport and logistics companies. Many firms, especially ports, airports and automated logistics/fulfilment hubs, have extremely high costs of any downtime, as well as being very protective of network security and safety concerns.

Owning and operating 4G / 5G wireless systems allows companies to define and optimise many network parameters themselves, taking direct responsibility for QoS, reliability, performance and reporting. For instance, a number of ports operate "fully redundant" cell sites, where any individual tower can go offline, yet full coverage and operation is maintained across the site. Aviation maintenance centres, with heavy use of video uplink from video inspections and metrology systems, can configure radios locally to reflect the traffic balance.

Private networks also mean that enterprises can choose their own mechanisms for redundancy and cybersecurity, aligning with sector-specific best practices and regulations. This is particularly important in areas such as rail, where there is a long history of unique standards and compliance approaches.

In the longer term some of the sectors here may acquire a custom "slice" of a public MNO 5G network via various APIs and "network exposure" capabilities, but this remains an unproven model and is only fully available when future versions of the 5G technology (3GPP Releases 17 / 18) become widespread.

There may also be a requirement to integrate the private cellular domain with other connectivity systems – such as PMR/LMR for critical communications, or with existing Wi-Fi installations. The added complexity and customisation requirements may mean that public 5G network operators are unsuited to those tasks.

Cost (and risk-avoidance)

Transport and logistics companies have traditionally had relatively limited use of public 4G/5G networks for on-site use, beyond vehicle fleets which require onsite and offsite connectivity, or passenger terminals which have required good coverage from MNOs.

However, they have often used other expensive, proprietary (and sometimes near-obsolete) radio systems for push-to-talk communications, or low-speed data connectivity. Private 4G/5G networks can be enable both reduced costs of ownership, and higher data throughput to support new applications. Further potential cost savings from private cellular are related to reducing the need for new fibre runs, especially for perimeter security cameras, or IoT devices in inaccessible locations such as rooftops.

The more complex cost calculations may come in future, when MNOs attempt to sell managed 5G services (perhaps in the form of "network slices") to enterprises in this sector. These will essentially compete with private cellular offerings, although various hybrids are likely. Indeed, some MNOs now sell dedicated on-premise 4G/5G solutions as private networks themselves.

Cloud

While certain subsectors such as rail are "conservative" about adoption of cloud technologies, others such as logistics demonstrate a growing link between private wireless and cloud platforms. The intersection point

typically involves the use of on-premise or near-premise edge computing. (Notably, Amazon operates distribution warehouses of its own, alongside its AWS cloud services – and now its own Private 5G capabilities).

There are two linked trends here:

- Private networks are directly enabled by edge servers, which can host software elements such as network cores, delivered via virtualisation and containers. Transport hub sites are ideal location for edge-computing nodes, both for their own purposes, and more broadly because they tend to have ample availability of power, fibre backhaul and good security.
- Many of the applications discussed in this eBook as private 4G/5G use-cases for transport/logistics could themselves exploit edge servers. Video analytics, robotics, remote-control vehicles, IoT monitoring, preventative maintenance and "digital twins" are good examples.

In coming years, there is likely to be even greater integration with private networks and edge-cloud requirements in transport and logistics sectors. Growing emphasis on automation and cybersecurity will drive the need for better (and more resilient) wireless networks for critical infrastructure sites, often with "sovereign" cloud/ compute onsite as well.

Compensation / Monetisation

Some of the transport sectors covered here, such as airports, can directly monetise private 4G / 5G by offering connectivity services to onsite tenants such as airlines, catering companies and others. Heathrow Airport in the UK, for instance, has its own Commercial Telecoms business unit, run in conjunction with industry group SITA.

There are also private cellular networks in operation on certain ships and aircraft, selling access or roaming services to their passengers.

In future, private networks at transport sites may also offer neutral-host functions to public MNOs – essentially "coverage as a service".

Spectrum options and trends

Overview

A key ingredient for transport/logistics-sector private networks is access to suitable spectrum for private 4G/5G deployments. Decisions and trends here involve a huge range of trade-offs in terms of coverage, capacity, cost, device availability – and also politics and regulation.

It also directly relates to the relevance and potential for "pure" private networks run by enterprises or specialists, versus those that are provided as a managed service by a mainstream telco that primarily runs public 4G/5G networks.

Although most spectrum suitable for cellular networks has been awarded on an exclusive regional/national basis to public mobile operators (MNOs), some transport sectors such as rail and aviation have had access to certain dedicated bands for operational reasons. Along with utilities, transport is often seen as "critical national infrastructure" and is treated differently to commercial sectors like manufacturing, logistics or local transit authorities by regulatory authorities. The latter groups have historically had far less direct access to such mainstream cellular bands without rare and complex leasing arrangements

This is now changing rapidly, as various national regulators make local licenses or various forms of shared spectrum available – and device / chip companies start to support them as well. As mentioned above, MNOs are also becoming more open to a range of new engagement models, including the creation of private campus networks decoupled from their main macro RAN and core infrastructure.

For private networks in transport/logistic sectors there are, broadly, three spectrum options:

- **Low-band:** Thin slices of spectrum below <1GHz are sometimes available, good for covering wide areas, but at low capacity. These options tend to be best-suited to critical communications (like push-to-talk), or narrowband sensor data and control systems. These are ideal for road and rail networks, as well as very large sites such as airports and ports.
- **Mid-band:** For indoor and campus-wide coverage suitable for warehouses, passenger terminals, stations and hangars, mid-band spectrum between 2-6GHz is generally optimal. This is where most deployments of private 4G/5G are occurring today.
- **mmWave bands:** Typically in the 26-60GHz range, higher bands are widely discussed for 5G but still rare – although in future they may prove especially useful for highly-concentrated applications requiring huge bandwidth. The extra "headroom" also makes it easier to create ultra-low latency networks. Some indoor coverage systems for airports use mmWave.

The following sections give more detail on some of the specific bands being made available around the world.

CBRS and other mid-band options

For site-specific or regional coverage, a growing number of countries are making sections of mid-band spectrum available for transport and logistics companies and organisations. Typically this is based on some form of spectrum-sharing, with either manual or database-driven licensing for specific areas and band rights. Sectors such as ports and warehousing/logistics have been some of the most powerful voices persuading governments and regulators of the potential economic benefits.

Among the most important examples are:

- **US:** In the US, the CBRS band between 3.55-3.7GHz has been made available on a shared and multi-tiered basis, with dynamic access managed by a number of automated SAS (Spectrum Access System) providers. The top tier of incumbent users (especially the Navy) has ultimate pre-emption rights, but a number of enterprises – notably John Deere - have acquired PAL (Priority Access Licenses) which give almost-guaranteed access to sections of the band on a county-area basis. This is well-suited to private networks and can be supplemented by using the on-demand GAA (general authorised access) tier. At present only 4G LTE equipment is readily available for use with CBRS, but that is likely to be extended to 5G products in the next 1-2 years. This band has attracted a large ecosystem already and is probably the closest to "spectrum-on-demand" and the wide democratisation of private networks.
- **Germany:** The 3.7-3.8GHz band has been reserved for localised private network licensing, either with 4G or 5G infrastructure. Licensees can request rights for specific locations from the national regulator – typically for campus-sized facilities. Manufacturing companies, especially in the automotive and engineering sectors, have been among the most enthusiastic about take-up.
- **France:** A 40MHz section of the 2.6GHz band has been made available for critical communications and industrial broadband use. While the initial users were mostly "infrastructure" organisations such as airports and railways, there has been a shift towards manufacturing during 2021 and early 2022. In addition, some of the MNOs' 5G midband licenses for 3.4-3.8GHz have regulatory mandates for cooperation with enterprises on private networks.
- **UK:** The 3.8-4.2GHz band is available for local 5G use, subject to protecting incumbent licensees. There are also small allocations at 1.8GHz (the original DECT guard band) and 2.3GHz. Public MNOs such as EE and Vodafone are also working on localised private network deployments, including for the manufacturing sector.
- **Japan:** Spectrum is available between 4.6-4.9GHz for local 5G
- **Taiwan:** Spectrum is available in the 4.8GHz band for private 5G.

A number of other countries in Europe and the EU regulatory advisory body RSPG have also suggested the 3.8-4.2GHz band for future potential shared/enterprise use. Many other countries have ongoing regulatory initiatives or consultations on suitable mid-band options for industry, including Spain, India and Saudi Arabia.

Other markets have the potential for local leasing of MNOs' allocated national spectrum (for instance in Australia, Sweden and Denmark), or the ability for regional operators specialising in industrial networks to obtain ordinary licenses in sparsely-populated areas (for instance in parts of Canada).

The main exception is probably China, which still tends to favour MNO national licensing.

It is also worth noting the potential for using unlicensed bands at 2.4GHz, 5GHz and increasingly 6GHz as well for private 4G/5G – although the lack of interference protection may limit the scope for mission-critical applications.

Sub-1GHz options

Low-band spectrum has only limited relevance for logistics, but is highly suitable for private wide-area communications in rail or road sectors. Its good indoor / underground propagation may also be useful for IoT and mission-critical voice communications, in some cases such as airports.

A number of markets have made such bands available to.

- **US:** Following an FCC ruling in 2020, a number of licensees have access to 900MHz spectrum, with 6 MHz for broadband use and 4 MHz for narrowband use. In particular, a major spectrum-holder, Anterix, works with a number of local utilities to create suitable infrastructure. It is unclear if it would extend to the manufacturing sector as well
- **Norway:** A number of oil and utility companies hold 700MHz and 900MHz spectrum for private offshore networks – but again, this may also be relevant for certain specialised manufacturers catering to the energy sector.

It is also possible to use narrowband IoT versions of 4G (NB-IoT & LTE Cat-M) in the various sub-GHz allocations, either licensed or unlicensed.

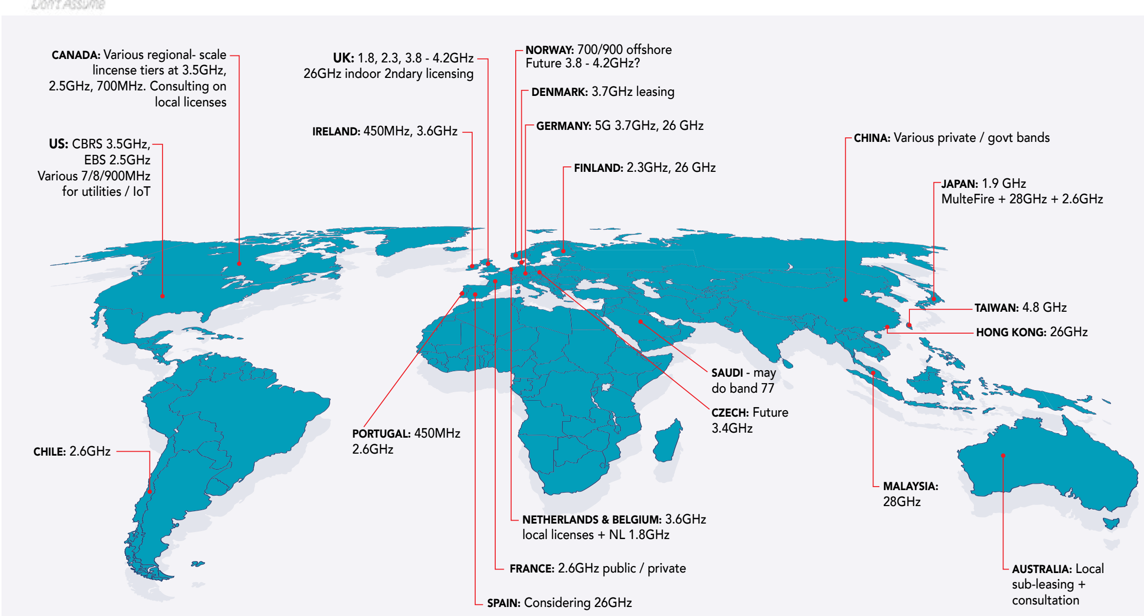
mmWave

A number of countries, including Germany, UK, Finland, Malaysia and Japan, have made 26GHz, 28GHz or other high-band spectrum available for local use. In the US, Italy and South Korea, some MNOs are also examining opportunities around mmWave private networks. This is mostly targeted at indoor/campus sites such as warehouses and mines, as well as high-density passenger areas such as airport terminals. However, there is also potential in areas such as ports and rail yards.

Key use-cases are for local high-capacity usage, such as remote-driven vehicles or high definition cameras, especially where mounted on vehicles, cranes or robots.

Disruptive Analysis
Don't Assume

New spectrum bands launching for non-public 4G/5G



Conclusion & long-term futures

The transport and logistics sector is already one of the leaders of the mainstream adoption of private cellular networks. It blends the early sectors requiring "critical communications" with more advanced uses of private 4G/5G in the realm of IoT / OT (operational technology) connectivity.

Among the keenest advocates of private cellular today are shipping ports and airports, which combine multiple high value use-cases on mid-size campuses, with high levels of existing technical skill and wireless connectivity usage. Many of the more valuable functions occur outdoors, where Wi-Fi and fibre are poor alternatives.

Modern warehouses and fulfilment centres form another category where private 4G/5G has been rapidly adopted, helped by high levels of automation, and an explosion in "greenfield" new-built sites in the eCommerce / delivery boom, designed from the ground up around robots and IoT systems.

While this report has focused on the radio aspects of private 4G/5G, it is important to recognise that the broader ecosystem – from core networks to edge computing and planning / design / test systems – is evolving in tandem, along with a huge range of systems integrators and vertical specialists.

There is growing maturity of enterprise-grade 5G technology, especially with transport-related features in 3GPP Release 16/17/18. Together with the wider availability of local or dedicated spectrum, there should be a continued healthy dynamism for many years to come. By 2025 there may be 1000s of private networks in transport and logistics, and perhaps tens of 1000s.

In addition, while greenfield logistics/warehouse sites may be "5G primary", in most instances there will be significant installations of other network technologies in place. Ports, airports, rail stations and similar organisations will maintain a complex array of networking and wireless technologies for different purposes – from Wi-Fi connectivity for passengers, to radar systems and dedicated train/air-traffic control protocols. There will also be many incumbent suppliers such as aviation systems or train manufacturing companies, that will often act as channels or integrators for (often own-branded) connectivity systems. The 5G industry needs to fit into, or around, these incumbents.

Table: Examples of Transport /Logistics private 4G/5G deployments/trials

Company	Country	Sector/Purpose	Spectrum/Owner
Port of Southampton	UK	Coverage of automotive shipping / storage	Local shared 3.4-3.8GHz
Heathrow Airport	UK	Ramp vehicles & other uses	3.5GHz (3UK band)
Brussels Airport	Belgium	Many uses, inc security cams, IoT, drone control, automated vehicles	3.5GHz (LTE + 5G)
CDG Paris Airport	France	Gate-side group voice & data comms for aircraft turnaround. Also in-hangar usage	2.6GHz LTE + 5G tests
Lufthansa Technik	Germany	Jet engine maintenance / remote inspection	3.7GHz Private 5G band
London St Pancras Stn	UK	Rail station IoT condition monitoring	3.8-4.2GHz 5G
Amazon Fulfilment Ctrs	UK	Truck control / cameras outside Amazon warehouse	CBRS Private LTE
Ferrovial / Silvertown Tnl	Poland	Road tunnel construction automation / data	3.8-4.2GHz Private 5G
Tokyu Railways	Japan	Trial of 5G cameras + AI for track abnormality detection + on-platform for safe door-closing	Thought to be 4.6-4.9GHz local 5G band
Port of HaminaKotka	Finland	Video & analytics, vehicles, worker PTT etc.	2.6GHz Private LTE
Port of Rotterdam	NL	Container-handling vehicles	3.7-3.8GHz Local LTE
Saab	Sweden	Aerospace manufacturing IoT	1.8GHz LTE , 3.7GHz 5G
Zyter	US	Smart warehouse system, inc AGVs, AR/VR, digital twin & IoT sensors	CBRS Private LTE
Ondas Networks	US	Critical communications for Class 1 railways	900MHz Private LTE

Source: Disruptive Analysis

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