

Four Thousand Vehicles Is Not a City

The Infrastructure Autonomy Still Lacks

Summary

Autonomous vehicles work. That question is settled, and this paper does not reopen it. Driverless services now carry roughly half a million paid rides a week across more than a dozen cities, and the Gulf has moved from demonstration to fare-charging commercial operation faster than any region outside North America.

The question this paper takes up is different. The most advanced autonomous fleet in the world numbers under four thousand vehicles across fifteen metropolitan areas. That is roughly two hundred and sixty vehicles per city. Between that figure and a city where autonomous movement is ordinary lie four constraints, and none of them is solved by building a better vehicle.

Human supervision has not been removed from autonomous driving. It has been relocated — off the vehicle, out of sight, and in one case offshore — and it scales in direct proportion to fleet size.

The vehicle can only act on the portion of the world its own sensors resolve. When that resolution fails on something as legible as a school bus with its stop arm extended, the failure is invisible until a child is standing next to it.

The record of what happened is held by the party under investigation. Existing recording regulation captures which system was driving. It does not capture what was physically present. And when seven autonomous vehicle operators were asked by the United States Senate how often their remote agents intervene, none of them answered.

The environment itself is uninstrumented. Global spending on sensing the road is under two billion dollars a year, against roughly two hundred thousand dollars of sensing and compute fitted to each individual vehicle.

These are not defects of particular companies. They are properties of an architecture that puts all perception, all reasoning and all recording inside the vehicle. A city cannot be made autonomous one vehicle at a time.

No layer of the kind this paper describes is in operation anywhere today. That is a statement about assembly rather than invention. Most of the components exist and are proven separately: distributed sensing, physics-governed reasoning, cryptographic anchoring of physical state. What has not happened is their assembly into a single governed layer — and one capability remains genuinely absent, which is the ability to carry a full reasoning workload at the sensor point itself rather than in a data centre somewhere behind it.

The final section sets out what that layer must do, in requirements rather than products, and argues that the Gulf — and Qatar specifically — has already taken the decision that makes it the natural place to build it.

01

What has actually been achieved

Any argument about the limits of autonomous driving has to begin by conceding how much of it now works.

A note on the levels, because the definition is the argument

Automated driving is graded on a six-point scale set out in SAE J3016 and adopted, with local variation, by most regulators.

Levels 0 to 2 keep the human responsible for driving at all times. Cruise control, lane centring and the various assisted-driving packages sold today sit here, however they are marketed. Level 3 allows the system to drive while the human remains available to take over when asked. Level 4 removes that requirement: within a defined operating domain, the system drives and no human is expected to intervene. Level 5 is Level 4 without the domain restriction, and nothing on the road is close to it.

The distinction that matters for everything that follows is the phrase “within a defined operating domain.”

Level 4 is not a measure of how well a vehicle drives. It is a declaration of where it is permitted to drive, and it is granted against an operating envelope the manufacturer defines and a regulator accepts. A system is not Level 4. It is Level 4 *in Yas Island, or in downtown Phoenix, or on three approved routes between the Ministry of Transport and Old Doha Port.*

Every Level 4 permit issued anywhere in the world is a statement about a map. That is why the boundary of the map, rather than the capability of the vehicle, is the constraint on scale.

Waymo carried approximately five hundred thousand paid rides per week by mid-2026 and has stated a target of one million weekly rides and more than twenty cities by year end. Fully driverless service runs in Phoenix, San Francisco, Los Angeles, Austin, Atlanta, Miami, Dallas, Houston, San Antonio and Las Vegas, with San Diego, Denver and Tampa following. Annualised revenue reached roughly \$355 million in February 2026, up from about \$125 million at the end of 2024. In February 2026 the company raised \$16 billion at a valuation near \$110 billion.

The Gulf has moved faster than most observers expected. WeRide and Uber launched the Middle East's first Level 4 fully driverless commercial operations in Abu Dhabi in November 2025, beginning on Yas Island and extending to Corniche Road, the Sheikh Zayed Grand Mosque, Khalifa City, Masdar City and Rabdan. Fully driverless fare-charging operations followed in Dubai across Jumeirah and Umm Suqeim, with trial permits extending into Dubai Silicon Oasis, Dubai Investment Park II and Jebel Ali Industrial First. In February 2026 the two companies committed to deploying at least 1,200 robotaxis across Abu Dhabi, Dubai and Riyadh by 2027 — the largest such commitment in the region's history. WeRide reports more than two hundred robotaxis operating regionally and operational profitability in its Middle East business.

Qatar entered the same territory in September 2025, when Pony.ai and Mowasalat deployed robotaxis on public roads in Doha under Ministry of Transport supervision. Karwa launched Qatar's first robotaxi service in December 2025. Phase one recorded more than 2,500 trial journeys at a stated operational success rate above 94 percent without human intervention. Phase two places two vehicles under remote operation with no safety officer on board across three approved routes.

This is genuine progress, achieved against real engineering difficulty. Nothing in what follows disputes it.

The number that frames everything else

Waymo's fleet stands at approximately 3,871 vehicles, distributed across fifteen or more metropolitan areas.

That is roughly two hundred and sixty vehicles per city.

It is worth sitting with that figure, because it is the most advanced autonomous deployment on earth and it is smaller than the taxi fleet of a mid-sized town. WeRide's regional fleet is around two hundred vehicles. Qatar's pilot, at phase two, is two.

The distance between a robotaxi service operating in a city and a city that drives autonomously is two to three orders of magnitude. That distance has not been crossed anywhere, by anyone, and the reasons are structural rather than incidental.

The human did not leave, the human moved

On 17 February 2026, Ryan McNamara, Vice President and Global Head of Operations at Waymo, published the following:

“As of February 17, 2026, there are approximately 70 Remote Assistance agents on duty worldwide at any given time, including ERT. For context, Waymo currently has a fleet of 3,000 vehicles.”

That is a ratio near one agent to forty-three vehicles. Waymo is careful, and correct, to note that these agents are not remote drivers: Remote Assistance responds to requests raised by the driving system and offers advice the system may use or reject. Median one-way latency is around 150 milliseconds from United States operations centres and 250 milliseconds from centres abroad. Every agent holds a driving licence and passes criminal background checks, drug testing, and colour blindness and spatial recognition assessment.

The distinction matters and this paper accepts it. But it does not change the arithmetic. A hundred-thousand-vehicle fleet at the same ratio requires roughly 2,300 trained, licensed, vetted people on duty at every moment of every day. The human cost of autonomous driving did not disappear. It moved from a seat in the vehicle to a desk somewhere else, and it grows in a straight line with the fleet.

Cruise, before its collapse, reportedly staffed around 1.5 workers per vehicle — a ratio sixty times heavier than Waymo's. The industry range is wide and largely undisclosed.

The Gulf provides the clearest statement of what this costs. WeRide's Abu Dhabi permit, which removed the requirement for an in-vehicle safety officer, was described by the company as the condition that let its robotaxi service reach breakeven on unit economics. The business case for autonomy does not close until the human comes out of the vehicle. What has not been demonstrated anywhere is a business case that closes once you count the humans who replaced them.

04 / CONSTRAINT TWO

The vehicle acts only on what it can resolve

In November 2025 Waymo recalled 3,067 vehicles. The defect was software that could cause the vehicle to pass a stopped school bus displaying flashing red lights with its stop arm extended.

School district officials in Austin documented nineteen separate instances during the 2025–26 school year. Atlanta recorded six more as of 5 December. The National Highway Traffic Safety Administration's (NHTSA) Office of Defects Investigation opened a probe in October; the National Transportation Safety Board opened a parallel investigation in January 2026.

A stopped school bus is the most rehearsed object in road safety. It is large, painted a standardised colour, fitted with lights designed to be unmissable and a mechanical arm that extends into the roadway for the specific purpose of being seen. It is the easiest hard case in driving. The most advanced autonomous system in commercial operation could not reliably resolve it.

The reason is architectural. Every sensor is on the vehicle. Qatar's Pony.ai robotaxis carry eleven cameras, four radars and four LiDAR units, giving 360-degree awareness from the vehicle outward. This is a capable sensor suite and it is entirely self-referential: it perceives the world from one moving point, in one moment, with no independent corroboration and no memory of the street that is not its own.

Where that suite is insufficient, the answer has been prior mapping rather than better perception. Operating envelopes exclude heavy snow, unmapped roads, and construction areas without map updates. The vehicle is not driving the city. It is driving a map of the city, and it stops where the map stops.

For the Gulf this is not an abstract limit. A city under continuous construction is a city whose map is continuously stale.

05 / CONSTRAINT THREE

The record belongs to the party being investigated

This is the constraint that will decide how quickly ministries authorise fleet-scale operation, and it receives the least attention.

A recording standard exists, and it records the wrong thing. UN Regulation 157, in force since January 2021, mandates a Data Storage System for Automated Driving (DSSAD) for vehicles with automated lane keeping. DSSAD records when the driving system was activated and deactivated, lane changes the system initiated, and — in the language of the working documents — who was driving before and after a significant safety-related event, and who was asked to drive.

That is a mode log. It establishes which agent held control. It says nothing whatever about what was physically present in the environment at that moment. Applied to the school bus cases, DSSAD would confirm that the automated system was engaged. It would not record whether a school bus with an extended stop arm was there, whether it was resolvable, or what the vehicle understood the object to be. The single fact that determines liability is the fact nothing is required to record.

In the United States, the expansion of Event Data Recorder requirements to capture broader pre-crash data has been deferred to a four-year phase-in beginning 1 September 2028.

Intervention rates are not disclosed by anyone. In February 2026 U.S. Senator Ed Markey wrote to seven autonomous vehicle operators — Waymo, Tesla, Zoox, Aurora, Motional, May Mobility and Nuro — asking how their remote assistance systems work. All seven responded. None disclosed how frequently remote assistants intervene. Network latency thresholds varied between companies, indicating that each operator sets its own view of what delay constitutes a safety risk. Markey described the industry's posture as “a stunning lack of transparency,” asked NHTSA to investigate, and began drafting legislation.

The intervention rate is the one number that would tell a regulator how autonomous these systems actually are. It is not published, not standardised, and not required.

And where the record exists, the operator controls it. On 2 October 2023 a pedestrian was struck by a human-driven car in a San Francisco crosswalk and thrown into the path of a Cruise autonomous vehicle, which then dragged her more than twenty feet while attempting a pullover manoeuvre.

What followed is the more instructive part. Cruise withheld the portion of the video showing the dragging from California regulators. The California Public Utilities Commission issued an Order to Show Cause in December 2023, stating it had not been provided with footage of the collision. Meetings at which the video was played to regulators were reported to have suffered connectivity problems that froze and blacked out the recording at key moments. In 2024 Cruise admitted to submitting a false report to NHTSA with intent to impede a federal investigation, entering a deferred prosecution agreement and paying a \$500,000 criminal fine.

Cruise no longer operates, and the structural problem it exposed is untouched. The only record of what an autonomous vehicle encountered is generated by the autonomous vehicle, held by its operator, and disclosed at the operator's discretion. A record under the exclusive control of the party being investigated is not evidence. It is testimony.

Insurers have arrived at the same conclusion from the other direction. Underwriting an autonomous fleet now requires assessing not the vehicle but the whole operating apparatus behind it — maintenance schedules, software update controls, remote assistance protocols, safety monitoring — with almost no historical loss data to price against. Auto liability, product liability, cyber and technology errors and omissions blur into one another during a claim. The industry is being asked to price a risk whose defining evidence does not exist in any form an underwriter can independently verify.

06 / CONSTRAINT FOUR

Nobody instrumented the road

The global market for cellular vehicle-to-everything roadside units was approximately \$1.29 billion in 2025 and is forecast near \$1.57 billion in 2026.

That is the world's entire annual spend on making roads legible to the vehicles using them. It is smaller than the cost of a single metro extension. And it buys communications equipment — devices that transmit messages between vehicles and infrastructure — rather than sensing or reasoning about the environment.

Set that against roughly \$200,000 of sensors and compute fitted to each individual autonomous vehicle. Capital has gone almost entirely into making vehicles smarter and almost none into making the environment knowable. The result is a fleet of highly capable machines, each independently rediscovering the same street, each blind to everything outside its own line of sight, and each generating a private account of what it saw.

What the missing layer has to do

The four constraints share one cause. Perception, reasoning and recording all live inside the vehicle. Everything the vehicle cannot see does not exist, and everything it does see is known only to its operator.

Closing that gap requires a layer between the road and the fleets running on it. Stated as requirements rather than as a product:

It must sense the environment, not from within it.

Continuous observation of the road network from fixed and distributed positions, so that the state of a junction does not depend on which vehicle happens to be approaching it. Independent observation is what makes corroboration possible, and corroboration is what turns a claim into evidence.

It must resolve physical state, not classify images.

What matters to a regulator is not what a model labelled an object, but where mass actually was, moving how fast, on what trajectory, at what moment. That is a question governed by physical law, and physical law does not vary by vendor, by training data, or by weather.

It must process at the edge, under the jurisdiction that owns the road.

Latency and sovereignty converge on the same answer. A supervisory decision that must travel to another continent and back is both slower and less governable than one made locally. Neither problem is solved by faster networks.

It must produce a record no single party controls.

Time-aligned, cryptographically anchored, readable by the regulator, the insurer and the court without the operator's cooperation. The Cruise case demonstrates precisely why the operator cannot be the sole custodian of the evidence about the operator.

It must hold no personal data.

A system that records the physical state of a road network, at scale, in a dense city, is a surveillance apparatus unless it is built from the outset not to be one. Zero personally identifiable information is a design constraint, not a policy layered on afterwards.

It must be vendor-neutral.

Waymo, WeRide, Pony.ai, Tesla, Zoox and every operator that follows must be measurable against the same record. A verification layer supplied by one fleet operator to assess its own fleet reproduces the problem it was built to solve.

08

Where this gets built

The Gulf is the most likely place, and the reasoning is not sentimental.

Fleet size is already a settled race. The 1,200-vehicle commitment across Abu Dhabi, Dubai and Riyadh sets a pace that later entrants will not beat by buying more vehicles. Competing on fleet count is competing on someone else's terms.

The layer beneath the vehicles is unclaimed. No jurisdiction anywhere has built it, and the operator that eventually needs it — every operator will — cannot credibly supply it to itself.

The conditions favour the Gulf technically. Heat, dust, and continuous construction degrade exactly the pre-mapped, vehicle-only architecture that works acceptably in temperate, stable, heavily surveyed North American cities. A layer that holds up in Doha holds up anywhere.

And one jurisdiction has already taken the decision that the rest of this argument depends on. When Pony.ai and Mowasalat deployed on public roads in Doha, the terms were explicit: all pilot data generated by the vehicles, sensors and operations is collected, stored and processed within the State of Qatar, in compliance with national data sovereignty requirements, with no raw sensor feeds and no personally identifiable information leaving the country.

That is worth stating plainly, because it is a more advanced position than the one the United States is currently arguing about. In February 2026 a United States Senate committee learned, under questioning, that half of the remote assistance agents supervising American robotaxis are located in the Philippines — a fact that prompted a senator to raise safety, national security and privacy concerns and to ask a federal regulator to investigate. Qatar wrote the answer to that question into the terms of its first pilot, before the question was asked.

A state that has already required its road data to stay within its borders has established the principle. The layer described in section 7 is what turns that principle into infrastructure.

09

A draft standard, offered for argument

The following is put forward as a starting point for a regional evidence standard for autonomous fleet deployment. It is deliberately minimal and deliberately vendor-neutral, and it is offered to be disagreed with.

E1

Independent observation.

Safety-relevant events on authorised autonomous routes shall be observed by at least one sensing source not owned or operated by the fleet operator involved.

E2

Physical state, not classification.

The record shall capture position, velocity and trajectory of relevant masses, time-aligned to a common reference, independent of any operator's object classification.

E3

Jurisdictional processing.

Sensing and reasoning shall be processed within the jurisdiction that authorises the route. Supervisory functions requiring extra-jurisdictional processing shall be declared and separately licensed.

E4**Custody separation.**

The evidentiary record shall be retained such that no fleet operator can alter, withhold or selectively disclose it. Regulator, insurer and court access shall not depend on operator cooperation.

E5**Intervention disclosure.**

Operators shall report the frequency, duration and category of all remote assistance interventions on a published schedule, in a common format.

E6**Declared latency thresholds.**

Operators shall declare the network latency beyond which remote assistance is deemed unsafe, and report exceedances. This shall not be set individually by each operator without disclosure.

E7**Zero personal data.**

The evidentiary layer shall retain no personally identifiable information by design, and this shall be independently verifiable rather than asserted.

E5 and E6 could be adopted tomorrow at no capital cost. E1 through E4 require the infrastructure this paper describes. E7 determines whether the public accepts any of it.

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Conclusion

The autonomous vehicle industry has spent roughly a decade and an extraordinary amount of capital making individual vehicles capable of driving themselves, and it has succeeded. Four thousand of them now do it commercially every day.

What has not been built is the layer that would let a city — rather than a fleet — operate this way: an independent, physically governed account of what is actually happening on the road, processed locally, readable by the people who must certify, insure and adjudicate it, and controlled by none of the companies whose vehicles it observes.

Until that exists, autonomy scales the way it has scaled so far. City by city, map by map, with a growing number of people watching screens somewhere else, and with the only record of what happened held by the party with the most to lose from it.

Four thousand vehicles is a remarkable achievement. It is not a city.

About the Publisher

Blackspire Group, Inc. is a Reality-Grounded Intelligence company — intelligence built on what is physically true, not on what history suggests is probably true. Blackspire derives the physical state of complex environments from live sensor signals using physics-governed models, producing a governed record of what is rather than an estimate of what is likely.

The company was co-founded by Brent Bursey, CEO, and lead inventor on six foundational patents in spatial-temporal reasoning and automated intelligence production, cited more than 553 times by IBM, Oracle and Microsoft among others, following more than thirty years in classified United States defense and intelligence programmes.

Blackspire's role in a layer of the kind described in this paper is structural rather than monolithic. The company does not propose to build every element of it. Distributed sensing, cryptographic anchoring, network transport and physical infrastructure are mature markets with capable suppliers already serving them. What has been missing is the glue: the reasoning layer that takes signals from sensors that were never designed to work together, resolves them against physical law into a single governed account of what is actually there, and does so fast and locally enough to be acted on. That is what Blackspire builds, and it is why the company works by assembling proven components from an existing partner stack rather than by replacing them.

Two capabilities determine how quickly such a layer can be brought into service. The first is the reasoning framework itself, which exists and is patented. The second is the ability to run that reasoning at the sensor point rather than in a data centre behind it — the difference between a network that reports what it saw and one that resolves what is there. Blackspire's development programme is directed at closing that second gap and fitting the resulting capability to sensor positions already installed as well as to new ones. A terrestrial network on those terms would raise what currently exists by several orders of magnitude.

Blackspire works with sovereign governments, defense and intelligence agencies, critical infrastructure operators and regulated enterprises in environments where being approximately right is not sufficient.

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The seven requirements as an instance of a general pattern

The requirements in section 9 are specific to autonomous road transport, but the problem they address is not. Any system in which autonomous agents act on the physical world and are later held accountable for it faces the same question: what independent record establishes what was true, and who is permitted to act on it.

Blackspire has set out that general structure elsewhere as a nine-layer trust stack. Seven of those layers move information, identity and value. Two do something different: they establish what is physically real, and whether a given action was permitted. Those two are **Proof of Reality** and the governance layer above it, and they are where the requirements in this paper land.

REQUIREMENT	FUNCTION IN THE GENERAL PATTERN
E1 — Independent observation	Proof of Reality: physical state established by a party with no interest in the outcome
E2 — Physical state, not classification	Proof of Reality: what was physically true, distinct from what any model inferred
E3 — Jurisdictional processing	Governance: authority over the record follows authority over the territory
E4 — Custody separation	Proof of Reality: evidentiary weight requires custody independent of the operator
E5 — Intervention disclosure	Governance: the record of who acted, and when, is itself governed
E6 — Declared latency thresholds	Governance: the conditions under which authority transfers are declared, not assumed
E7 — Zero personal data	Constraint across both: the layer must be adoptable by a state without becoming a surveillance apparatus

The remaining seven layers of the stack — the ones that carry information, identity and value between systems — are largely built, commercially available, and not the subject of this paper. The two that establish what is real and what is permitted are the ones nobody has assembled.

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