

SPACE-BASED DATA CENTERS ROADMAP: THE CASE FOR CAUTION

November 2026

Text Box 3-1:

Autonomous Vehicles — Lessons in Safety Regulation

Roger Aines



Innovation for Cool Earth Forum

WORKING PAPER

Text Box 3-1:

AUTONOMOUS VEHICLES—LESSONS IN SAFETY REGULATION

Roger Aines

Large constellations of space-based data centers (SBDCs) have a pertinent analogy on the ground—autonomous vehicles. In the past 12 years, the California state government went through several stages of regulation in which important learnings were translated into new safety controls.[a] Companies and regulators learned which safety controls worked well and which needed significant revision.

In 2014, California regulators allowed testing of autonomous vehicles on public roads for the first time. Drivers capable of taking control of the wheel were required to be in the vehicles at all times. Manufacturers had to first test the vehicles under controlled conditions and demonstrate $5 million in financial responsibility.

In 2018, regulators allowed autonomous vehicle manufacturers to apply to remove the safety driver.[1] Manufacturers were required to identify the roads, weather, speeds and other conditions in which the vehicle was designed to operate—its "operational design domain"—and provide remote communication, a safe-stop capability and a plan for dealing with police and emergency responders.

In 2020, the California Public Utilities Commission (CPUC) allowed deployment under controlled conditions after submission of a Passenger Safety Plan.

Original reporting measures focused on miles driven, collisions and disengagements—times a remote operator had to take control.[2] By 2023, it was clear that expansion had been permitted without adequate controls based on real-world experience from San Francisco.[3] Several key issues were among the corrections: replacing disengagement counts—which the California Department of Motor Vehicles (DMV) concluded did not provide meaningful safety insight—with reports of actual system failures, hard braking, immobilized vehicles, crashes and traffic violations; giving first responders direct communication, vehicle-override and emergency-

[a]Many other national and regional governments, including other US states, went through similar regulatory development processes around autonomous vehicles, but we highlight California because of the scale and advanced stage of autonomous vehicle deployment there.

geofencing tools; and requiring safety cases to be refined throughout the system's life rather than treated as a one-time approval document.[4]

Significant changes in regulations were made based on real-world learnings. For instance, in 2023, a Cruise vehicle dragged an injured pedestrian approximately 20 feet, and Cruise failed to disclose important post-crash details fully. The DMV immediately suspended Cruise's driverless-testing and deployment permits, while leaving it able to test with a safety driver.[5,6] Cruise had about 300 autonomous vehicles on the road in San Francisco at its peak,[7] but in 2024, GM began winding down Cruise after this major safety violation.[8]

Waymo chose to expand gradually despite the CPUC putting no explicit limits on vehicle count.[9] The CPUC relied on monitoring and the ability to suspend permits. Meanwhile Waymo continued to develop its San Francisco service, and by 2025 had permits for almost 2000 vehicles, from a 2023 commercial launch level of about 250 cars. They continue to operate in the city today and release detailed performance and safety data for third-party analysis.[10]

Today California has a revised set of regulations based on 12 years of on-the-road experience with autonomous vehicles.[11] Key regulations include the following:

- Testing first with a safety driver and then without one
- 50,000 test miles at each stage for light-duty vehicles
- A structured safety case covering hardware, software and operations
- Reporting of system failures, immobilizations, hard braking and mileage
- Human response to first-responder calls within 30 seconds
- Fleet withdrawal from emergency geofences within two minutes
- Authority for the DMV to restrict fleet size, location, speed or weather conditions when safety requires it

California uses several terms in its autonomous vehicle regulations that could apply to SBDC deployment, including "phased approach," "minimal risk condition" and "unreasonable risk to public safety."

California's experience regulating autonomous vehicles was less legally complex than SBDC regulation, involving fewer jurisdictions and areas of law. Still, California's approach to autonomous vehicle regulation provides a helpful model for managing the risks of SBDCs.

Key lessons from California's experience with autonomous vehicles include the following:

- Real-world experience in responding to unexpected events is crucial for deploying new technologies with safety risks. Initial assumptions about the performance of a technology may need to be significantly modified in practice.
- Regulators need to build internal capacity to understand the appropriate reporting requirements and a balanced set of regulations.

- Accidents will happen. Transparent reporting is vital to building public and regulator confidence.
- Gradual rollout, data gathering and sharing, repeated safety reviews, and fleet-wide corrections can contribute to public safety and public confidence in a new technology.

A. References

1 California Public Utilities Commission (CPUC) Autonomous Vehicle Programs. Autonomous Vehicle Passenger Service Programs; CPUC, San Francisco, California, https://www.cpuc.ca.gov/regulatory-services/licensing/transportation-licensing-and-analysis-branch/autonomous-vehicle-programs (Accessed August 2026).

2 California Department of Motor Vehicles (DMV). Second Modified Express Terms: Testing of Autonomous Vehicles (California Code of Regulations, Title 13, Division 1, Chapter 1, Article 3.7), pgs. 22–27; CA DMV, Sacramento, California, https://www.dmv.ca.gov/portal/file/second-modified-express-terms-testing-of-autonomous-vehicles-pdf (Accessed August 2026).

3 David Chiu (San Francisco City Attorney). San Francisco seeks reprieve from CPUC decision allowing unfettered autonomous vehicle expansion (Press Release); City and County of San Francisco, San Francisco, California, https://www.sf.gov/news-san-francisco-seeks-reprieve-from-cpuc-decision-allowing-unfettered-autonomous-vehicle-expansion (2023).

4 California Department of Motor Vehicles (DMV). Final Statement of Reasons, pgs. 2-9; CA DMV, Sacramento, California, https://www.dmv.ca.gov/portal/file/final-statement-of-reasons-regulations-pdf (2026).

5 National Highway Traffic Safety Administration (NHTSA). NHTSA Announces Consent Order with Cruise After Company Failed to Fully Report Crash Involving Pedestrian; NHTSA, Washington, D.C., https://www.nhtsa.gov/press-releases/consent-order-cruise-crash-reporting (2024).

6 California Department of Motor Vehicles (DMV). DMV Statement on Cruise LLC Suspension; CA DMV, Sacramento, California, https://www.dmv.ca.gov/portal/news-and-media/dmv-statement-on-cruise-llc-suspension/ (2023).

7 Lyanne Melendez & Juan Carlos Guerrero. Robotaxis may start charging fares 24/7 in San Francisco. But should the restrictions be lifted?; ABC, Inc., KGO-TV San Francisco, San Francisco, California, https://abc7news.com/post/robotaxis-san-francisco-are-safe-self-driving-car-autonomous/13623803/ (2023).

8 General Motors (GM) News. GM to refocus autonomous driving development on personal vehicles; General Motors, Detroit, Michigan, https://news.gm.com/home.detail.html/Pages/news/us/en/2024/dec/1210-gm.html (2024).

9 Public Utilities Commission of the State of California (CPUC) Consumer Protection and Enforcement Division Transportation Licensing and Analysis Branch. Resolution approving Waymo LLC's application for Phase I Driverless Autonomous Vehicle Passenger Service Deployment Program (Agenda Resolution TL-19144); CPUC, Sacramento, California, https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M516/K812/516812344.PDF (2023).

10 Governors Highway Safety Association (GHSA). New IIHS Research Finds Waymo Driverless Vehicles Crash Less Often Than Human Drivers; GHSA, Washington, D.C., https://www.ghsa.org/news/new-iihs-research-finds-waymo-driverless-vehicles-crash-less-often-human-drivers (2026).

11 California Department of Motor Vehicles (DMV). New Autonomous Vehicle Regulations Strengthen Oversight and Enforcement, Authorize Trucks and Transit; CA DMV, Sacramento, California, https://www.dmv.ca.gov/portal/news-and-media/new-autonomous-vehicle-regulations-strengthen-oversight-and-enforcement-authorize-trucks-and-transit/ (2026).