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Physical AI and the Department of Transportation

Opportunities for automation across diverse geographies: what the work is, which constraint binds it, and how far along each class actually sits.

Michael Hiner, Industrial Research Fellow · The Hiner Lab
With Ronnie Gomez and Grant Markhart, Industrial Research Fellows, and Dean David Jean Charlot.

156 graded figures | 11 hypotheses | 57 quantities recorded as not located | 4 terrain classes

A transportation estate is not one estate. This review partitions the United States road network into four terrain and climate classes, anchors each in a named counterparty, and asks of each the same three questions: what is the work, which constraint binds it, and where on the trajectory does it sit today. The national baseline is 8,865,888.676 lane-miles across 4,208,454 centerline miles [1,2], of which state highway agencies own 827,408 miles, under 20 percent [2], while local governments spend 43.03 billion dollars of the 78.39 billion dollar annual maintenance and traffic services pool against state agencies' 35.09 billion [12]. Eleven hypotheses are stated, each resolving to a position in degrees, a binding constraint drawn from material science, engineering implementation, energy, computation efficiency, AI algorithms, regulation or workforce, and a threshold carrying a quantity. Five of the eleven bind on regulation, three on workforce, three on engineering implementation, one on material science and one on energy: the most common binding constraint across this estate is not a technical class. One hypothesis is a deliberate refuter of the review's own partition, and it survives in part. Within the Appalachian class the poor-bridge share ranges from 3.43 to 17.79 percent [41] while the national figure is 6.68 percent, and no candidate sorting variable can be distinguished on four anchor states. Terrain is retained here as a partition of the physical work, which the evidence separates by factors of 3.0 to 123, and is explicitly

not claimed as a predictor of asset condition. Fifty-seven quantities were searched for and recorded as not located rather than estimated.

1. What is in scope, and how were the classes chosen?

This review asks what road and bridge automation is worth to a transportation agency, and it asks the question four times, in four physical settings, because the answer is not the same in each. The unit of analysis is the terrain and climate class rather than the state agency or the vehicle mode. The reason for that choice is that terrain decides what the work physically is: a crew reaching an asset across a water gap, a crew waiting for a pass to open, a crew grading an earth road and a crew rebuilding a gorge alignment are four different problems that happen to share a federal funding code.

Four classes are examined, each with a named anchor and a named counterparty. The archipelagic class is anchored in Puerto Rico and the Philippines, against the Puerto Rico Highways and Transportation Authority and the Department of Public Works and Highways. The Appalachian mountain class covers West Virginia, Tennessee, North Carolina and Virginia. The cold and avalanche class covers Alaska with the Cascade and Rocky Mountain passes, against Alaska DOT and Public Facilities, the Washington State DOT and the Colorado DOT. The arid tribal and sparse rural class covers the Navajo Nation and Hopi lands, against the Bureau of Indian Affairs road programme and the Arizona DOT.

Every quantity carries one of four verification grades. A figure is verified when it comes from a primary series, a statutory instrument or a peer-reviewed publication and was retrieved from that source rather than from a summary of it. It is reported when a named source states it and this review did not independently confirm it. It is self-published when it originates with the party running the programme it describes, including that party's own forward-looking targets, regardless of which outlet relayed it. It is modelled when it is computed here from sourced inputs, which is to say it is the authors' own arithmetic and is never presented as a measurement. Of the 156 graded figures behind this review, 88 are verified, 38 reported, 18 modelled and 12 self-published.

Each hypothesis below resolves to three things. The first is a position on the trajectory, stated in degrees out of ninety, where ninety would mean the application is routine and commercially settled. The second is the binding constraint, named from material science, actual engineering implementation, energy, computation efficiency or AI algorithms, with regulation and workforce admitted as separate classes because in this domain they frequently dominate. The third is a threshold: the specific published quantity whose movement would change the answer. A hypothesis without a threshold carrying a number is not testable and is not included here.

One further discipline governs this review. Where a quantity was sought and not found, that is recorded as a quantity this review did not locate, together with what was searched, rather than as a statement that the quantity is unpublished. Fifty-seven such records were made. Several of them bear directly on conclusions below, and Section 11 sets out the ones that matter most.

Class	Anchor and counterparty	What makes the work different	Binding constraint found
Archipelagic	Puerto Rico (PRHTA); Philippines (DPWH)	Water gaps between the agency and its own assets; a mountain core inside the island	Regulation, then supply-chain engineering
Appalachian mountain	WV, TN, NC, VA (state DOTs)	Steep alignments, post-Helene rebuild, a mobile-coverage floor	Engineering implementation of the mobile layer
Cold and avalanche	Alaska DOT&PF; WSDOT; CDOT	Two availability regimes: seasonal months and control-driven hours	Material science on the seasonal side; workforce on the incident side
Arid tribal and sparse rural	Navajo Nation, Hopi; BIA; ADOT	Unpaved default surface, off-grid points of presence, shrinking denominator	Engineering implementation of the running surface; energy as delivery

Table 1. The four terrain and climate classes, their anchors and the constraint each was found to bind on. The constraint column is a result of this review, not an assumption of it.

2. Who owns the estate, and what two markets sit inside it?

The United States public road network is 8,865,888.676 lane-miles across the fifty states and the District of Columbia, for reference year 2024 [1]. Measured as centerline miles the same network is 4,208,454 [2], so which denominator a coverage claim uses changes the implied result by a factor of 2.1. The Interstate System is 231,104 lane-miles of the total, 2.6 percent of the estate [1]. That 2.6 percent is the only part of the network carrying mandatory annual condition data over its full extent, and it is also where the largest share of work zone fatal crashes occurs, so the sensing case and the safety case coincide there and nowhere else.

Ownership decides who can sign a purchase order. State highway agencies own 827,408 of the 4,208,454 centerline miles, counties own 1.80 million and towns, townships and municipalities own 1.33 million [2]. A programme led by a state DOT therefore commands directly under 20 percent of the estate. The recurring money runs the other way: of 78.394 billion dollars in maintenance and traffic services disbursements for 2024, local governments spent 43.028 billion and state agencies 35.090 billion [12]. The larger half of the maintenance market sits with roughly three thousand county and nineteen thousand municipal owners, which is also the owner class with the least survey data and the least procurement capacity.

That data gap is measurable. Table HM-60 codes lane counts for every functional system except rural minor collector and rural and urban local, which the Federal Highway Administration estimates at two lanes [1]. Adding the three affected systems as published gives 4,051,719.302 rural local, 1,776,947.814 urban local and 517,390.740 rural minor collector lane-miles, which is 6.35 million of the 8.87 million total resting on an assumed lane count. Any national per-lane-mile automation figure is therefore quoted against a denominator that is partly an assumption, and the binding constraint on the national claim is inventory data quality rather than machine capability.

The maintenance pool an automation vendor addresses is also smaller than the highway budget suggests. State highway agency maintenance was 24.756 billion dollars in 2024 against 116.294 billion dollars of capital outlay, a ratio of about one to 4.7 [11]. The Interstate absorbed 7.082 billion of that maintenance, 28.6 percent of the state total on 2.6 percent of national lane-miles [11]. Federal formula money is apportioned through named programmes, and eligibility is a real gate: the National Highway Performance Program at 30.784 billion dollars is 54.2 percent of the 56.811 billion dollar anticipated FY 2026 apportionment and is the programme tied to the condition measures, while the Highway Safety Improvement Program, the channel for work zone countermeasures, is 3.246 billion, 5.7 percent of the total [13].

Segment	Extent	Condition data	Owner and recurring spend
Interstate	231,104 lane-miles, 2.6 percent of the estate [1]	Annual, full extent, sampling forbidden [6]	State agencies; 7.082 bn dollars maintenance [11]
Non-Interstate NHS	218,100 miles reported by roughness band [7]	Required since 2020 [6]	State agencies [11]
Local and rural collector	6.35 mn lane-miles on an assumed lane count [1]	No coded lane count [1]	Counties and municipalities; 43.028 bn dollars [12]
All owners, all systems	8,865,888.676 lane-miles [1]	Partial	78.394 bn dollars maintenance and traffic services [12]

Table 2. The estate divided by what is measured rather than by who drives on it. The two rows in the middle are where federal rule creates recurring demand; the third row is where the money is.

3. What does compliance require, and why does it gate the sale?

The strongest constraint on automated condition assessment in this domain is not sensing performance. It is the shape of the output a federal rule will accept. Bridge condition is classified by the minimum of condition rating method applied to three integer human judgements on a zero to nine scale: National Bridge Inventory items 58, 59 and 60, or item 62 for culverts. A structure is Good when the lowest of the three is 7, 8 or 9, Fair when the lowest is 5 or 6, and Poor when the lowest is 4 or below [4]. A system with better physical resolution than a human inspector still fails the compliance test if it cannot emit those three integers, and the decision boundary that carries money is one integer step, from a lowest rating of 5 to a lowest rating of 4.

Pavement is gated the same way and more tightly. A section is Good only if all three of roughness, cracking percent and rutting or faulting are Good, and Poor if two or more of the three are Poor [6]. A sensor suite that measures roughness excellently but cannot report cracking percent produces data that cannot form the federal measure at all. This is the specific reason a vendor accuracy claim stated on the International Roughness Index alone does not establish compliance, and it is why automated pavement assessment is a multi-sensor engineering problem rather than a single-camera one.

The same rule that constrains the output also creates the demand. For the Interstate System, data must be collected from the full extent of the mainline in one consistent lane, continuously, in nominally uniform sections of 0.10 mile, annually, and estimating conditions from samples of the full extent is not permitted [6]. Against 231,104 Interstate lane-miles that is on the order of 2.3 million reportable sections a year before the non-Interstate National Highway System is added. Federal rule already forces a data volume manual methods cannot meet, which is why automated data collection vehicles are the one part of this estate where automation is the default rather than a proposal. The binding constraint there has moved downstream, to the computation efficiency of processing and quality-assuring the resulting imagery and profiles.

Where the rule creates demand it does so unevenly, and the national averages conceal it. Interstate pavement has held between 61.1 and 62.2 percent Good and between 0.8 and 0.9 percent Poor across the five reported years to 2022 [5], against a federal minimum-condition threshold of 5.0 percent Poor, or 10.0 percent in Alaska [6]. The national estate sits at roughly one sixth of the penalty threshold, so no national financial pressure is pushing Interstate pavement automation and any real case is state-specific. Bridges are the opposite. Good deck area on the National Highway System fell in every one of six consecutive reported years, from 43.4 to 40.4 percent, while Poor also fell from 4.5 to 4.0 percent [5]. Both moving down means the estate is draining out of Good into Fair faster than Poor is being repaired, and Fair-condition deck area is precisely where preventive work has the highest return. Of 409,265,353 square metres of national deck area, 219,125,109 are Fair [3].

Instrument	What it fixes	The number that gates it	Constraint class
23 CFR 490.409 [4]	Bridge Good / Fair / Poor by minimum of three integers	Lowest rating 5 versus 4	Regulatory
23 CFR 490.411 [4]	NHS structurally deficient ceiling	10.0 percent of NHS deck area	Regulatory
23 CFR 490.313 [6]	Pavement composite rating, three metrics	IRI 95 and 170; two of three Poor	Regulatory
23 CFR 490.309 [6]	Annual full-extent Interstate collection	0.10-mile sections, sampling forbidden	Computation efficiency, downstream
23 CFR 490.315 [6]	Interstate pavement Poor ceiling	5.0 percent, 10.0 percent in Alaska	Regulatory

Table 3. The federal instruments that decide whether an automated measurement counts. Each names a quantity, and in every case the quantity is an integer or a percentage rather than a physical resolution.

4. How much of the exposure is actually addressable?

Removing people from live traffic is the strongest quantified argument for maintenance automation in the federal dataset, and it is also the one most often overstated. National work zone fatalities were 863 in 2020, 963 in 2021, 903 in 2022, 905 in 2023 and 850 in 2024 [8]. The series has not fallen below its 2020 level in five years, and a six percent year-on-year decrease inside a five-year range of 850 to 963 does not establish a trend. the position is that work zone fatality exposure is flat.

The addressable share is much smaller than the headline. In 2024, 673 of the 850 work zone deaths were drivers and passengers passing through, and 169 were pedestrians and pedalcyclists [8]. Worker-removal automation can address the pedestrian category and not the occupant category, and that category also contains non-worker pedestrians, so the true ceiling is below 169. A claim that maintenance robotics addresses work zone deaths as a whole overstates the addressable share by roughly a factor of five. The occupational series is separate and smaller again: between 82 and 143 worker fatalities a year at road construction sites over 2015 to 2024, of which 52.7 percent over 2022 to 2024 were workers on foot struck by a motor vehicle and a further 24.8 percent were workers in a crash [14]. The two series count different populations, by roadway location and by employment status, and must not be added.

Which automation intersects the causal mechanism is a separate question from which automation removes the worker. Speeding was a factor in 34 percent of fatal work zone crashes in 2024, up from 29 percent in 2023, while total fatalities fell, and more than half of fatal work zone crashes occurred at night [8]. That combination favours automated speed enforcement, automated queue warning and automated lighting or delineation over maintenance robotics, because the dominant mechanism is approaching-driver behaviour. It also locates the exposure on the night shift, which is the one where a machine's insensitivity to darkness is a genuine physical advantage rather than a marketing claim. Sequencing follows from geography as well: on the 2022 to 2024 average the Interstate carried about 47 percent of fatal work zone crashes [9] while being 2.6 percent of national lane-miles [1]. Finally, proportion matters: the 850 work zone fatalities of 2024 are 2.17 percent of the 39,254 national traffic fatalities that year [10].

Population	Most recent figure	What automation can reach	Series
All work zone fatalities	850 (2024)	Part	FARS via FHWA [8]
Vehicle occupants in work zones	673 of 850 (2024)	Not by worker removal	FARS via FHWA [8]

Pedestrians and pedalcyclists in work zones	169 of 850 (2024)	Upper bound, includes non-workers	FARS via FHWA [8]
Worker fatalities at road construction sites	82 to 143 per year, 2015–2024	52.7 percent struck on foot	BLS CFOI via the Clearinghouse [14]
All US traffic fatalities	39,254 (2024)	Context, not target	NHTSA FARS [10]

Table 4. The work zone safety case sized to the evidence. The addressable population is the fourth row, not the first, and the first row has been flat for five years.

5. In the archipelagic class, what does the gap price?

Puerto Rico carries 19,964 miles of public road, of which the state highway agency owns 4,761 and municipalities own 15,182 [15]. A 76 percent municipal share means an automated inspection or maintenance programme addresses an estate whose majority owner is 78 separate municipalities rather than the territorial DOT. The managed network is 4,851.82 centerline miles and 11,394.42 lane-miles, of which 83.5 percent of centerline length is non-National Highway System local and collector road [16]. Bridge condition is drifting: all bridges moved from 428 Good and 332 Poor in 2024 [17] to 414 Good and 344 Poor in 2025 on a rising total, with Fair holding at about 68 percent [18].

The event that resets this estate is quantified. Hurricane Maria made landfall near Yabucoa at 135 knots and 920 millibars, with an eyewall replacement that tripled eye diameter from 9 to about 28 nautical miles before landfall, which is why the reset was island-wide [19]. Damage was estimated at 90 billion dollars against a previous island record of about 5 billion, an eighteen-fold jump [19]. Eighty percent of utility poles and all transmission lines were knocked down [19], and restoring power to all customers with structures deemed safe took roughly eleven months [20]. Any automation depending on grid power or roadside sensing inherits that interval as an availability schedule.

Where the damage fell is the finding that matters for the class thesis. The United States Geological Survey mapped 71,431 landslides across 72 of the 78 municipalities, with zero documented on the water-separated island municipalities of Culebra and Vieques and the highest densities in the Cordillera Central interior [22]. The Federal Emergency Management Agency record agrees: Utuado recorded 330 roads-and-bridges projects and Orocovis 312, against two each for Vieques and Culebra [23]. Within an archipelago, the binding physical constraint on the road estate was slope and rainfall, not separation by sea. The water gap binds somewhere else, on supply and crew access.

Priced in days rather than dollars the gap is sharper still. The Port of San Juan reopened for daylight operations three days after landfall, and every airport and seaport ran at limited capacity for about seven days, with few if any materials stockpiled locally and some equipment used on the island not standard in the continental United States [21]. That is the clearest published statement of what separation by water does to the cost of reaching an asset, and it applies to a spare part for an automated machine exactly as it applied to a utility pole. The resupply channel itself is ageing: four Jones Act carriers operate seventeen vessels whose containerships average 39 years against an expected useful life of about 30, and whose barges average 31 against about 27 [36]. That is a material and engineering constraint on the channel, and the same audit states it could not validate the shipper-reported rate examples, which is the limit on how far a cost premium can be quantified from it.

The permanent-work phase, not the emergency phase, is where the time goes. Across 3,036 category C projects, first obligations ran 5 in 2018, 161 in 2019 and 1,785 in 2020, with 244 projects still receiving obligations in 2026 and the latest first obligation dated 27 February 2026 [23]. The median project was not obligated until about two and a half years after landfall. Federal quick-release road money by contrast moved within weeks, at 72.5 million dollars for Puerto Rico [26], two orders of magnitude below the 2.98 billion dollars eventually obligated for roads and bridges [24]. Automation deployed to speed damage assessment is competing against a process whose slow step sits downstream of assessment. Of 23.4 billion dollars in Public Assistance awarded as of June 2023, 1.8 billion had been spent, and about 11.3 billion required federal authorisation before the territory could expend it, with subrecipients planning to access remaining funds through 2030 and possibly beyond [25].

The Philippine anchor separates the class further. Typhoon Haiyan struck Guiuan at 168 knots on a one-minute basis and 118 knots on a ten-minute basis at the same timestamp [29], a 40 percent disagreement that any wind-load specification must declare. Yet roads and bridges together were 1.65 billion of 89.6 billion pesos of damage, about 1.8 percent, while the social sector was 61 percent [30], and 1,084,762 houses were damaged of which 489,613 were totally destroyed [30]. The whole national-road reset was about 105 kilometres [31], roughly 0.3 percent of the national network. The same terrain class produced a road-dominated reset in one anchor and a housing-dominated reset in the other, which constrains any claim that the class alone fixes the binding constraint. What the water gap does price is movement: domestic inter-island freight runs at 1.20 dollars per nautical mile Manila to Davao against 0.40 for Hong Kong to Manila, a factor of 3.0 [34]. That multiple applies to a spare part or a replacement machine exactly as it applies to a pole. It is also not fixed by geography, because a change of crossing mode to roll-on roll-off moved commodity freight costs by 20 to 68 percent [34], a larger swing than most automation efficiency claims.

Two further quantities bound what monitoring is worth in this class. On the National Highway System, the territory's own asset management plan identifies six locations needing repair more than once across 25 years of declared emergencies [27]. Predictive site-level monitoring on that network has almost no repeat-failure signal to learn from, because the reset is a whole-system event rather than an accumulation of recurring points. And the reset dominates the maintenance cycle rather than the reverse: the 2.98 billion dollars obligated for roads and bridges after Maria [24] is more than five times the highway authority's roughly 560 million dollar annual capital expenditure [28]. The Philippine appropriation shows the water gap entering a maintenance budget as a standing line: alongside 8.502 billion pesos for routine maintenance of national roads and 1.788 billion for national bridges sits 1.342 billion pesos for maintenance and operations of departmental floating equipment [32], a cost with no analogue in a continental road agency. At the crossing itself the charge is published per lane metre: 283 to 366 pesos per lane metre and 1.5 to 2 hours of transit on a 24 nautical mile Batangas to Calapan leg [35], which is the marginal cost an autonomous road vehicle would still incur at an archipelagic route break.

Quantity	Value	Grade	What it constrains
Puerto Rico municipal road share	15,182 of 19,964 miles	verified 15	Counterparty count, 78 municipalities
Landslides on water-separated municipalities	0 of 71,431	verified 22	Damage is slope-driven, not sea-driven
Median first obligation after landfall	2020, about 2.5 years	verified 23	Assessment is not the slow step
Roads and bridges share of Haiyan damage	1.8 percent	verified 30	The class does not fix the constraint
Domestic inter-island freight multiple	3.0 times per nautical mile	reported 34	Every part crossing the gap
Movement achieved by changing crossing mode	20 to 68 percent	reported 34	The constraint is regulatory and terminal

Table 5. The archipelagic class. The two rows in bold contrast are the second and the fifth: within the island the mountain binds, and between the islands the crossing binds.

6. In the mountain class, what does the link budget decide?

The Appalachian Regional Commission region is 423 counties across 13 states, 206,000 square miles and 26.6 million residents [37]. Its purpose-built corridor network is 92.1 percent built after six decades: 2,846 of 3,090 authorised miles complete, open or under construction as of 30 September 2025, with 197 miles still in location studies [42]. The cost to complete the remainder was estimated at 15.154 billion dollars in 2025 dollars, up from 10.3 billion in 2021 dollars, an escalation the Commission attributes partly to national highway construction costs rising about 14 percent a year since 2021 [43]. Dividing the state cost-to-complete figures by miles not open to traffic gives 43.5 million dollars per mile in Tennessee, 39.2 million in Virginia, 37.3 million in West Virginia and 26.2 million in North Carolina [43], an order of magnitude above ordinary rural two-lane construction. The cheapest route to automated freight in this class is to route onto existing corridors rather than to expect new geometry to be built for it.

The class is not economically uniform, and that matters for any labour-substitution case. Appalachian North Carolina, the terrain Helene hit hardest, contains zero distressed counties, while West Virginia contains eleven distressed and twenty at risk [38]. Per capita market income runs 32,783 dollars in Appalachian Virginia, 57.4 percent of the national 57,066, against 40,589 in Appalachian North Carolina [38]. The wage a machine must beat is roughly four sevenths of the national figure in the part of the class where capital cost per mile is highest, which pushes the break-even point outward exactly where the terrain argument would push it inward.

Hurricane Helene supplies the stress case. Peak rainfall reached 30.78 inches at Busick in Yancey County, North Carolina, against 6.11 inches at Bluefield, West Virginia [44], a factor of five in the forcing term inside one terrain class. North Carolina recorded 107 of the 250 United States deaths, with more than a thousand of the 2,700 high-water rescues from freshwater flooding in the western mountains [44]. The state assessed roughly 5,000 miles of state-maintained road as severely impacted, with 674 bridges and 712 culverts damaged and more than 7,000 private roads, bridges and culverts affected [48]. Against 80,592 state-agency miles [39], 5,000 miles is 6.2 percent of the state-maintained system rendered unusable in a single event.

The legal footprint of the event shows the class boundary again. North Carolina's declaration covered 40 designated areas with both household and public assistance, Virginia's 18 and 37 areas respectively, and Tennessee's 8 and 14, while West Virginia's covered one county with household assistance and no public assistance at all [45]. Obligations follow: 2.401 billion dollars of public assistance in North Carolina against 582.9 million in Tennessee, 101.7 million in Virginia and none in West Virginia [46]. Federal road money moved fastest of all, with quick releases issued the day before and the day of landfall, at 250 million dollars to North Carolina against 70 million to Tennessee and 10 million to Virginia [53]. North Carolina's own assessment put total damage and needs above 59.6 billion dollars [47], which is 24.8 times what federal public assistance has actually obligated, and that gap is the quantity a resilience argument turns on. Within the transportation total of 10.342 billion dollars, 2.185 billion of the 8.185 billion of road and bridge damage sits on roads no state DOT controls, 27 percent [47].

Restoration duration is measurable and long in the tail. NCDOT reported 6,900 damaged sites on 14 October 2024 [50] and nearly 9,500 at eighteen months [49], so the assessment itself took about a year to converge: reporting latency, not repair latency, dominated the first phase. At eighteen months 87 percent of sites were repaired, and by July 2026 more than 99 percent of closed roads had reopened [51]. The residual is where the terrain is: Interstate 40 through the Pigeon River Gorge is a two billion dollar rebuild targeted for late 2028, and permanent reconstruction on US 64, US 74A and US 176 runs to 2029 [51]. On the Blue Ridge Parkway, at least 57 landslides affected nearly 200 miles in North Carolina, roughly one per 3.5 miles, with more than four dozen in a single 38-mile section [52]. Slope instability persists after the water recedes, so an automated route through gorge terrain faces a five-year window in which the road geometry itself is a moving target. That is a mapping and change-detection constraint rather than a driving-policy one.

The constraint that binds this class hardest is the mobile link, and it is priced. Rural combined fixed and mobile coverage at the end of 2022 was 29.4 percent in West Virginia against 52.3 percent in North Carolina, 51.0 percent in Tennessee and 42.1 percent in Virginia [54], a 23-point spread inside one class. At county resolution the spread is wider and does not track density: Ashe County, North Carolina reports 99.5 percent fixed and 21.1 percent mobile at 63.6 people per square mile, while Graham County reports 43.0 percent fixed and 28.1 percent mobile at 27.3 [54]. In Buchanan County, Virginia the figures are 91.0 percent fixed and 1.8 percent mobile [54], which isolates the failure precisely to the layer a moving vehicle needs. In Pocahontas County, West Virginia both layers fail together at 0.7 percent combined [54].

That constraint is moving, and this is the fastest-moving quantity located in the review. Appalachian household broadband subscription rose 11.1 percentage points between the 2014 to 2018 and 2019 to 2023 American Community Survey periods, to 86.2 percent against 89.7 percent nationally [55]. Committed capital is allocated: 1.533 billion dollars to North Carolina, 1.481 billion to Virginia, 1.211 billion to West Virginia and 0.813 billion to Tennessee under the Broadband Equity, Access and Deployment programme [56]. What that money buys is where terrain shows itself most clearly. Inside western North Carolina the average build cost is 4,509 dollars per location, but McDowell County runs at 18,274.73 dollars and six counties are served entirely by low-earth-orbit satellite at 600 dollars per location [58], a thirty-fold spread within one mountain region. Where the terrain wins, the state programme chose an orbital link over a trench. North Carolina's own award schedule puts service by 2030 with projects launching in mid-2026 [57], which dates the earliest point at which this constraint could be materially relaxed.

Quantity	Value	Grade	Constraint
ADHS completion after six decades	92.1 percent, 197 miles still in location study	verified [42]	Engineering implementation
Cost per remaining corridor mile	26.2 to 43.5 million dollars	modelled [43]	Engineering implementation
Peak rainfall gradient inside the class	30.78 in NC against 6.11 in WV	verified [44]	The class shares no hazard profile
State-maintained network lost in one event	about 5,000 of 80,592 miles, 6.2 percent	reported / verified [48,39]	Engineering implementation
Rural combined coverage spread	29.4 to 52.3 percent	verified [54]	Engineering implementation, mobile layer
BEAD cost per location, one region	600 to 18,274.73 dollars	reported [58]	Terrain changes the technology class

Table 6. The Appalachian class. The last row is the strongest single piece of terrain evidence in this review: at the extreme, terrain does not raise the price of the trench, it replaces the trench with a satellite.

7. In the cold class, why are there two availability markets?

Availability, not capability, is the governing variable in this class, and it comes in two regimes that respond to different interventions. The seasonal regime is measured in months. State Route 20 over the North Cascades closed on 18 November 2024 and opened on 22 April 2025, 155 days or 42.5 percent of the year [59,60]; the following winter it closed on 4 December 2025 and reopened on 25 June 2026, 203 days or 55.6 percent, the latest opening on record [61]. State Route 410 over Chinook Pass closed for 204 days in 2024 to 2025, 55.9 percent [59]. Colorado 82 over Independence Pass, at a 12,095 foot summit, closes about 195 days on its typical dates, 53.4 percent [63]. Two ranges and a 6,600 foot elevation difference produce the same answer, which suggests the closure fraction in this class is set by the operating decision rule rather than by elevation.

The segment over which that penalty applies is small enough to matter. The North Cascades seasonal gate closure runs from milepost 134 to milepost 171, 37 miles [62], and the Independence Pass closure covers about 37 miles between mileposts 47.2 and 84.2 [63]. Both are within single-charge range of current ground platforms, so on these segments the constraint is calendar access rather than platform endurance. The severity envelope on the Alaska anchor is a different matter: Thompson Pass receives nearly 46 feet of snow a year, and a single station at 6,620 feet is treated as notable enough to publicise [77], which indicates how sparse the instrumentation baseline is and makes enclosure survival a materials problem before it is a sensing one.

The seasonal constraint is written into the procurement instrument, which makes it harder to move than a weather pattern. Alaska highway construction contracts require seeding between 15 May and 15 August absent written approval, a 93-day window, 25.5 percent of the year, for the closing activity of a project [64]. Asphalt may not be placed when air temperature is below 40 degrees Fahrenheit, and hot mix leveling course may not be placed when the roadway surface is colder than 40 degrees [64]. Seasonal suspension of work and winter shutdown are standing contract terms [64]. This names the physical variable exactly: a paving process tolerant below 40 degrees Fahrenheit would extend availability, whereas a faster or autonomous paver operating under the same threshold would not. The constraint here is material science, and an autonomous construction fleet in this class is idle by contract for part of the year, which changes the utilisation assumption under any capital-intensive automation.

The incident regime is measured in hours and is where deployed automation already sits. Colorado recorded 1,707 hours of avalanche control closures in the 2018 to 2019 season, with 1,615 explosions, 877 avalanches triggered and 51 control missions [65]. Of 522 identified avalanche paths above Colorado highways, 278 are regularly monitored and controlled [65], leaving a 244-path gap. Remote control systems on three paths at Red Mountain Pass cost 744,900 dollars, roughly 248,000 dollars per controlled path [67], which sets the order of magnitude for closing that gap and is an engineering-implementation cost rather than an algorithmic one. Alaska sits earlier: two instrumented infrasound locations statewide against 200 paths reported on the Seward Highway alone, funded by a 1.1 million dollar federal grant [68]. The agency's own page counts 60 common avalanche areas statewide [69], which is a different unit of account from the programme manager's 200 paths on one highway, and this review did not locate a published definition reconciling the two. Any coverage claim in this class has to state which unit it uses.

Forecasting and clearing sit on opposite sides of the automation case. Colorado's contribution to statewide highway avalanche forecasting is 1,107,265 dollars a year, 30 percent of the forecasting centre's revenue, of which 67 percent of expenditure is personnel [66]. Against 522 identified paths the per-path forecasting cost is low, so automation savings in forecasting are small in absolute terms. Clearing is the opposite. A single avalanche closed the Richardson Highway at milepost 12 to 18 on 24 January 2014, with full reopening on 5 February: twelve days on the only road to Valdez, 200,000 cubic yards of snow removed from debris about 40 feet deep, with cleanup running 24 hours a day for five days [70]. That is a materials-handling problem, not a sensing or decision problem. Exposure decides where an hour is worth most: Interstate 90 over Snoqualmie Pass carries about 28,000 vehicles a day of which about 5,600 are freight, under more than 450 inches of annual snowfall, against about 4,500 vehicles a day on US 2 over Stevens Pass [73].

Two findings cut against a simple cold-is-the-constraint reading. On five-year averages, winter maintenance costs 3,043.44 dollars per lane-mile in Colorado and 3,072.42 in Washington, against 1,541.37 in Alaska and 1,205.26 in Montana [72]. If cold alone set the cost the ordering would reverse. Workforce density behaves the same way: 67.4 winter maintenance workers per thousand state-maintained lane-miles in Colorado and 68.2 in Washington, against 36.3 in Alaska, 28.9 in Montana and 28.1 in Wyoming [71]. Colorado and Washington, not Alaska, hold the largest per-lane-mile labour pool a substituting automation could displace. A caveat belongs with those figures: Alaska's return reports labor and equipment costs summing to 26.387 million dollars in 2024 to 2025 against a stated snow and ice total of 10.035 million, with materials blank, and the same pattern appears in the two prior years [71]. This review did not locate an Alaska primary source reconciling them, so the cold-cost question cannot currently be settled using that state.

Where the displaceable workforce actually is, it is already thin. The Anchorage maintenance station runs six operators on an average shift across 1,187 lane-miles of highway and 160 miles of sidewalk, after a stated 27 percent regional budget reduction and fifteen lost positions [76]. This is the clearest case in the review where automation is asked to substitute for a workforce already cut rather than to slow a growing one. The equipment mix also does not transfer between members of the class: Alaska runs 8.4 road graders per thousand lane-miles against Colorado's 3.6 and Washington's 1.8, and applies 12.93 tons of abrasive per lane-mile where Colorado applies none [71]. A platform validated on a plough-and-chemical regime is not validated on a grader-and-abrasive one. Finally, the benchmark any automated intervention must beat is not zero: a regulatory change, Colorado's updated Traction Law, coincided with closure hours falling 21 percent for crash closures and 35 percent for non-crash emergency responses in a single autumn quarter comparison [75].

Regime	Unit	Measured value	Constraint	Where automation already is
Seasonal closure	Months	42.5 to 55.9 percent of the year [59,60,61,63]	Material science, the 40 degree gate [64]	Not deployed
Contractual work window	Days	93-day seeding window [64]	Regulatory, written into contract	Not deployed

Avalanche control	Hours	1,707 hours, 2018–19 Colorado [65]	Engineering implementation coverage	278 of 522 paths [65]
Incident and crash closure	Hours	142 hours in one autumn quarter, I-70 [75]	Workforce and driver behaviour	Traction Law achieved 21 to 35 percent [75]

Table 7. The cold class holds two availability markets. They are measured in different units, bind on different constraints, and only one of them currently has automation deployed against it.

8. In the arid and sparse rural class, what comes first?

The distinguishing variable in this class is not how far apart the roads are. Navajo Nation route density is 0.580 route-miles per square mile against 0.662 for Arizona statewide and 1.187 for the United States [84], so the network is 88 percent as dense as its own state. What distinguishes it is the surface. Of 14,167.6 total roadway miles, only 23.4 percent are paved, and four owners share the network: the Bureau of Indian Affairs holds 5,994.5 miles, the Nation 4,889.9, the state 1,644.8 and counties 1,638.4 [79]. The federal component is starker still: 6,017 BIA-owned miles in the Navajo Region comprise 1,506 paved, 90 gravel and 4,420 earth [78]. Nationally the discontinuity is an ownership boundary rather than a gradient, with 5.8 percent of tribally owned inventory miles paved against 93.7 percent of state-owned miles inside the same inventory [78]. An automated vehicle crossing from a state route onto a tribal route changes problem class at the property line.

The class sits inside a larger federal estate with the same properties. The Bureau of Indian Affairs maintains 29,300 miles of road and 1,080 bridges nationally, of which approximately 16,900 miles are unimproved or earth surface, 57.7 percent, inside a total public network serving Indian Country of more than 156,000 miles [80]. The Navajo Region alone holds about a fifth of BIA road miles, and it carries 66.14 million dollars of the 289.67 million dollar national BIA deferred maintenance backlog, 22.8 percent [101]. Scale sets the amortisation problem: the Navajo Nation reservation and off-reservation trust land measure 24,429.534 square miles [81], and widely repeated secondary figures of 27,000 square miles run 10.5 percent above that census measurement. Hopi lands, 2,532.07

square miles [81], sit enclosed within the Navajo estate with 6,377 residents and 2,483 housing units [83], so any route network serving Hopi villages crosses Navajo jurisdiction and utilisation rather than capability governs the case there.

Paved does not mean machine-legible here either. About 10 percent of the paved system is in good or better condition, 20 percent fair, and the remaining 70 percent poor or failing [79]. Lane-marking retroreflectivity, edge definition and surface friction assumptions carried over from state-highway conditions do not hold. The price ladder for changing that is published: 750 dollars per mile for blading a dirt road, 2,000 for gravel maintenance and 6,000 to 10,000 for paved maintenance [79], against 250,000 dollars per mile to gravel a road and 3 million per mile for permanent pavement [103]. Total funding available over a twenty-year period is 820 million dollars against a stated need of 7.9 billion [79], a gap of 9.6 to one. If the surface does not change, the automation problem does not change, and no vehicle-side advance alters that.

Energy in this class is a delivery cost per point of presence, not a generation problem. Distributed photovoltaic capacity factor on Navajo lands is 27.9 percent, the joint highest of any tribal area in the country and 1.78 times the national residential mean of 15.7 percent [92]. What binds is the wire and the meter. The utility reports 4.06 customers per mile of line against a stated urban comparison of about 500, a ratio of about 123 [87], and states a cost of approximately 40,000 dollars to connect one home [86]. Reliability compounds it: utility customers in Arizona lost 506.61 service-minutes in 2024 against an Arizona statewide average of 87.5, and 305.25 minutes even with major event days removed against a statewide 87.5 [88]. Any roadside asset depending on mains power in this class needs local storage sized to a several-hundred-minute annual outage budget rather than the tens of minutes assumed in urban designs.

Headroom on the distribution system is smaller than customer counts suggest. Connected households in this class consume 5,995 kilowatt-hours per residential customer per year against a national 10,072, 59.5 percent of the national figure [89]. Adding vehicle charging to feeders sized for six megawatt-hour households is a distribution-capacity question rather than a generation one, which is the same conclusion the capacity-factor figure reaches from the opposite direction.

The trajectory on electrification is real and slow. Households lacking electricity moved from 36.7 percent in 2000 [85] to an estimated 21 percent, 14,063 homes, in the 2023 report to Congress [85]. The volunteer connection channel achieved more than 230 homes in 2019, 137 in 2022, 159 in 2023, 170 in 2024 and at least 200 in 2025 [91], at about 3.1 homes per mile of new line [87]. At roughly 170 homes a year against a residual of 10,000 to 14,063, that channel alone closes the gap on a multi-decade horizon. Two measurement cautions belong here. The 21 percent share rests on a housing denominator of 68,101 that exceeds the 2020 Census count of 57,479 units by 18.5 percent [82], and the independent check is the utility's own 43,308 metered connections [88]. Separately, a primary series that does not depend on any grid estimate points the same way: of 50,333 occupied units, 32,696 heat with wood and 6,337 with electricity [90].

The reporting layer fails alongside the power layer. Of 50,333 Navajo households, 26,255 have no internet access of any kind, 52.2 percent, and 21,740 have broadband of any type [93]; the Hopi figures are statistically indistinguishable at a tenth the land area [94]. On Arizona federal reservations, 19.6 percent have fixed terrestrial 100/20 service and 17.3 percent have both fixed and mobile, against 65.9 percent for all tribal lands nationally [95]. The metric that matters for a moving vehicle is worse and is not improving monotonically: outdoor stationary 5G-NR at 35/3 on rural federal reservations fell from 71.8 percent in 2021 to 53.8 percent in 2022 [95]. The Nation's own plan prices the fix at approximately 76 new towers and 1,529 miles of fibre for 267 million dollars of middle-mile work, excluding permitting and right-of-way [96], which is a connectivity build roughly one tenth the length of the road estate it would serve.

The demand side cuts both ways, and both directions belong in the record. Against automation: under the state's own medium forecast Navajo County population falls 12 percent by 2060, corridor employment falls from 669 to 588, and population around the SR 264 corridor already dropped 15 percent between 2020 and 2023 [99]. A per-vehicle business case here faces a shrinking denominator that no engineering advance moves. For automation: 6,946 of 50,333 households, 13.8 percent, have no vehicle available [102], 17 percent of the SR 264 corridor population has no vehicle and 48 percent lack reliable internet [97], and in the Four Corners region 583 fatalities over 2013 to 2019 included 61 percent unrestrained occupants, 43 percent with a driver at or above 0.08 blood alcohol and 36 percent involving speeding [100]. Those three mechanisms are precisely what an automated driving system addresses. The per-capita safety return in this class is unusually high even though the traffic volume is unusually low: SR 264 carries 1,300 to just under 3,000 vehicles a day at speeds up to 65 miles per hour across 323 access points including 113 dirt driveways [98]. That is unprotected high-speed conflict at low volume, the inverse of the dense low-speed conflict urban deployments have been tuned against. It cannot currently be demonstrated from records either, because the state agency of record states its own crash dataset is incomplete on tribal land [98].

Layer	**Quantity**	**Value**	**Grade**	**Constraint**
Surface	Paved share of the network	23.4 percent	self-published 79	Engineering implementation
Surface	Paved miles poor or failing	70 percent	self-published 79	Engineering implementation
Surface	Twenty-year funding against need	820 mn against 7.9 bn dollars	self-published 79	Capital, driving engineering
Energy	Solar capacity factor against national mean	27.9 against 15.7 percent	modelled 92	Not generation
Energy	Customers per mile of line	4.06 against about 500	self-published 87	Energy as delivery
Energy	Service minutes lost, 2024	506.61 against 87.5 statewide	verified 88	Local storage sizing
Reporting	Households with no internet access	26,255 of 50,333	verified 93	Engineering implementation

Demand	Households with no vehicle	6,946 of 50,333	verified 102	The unmet-mobility case

Table 8. The arid class layer by layer. The energy rows are the ones that matter for framing: the resource is the best in the country and the delivery is the worst, so the constraint is the wire rather than the joules.

9. Does terrain partition the problem?

This review was designed to include a hypothesis capable of overturning its own organising choice, and that hypothesis partly survives. It states that inside the Appalachian class the automation-relevant quantities sort by ownership and connectivity rather than by slope, which if it holds means terrain is the wrong partition and the central claim fails on its own evidence. The test quantity is the share of bridges in poor condition, and it splits the class: 17.79 percent in West Virginia, 7.14 in North Carolina, 4.35 in Tennessee and 3.43 in Virginia, against a national 6.68 percent [41]. Two of the four steep-terrain anchor states sit below the national figure. Only West Virginia is an outlier, at 2.66 times national. Steep terrain does not by itself predict deteriorated structures.

The alternative the hypothesis proposes does no better on the same four points. State highway agency ownership shares, computed from the published mileage, are 87.9 percent in West Virginia, 78.9 in Virginia, 74.1 in North Carolina and 14.7 in Tennessee [39]. The most consolidated state has the worst bridges and the most fragmented state has nearly the best, so the ordering does not follow ownership either. Ranked against poor-bridge share the two series give a Spearman coefficient of 0.4, and rural mileage share [40] gives 0.8; on four observations a coefficient of 1.0 is required before anything can be said. Removing West Virginia leaves three states at 3.43, 4.35 and 7.14 percent, straddling the national figure. the reading is that on four anchor states no candidate sorting variable can be distinguished, and one outlier drives the entire picture.

There is a deeper reason the test cannot settle the question, and it is worth stating plainly because it also limits what this review claims. The terrain variable itself is unmeasured. This review searched the Federal Highway Administration Highway Statistics series, state route-characteristics documentation and design documentation for the four states and did not locate a published percent-grade or curvature distribution for any of them. The only quantified terrain statements located are a state budget office's report that western North Carolina has 25 percent more public bridges than the state average, that municipal and private roads are 48 percent of the region's total against 41 percent statewide, and that average elevation is two to three times that of the Piedmont [48]. A partition cannot be confirmed or refuted against a variable this review did not locate in any published series, having searched the federal and state inventories named above. On the evidence needed to decide it, this question sits at about 5 of 90 degrees.

Poor-bridge share is in any case the wrong outcome to test terrain against. It is a legacy of decades of capital spending and inspection practice, not a measure of what the automation work is. Where this review does measure the work, the class separation is large and it is measured rather than inferred: 123 times on customers per mile of electrical line [87], 30 times on per-location connectivity build cost inside a single mountain region [58], 3.0 times on per-nautical-mile domestic freight [34], and a factor of about two on the fraction of the year a corridor is open [59,60,63]. Terrain is therefore retained here as a partition of the physical work and of the constraint that binds it, and it is explicitly not claimed as a predictor of asset condition. Section 10 states what would settle the question: publication of a percent-grade or minimum-radius distribution for state-maintained mileage in the four anchor states, tested against those four poor-bridge shares.

Anchor state	Poor bridges [41]	State-owned share [39]	Rural share [40]	Rank agreement with poor share
West Virginia	17.79 percent	87.9 percent	85.2 percent	1st on all three
Virginia	3.43 percent	78.9 percent	62.9 percent	4th against 2nd and 4th
North Carolina	7.14 percent	74.1 percent	63.8 percent	2nd against 3rd and 3rd
Tennessee	4.35 percent	14.7 percent	68.2 percent	3rd against 4th and 2nd

Spearman coefficient, n = 4	reference series	0.4	0.8	1.0 required to conclude

Table 9. The refuter tested, including against its own alternative. Neither ownership nor rural share sorts poor-bridge condition on four states, and the terrain variable that would settle it was not located in published form. The final row is the authors' arithmetic on the four preceding rows.

10. What binds each hypothesis?

Eleven hypotheses were stated before the evidence was assembled, and each resolves below to a position in degrees, a binding constraint and a threshold carrying a quantity. The distribution of constraints is itself the review's most portable result. Four of the eleven bind on regulation, three on workforce, three on engineering implementation, one on material science and one on energy; H6 is counted in two columns, so the twelve counts cover eleven hypotheses. Not one binds on AI algorithms, and only one binds on computation efficiency, and that one sits downstream of a compliance rule rather than upstream of a capability. On this estate, the question of whether a machine can do the work is settled more often than the question of whether the work can be bought, measured or reached.

Positions cluster low, and they cluster low for a reason that is visible in the evidence. The single application already at scale is automated pavement data collection on the Interstate, and it is at scale because 23 CFR 490.309 forbids sampling and thereby creates a data volume no manual method can meet [6]. Where no rule creates the volume, adoption sits below 30 degrees almost everywhere in this review. The exception in the other direction is instructive: remote avalanche control in Colorado is at 278 of 522 paths [65] without any federal mandate, because the closure hours it removes have a price on a corridor where an hour is worth a stated two million dollars [74]. Demand created by rule and demand created by corridor value are the two mechanisms visible here, and neither is a technology mechanism.

Hypothesis	Position	Binding constraint	Threshold that would settle it

H1 Buyer fragmentation is national	25 of 90	Regulatory, inventory rule	FHWA publishing coded lane counts for systems now estimated at two lanes [1]
H2 Compliance output gates the sale	60 pavement, 15 bridges	Regulatory	An automated method emitting NBI items 58, 59 and 60 defensibly at the 5-to-4 boundary [4]
H3 Work zone addressable ceiling	18 of 90	Workforce crossed with eligibility	Share of maintenance tasks with no worker on foot in the traffic-exposed zone [8]
H4 Archipelago obligation lag caps assessment value	12 of 90	Regulatory	Median first-obligation interval falling below the 2.5 years measured after Maria [23]
H5 The water gap prices logistics, not sensing	30 of 90	Engineering implementation, supply chain	Domestic per-nautical-mile freight multiple falling below 3.0 [34]
H6 Terrain is the wrong partition (refuter)	5 of 90 on deciding it	Regulatory and workforce, as counterparty count	A published percent-grade or minimum-radius distribution for the four states
H7 Appalachian link budget sets usage	22 of 90	Engineering implementation, mobile layer	Rural combined coverage rising from 29.4 percent in West Virginia [54]
H8 The cold class holds two availability markets	35 incident, 10 seasonal	Material science, the 40 degree gate [64]	A placement process qualified below 40 degrees Fahrenheit

H9 The displaceable pool is bounded and mislocated	20 of 90	Workforce	Colorado and Washington at 67.4 and 68.2 workers per 1,000 lane-miles [71]
H10 Arid surface and shrinking denominator	8 of 90	Engineering implementation, running surface	The 9.6-to-1 gap between 7.9 bn need and 820 mn funding [79]
H11 Arid energy is a delivery cost per point	30 electrification	Energy as delivery	Connection rate above about 170 homes a year against 10,000 to 14,063 [91]

Table 10. All eleven hypotheses. Five bind on regulation and three on workforce; none binds on AI algorithms. Positions are the authors' assessments against the cited quantities, not measurements.

11. Where is the open ground?

Fifty-seven quantities were searched for and not located. Recording them is part of the method, because an absent figure that is quietly replaced by an estimate becomes indistinguishable from a measurement two citations later. Four of the absences bear directly on conclusions above and are stated here with what was searched.

First, no published percent-grade or curvature distribution was located for state-maintained mileage in West Virginia, Tennessee, North Carolina or Virginia. The Highway Statistics HM series, NCDOT route-characteristics field descriptions, Tennessee design documentation and open search were used. This is the variable that would settle Section 9, and its absence is the reason that section reports a limit rather than a conclusion. Second, no federal series publishing state maintenance expenditure per lane-mile as a ratio was located; the full Highway Statistics 2024 table index was searched by title and the two component tables were retrieved and parsed [11,1]. A quotient computed from them would be the authors' own arithmetic and would in any case be miscast, because the expenditure table covers only state highway agencies while the lane-mile table covers all owners. Third, no federal series recording lane-miles maintained per full-time-equivalent maintenance worker was located, which is why the workforce figures in Section 7 come from a pooled-fund programme of self-reported state returns [71] rather than from a federal count. Fourth, no documented automated-driving, connected-vehicle or teleoperation pilot on Navajo Nation or Hopi roads was located; the state DOT corridor study final report of December 2025 contains no intelligent-transportation, connected-vehicle or automation element in its recommendations [98].

Several absences are properties of the sources rather than of the subject, and they constrain what can be claimed rather than what is true. Philippine national road length here is the 2011 figure of about 31,400 kilometres [33] because the current departmental atlas could not be retrieved from its host. Puerto Rico route-kilometre and bridge counts for Vieques and Culebra separately from the main island were not located. Current county-level broadband availability was not obtainable, so the availability figures throughout carry a 31 December 2022 reference date [54,95]. Alaska's winter maintenance cost components do not reconcile in the only dataset that publishes them, and no primary source reconciling them was located [71], so the question of whether cost per lane-mile rises with cold cannot be settled using the coldest state in the class. Each of these is a limit on this review, and each is stated so that a later reading can close it rather than inherit it.

Absent quantity	Bears on	Consequence for this review
Percent-grade or curvature distribution, four states	Section 9, the partition test	Section 9 reports a limit, not a conclusion
Federal maintenance expenditure per lane-mile	Section 2, the addressable pool	No per-lane-mile ratio is asserted
Lane-miles per maintenance FTE, federal series	Section 7, the displaceable pool	Workforce density is self-reported [71]
Any AV or teleoperation pilot on Navajo or Hopi roads	Section 8, the position estimate	H10 position rests on surface and demand figures alone
Alaska winter cost reconciliation	Section 7, cost against cold	The question is left open in the anchor state

Current county broadband availability	Sections 6 and 8	All availability figures date to 31 December 2022

Table 11. The absences that constrain the conclusions above. This review did not locate these quantities; that is a statement about this search, not about whether the figures exist.

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9. [9] FHWA, '2026 National Work Zone Awareness Week' fact sheet, publication FHWA-HOP-26-060, chart 'Distribution of Fatal Work Zone Crashes by Functional Classification and Land Use, 2022-2024 Average'; data source NHTSA FARS 2022-2023 Final Files and 2024 Annual Report File. Graded reported rather than verified because the urban/rural assignment of each pair was read from chart geometry in the PDF rather than from a labelled data table; the percentages themselves are as published. https://ops.fhwa.dot.gov/publications/HOP-26-060_FHWA_NWZAW_Factsheet.pdf
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highway, and national totals cover the 50 states and DC only. The 52.7 and 24.8 percent values were confirmed present in the page source. https://workzonesafety.org/work-zone-data/worker-fatalities-and-injuries-at-road-construction-sites/
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