STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT DOCUMENTATION PAGE

TR-0003 (REV 04/2024)

Lock Form

1. REPORT NUMBER	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
4315		

4. TITLE AND SUBTITLE	5. REPORT DATE
Impacts of Changing Agriculture Supply Chains on California Roads and Bridges	April 28, 2025
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR	8. PERFORMING ORGANIZATION REPORT NO.
Shailesh Chandra, Benny Herrera and Yashashwini Dasamapura	4315
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NUMBER
California State University, Long Beach Research Foundation 6300 State University Dr. Suite #332, Long Beach, CA 90815	
	11. CONTRACT OR GRANT NUMBER
	65A1149
12. SPONSORING AGENCY AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
California Department of Transportation 1727 30th Street, MS 65; Sacramento, CA 95816	Final Report: 5/1/24-4/30/25
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Conducted in cooperation with the California Department of Transportation.

16. ABSTRACT

Agriculture is a significant contributor to national, state, and regional economies. In 2020, California generated approximately $49.1 billion in agricultural cash receipts, comprising 13.7 percent of the nation (CA number 1). During the same year, agricultural production and processing industries accounted for 2.8 percent of the state's gross domestic product. Historically, large amounts of agricultural produce were transported by rail; however, in the 20th century, many rail lines consolidated, and agricultural goods were shifted to trucks. The shift resulted in the need for improved roadways and bridges to accommodate heavy trucks and agricultural equipment. However, little or no research exists on the impacts of ag-related heavy commodity transport and highway impacts. This research proposes to determine which state routes might be most heavily impacted by agricultural goods movement and metrics to ensure that these impacts are monitored and addressed. This would provide the foundation to improve compliance with 49 USC §70202 requirements by improving our understanding of the heavy-vehicle network for the California Freight Mobility Plan. The objective of this research is to: Examine the historical context of California's agriculture production and transportation networks used in moving products to domestic and international markets.

- Identify and document key farm-to-market routes highway corridors in the state and determine metrics that could be used to influence funding, design, construction, and maintenance of agriculture-dependent highways and intermodal connections.
- Explore policies and best practices for assessing farm-to-market network resiliency and sustainability. Develop a template and case studies for how the recommended performance metrics could be applied to future statewide freight plans.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
corridor, performance measures, mobility, safety, reliability, sustainability, freight, agriculture, commodity, movement of goods, trucks, Critical Rural Freight Corridors (CRFCs), National Highway Freight Network (NHFN)	No restrictions

19. SECURITY CLASSIFICATION *(of this report)*	20. NUMBER OF PAGES	21. COST OF REPORT CHARGED
Unclassified	101	

Task 4315: Impacts of Changing Agriculture Supply Chains on California Roads and Bridges

FINAL REPORT

Submission Date: April 28, 2025

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Introduction and Literature Review

The research team reviewed various publications, including relevant reports and journal articles, and conducted preliminary analysis within the scope of this task to create this draft document. Only publicly available and relevant literature essential to achieving the task's objectives has been cited. Citations are included throughout the text of this draft where applicable.

The agricultural product transportation regulations and practices across the ten States reviewed, namely, Kansas, Indiana, Illinois, Minnesota, Wisconsin, North Carolina, Texas, Iowa, Nebraska, and California. The findings have been documented section-wise as follows:

i. The historical farm-to-market / farm-to-ranch was determined.

Review of available publications and reports online reveal that most state Departments of Transportation (DOTs) - from California, Iowa, Nebraska, Texas, Illinois, Minnesota, Kansas, Indiana, North Carolina, and Wisconsin - lack specific historical data on farm-to-market or farm-to-ranch routes. This gap in data and information was also highlighted in a recent FHWA article ([1]). Generally, state DOTs adopt a comprehensive approach to transportation planning, covering all roadways, including those essential for agricultural connectivity. A few states, however, do provide some information on farm-to-market or farm-to-ranch route designation and other agricultural related infrastructure programs:

I. The Texas Department of Transportation (TxDOT) has established specific laws and formal processes for designating critical local roadways that link farms to markets, integrated into their operations and long-range planning through the Farm to Market (FM) and Ranch to Market (RM) road systems. According to Section 201.104 of the Texas Transportation Code, the commission may designate any county road as a farm-to-market road for construction, reconstruction, and maintenance if the county waives certain rights for state participation in construction debts ([2]).

II. In Iowa, the FM road system is outlined in Iowa Code Section 310.10, which specifies the criteria and purpose of these roads. Modifications to the FM road system are governed by Iowa Code Section 306.6A, which defines the process for changes ([3]). The designation and modification of FM roads involve three steps:
    i. County Initiation: The county board of supervisors initiates modifications by submitting a resolution to the Iowa DOT.
    ii. Review Board Evaluation: The Farm-to-Market Review Board assesses proposed changes based on factors such as continuity, traffic potential, land use, location, and equitable mileage distribution among counties.
    iii. Approval and Implementation: Once approved, the Iowa DOT processes these changes, integrating them into state transportation planning.

III. The Wisconsin Department of Transportation (WisDOT) uses various programs and planning processes to integrate and designate key local roadways connecting farms to markets. The Agricultural Roads Improvement Program (ARIP), established in June 2023 through Senate Bill 247 (Act 13), aims to improve rural transportation infrastructure, focusing on local roads, bridges, and culverts that serve agricultural areas. This program enhances the efficiency and safety of transporting agricultural goods, including forest products, across the state ([4]).

ii. How key states determine and evaluate agriculture routes.

Although specific methodologies for determining and evaluating agricultural routes for the reviewed states are not well-documented, multiple metrics, including commodity flow, geographic access, infrastructure, and intermodal connections, could be employed to identify popular agricultural routes, especially State Routes and Interstates, that support both agricultural and other types of freight.

Reviews of reports and publications indicate that California leads in fruits, vegetables, and tree nuts, while the Midwest, including Iowa and Illinois, focuses on corn and soybeans. This specialization in specific agricultural production and their subsequent transportation could influence how states leverage harvest seasons and existing transportation infrastructure for transporting agricultural produce to domestic and export markets ([5]). In Wisconsin, logging operations intensify when pavement is frozen because heavier loads can be transported with minimal risk of damage ([6]).

Proximity to key infrastructure like rivers, railways, and ports significantly influences route planning. For example, the Mississippi River serves as a critical corridor for corn and soybean shipments from Iowa, Illinois, and Minnesota, facilitating bulk transport to export markets ([7]). California, with multiple seaports, relies on both road and sea routes to export perishable goods. One study highlighted the impact rural road conditions had on the agricultural produce transportation ([8]).

States integrate rail, highway, and waterway systems for seamless multimodal transportation. Cotton, which is a major field crop in Texas, is transported via Dallas-Ft. Worth and Houston roadways to access container transport to the international market ([9]). Texas and Nebraska, major livestock producers, rely on access to feed inputs (forage/crop residue, corn, DGs, soybean meal, etc.), proximity to existing processing, transportation and location infrastructure to have definite comparative advantages over other cattle producing states ([10]), while grain-producing states such as Kansas optimize rail connections for large shipments to export terminals.

iii. How states address heavy vehicle networks within their state freight plans

The findings have been documented for each of the ten States based on the review of their freight plans, as follows:

I. North Carolina

Trucks are the predominant mode for transporting freight within and across North Carolina. Heavy truck flows dominate the state's highway system, moving bulk goods, including wood products (e.g., logs), fertilizers, and food products. In 2017, trucks accounted for 86% of the freight weight and over 83% of freight value moved across North Carolina. North Carolina Department of Transportation (NCDOT) and regional organizations prioritize major highways, such as I-85 and I-40, which experience high truck volumes. To support these efforts, non-interstate corridors like U.S. 74 and U.S. 70, which handle thousands of trucks daily, are also integrated into freight planning ([11]).

The state anticipates a nearly 42% increase in highway freight demand by 2050, which will place additional strain on infrastructure, particularly for moving bulk goods such as logs and wood products. To address these infrastructure challenges, North Carolina's Metropolitan Planning Organizations (MPOs), including the Charlotte Regional Transportation Planning Organization (CRTPO) and Capital Area Metropolitan Planning Organization (CAMPO), led the approval of Critical Urban Freight Corridors (CUFCs) in urbanized areas. Corridor selection for Critical Rural Freight Corridors (CRFCs) was based on connectivity to the National Highway Freight Network

(NHFN) and requirements under the FAST Act. NCDOT, the State Freight Advisory Committee (FAC), and MPOs/Rural Planning Organizations (RPOs) collaboratively determined corridor designations, ensuring a comprehensive approach to freight network development and resilience.

II. Iowa

The state's freight infrastructure includes 4,027 miles of highways known as the Iowa Multimodal Freight Network (IMFN), designed to support efficient freight transportation. High-traffic corridors such as I-80 and I-35 are essential for both local and regional freight flows. Additionally, the states freight plan highlights the significant issuance of oversize and overweight (OSOW) permits to facilitate the movement of large agricultural equipment, wind turbine components, and construction materials. Non-interstate routes like U.S. 59 are crucial for allowing OSOW vehicles to navigate around height restrictions on interstate highways ([12]).

Heavy vehicles, particularly OSOW traffic, contribute to pavement and infrastructure wear, prompting Iowa to monitor road conditions using the Infrastructure Condition Evaluation (ICE) tool. This tool helps assess traffic volumes, pavement quality, and bridge conditions to prioritize maintenance needs. To support reliable heavy vehicle routes with sufficient capacity and minimal restrictions, Iowa has designated Critical Rural Freight Corridors (CRFCs) and Critical Urban Freight Corridors (CUFCs). These corridors are strategically connected to production sites, intermodal facilities, and export hubs, ensuring seamless freight movement across the state.

Iowa's state freight plan also underscores the importance of rural infrastructure, such as highways and bridges, which serve as vital first and last mile connections. Furthermore, Iowa's freight system is well-integrated, with highways connected to barge terminals along the Mississippi River and rail lines, supporting the smooth, large-scale transportation of agricultural goods, particularly grain destined for export.

III. Wisconsin

Wisconsin's 2023 State Freight Plan focuses on enhancing heavy vehicle freight networks to support heavy vehicle freight transportation. A central component of this plan is the establishment of a comprehensive OSOW (Oversize/Overweight) Truck Routes network, designed to handle vehicles exceeding standard weight and size limits, often carrying heavy agricultural equipment. Additionally, the Corridors 2030 initiative, comprising Backbone and Connector Routes, facilitates the efficient movement of high-weight agricultural goods, connecting major economic centers and agricultural hubs within the state and to neighboring markets ([13]).

Local roads also play a crucial role in the first and last-mile movement of agricultural products, though they face wear from frequent overweight truck use. Wisconsin has responded by making targeted investments to upgrade these rural roads and bridges, enhancing support for agricultural transport. To streamline logistics further, Wisconsin implemented an automated OSOW permit system, reducing time and costs associated with permit acquisition, particularly during peak transport periods. Maintaining the reliability of critical freight routes remains a priority, with investments directed toward reducing bottlenecks and ensuring the smooth, uninterrupted flow of goods during high-demand times, such as the harvest season.

IV. Nebraska

Nebraska's 2023 State Freight Plan highlights strategic infrastructure planning to support heavy vehicle freight networks for agricultural commodities and livestock. The foundation of Nebraska's

freight system is its highway network, which handles significant truck traffic carrying livestock, grains, and animal feed across primary routes like US 20, US 34, US 281, US 75, US 81, and I-80. Policies allowing longer combination trailers on state highways have been adopted to enhance freight efficiency by increasing the load capacity per trip, reducing the overall number of heavy trucks on the roads and helping to ease road maintenance demands ([14]).

The plan also emphasizes the importance of the National Highway Freight Network (NHFN), including the Primary Highway Freight System (PHFS), Critical Rural Freight Corridors (CRFCs), and Critical Urban Freight Corridors (CUFCs), which are vital for maintaining steady freight flows. Nebraska's Supply Chain Optimization Model (NESCOM) is utilized to analyze commodity flow, offering valuable insights for prioritizing infrastructure investments. Key corridors, particularly I-80, play a crucial role in linking production sites to national markets. The plan also accounts for alternative routes to maintain resilience in the network, ensuring continued freight movement during emergencies or adverse weather conditions.

V. Kansas

The Kansas State Freight Plan outlines the importance of heavy vehicle freight networks for transporting various commodities across the state. Key highways, including I-70, I-35, U.S. 50, and U.S. 54, serve as primary corridors within the state's freight system, connecting rural agricultural zones to major urban centers. These routes are part of the Primary Highway Freight System (PHFS) and Critical Rural Freight Corridors (CRFCs), enabling efficient transportation of key agricultural products like cereal grains, animal feed, and livestock. The state also issues numerous Oversize/Overweight (OSOW) permits to facilitate the movement of large agricultural equipment and oversized loads, reflecting the critical role of agriculture in Kansas's freight landscape.

Agricultural commodities account for a significant portion of Kansas's freight flows, with trucks being the primary mode of transportation, carrying 92% of these goods by tonnage. Major trading partners, including Texas, Oklahoma, and Nebraska, receive large volumes of Kansas's grain and livestock. Kansas also maintains intermodal and multimodal connections to link agricultural processing facilities with major highways, ensuring efficient first-mile and last-mile transport between road and rail networks. The Marine Highway M-29 along the Missouri River provides additional support for agricultural shipments, although trucking remains the predominant mode for these goods. The state's Freight Corridors of Significance (FCS) are prioritized for investments to enhance efficiency and maintain critical freight routes.

VI. Illinois

The Illinois 2023 State Freight Plan emphasizes the essential role of heavy vehicle freight networks in supporting the state's robust agricultural sector, particularly in the transportation of crops like corn and soybeans, as well as animal products. Illinois's network includes approximately 770 grain elevators, serving as key consolidation points for crops before further distribution via truck, rail, or barge. As agricultural operations grow and shift towards larger, high-volume facilities, the demand on rural roads increases, requiring infrastructure capable of handling heavier and longer hauls ([15]).

The plan highlights Illinois' Priority Freight Network (PFN), which connects agricultural production areas to regional and national markets, ensuring efficient transport through a strategically planned network. Trucks account for 53% of Illinois's freight movement by tonnage and value, with major highways, including interstates around Chicago (I-294, I-94, I-80, I-90) and rural routes like I-70 and I-57, supporting high-volume agricultural freight. The Illinois Department of Transportation

(IDOT) is set to update Critical Urban Freight Corridors (CUFC) and Critical Rural Freight Corridors (CRFC) to align with guidelines under the Infrastructure Investment and Jobs Act (IIJA), further strengthening the state's multimodal freight infrastructure.

VII. Minnesota

Minnesota's agriculture sector generates high freight volumes, with trucks playing a vital role in moving cereal grains, animal feed, and live animals directly from farms or through specialized haulers to processing facilities and export terminals. Key highways, including I-35, I-90, and I-94, serve as primary truck corridors and are part of the Primary Highway Freight System (PHFS), facilitating the movement of agricultural and forestry products and linking production regions with regional and national markets. Forecasts predict substantial growth in the transport of agricultural goods and livestock by 2050, driven by increased domestic and export demand ([16]).

Minnesota has designated Critical Urban Freight Corridors (CUFCs) and Critical Rural Freight Corridors (CRFCs) to improve the efficient flow of goods within urban and rural areas, focusing on essential industries and high-demand routes. The state employs a "project-first" approach, where the Minnesota Department of Transportation (MnDOT) prioritizes projects connected to the National Highway Freight Network (NHFN) and designates CUFC or CRFC segments post-award. Examples include US 61 and MN 41 for CUFCs and US 169 and MN 43 for CRFCs.

VIII. Indiana

The Indiana Multimodal Freight and Mobility Plan 2023 focuses on the role of Indiana's freight truck network in transporting key commodities, including agricultural products and fertilizers. Agricultural goods, such as cereal grains, are significant freight items, with trucks carrying a substantial portion alongside rail transport. In 2022, cereal grains comprised about 11% of the state's truck freight tonnage, emphasizing their importance within the freight system. Indiana's Preferred Freight Corridors (PFCs), including major routes like I-69, I-70, and US Highways 30 and 31, support the movement of high-demand goods. These corridors, along with Extra Heavy-Duty Highways (XHDH) that allow for specialized truck configurations, are projected to see increased volumes by 2045 ([17]).

The Indiana Department of Transportation (INDOT) has not chosen to designate Critical Rural Freight Corridors (CRFC) or Critical Urban Freight Corridors (CUFC).

IX. Texas

The Texas Freight Mobility Plan emphasizes the role of the state's extensive highway network in transporting freight commodities. Major highways, including I-10, I-20, I-35, and I-45, are vital corridors for moving crops and livestock across Texas, facilitating connections between agricultural production areas and distribution points. Texas also serves as a crucial gateway for livestock coming from Mexico, with border crossings like Laredo and Eagle Pass playing significant roles in international agricultural trade. The Texas Multimodal Freight Network (TMFN) incorporates highways, rail lines, and ports, with key corridors like I-10, I-20, and U.S. routes 84 and 287 supporting the agricultural supply chain ([18]).

The Texas Freight Mobility Plan also highlights the movement of fertilizers, which are distributed via road and rail to farmland across the state, with intermodal facilities enhancing efficiency. Additionally, Texas highways facilitate the transportation of lumber and wood products, linking logging regions in East Texas to construction and manufacturing hubs both within Texas and

in neighboring states like Louisiana, Arkansas, and Oklahoma. Ports, including Port Houston and Port Freeport, are integral to the export of agricultural products, further supporting Texas's position as a vital hub in agricultural and freight logistics. The TMFN ensures seamless connectivity across these various modes of transport, enhancing Texas's capacity to handle agricultural and industrial freight. The map in Fig. 1 shows agriculture supporting network and spatial distribution of commodities.

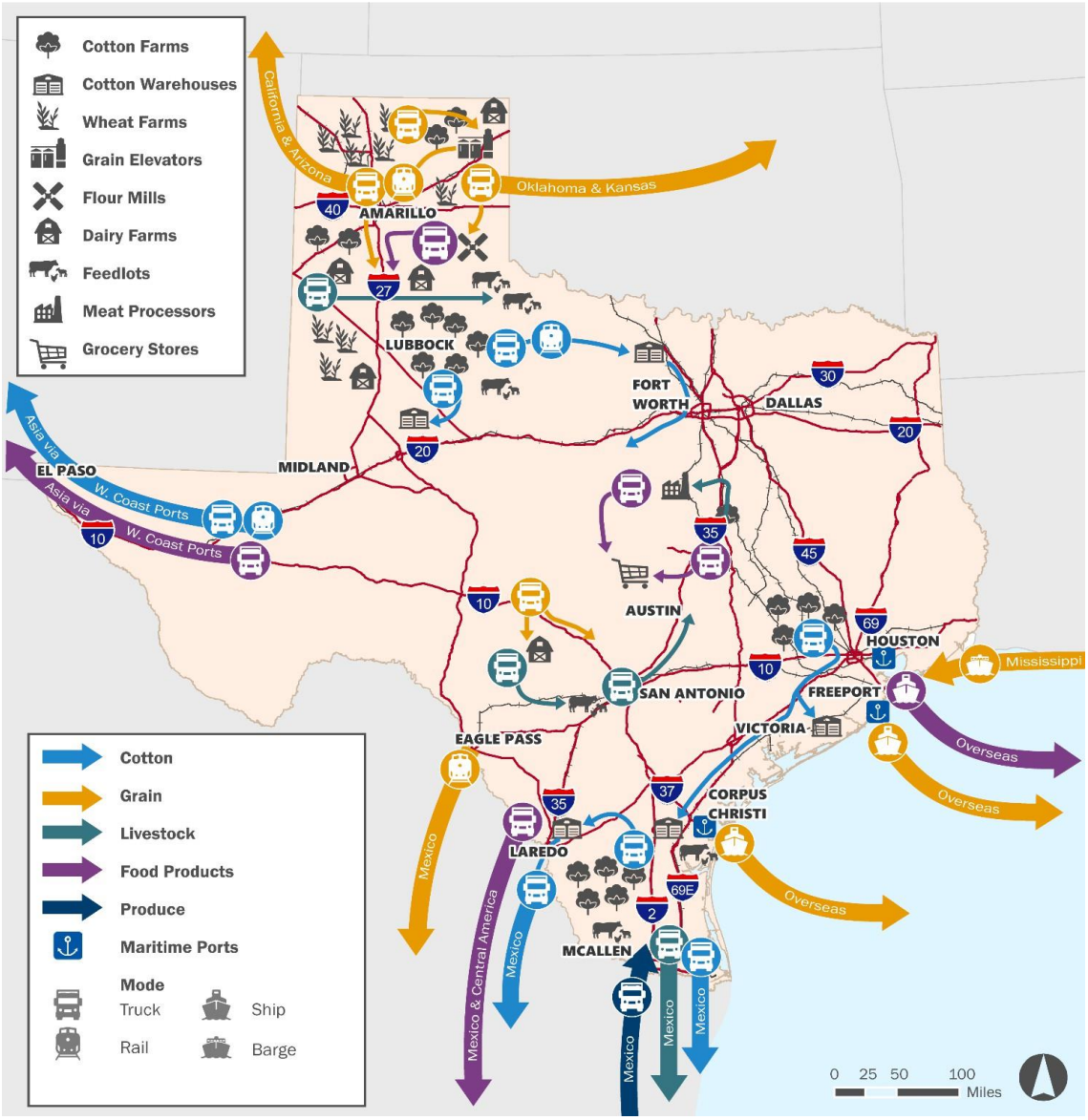


Figure 1: Texas' Agriculture Supply Chains (Map source: Texas Delivers 2050 - Texas Freight Mobility Plan, 2023)

X. California

Key California freight transportation highways, including I-5 and SR 99, facilitate the movement of agricultural products, connecting the Central Valley to statewide and out-of-state markets. The Cold Supply Chain, which includes refrigerated trucks, is crucial for transporting perishable goods like dairy, fruits, and meats from farms to processing and distribution centers. For timber, highways such

as SR 299, SR 36, and SR 44 connect Northern California's forested regions to mills and other processing points. Fertilizers, often imported through the Port of Stockton, are then distributed across the state via highways like I-5 and SR 152 to reach the Central Valley's agricultural hubs ([19]).

Livestock transport relies on major corridors like I-5 and SR 58, as well as smaller rural routes connecting ranches to markets and processing facilities. Regulations such as the Electronic Logging Device (ELD) rule and Hours of Service (HOS) requirements impact livestock haulers due to the need for timely transport to ensure animal welfare. California also maintains 144 weigh-in-motion (WIM) scales to monitor heavy vehicle traffic, providing data for pavement maintenance and capacity planning. Additionally, the state's Critical Urban Freight Corridors (CUFC) and Critical Rural Freight Corridors (CRFC), managed by Caltrans and regional Metropolitan Planning Organizations (MPOs), enhance connections to key freight facilities, including ports and rail yards. Examples of CUFCs include SR 37 and US 101, while CRFCs include SR 89 and SR 97, supporting California's agricultural and natural resource sectors effectively.

iv. Critical infrastructure requirements for the agriculture sector and factors that could contribute to the failures of agricultural supply chain

The findings on critical infrastructure, based on the review of various state freight plans, are documented as follows

a. Critical Infrastructure Requirements for the Agricultural Sector:

i. Primary Highways and Interstates: The agricultural sector relies heavily on major highways and interstates for the efficient movement of goods. For instance, North Carolina utilizes I-85 and I-40, which support high volumes of truck traffic carrying agricultural commodities, logs, fertilizers, and livestock. Similarly, Iowa's freight infrastructure depends on interstates like I-80 and I-35 to facilitate regional and local freight flows, especially for agricultural products.
ii. First and Last-Mile Connectivity: Non-interstate highways such as U.S. 74 and U.S. 70 in North Carolina play a vital role in freight transportation, handling thousands of trucks daily. Local roads, which comprise a significant portion of states' road networks (e.g., 90% in Wisconsin), are crucial for connecting rural agricultural operations to major freight corridors. They enable the movement of goods from farms to processing facilities and markets.
iii. Accommodation of Heavy and Large Vehicles: Transporting large agricultural equipment, bulk commodities, and livestock often requires vehicles that exceed standard size and weight limits. States like Iowa and Wisconsin issue OSOW permits and have designated OSOW truck routes to facilitate these movements. Wisconsin's automated OSOW permit system streamlines logistics planning, especially during peak agricultural seasons.
iv. Critical Rural and Urban Freight Corridors: States designate Critical Rural Freight Corridors (CRFCs) and Critical Urban Freight Corridors (CUFCs) to ensure that heavy vehicles have reliable routes with sufficient capacity and minimal restrictions. These corridors connect production sites, intermodal facilities, and export hubs. For example, Nebraska's NHFN includes CRFCs and CUFCs critical for maintaining efficient freight flows of agricultural commodities.
v. Integration with Rail and Waterways: Combining highways with rail lines, barge terminals, and ports allows for seamless transportation of bulk agricultural goods. States like Iowa

integrate highways with Mississippi River barge terminals and rail connections, essential for large-scale movements of grains destined for export. Texas leverages its Multimodal Freight Network to support agricultural supply chains through highways, railroads, and ports.

vi. Sustained Investment in Infrastructure: Regular maintenance and upgrades of highways, bridges, and local roads are essential to support agricultural transport effectively. Wisconsin emphasizes maintaining critical freight routes that support agricultural transportation, focusing on reducing bottlenecks and ensuring reliability during high-demand periods like harvest seasons.

vii. Resilience Planning and Monitoring: Utilizing tools like Iowa's Infrastructure Condition Evaluation (ICE) helps assess road conditions, prioritize maintenance, and enhance the resilience of freight routes. Indiana incorporates design modifications to handle extreme weather conditions, ensuring that key infrastructure remains operational during natural events.

b. Factors That Could Contribute to Failures of the Agricultural Supply Chain

i. Infrastructure Degradation: Increased volumes of heavy trucks, especially OSOW traffic, accelerate the deterioration of pavements and bridges. Without adequate maintenance, this can lead to infrastructure failures. For example, Iowa notes that heavy vehicles contribute to pavement degradation, necessitating continuous monitoring and repair.

ii. Strain on Rural Routes: Local roads are crucial for first and last-mile connections but often face challenges due to the strain from overweight trucks. In Wisconsin, maintaining these local roads is a challenge, and neglect can disrupt the movement of agricultural goods from farms to markets.

iii. Capacity Constraints and Congestion: High traffic volumes on key highways can cause congestion and delays. North Carolina anticipates a nearly 42% increase in highway freight demand by 2050, which could exacerbate congestion on major routes like I-85 and I-40, impacting the timely delivery of goods.

iv. Vulnerability to Extreme Conditions: Infrastructure not designed for resilience may be susceptible to damage from flooding, extreme temperatures, or other weather events. Indiana addresses this by incorporating hydraulic and seismic design updates to withstand environmental disruptions, but failure to do so elsewhere can lead to route closures.

v. Regulatory Constraints: Regulations such as Hours of Service (HOS) rules can affect time-sensitive transport of perishable goods and livestock. In California, livestock haulers are impacted by HOS regulations, which can lead to delays and animal welfare concerns during transit.

vi. Lack of Alternative Routes: Dependence on a few major routes without sufficient alternatives increases vulnerability to disruptions from accidents, maintenance closures, or natural disasters. Nebraska includes alternative routes in its freight planning to ensure resilience, but not all states have such provisions.

vii. Growing Pressure on Infrastructure: Anticipated growth in freight volumes will place additional strain on existing infrastructure. For instance, North Carolina's expected increase in truck traffic will intensify pressure on the state's highway system, potentially leading to failures if capacity is not expanded.

v. California's key commodities are seasonal produce, seasonal products, and flows.

California's agricultural production varies by season as outlined below in table 1. Although specific data or publications on seasonal produce and truck flows were unavailable, we conducted an

approximate analysis by combining data from the top 10 agricultural counties in California (see table below), seasonal patterns for California's fruit and vegetable crops, and GIS visualizations of commodity flow from the FAF5 network data (FAF Highway Assignment Results, 2022). The findings from this analysis are summarized as follows:

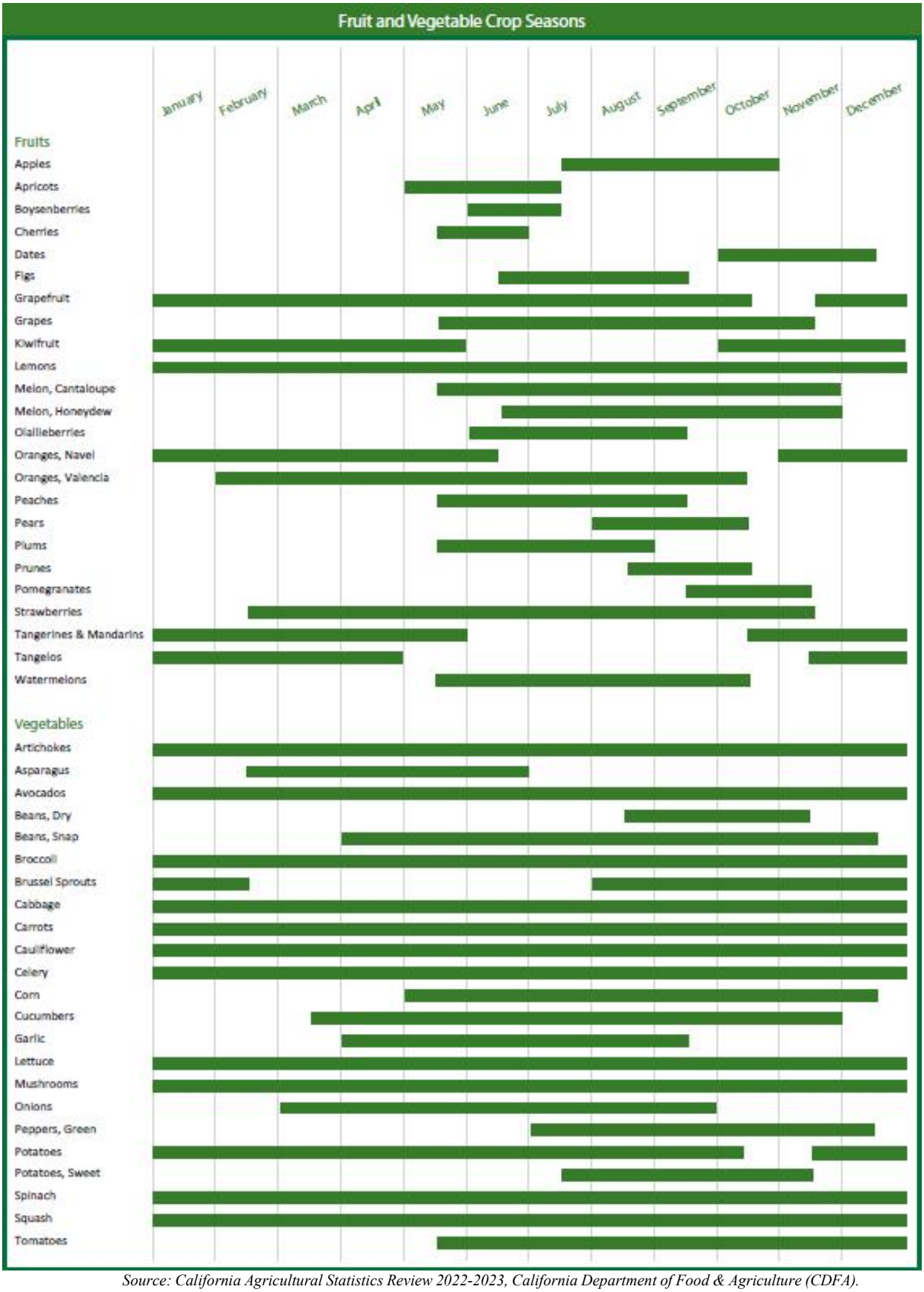
1. Winter (January - March):
    - Produce: Key products include oranges, avocados, and broccoli.
    - Truck Flows Example: In 2022, Tulare County, known for its high orange production, had up to 423 daily truck trips on SR 99.
2. Spring (April - June):
    - Produce: Peak production of strawberries, lettuce, and various other vegetables.
    - Truck Flows Example: Monterey County saw up to 107 daily trips in 2022 for strawberries, lettuce, and other vegetables on US 101.
3. Summer (July - September):
    - Produce: High yields of grapes, almonds, tomatoes, and additional vegetables like lettuce and broccoli.
    - Truck Flows Example: Fresno and Kings counties recorded up to 917 daily trips in 2022 for grapes, almonds, and tomatoes on Interstate 5 (I-5).
4. Fall (October - December):
    - Produce: Prominent products include almonds, pistachios, and citrus fruits like lemons.
    - Truck Flows Example: Merced and San Joaquin counties saw up to 917 daily trips in 2022 for almonds on I-5 and SR 99.

Table 1: Top 10 Agricultural Counties in California, 2021-2022

County	**Leading Commodities**
Tulare	Milk, Oranges (All), Grapes (All), Cattle
Fresno	Grapes (All), Almonds, Pistachios, Milk
Kern	Grapes (All), Oranges (All), Almonds, Milk
Monterey	Lettuce (All), Strawberries, Broccoli, Cauliflower
Merced	Milk, Almonds, Chickens, Cattle
Stanislaus	Milk, Almonds, Horticulture (All), Cattle
San Joaquin	Milk, Almonds, Grapes (All), Cherries
Imperial	Cattle, Lettuce (All), Alfalfa (All), Livestock (Misc)
Kings	Milk, Pistachios, Tomatoes (Processing), Cotton (Lint)
Ventura	Strawberries, Avocados, Horticulture (All), Lemons

Source: California County Agricultural Commissioners' Reports and California Agricultural Statistics Review 2022-2023, California Department of Food & Agriculture (CDFA).

The seasonal pattern suggests that summer and fall are likely the busiest periods for agricultural transport activities, as these seasons align with the peak harvest for a variety of crops – see below.



Source: California Agricultural Statistics Review 2022-2023, California Department of Food & Agriculture (CDFA).

vi. A listing of key metrics and resiliency.

Based on various states freight plans and other pertinent resources, below is the summary of resilience measures (and its similar forms) used across various states based on their freight plans:

California

California emphasizes truck travel time reliability, crucial for agricultural goods needing timely delivery, and Cold Supply Chain management to ensure temperature control for perishables like dairy and meat. The state also assesses goods movement efficiency through commercial vehicle metrics on key corridors (e.g., I-5 and SR 99) and implements weigh-in-motion scales for monitoring heavy freight. For corridor designations, California utilizes a formula-based system, managed by Caltrans and MPOs, to designate Critical Urban and Rural Freight Corridors (CUFC/CRFC), enhancing connectivity to key facilities like ports and rail yards.

Illinois

Illinois focuses on operational sufficiency, addressing infrastructure limitations that affect freight flow, particularly for agriculture. The state relies on multimodal routes (trucks, trains, barges) for grain transport, supported by the Mississippi River for bulk exports. Illinois uses resilience metrics like infrastructure condition scores and system recovery metrics, monitoring the number of facility closures and resiliency-related projects. Flood-flow deficient structures are prioritized for improvement, enhancing the network's robustness, especially along routes critical for grain exports.

Texas

Texas takes a structured approach to freight resilience, beginning with corridor and hazard identification. Texas assesses corridors for specific vulnerabilities, prioritizing mitigation on critical routes affected by natural hazards. Resilience strategies include continuous planning and coordination with emergency agencies, with a focus on hazard assessment to manage disruptions efficiently. This approach ensures that Texas's freight corridors are equipped to handle high traffic and disruptions, supporting key agricultural and industrial routes.

Iowa

Iowa employs a composite resilience assessment with its Infrastructure Condition Evaluation (ICE) tool, assessing pavement, bridge conditions, and traffic congestion to rank highway segments by resilience. Iowa also has a flood resiliency analysis that considers the robustness of roadways, redundancy (alternative routes), and criticality (route importance), focusing on flood-prone areas with targeted infrastructure improvements to maintain freight continuity.

Minnesota

Minnesota uses the Truck Travel Time Reliability Index (TTTRI) to monitor and enhance freight route resilience, aiming for minimal travel time deviations under adverse conditions. Minnesota’s resilience strategies include investing in infrastructure reliability, managing disruptions, and using metrics to maintain the network's efficiency, particularly for agriculture and forestry freight.

North Carolina

North Carolina employs the Geo-FRIT platform and vulnerability assessments like the FHWA’s VAST tool to model disaster impacts and evaluate infrastructure risks. Tools for flood simulation and climate adaptation aid in preparing for extreme weather events, especially in coastal regions. This proactive approach strengthens North Carolina’s freight network against environmental challenges.

Indiana
Indiana prioritizes freight route resilience by enhancing infrastructure against extreme weather and seismic activity, with flood mitigation on vulnerable routes. The state's Transportation Asset Management Plan (TAMP) includes resilient pavement and bridge designs for high-traffic corridors, complemented by interactive systems providing real-time data on disruptions to support continuous freight operations. Indiana's strategies ensure reliable transportation through extreme conditions.

Federal Regulations: 23 CFR Part 658.17 Weight

CFR 658.17 ([20]) sets weight limits for vehicles on the Interstates, establishing an 80,000-pound maximum gross weight, with specific axle limits: 20,000 pounds for single axles and 34,000 pounds for tandem axles. The Federal Bridge Formula shown below calculates the allowable weight based on axle spacing, with certain configurations allowed exceptions:

$$W = 500\,\% \frac{LN}{N-1} + 12N + 36.$$

where,

W = overall gross weight on any group of 2 or more consecutive axles to the nearest 500 pounds,
L = distance in feet between the extreme of any group of 2 or more consecutive axles, and
N = number of axles in the group under consideration.

The regulation requires states to follow the federal standards for consistency, though they may issue permits for nondivisible loads. Historical "grandfathered" limits from specific dates remain valid, allowing some states to operate under previously authorized weight limits.
States may not impose stricter weight limits than the federal standards, ensuring uniformity across interstate routes. Certain conditions, such as tire width limits and specific axle weights, are mandated, with exceptions for steering axles and nondivisible loads. States can also permit divisible loads above 80,000 pounds if authorized by federal or grandfathered laws. Appendix C to Part 658 further defines these limits for longer or heavier vehicles on the interstate and national networks, referencing grandfathered rights frozen at 1991 levels, allowing certain vehicles to exceed standard size or weight limits under controlled conditions.

Quantification of Impacts on Pavements

NCHRP Research Report 1019 ([21]) documents the effects of agriculture vehicles or Implements of Husbandry (IoH) vehicles on both flexible and rigid pavements, comparing them with standard commercial truck traffic. The study details the damage to flexible pavements from IoH vehicles and an overloaded commercial truck in Des Moines, Iowa, and documents the cracking in rigid concrete pavements in Columbus, Ohio, caused by IoH versus trucks. The key findings are summarized as follows:

Damage in Flexible Pavements

- Pavement Structure:
  - 4-inch HMA layer, 6-inch aggregate base, and subgrade.
- Vehicles Analyzed:
  - IoH Vehicle: John Deere 8230 tractor with a 6,000-gallon tank traveling at 20 mph

- Reference Truck: 102-kip overloaded truck traveling at 60 mph.

Key Findings:

- IoH vs. Truck Damage:
  - One IoH pass can cause fatigue damage equivalent to 5.3 truck passes and subgrade damage equal to 2.9 truck passes, depending on the season.
  - IoH traffic can raise the risk of shear failure in the base layer due to axle configuration.
- Seasonal Variation:
  - IoH-induced damage peaks during cooler months, while truck damage is most severe in warmer months.
- HMA Layer Failure:
  - In June, failure occurs after 46,000 IoH passes compared to 142,000 truck passes.

Damage in Rigid Pavements

- Pavement Structure:
  - 8-inch PCC layer with a 6-inch aggregate base and undoweled joints.

Key Findings:

- IoH vs. Truck Damage:
  - One IoH pass can cause:
    - Between March and September, bottom-up fatigue damage equal to 4.6–6.0 truck passes. For the remaining months, one pass of the IoH vehicle causes damage equal to even greater numbers of truck passes, but the absolute magnitude of damage decreases.
    - Top-down cracking damage equivalent to 7.1–9.3 truck passes.
    - Transverse joint damage equal to 10.5–13.1 truck passes.
- Seasonal Variation:
  - Bottom-up fatigue damage peaks in April, while top-down cracking is most severe in September.

Due to the unavailability of detailed information on specific attributes of agricultural routes in the reviewed states, the research team conducted GIS mapping and analysis using freight route data from the FAF Highway Assignment Results. This approach documented daily truck trips in both directions for routes within each state. Additionally, no publicly accessible methodologies for the design, construction, or maintenance of agricultural routes were found in the states examined. Consequently, it is assumed that transportation agencies perform routine construction and maintenance for these routes.

Table 2: Agricultural route attributes

State	Route (interstate (I), State Route (SR), US route etc.)	Route Attributes (Source: FAF Highway Assignment Results, 2022)				Other Details (Methodology for designing, constructing, and maintaining ag-related heavy vehicle network components)
		Speed Limit (mph)	**Daily Truck Trips in Both Directions** (Farm Products)	**Daily Truck Trips in Both Directions** (Food Products)	**Daily Truck Trips in Both Directions** (Logs)	
Kansas	US 69	75	822	464	2	Routine reconfiguration/resurfacing and/or reconstruction methods for the prominent highways
	US 83	65	380	5	1	
	US 81	70	133	130	3	
	US 54	65	243	7	2	
	I 135	75	54	220	4	
	I 70	75	830	464	18	
	I 35	75	250	450	1	
	SR 27	65	380	3	2	
Indiana	I 65	65	653	854	38	Routine reconfiguration/resurfacing and/or reconstruction methods for the prominent highways
	I 70	65	640	860	2	
	I74	65	650	844	38	
	I 80	65	1,155	1,507	1	
	US 41	55	635	3	2	
	US 231	55	5	7	85	

	SR 32	70	651	5	1	
	SR 9	70	3	854	38	
	SR 3	70	2	3	85	
	IN 3	60	1	2	38	
	IN 46	60	2	1	85	
Illinois	I 88	65	525	328	15	Routine reconfiguration/resurfacing and/or reconstruction methods for the prominent highways
	I 80	65	2,683	1,649	14	
	I 39	65	525	331	2	
	I 74	65	2,656	5	41	
	I 72	65	2,677	1	1	
	I 64	65	2,663	2	3	
	I 94	65	3	1,660	6	
	I 57	65	2	3	41	
	I 70	65	5	4	98	
Minnesota	MN 210	60	2,229	1	3	Routine reconfiguration/resurfacing and/or reconstruction methods for the prominent highways
	MN 60	70	3	69	1	
	MN 61	60	2	2	280	
	I 94	70	2,213	275	3	
	I 90	70	799	473	4	
	I 35	65	799	473	1	
	SR 6	70	1	2	140	
	SR 7	70	799	3	2	
	SR 72	70	2	1	140	
	SR 99	70	3	473	1	

	SR 11	70	2	1	140	
	SR 200		1	3	61	
	US 71	65	799	2	1	
	US 53	65	2	1	280	
Wisconsin	I 90	70	303	585	1	Routine reconfiguration/resurfacing and/or reconstruction methods for the prominent highways
	1 94	70	303	585	2	
	1 39	70	303	950	139	
	I 41	70	152	301	1	
	US 53	70	1	3	32	
	US 2	70	2	3	578	
	US 51	70	1	2	578	
North Carolina	I 40	70	258	282	2	Routine reconfiguration/resurfacing and/or reconstruction methods for the prominent highways
	1 77	70	254	580	1	
	1 85	70	250	282	1	
	1 95	70	500	581	213	
	US 17	65	502	2	620	
	US 64	65	504	1	621	
	US 29	65	1	277	1	
	SR 41	70	258	3	1	
	SR 32	70	1	2	213	
Texas	I 40	60	1,551	676	7	Routine reconfiguration/resurfacing and/or reconstruction methods for the prominent highways
	I 27	60	1,525	134	2	
	I 10	60	521	309	2	
	I 20	60	1	379	92	

	I 35	60	2	1	92	
	I 45	60	1	399	92	
	US 287	70	1,555	398	92	
	US 281	70	274	242	1	
	US 59	70	521	2	2	
	US 190	70	1	3	92	
	US 175	70	1	3	92	
	US 69	70	2	1	243	
	US 96	70	1	2	243	
	US 291	70	2	3	243	
Iowa	I 80	70	4,984	1,369	76	Routine reconfiguration/resurfacing and/or reconstruction methods for the prominent highways
	I 35	70	3	630	1	
	I 380	70	1,440	3	1	
	US 30	55	4,981	1	21	
	US 20	55	4,988	632	76	
	US 218	55	1	635	4	
	US 61	55	2	3	76	
	US 151	55	1	4	76	
Nebraska	I 80	75	1,551	1,065	10	Routine reconfiguration/resurfacing and/or reconstruction methods for the prominent highways
	US 30	70	886	411	3	
	US 77	70	453	408	4	
	US 81	70	886	388	3	
	US 385	70	1	2	3	
	SR 2	70	886	411	3	
California	I 5	55	919	1,088	150	

	I 80	55	420	554	1	Routine reconfiguration/resurfacing and/or reconstruction methods for the prominent highways
	I 15	55	917	1,096	1	
	I 40	55	912	552	3	
	I 10	55	900	554	1	
	US 395	55	320	1,091	2	
	US 101	55	2	1	149	
	SR 99	65	917	1,090	3	
	SR 152	65	421	1,099	3	
	SR 41	65	418	554	2	
	SR 36	65	1	3	89	
	SR 299	65	1	2	91	
	SR 70	65	3	3	150	
	SR 4	65	1	1	277	
	SR 20	65	3	1	279	

In compiling the inputs for the table on critical infrastructure attributes, we prioritized gathering information on key corridors and routes across each state. Some of these routes are designated as Critical Rural Freight Corridors (CRFCs), which are integral to the National Highway Freight Network (NHFN) in the United States. These routes predominantly support agricultural activity, providing access to facilities such as grain elevators, agricultural centers, forestry sites, and intermodal hubs ([22]).

Table 3: Critical infrastructure attributes
(note: these findings will be reported in Excel with the final report submission)

States	***Critical Infrastructure (routes, intermodal connectors or bridges, etc.)***	***Commodities transported (if available)*** (Data reported are aggregate for all critical infrastructure – since individual infrastructure was not available. This aggregate information was obtained through GIS analysis using data from the FAF Highway Assignment Results, 2022)	***Methodology for identifying ag-related infrastructure and its critical elements***	***Metrics used (weight restrictions, pavement/bridge conditions, proper turn radius, etc.)***
North Carolina	Interstate Highways ○ I-40: Runs east-west across the state, connecting cities like Asheville, Winston-Salem, and Raleigh. ○ I-95: Runs north-south along the eastern part of the state, connecting cities like Rocky Mount, Fayetteville, and Lumberton. US Highways ○ US 64: Runs east-west through central North Carolina, connecting cities like Raleigh, Rocky Mount, and Asheville. ○ US 70: Runs east-west across the state, passing through cities such as	Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood, Milled grain products, other foodstuffs, Logs and other Wood Products	There is no publicly accessible data or report available on the methodology for identifying agriculture-related infrastructure and its critical elements	Truck weight limits for vehicles in regular operations is shown below ([23],[24],[25]): Single Axle 20,000 lbs. Tandem Axle 38,000 lbs. Gross Weight 80,000 lbs. **Permits for Oversize/Overweight Loads** • **Special Permits**: Required for loads exceeding standard size and weight limits. These permits specify allowed routes and travel conditions. ***Commodity Exemptions*** **Various Commodities**: Vehicles transporting the following commodities within 150 miles of the point of origination are exempt from State weight limitations on non-Interstate highways up

	Durham, Raleigh, and Goldsboro.			to 22,000 lbs. on a single axle, up to 42,000 lbs. on a tandem axle, and up to 90,000 lbs. GVW; up to 26,000 lbs. on a single axle and 44,000 lbs. on a tandem axle for a vehicle with five or more axles and an overall wheelbase of at least 48 inches and 11 inches between the center of axle one and axle two; or up to 27,000 lbs. on a single axle and up to 37,000 lbs. GVW on a two-axle vehicle with at least a 14-inch wheelbase: • Agriculture crop products transported from a farm to a processing plant or market; • Water, fertilizer, pesticides, seeds, fuel, or animal waste transported to or from a farm; • Meats, livestock, or live poultry transported from the farm where they were raised to a processing plant or market; • Forest products originating and transported from a farm or woodlands to market with delay interruption or delay for further packaging or processing after initiating transport; • Wood residuals, including wood chips, sawdust, mulch, or tree bark from any site; • Raw logs to market; or • Trees grown as Christmas trees from field, farm, stand, or grove to a processing point. • **Cotton**: A vehicle equipped with a self-loading bed and designed exclusively to transport compressed seed cotton from the

				farm to a cotton gin, or sage to market, may operate on non-Interstate highways with a tandem-axle weight up to 50,000 lbs. (N.C. Gen. Stat. §20-118[k]). **1. Seasonal Restrictions** • **Spring Thaw Restrictions**: During thaw periods, weight limits on certain roads may be reduced to prevent damage. **2. Agricultural Exemptions** • **Farm Equipment**: Exemptions may apply for farm vehicles and equipment moving between fields or to local storage facilities. Specific guidelines are outlined in North Carolina statutes. • **Harvest Season Permits**: Special permits may be available to accommodate increased agricultural transport needs during harvest seasons.

Wisconsin	Interstate Highways I-94: Runs east-west through southern Wisconsin, connecting major cities like Milwaukee, Madison, and Eau Claire. It is a critical route for agricultural goods transport. I-90: Runs east-west along the southern border of Wisconsin, connecting to major cities like La Crosse and Madison. It is important for transporting goods to and from neighboring states. US Highways US 51: Runs north-south through central Wisconsin, connecting agricultural regions to major cities like Wausau and Stevens Point. It serves as a key route for agricultural transport. US 41: Runs north-south through eastern Wisconsin, connecting Milwaukee, Appleton, and Green Bay. It is heavily used for transporting agricultural products to urban markets. State Highways	Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood, Milled grain products, other foodstuffs, Logs and other Wood Products	There is no publicly accessible data or report available on the methodology for identifying agriculture-related infrastructure and its critical elements	Truck weight limits for vehicles in regular operations is shown below ([26],[27],[28],[29]): Single Axle 20,000 lbs. Tandem Axle 34,000 lbs. Gross Weight 80,000 lbs. **1. Permits for Oversize/Overweight Loads** • **Special Permits**: Required for loads exceeding standard size and weight limits. These permits specify allowed routes and times of travel. Information can be found through the Wisconsin Department of Transportation (WisDOT) Oversize/Overweight Permits page. • **Forest Products**: The Department of Transportation may issue an overweight permit to vehicles transporting peeled or unpeeled forest products, lumber or forestry biomass while traveling on US Highway 2 in Iron County or Ashland County[168] or on US Highway 2 in Bayfield County from the Ashland County line through Hart Lake Road (Wis. Stat. Ann. §348.27[9][a][1][b]). • **Bulk Potatoes**: Permits may be issued for bulk potatoes from storage facilities to rail loading facilities in vehicle combinations that exceed the maximum gross weight by not more than 10,000

	WI 29: Runs east-west across northern Wisconsin, connecting agricultural areas to cities like Green Bay and Wausau. WI 73: Runs north-south through central Wisconsin, providing access to agricultural regions and connecting to major highways.			lbs. The permit authorizes the operation of any vehicle combination at a maximum gross weight up to 90,000 lbs. It is valid on STH 64 between CTH "H" and USH 41 in Langlade, Oconto and Marinette counties; USH 41 between STH 64 and the Wisconsin-Michigan border; and any highway for a distance not to exceed 15 miles from any portion of STH 64 or USH 41 specified in this subsection in order to obtain access to STH 64 or USH 41[169] (Wis. Stat. Ann. §348.27[9t]). • **Grain**: Permits may be issued for the transportation of grain, coal, iron ore concentrates, or alloyed iron to exceed statutory weight limits over any class of roadway for up to 5 miles from the Wisconsin State line. This permit does not allow travel on Interstate highways (Wis. Stat. Ann. §348.27[10]). **2. Seasonal Restrictions** • **Spring Thaw Restrictions**: During thaw periods, weight limits may be reduced on certain roads to prevent damage. **3. Agricultural Exemptions** **Livestock**: Trucks hauling livestock may exceed applicable axle or axle group limits by 15 percent. This increase does

				not apply to Interstate highways except for the following routes (upon their Federal designation as I 39): • USH 51 between Wausau and STH 78, and • STH 78 between USH 51 and the I 90/94 interchange near Portage. (Wis. Stat. Ann. §348.15[e]). **Milk for Human Consumption**: Milk and dairy production vehicles are limited to the following weights: one axle: 21,000 lbs.; two axles: 37,000 lbs. spaced 8-feet or less apart; three consecutive axles: 2,000 lbs. greater than the corresponding limit in the State bridge table. The GVW is limited to 80,000 lbs. This does not apply to Interstate highways except for the following routes (upon their Federal designation as I 39): • USH 51 between Wausau and STH 78, and • STH 78 between USH 51 and the I 90/94 interchange near Portage. (Wis. Stat. Ann. §348.15[3][bg]). **Forest Products**: Vehicles transporting peeled or unpeeled forest products are limited to the following weights: one axle: 21,500 lbs.; two axles: 37,000 lbs. spaced 8-feet or less apart; three consecutive axles: 4,000 lbs. greater than the corresponding limit in the State bridge table. The GVW is limited to

				80,000 lbs. This does not apply to Interstate highways except for the following routes (upon their Federal designation as I 39): • USH 51 between Wausau and STH 78, and • STH 78 between USH 51 and the I 90/94 interchange near Portage. (Wis. Stat. Ann. §348.15[3][br]). In addition, while hauling peeled or unpeeled forest products for winter maintenance,[166] vehicles may operate in excess of State gross weight limits. Such vehicles are allowed on Class A or Class B highways (Wis. Stat. Ann. §348.175).
Minnesota	Major Interstate Highways • I-35: Runs north-south through the state, connecting agricultural regions to major cities like Minneapolis and Duluth. Standard interstate weight and size limits apply. • I-90: Runs east-west across southern Minnesota, important for agricultural transport. Standard interstate weight limits apply.	Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood, Milled grain products, other foodstuffs, Logs and other Wood Products	There is no publicly accessible data or report available on the methodology for identifying agriculture-related infrastructure and its critical elements	Truck weight limits for vehicles in regular operations is shown below ([30], [31], [32], [33], [34],[35],[36]): Single Axle 10,000 lbs. per single tire 20,000 lbs. Tandem Axle 34,000 lbs. Tridem Axle 42,000 lbs. Gross Weight 80,000 lbs. Here are some key regulations and requirements: **1. Permits for Oversize/Overweight Loads**

	• I-94: Runs east-west through the central part of the state, connecting Minneapolis to Fargo. Standard interstate weight and size restrictions are in place. US Highways •US 2: Runs east-west through northern Minnesota, serving as a key route for agricultural transport. Standard weight and size limits apply. •US 52: Runs southeast from the Twin Cities to Rochester and Iowa, heavily used for agricultural transport with standard weight restrictions. •US 71: Runs north-south through the central part of the state, connecting agricultural areas. Standard weight and size limits apply. State Routes •MN 60: Runs east-west in southern Minnesota, connecting to agricultural areas. Local weight restrictions may apply. •MN 23: Runs northwest-southeast across the state,			Special Permits: Required for vehicles and loads exceeding the standard size and weight limits. These permits specify the allowed route, travel time, and additional safety requirements. o **Forest Products**: Vehicles or combinations of vehicles with six or more axles that are carrying raw or unfinished forest products and have a gross vehicle weight of up to 90,000 lbs. or up to 99,000 lbs. during an authorized winter seasonal increase may be issued an annual permit to operate on ***non-Interstate highways***. Such vehicles may exceed legal axle weight limits by up to 12.5 percent or up to 23.75 percent when seasonal increases are in effect, but may not exceed 20,000 lbs. gross weight on any single axle (Minn. Stat. Ann. §169.8261). o **Pulpwood Vehicle**: Vehicles or combinations of vehicles with six or more axles may operate, on ***non-Interstate highways***, with a gross vehicle weight up to 82,000 lbs. when transporting pole-length pulpwood. Such vehicles must comply with State axle weight limits (Minn. Stat. Ann. §169.863). o **Farm Products**: A road authority is authorized to issue an annual permit for vehicles or

	serving agricultural regions. Local restrictions may apply. •MN 169: Runs north-south, heavily used for agricultural transport. Local road conditions and restrictions may vary.			vehicle combinations to haul raw or unprocessed agriculture products with the following axle and weight limits: • Up to 90,000 lbs. with six axles (99,000 lbs. during a seasonal increase); and • Up to 97,000 lbs. with seven or more axles (99,000 lbs. during a seasonal increase). These vehicles ***may not travel on Interstate highways*** **(except for sealed intermodal containers as allowed by the Federal Government)** and must comply with State axle weight limits and seasonal load restrictions (Minn. Stat. Ann. §169.865). o **Canola**: The Commissioner of Transportation is authorized to issue a special canola-hauling vehicle annual permit for a three-unit combination of vehicles with a gross vehicle weight of up to 105,500 lbs. Such vehicles may only be operated on the following routes: • Trunk Highway 175 from Hallock to the North Dakota border; • U.S. Highway 75 from Hallock to Donaldson; and

				• Trunk Highway 11 from Donaldson to the North Dakota border. These vehicles may not travel on Interstate or NN highways and may not take advantage of the seasonal weight increases. They also must comply with State axle and tire weight limits and seasonal load restrictions (Minn. Stat. Ann. §169.866). o **Livestock**: Vehicles or combinations of vehicles with six or more axles may operate on ***non-Interstate highways*** with a gross vehicle weight of up to 88,000 lbs. when exclusively engaged in hauling livestock (Minn. Stat. Ann. §169.824[2][a][2]). o **Milk**: Single-unit vehicles hauling milk are allowed a 10 percent weight tolerance, but they may not exceed the manufacturer's GVW rating or other certification of GVW rating that complies with Federal regulations. These vehicles ***may not travel on Interstate highways, may not take advantage of the seasonal weight increases***, and must comply with seasonal load restrictions (Minn. Stat. Ann. §169.867).

				○ **Harvest Season Permit**: State weight limits are increased by 10 percent from the beginning of harvest to November 30 each year for the movement of sugar beets, carrots, and potatoes from the field of harvest to the point of the first unloading. Transferring the product from a farm vehicle or a small farm trailer to another vehicle is not considered to be the first unloading. A permit is required for this increase (Minn. Stat. Ann. §169.826[1a]). ○ **Excess Weight Permit**: When a 10 percent winter increase is in effect, a permit is required for vehicles or vehicle combinations in excess of 80,000 lbs. gross vehicle weight and 20,000 lbs. single axle weight while ***traveling on Interstate highways*** (Minn. Stat. Ann. §169.826[3]). **2. Seasonal Permit for Haulers**: The Commissioner may issue special permits annually to any hauler allowing the hauler to move vehicles or vehicle combinations with weights exceeding State weight limits by up to 10 percent on ***Interstate highways*** during specified times and within approved zones (Minn. Stat. Ann. §169.86[1a]).

				3. Agricultural Exemptions • **Farm Equipment**: Certain farm vehicles and equipment may be exempt from standard size and weight limits when moving between fields or to local storage facilities. Specific exemptions and requirements can be found in Minnesota's statutes.
Illinois	Interstate Highways: Major corridors such as I-55, I-57, I-80, I-90, I-94, and I-70, which support high-capacity freight movement. US Highways and State Routes: US 20, US 30, US 34, US 51, and state routes such as IL 1, IL 47, IL 54, and IL 126, among others, also facilitate agricultural transport. State Routes: IL 47: Runs north-south through central Illinois, important for connecting agricultural areas. May have weight restrictions on certain segments. IL 54: Runs northeast-southwest, connecting smaller agricultural communities. Local	Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood, Milled grain products, other foodstuffs, Logs and other Wood Products	There is no publicly accessible data or report available on the methodology for identifying agriculture-related infrastructure and its critical elements	Truck weight limits for vehicles in regular operations is shown below ([37],[38],[39],[40],[41]): Single Axle 20,000 lbs. Tandem Axle 34,000 lbs. Tridem Axle 42,000 lbs. Gross Weight 80,000 lbs. **1. Permits for Oversize/Overweight Loads** Special Permits: Required for vehicles and loads exceeding the standard size and weight limits. These permits specify the allowed route, travel time, and additional safety requirements. **2. Seasonal Restrictions** Seasonal Weight Limits: During periods of thawing, certain roads may have reduced weight limits to prevent damage. These restrictions

	restrictions may apply based on road conditions.			are typically posted on the IDOT website. **3. Agricultural Exemptions** Farm Equipment: Certain farm vehicles and equipment may be exempt from standard size and weight limits when moving between fields or to local storage facilities. Specific exemptions and requirements can be found in the Illinois Vehicle Code. (625 ILCS 5/ Illinois Vehicle Code) Harvest Season Permits: Special permits may be available for increased weight limits during harvest seasons to accommodate the higher volume of agricultural products being transported. (625 ILCS 5/15-301) o Agricultural Products: The Illinois Department of Transportation is authorized to issue special permits for a period of up to 40 days that authorize the movement of agricultural commodities on the following: • Two-axle SU vehicles with axle loads not to exceed 35 percent above State axle weight limits • Three- or four-axle vehicles with axle loads not to exceed 20 percent above State axle weight limits

				• Five-axle vehicles not to exceed 10 percent above State axle weight limits The total gross weight of the vehicle, however, may not exceed the maximum gross weight of the registration class of the vehicle, and all vehicles operating under permit must be registered with the Secretary of State. Trips cannot exceed 50 miles from a field, an on-farm grain storage facility, a warehouse, or a livestock management facility. Vehicles with such permits may travel on any non-Interstate highway. "Agricultural commodities" are defined as follows: • Cultivated plants or agricultural produce, including but not limited to corn, soybeans, wheat, oats, grain sorghum, canola, and rice; • Livestock, including but not limited to hogs, horses, sheep, and poultry; • Ensilage; and • Fruits and vegetables. If the Governor declares an emergency harvest situation, this special permit is not required from September 1 through December 31 for otherwise eligible vehicles carrying agricultural commodities, provided the weight does not exceed 20 percent above normal limits (Ill. Rev. Stat. ch. 625, §5/15-301[e] – [e-1]). Raw Milk: The Illinois Department of Transportation (IDOT) can issue special permits for continuous limited operation

				authorizing the transport of raw milk loads exceeding the State weight limits, provided no single axle exceeds 20,000 lbs. and the gross weight does not exceed 80,000 lbs. Such permits do not allow travel on Interstate highways (Ill. Rev. Stat. ch. 625, §5/15-301[o]).
Indiana	Highway Routes**:** Major corridors for freight transport in Indiana include Interstate highways such as I-70, I-65, and I-69. These routes generally support higher weight limits suitable for commercial vehicles. State Highways: State routes like US-31, US-41, and SR-67 connect agricultural regions to distribution centers. These routes have varying weight limits and restrictions based on their classification and local conditions. Bridge and Clearance Restrictions: Indiana enforces height and weight restrictions on bridges and overpasses to prevent damage and ensure safety. Oversized loads or large agricultural equipment must comply with these restrictions to	Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood, Milled grain products, other foodstuffs, Logs and other Wood Products	There is no publicly accessible data or report available on the methodology for identifying agriculture-related infrastructure and its critical elements	In Indiana, the truck weight limits in regular operations have been compiled below ([42],[43],[44],[45]): State and Interstate Highways Single Axle 20,000 lbs. Tandem Axle 34,000 lbs. Tridem Axle 50,000 lbs. with lift axle, 48,000 lbs. otherwise Gross Weight 80,000 lbs. Heavy Duty Highways Single Axle 22,400 lbs. Tandem Axle 36,000 lbs. (18,000 lbs. for each axle) **Gross Weight** 80,000 lbs. 90,000 lbs. on Indiana Toll Road Extra Heavy Duty Highways Single Axle 18,000 lbs. Tandem Axle 65,000 lbs. on one specified intersection 32,000 lbs **Gross Weight** 134,000 lbs. 90,000 lbs. on one specified route. **1. Commodity Exemptions** Farm commodities include logs, wood chips, bark, sawdust, and bulk milk. In the case of wood chips, bark,

	avoid accidents and infrastructure damage. **Grandfathered Routes** I- 0/90 Indiana Toll Road from Toll Gate 21 to Ohio; I-90 Indiana Toll Road from Illinois to Toll Gate 21. Extra Heavy-Duty Highways (Ind. Code Ann. §9-20-5-4) • Highway 41, from 129th Street in Hammond to Highway 312 • Highway 312, from Highway 41 to State Road 912 • Highway 912, from Riley Road in East Chicago to the U.S. 20 interchange • Highway 20, from Clark Road in Gary to Highway 39 • Highway 12, from one-fourth (1/4) mile west of the Midwest Steel entrance to Highway 249 • Highway 249, from Highway 12 to Highway 20 • Highway 12, from one and one-half (1 1/2) miles east of the Bethlehem Steel entrance to Highway 149			and sawdust, the 10 percent tolerance applies at all times for both gross weight and axle weight (Ind. Code Ann. §9-20-4-2). **2. Size and Weight Limits** Indiana adheres to federal weight limits, with specific exemptions for farm equipment temporarily operated on highways. For example, farm equipment is exempt from state weight limits when being moved temporarily for agriculture-related practices. **3. Permit Requirements** Oversize or overweight loads often require special permits from the Indiana Department of Transportation. These permits ensure compliance with state regulations and may specify designated routes or times of travel)

	• Highway 149, from Highway 12 to a point thirty-six hundredths (.36) of a mile south of Highway 20 • Highway 39, from Highway 20 to the Michigan State line • Highway 20, from Highway 39 to Highway 2 • Highway 2, from Highway 20 to Highway 31 • Highway 31, from the Michigan State line to Highway 23 • Highway 23, from Highway 31 to Olive Street in South Bend • Highway 35, from South Motts Parkway thirty-four hundredths (.34) of a mile southeast to the point where Highway 35 intersects with the overpass for Highway 20/Highway 212 • State Road 249 from U.S. 12 to the point where State Road 249 intersects with Nelson Drive at the Port of Indiana • State Road 912 from the 15th Avenue and 169th Street interchange one and six hundredths (1.06) miles			

	north to the U.S. 20 interchange • U.S. 20 from the State Road 912 interchange three and seventeen hundredths (3.17) miles east to U.S. 12 • U.S. 6 from the Ohio State line to State Road 9 • U.S. 30 from Allen County/Whitley County Line Road (also known as County Road 800 East) to State Road 9.(20) State Road 9 from U.S. 30 to U.S. 6 • State Road 39 from Interstate 80 to U.S. 20			
Kansas	Interstate Highways ○ Major interstates such as I-70, I-35, and I-135 are commonly used for agricultural freight. These routes have fewer restrictions but require adherence to federal weight and size limits. State Highways ○ Kansas state highways are essential for connecting rural agricultural areas to larger interstate routes. Key state highways include US-36, US-50, and US-81. These routes may have	Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood, Milled grain products, other foodstuffs, Logs and other Wood Products	There is no publicly accessible data or report available on the methodology for identifying agriculture-related infrastructure and its critical elements	The truck weight limits in regular operations have been compiled below ([46],[47],[48]): Single Axle 20,000 lbs. Tandem Axle 34,000 lbs. Tridem Axle 43,500 lbs. at 10ft spacing 42,000 lbs. at more than 8 feet spacing but less than 9 feet 42,500 lbs. at more than 9 feet spacing but less than 10 feet Gross Weight 80,000 lbs. on Interstate highways 85,500 lbs. on non-Interstate highways A summary of the key regulations are as follows: **1. Cotton**: The gross weight on tandem axles of a cotton module issued a

	specific restrictions regarding weight limits, particularly on bridges and during periods of road maintenance or adverse weather conditions.			special permit may not exceed 50,000 lbs. A cotton module with a tandem gross axle weight of 50,000 lbs. or less is not be considered a superload (Kan. Stat. Ann. §8-1916). 2. **Oversize and Overweight Permits**: Kansas has specific permits for oversize and overweight loads. The maximum dimensions and weights for these loads are strictly regulated, and special permits are required if these limits are exceeded. 3. **Pilot/Escort Vehicle Requirements**: Pilot or escort vehicles must meet specific requirements, including vehicle dimensions and mandatory equipment like "Oversize Load" signs, amber lights, and safety gear. These vehicles must be fully insured and operated by licensed drivers. 4. **Farm Tractors and Farm Machinery**: No permit is required to authorize moving or operating any farm tractors, combines, fertilizer dispensing equipment or other farm machinery, or machinery being transported to be used for terracing or soil or water conservation work upon farms, or vehicles owned by counties, cities, and other political subdivisions of the State.
Texas	Interstates: I-10: Runs east-west across Texas, connecting agricultural areas in West Texas with markets in Houston and the ports along the Gulf Coast.	Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood, Milled grain products, other foodstuffs, Logs and other Wood Products	There is no publicly accessible data or report available on the methodology for identifying agriculture-related infrastructure and its critical elements	In Texas, agricultural roads east of U. S. 281 are generally designated farm to market roads and those roads that are west of US 281 are generally designated ranch to market roads ([49]). The Farm to Market system connects metropolises, ranches, farms, and railroad hubs in Texas.

	I-35: A major north-south corridor connecting Texas's agricultural heartland with distribution hubs in Dallas-Fort Worth and beyond to Oklahoma and northern markets. I-20: Supports the movement of agricultural goods from West Texas to the Dallas-Fort Worth region and connects with I-10 for eastward shipments. I-45: Connects the Houston area with Dallas, providing a critical route for goods heading from the coast to northern Texas and beyond. State Highways: SH 6: Runs from the Gulf Coast up through College Station to Waco, supporting the movement of cattle and crops from agricultural regions. SH 36: Extends from the Gulf Coast to central Texas, facilitating the transport of cotton and grains from the Texas plains. SH 59: Known as the future route of Interstate 69, SH 59 links south Texas agriculture regions,			Texas has truck weight limits for vehicles in regular operations which are stated below ([50]): Single Axle 20,000 lbs. Tandem Axle 34,000 lbs. Gross Weight 80,000 lbs. Other 5 percent tolerance on GVW up to 80,000 lbs. (Tex. Transportation Code Ann. §621.403) 5 percent tolerance on axle weight (Tex. Transportation Code Ann. §621.404) Commodity exemptions exist for the following: **Milk**: A vehicle used exclusively to transport milk may be operated without weight limits on non-Interstate public highways if the weight on any group of axles is less than 68,000 lbs. and the vehicle complies with a specific axle spacing requirement (Tex. Transportation Code Ann. §622.031). **Cotton or Chile Pepper Modules**: State weight limits do not apply to single-motor vehicles used exclusively to transport or process chile pepper modules, seed cotton, or equipment, provided that the GVW of a vehicle hauling seed cotton or equipment is 64,000 lbs. or less and the GVW of a vehicle hauling chile pepper modules or equipment is 54,000 lbs. or less. Such vehicles may only travel on non-Interstate highways (Tex. Transportation Code Ann. §622.953). **Contracts to Cross Roads:** The Department of Transportation may enter into contracts allowing private

	particularly around the Rio Grande Valley, to Houston. 3. Local Roads and Farm-to-Market Roads: Farm-to-Market Roads (FM roads): FM 60 and FM 50 are important in central Texas for moving cattle and grain. US 281: Runs north-south through rural Texas areas, connecting ranches and farms to major agricultural hubs and the broader highway network.			overweight vehicles to cross non-controlled access highways from private property to private property. If the vehicle is transporting grain, sand, or another commodity or product, the GVW cannot exceed 110,000 lbs. (Tex. Transportation Code Ann. §623.051 and §623.052). **Bales of Hay**: The department of motor vehicles may issue a permit for the movement on State highways of an overweight vehicle carrying cylindrically shaped bales of hay (Tex. Transportation Code Ann. §623.071[a]). Routes for such permits shall be listed on the permit and determined by municipalities with State highways in their territories or by the department of motor vehicles (Tex. Transportation Code Ann. §623.072 and §623.080). **Implements of Husbandry**: The department of motor vehicles may issue a permit for the movement on State highways of implements of husbandry, water well drill equipment, or harvesting equipment being moved for an agriculture operation (Tex. Transportation Code Ann. §623.071[c][1 and 2] **Timber transportation**: There is a requirement for an annual permit for overweight vehicles hauling timber on non-Interstate highways.

Iowa	Interstate Highways: I-80: The east-west corridor traverses the entire state, facilitating the movement of agricultural goods between Iowa and other states, connecting major urban areas. I-35: Running north-south through Iowa, I-35 is a crucial route for transporting agricultural products, to and from the Midwest and connecting with I-80 for broader distribution. I-380: Connects Cedar Rapids and Waterloo U.S. Highways: US 20: Key east-west route across northern Iowa. US 30: Running parallel to I-80, US 30 serves central Iowa's farming communities. US 61: The north-south route along the eastern edge of Iowa supports transport between the Mississippi River ports and inland farming areas. US 18: Serves northern Iowa for agricultural distribution. State Highways: IA 3, IA 141, and IA 92 serves key agricultural areas.	Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood, Milled grain products, other foodstuffs, Logs and other Wood Products	There is no publicly accessible data or report available on the methodology for identifying agriculture-related infrastructure and its critical elements	The provisions of various limits, including overweight limits, of trucks in Iowa can be found in Iowa Code Ann. §§321.452 and Iowa Code Ann. §§321E.1, with exceptions provided in exceptions are provided in Iowa Code §321.463[5][a-e]. Agricultural vehicles are allowed higher single axle weights and gross vehicle weights on a seasonal basis. In general, the limits applicable are compiled below. Single Axle 20,000 lbs. Tandem Axle 35,000 lbs. Gross Weight 80,000 lbs. on primary* and non-primary highways** 90,000 lbs. on non-Interstate highways for six-axle vehicles 96,000 lbs. on non-Interstate highways for seven-axle vehicles (*Primary highway system includes all State and Federal highways and the Interstate System.) (**The non-primary highway system includes all city and county roads) Other Five-axle livestock transports with a spread-axle semitrailer: 86,000; Six-axle: 90,000; Seven-axle: 96,000* **Specific exemptions ([51]):**

	County Roads and Farm-to-Market Roads: Numerous county roads and designated farm-to-market roads across Iowa support the movement of agricultural goods from farms to larger state and interstate highways. **Grandfathered Routes:** Grandfather provision allows 129,000 lbs. gross vehicle weight (GVW) only when entering Sioux City from South Dakota or South Dakota from Sioux City. 95,000 lbs. GVW is the grandfathered limit when entering Sioux City from Nebraska or Nebraska from Sioux City.			A summary of agricultural commodity exemptions and vehicles is provided below: **Feeder, Grain Cart, or Tank Wagon**: The maximum gross vehicle weight of these vehicles may not exceed 96,000 lbs. **Livestock Transporters**: A livestock vehicle with five axles is allowed a gross vehicle weight of up to 86,000 lbs. **Implements of Husbandry:** The weight limits generally do not apply to implements of husbandry when moved or moving on a non-Interstate highway. Iowa Code §321.453 and §321.463 lays down that a tracked implement of husbandry has a gross vehicle weight limit of 96,000 lbs. when operated on highways; the limit is 80,000 lbs. when operated on non-Interstate highway bridges. Self-propelled implements of husbandry that are used exclusively for the application of plant food materials, agricultural limestone, or agricultural chemicals, however, are subject to State weight limits or applicable permits.
Nebraska	Interstates: I-80: The main east-west corridor across Nebraska, connects Omaha, Lincoln, and other central regions to major markets. State Highways: Highway 2: Runs across central Nebraska. Highway 34: Parallels I-80 in some areas	Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood, Milled grain products, other foodstuffs, Logs and other Wood Products	There is no publicly accessible data or report available on the methodology for identifying agriculture-related infrastructure and its critical elements	The Carrier Enforcement Division of the Nebraska State Patrol ([52]) provide state weight limits, as compiled below: Single Axle 20,000 lbs. Tandem Axle 34,000 lbs. Gross Weight 80,000 lbs. on Interstate highways 95,000 lbs. on non-Interstate highways. **Agricultural Floater-Spreaders**: Any vehicle that is self-propelled equipment designed to carry and apply fertilizer,

	Highway 6: The east-west route serves towns not directly on the interstate. Highway 92: Extends east-west across the state, connecting smaller rural areas and providing access to grain elevators and agricultural processing facilities. Highway 275: Runs from northeast Nebraska into Omaha. **Grandfathered Routes**: The grandfather provisions apply to all non-interstate routes with lengths between 65 and 71.5 feet, and with lengths greater than 71.5 feet, the grandfather provisions apply only to I-80 between Wyoming and Exit 440.			chemicals, or related products to agricultural soil and crops with a gross laden weight of 48,000 lbs. or less is not subject to axle limits or the gross weight table while traveling on non-Interstate highways. (reference: Neb. Rev. Stat. §60-6,294.01). **Livestock Haulers**: Trucks hauling livestock are allowed to exceed State weight limits if the gross vehicle weight is within the State maximum and applies only to non-Interstate highways (Neb. Rev. Stat. §60-6,301[2]). **Grain/Seasonal Harvest Products**: Grain or seasonal harvest products may be hauled with weight limits exceeding by 15 percent and exemption applies only to non-Interstate highways (Neb. Rev. Stat. §60-6,301[5]). These permits may include a special, continuing, or continuous permit authorizing the operation of vehicles that haul grain or seasonally harvested products from the field to storage, market, or stockpile in the field, or from stockpile to market or factory.
California	Interstates: I-5: Runs north-south through the Central Valley, I-5 is a major corridor for transporting fruits, vegetables, nuts, and other agricultural products from California's top-producing agricultural areas. I-80: Connects Sacramento to the Bay Area and	Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood, Milled grain products, other foodstuffs, Logs and other Wood Products	There is no publicly accessible data or report available on the methodology for identifying agriculture-related infrastructure and its critical elements	Truck size and weight in the State of California are found in California Vehicle Code §§35000-35796. Section 35551 of the Vehicle Code is amended for the total gross weight in pounds imposed on the highway by any group of two or more consecutive axles. The truck weight limits for vehicles in regular operations is compiled below:

	continues eastward, I-80 is vital for transporting agricultural products, especially to ports for export. State Highways: SR 99: Runs parallel to I-5 in the Central Valley and is a critical agricultural artery for commodities like almonds, dairy, and grapes. SR 58: Connects the Central Valley to Interstate 15, and facilitates the movement of agricultural goods toward Southern California and other states. SR 12: Connects the wine-producing regions of Napa and Sonoma. SR 46: Serves San Luis Obispo and Kern counties, and supports the transport of produce, including vegetables and fruit.			Single Axle 18,000 lbs. Tandem Axle 33,60034,000 lbs. Gross Weight 82,00076,800 lbs. on Interstate highways **Exemptions and Special Operations** ([53], [54]): **Logs**: Trucks and vehicle combinations transporting loads composed solely of logs are allowed to exceed the tandem axle limit by up to 1,500 lbs. for a maximum tandem axle gross weight of 35,500 lbs. Two consecutive sets of tandem axles are allowed a combined gross weight of up to 69,000 lbs. provided no axle exceeds 35,500 lbs. and the overall distance between the first and last axle of such consecutive sets of tandem axles is 34 feet or more. **Cotton**: Between September 15 and March 15 each year, State weight limits do not apply to cotton module movers or any truck tractor pulling a semitrailer that is a cotton module mover. These vehicles may exceed the tandem axle limit (34,000 lbs.) by 6,000 lbs. This exemption does not, however, apply to those highways designated by the United States Department of Transportation as national network routes. **Livestock**: The gross weight limit provided for weight bearing upon any one wheel, or wheels, supporting one end of an axle does not apply to vehicles which consists of livestock (Cal. Vehicle Code §35550[b]).

				Trucks transporting bulk grains or bulk livestock feed: Trucks transporting bulk grains or bulk livestock feed are exempt from that section's front axle weight limits (Cal. Vehicle Code §35551.5[b]). **Permits for Overweight Vehicles:** The California Department of Transportation is authorized to issue permits for vehicles exceeding state weight limits by up to 25 percent. However, such overweight loads are restricted to a maximum travel distance of 75 miles on highways. These permits may cover either single trips or ongoing operations, with the permitting authority reserving the right to limit the number of trips, impose seasonal or other time-based restrictions, or otherwise regulate vehicle movement. It should be noted that permits for loads exceeding state weight limits do not apply to routes on the National System of Interstate and Defense Highways. (Cal. Vehicle Code §35780, §35788, and §36782).
Kansas, Indiana, Illinois, Minnesota, Wisconsin, North Carolina, Texas, Iowa, Nebraska and California	These routes, included grandfathered routes and for implements of husbandry, ~~have been provided in detail in **Appendix A.**~~	Specific commodities and routes used have been presented using GIS mapping and spatial analysis. The output maps for all the ten States have been presented in **Appendix B**	While we did not find specific literature detailing the methodology for identifying ag-related infrastructure and its critical elements, GIS mapping and spatial analysis were commonly used methods for this purpose ([55]). The major critical routes and ramps for each state are highlighted in the maps presented in **Appendix B**. Freight resilience for assessing freight routes can be evaluated using several key metrics ([56]). These include the Decay Duration, which represents the length of	The freight truck routes are provided by the Freight Analysis Framework (FAF) network of the Bureau of Transportation Statistics (BTS) and Federal Highway Administration (FHWA). All the States reviewed issue permits for overweight vehicles and have a quantified limits for trucks in normal operations. These can be found in detail in **Appendix A** of this draft report.

			time over which a corridor's performance declines, and the Decay of Travel Time, which is the increase in travel time during this decay period. The Angle of Decay refers to the slope of the decline in performance. On the recovery side, metrics include the Recovery Duration, which tracks how long it takes for corridor performance to return to normal, and the Recovery of Travel Time, which measures the improvement in travel time during this recovery. The Angle of Recovery indicates the slope of the performance improvement, while the Recovery Rate is the ratio of recovered travel time to decayed travel time. Together, these metrics help in analyzing how quickly and effectively freight corridors bounce back from disruptions.	

Data Collection

The objective of this research was also to collect data on critical transportation corridors, intermodal connectors, and bridges for agriculture supply chain in California by interviewing stakeholders. Stakeholders interviewed included truck drivers, distributors, and managers of trucking companies. Inputs on critical routes and ramps were obtained from Caltrans collected using permit requests. While initial attempts to conduct interviews via phone, Zoom, or email were unsuccessful, the research team conducted in-person interviews by visiting trucking companies, dairy farms, lumber companies, and sawmills. The questions focused on identifying critical infrastructure, evaluation metrics, improvement priorities, and seasonal patterns of heavy vehicle trips. Findings regarding critical locations for agricultural transport across California have been mapped and documented accordingly.

In this research, data were gathered and insights on critical routes and ramps frequently traveled by agriculture-related freight trucks were obtained. Three primary data sources were utilized for this purpose:

A. In-person interviews with trucking companies and related businesses in Bakersfield, CA
B. In-person interviews with truckers in the logging industry along US 101
C. Critical routes and ramps for oversize/overweight farm vehicles using information obtained from Caltrans

The following sections outline the interview methodologies, analytical approaches, and additional findings from this data-gathering effort.

A. In-person interviews with trucking companies and related businesses in Bakersfield, CA

On Monday, November 25, 2024, the research team conducted site visits to several Bakersfield-based trucking companies and businesses involved in transporting agricultural commodities. This direct engagement was necessary because the companies were hesitant to share private information or detailed findings over the phone. By meeting personnel in person, the team gained firsthand insights into their infrastructure operations and any route challenges they encounter when moving agricultural goods.

These site visits provided a comprehensive understanding of the unique logistical and infrastructural requirements in Southern California. Each location was coded and mapped in GIS, as shown in the map of Fig. 2. A survey questionnaire, included in the Appendix, was employed to collect data during these visits.

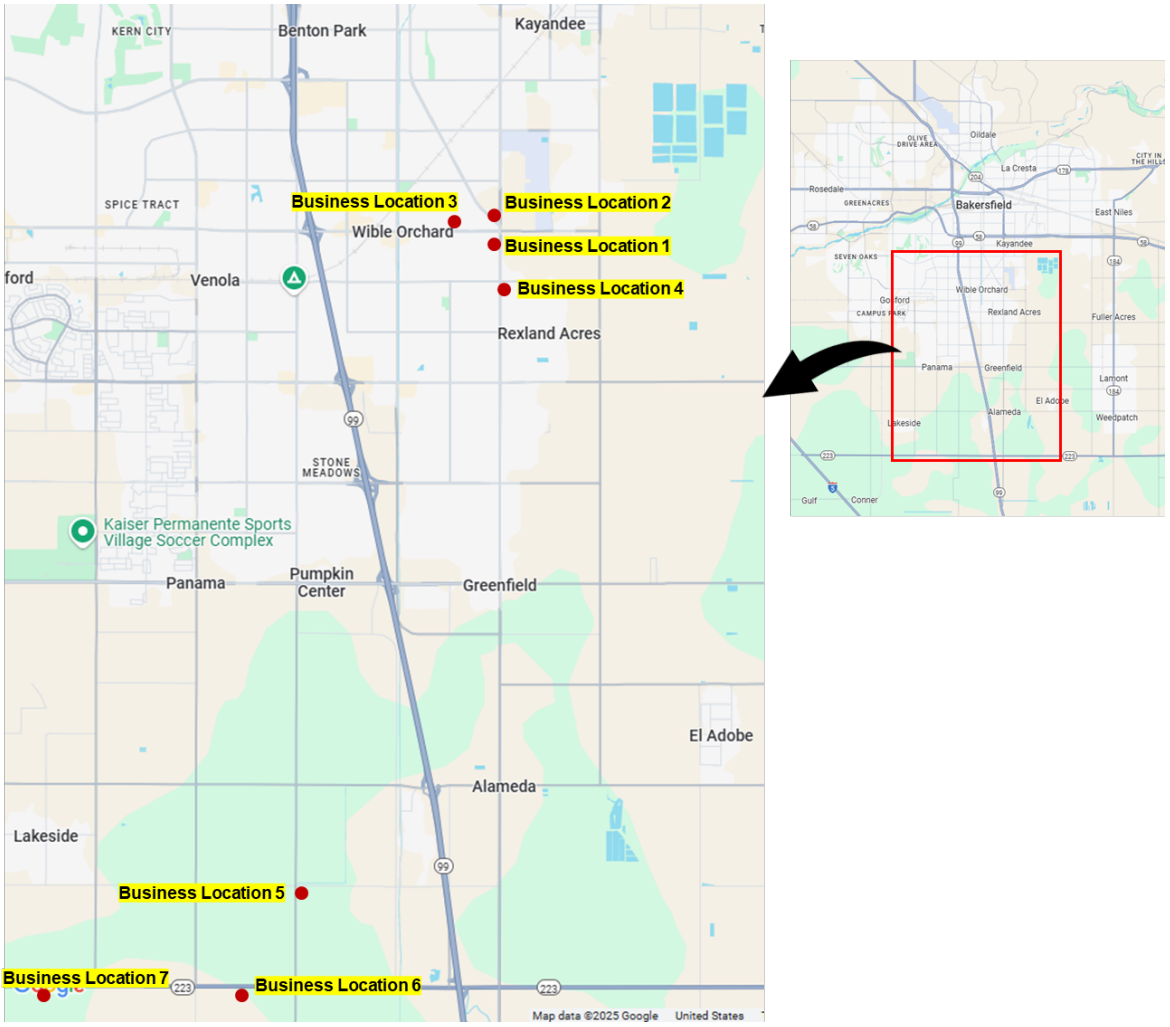


Figure 2: Agriculture-related business locations visited in Bakersfield, CA

One of the interviewed trucking companies reported operating across most of California's Central Valley, including Fresno, Kern, Tulare, and San Joaquin counties. Respondents primarily represented trucking carrier companies, distributors, and producers linked to the farming sector. One business noted it transports fresh produce year-round, with typical haul weights ranging between 20 and 30 tons. Additional survey inputs are detailed below.

Location 1: Green Globe Inc.
The Green Globe Inc., located on S Union Ave in Bakersfield, CA, dispatch truck fleet to transport California's agricultural produce from Bakersfield and Delano to out-of-state destinations. During the visit at their office location, we spoke with two truck drivers and a safety manager, who highlighted significant challenges on the I-5 and SR-99. The manager stated, 'Any accident is a shutdown,' emphasizing how even minor incidents cause major delays on the interchange of these two highways. Closures and construction on these freeways were noted as recurring issues. As a result, the I-40 was identified as a critical route with frequent closures when heading east. Other freeways of concern included the I-10 and I-20, particularly for routes extending to Florida.
Location 2: Rai Trucking and Dispatch

At this business location, we could only interact with a owner of the trucking company, who pointed out SR 99 was the most critical and would pose challenge for truckers due to congestion.

Location 3: 84 Lumber

This company, which specializes in processed lumber, noted the issue of traffic congestion in Los Angeles as the most problematic aspect of their routes. They noted heavy delays along the I-5, US-101, and I-710, especially during peak hours. Los Angeles was always noted as a focal point for infrastructure challenges, mainly due to heavy traffic.

Location 4: Torres Feed & Pet Supply

This company sources feed locally livestock primarily from Los Angeles and San Diego. Their source of transportation is light to medium trucks depending on the haul size. Key issues were road closures on the I-5 and frequent bottlenecks near major interchanges. As a result, the traffic congestion near distribution hubs was also highlighted as a recurring challenge.

Location 5: Capitol Truck Lines

At this location, we spoke with a representative who expressed their interest in the need to address logistical hurdles to improve route efficiency. Although specific mentions of traffic congestion were minimal, challenges related to infrastructure was identified as an area needing improvement.

Locations 6 & 7: Dairy Farms

The researchers also visited two dairy farms located on CA 223. The inputs we received from the cattle indicated that SR 58 is often used as a regular highway for transporting livestock.

Findings

Based on information gathered from on-site interviews with agricultural businesses and the three interviewed truck operators and managers involved in transporting California's agricultural goods, our analysis reveals a high degree of overlap in the routes utilized by freight carriers. Most respondents identified the major interstate freeways passing through Bakersfield—particularly I-5, SR-99, and other principal arterials heading to Los Angeles—as their primary travel corridors.

While truck operators reported minimal challenges navigating Bakersfield itself, they faced significant difficulties upon approaching Los Angeles. Commonly cited causes of delay included road closures, heavy traffic, and various logistical bottlenecks, with I-5, SR-99, and I-40 frequently mentioned as major trouble spots. Figs. 3 and 4 illustrate the spatial distribution of daily truck trips for farm and food products, respectively, using 2022 assignment model data from the Freight Analysis Framework (FAF[57]). These maps emphasize the critical highways facilitating the movement of farm and food commodities across California.

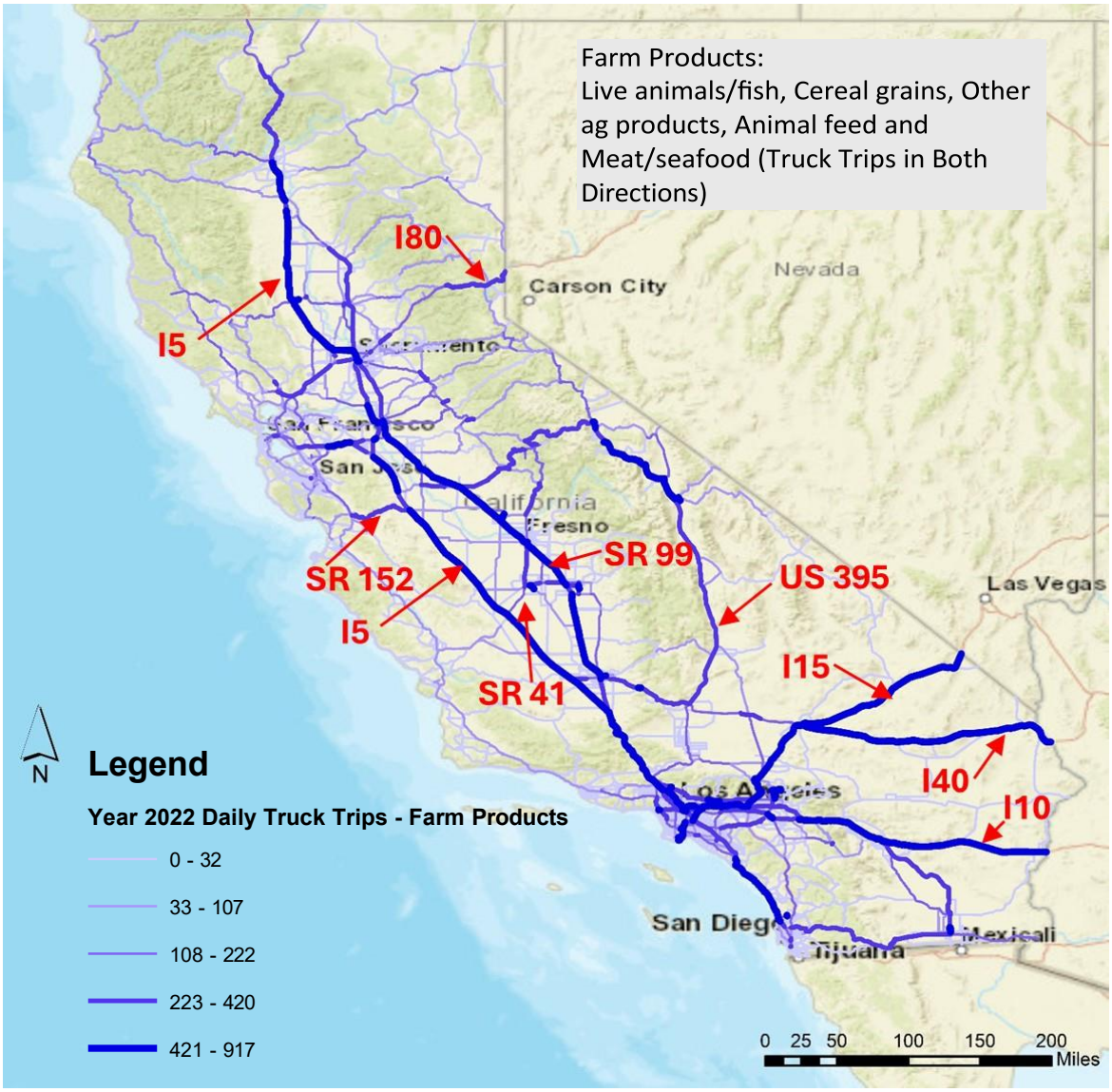


Figure 3: Spatial distribution of daily truck trips of farm products in California

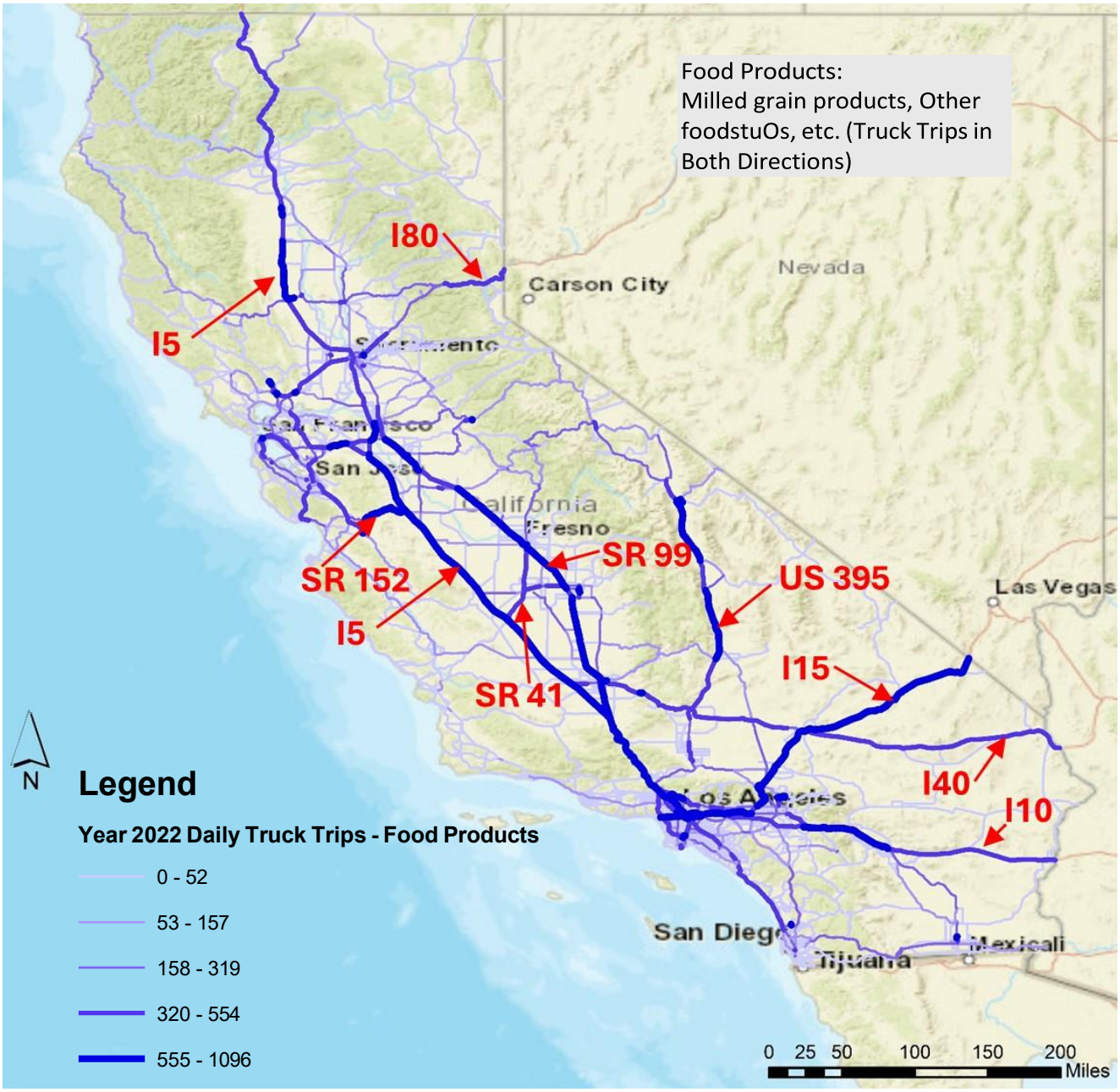


Figure 4: Spatial distribution of daily truck trips of food products in California

B. In-person interviews with truckers in the logging industry along US 101

Data collections were carried out on Thursday, December 19, 2024, by visiting three primary sawmill locations along US 101 - Cloverdale, Ukiah, and Scotia - and using an in-person interview. The Ukiah and Scotia mills lie in Mendocino and Humboldt counties, respectively, and the travel route is depicted in Fig. 5.

Figure 5: Sawmill locations visited along US 101

During these visits, two logging truck drivers and two sawmill staff members mentioned that July and August are considered peak transportation months for logging trucks. The truckers noted that route interruptions and delays frequently occur along major corridors such as US 101, CA 299, and CA 36 due to bridge repairs, slide removal, and resurfacing projects. Feedback from operators, confirmed by Caltrans QuickMap Travel Alerts, highlights these disruptions. Fig. 6 shows the site of bridge work on US 101, including a structure built in 1957 (source: American Road & Transportation Builders Association[58]). Despite the identified vulnerabilities, they reported few difficulties driving along US 101 and most Northern California routes. Their extensive experience, familiarity with local roads, and practice of starting work before dawn help them anticipate slowdowns and avoid peak traffic congestion.

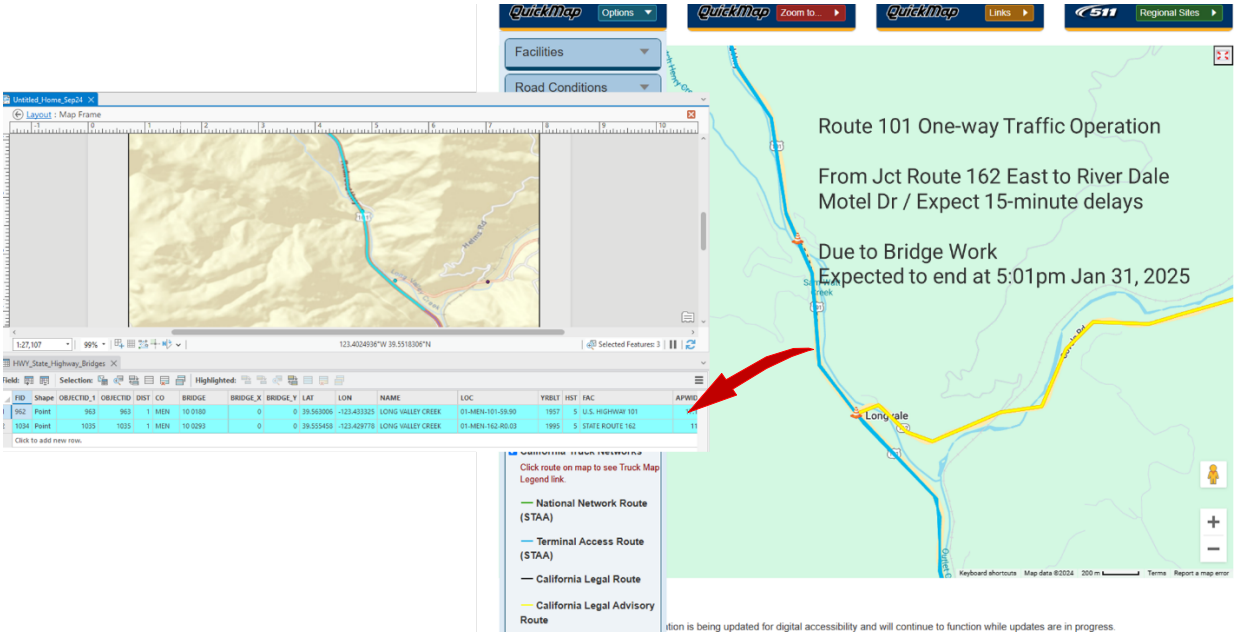


Figure 6: Location of bridge work on US 101

Unforeseen detours also pose challenges, notably the closure of CA 70 near Hotel Marysville, which has significantly extended travel times. Fig. 7 illustrates this vulnerability by indicating the hotel's location near CA 70.

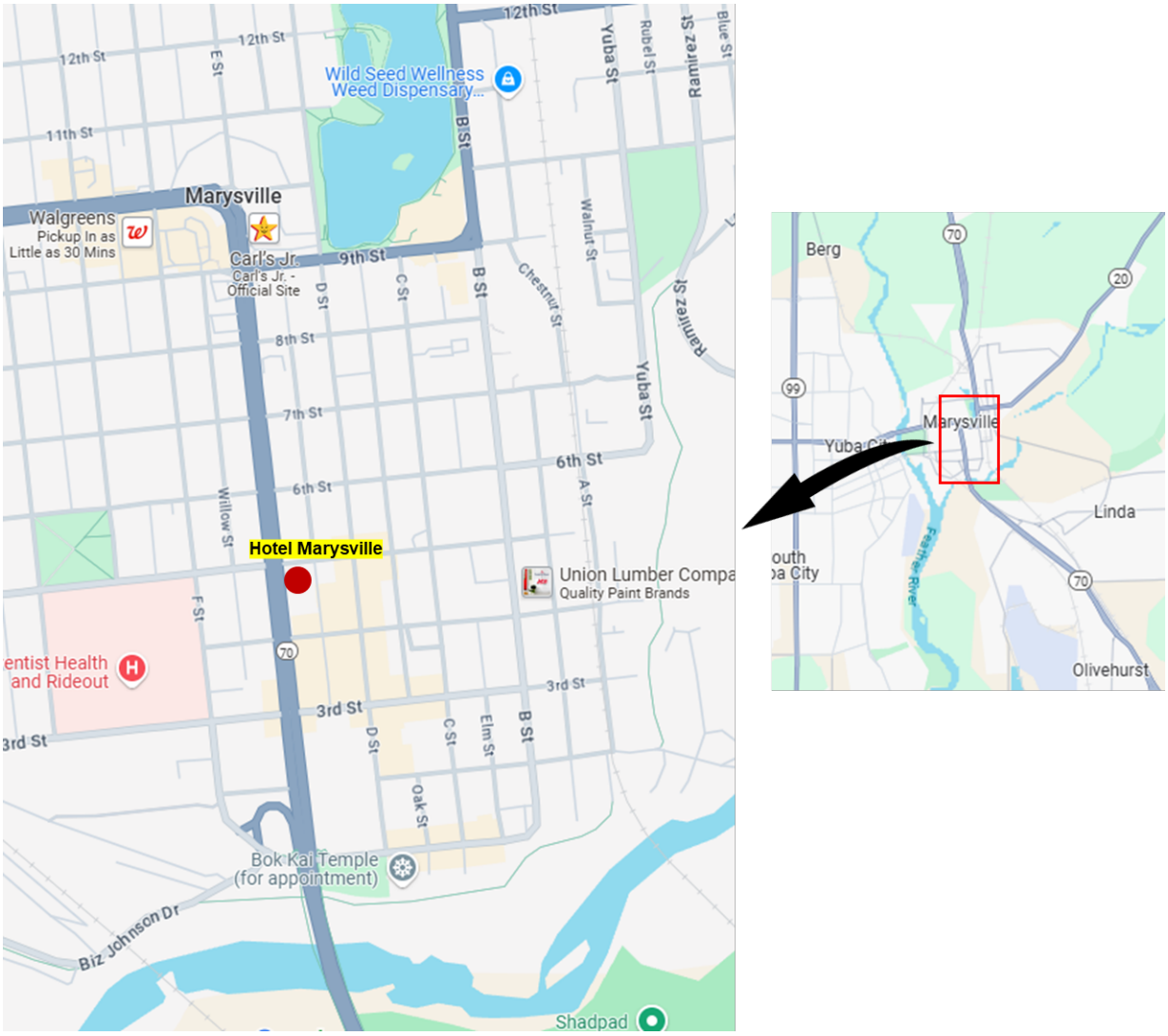
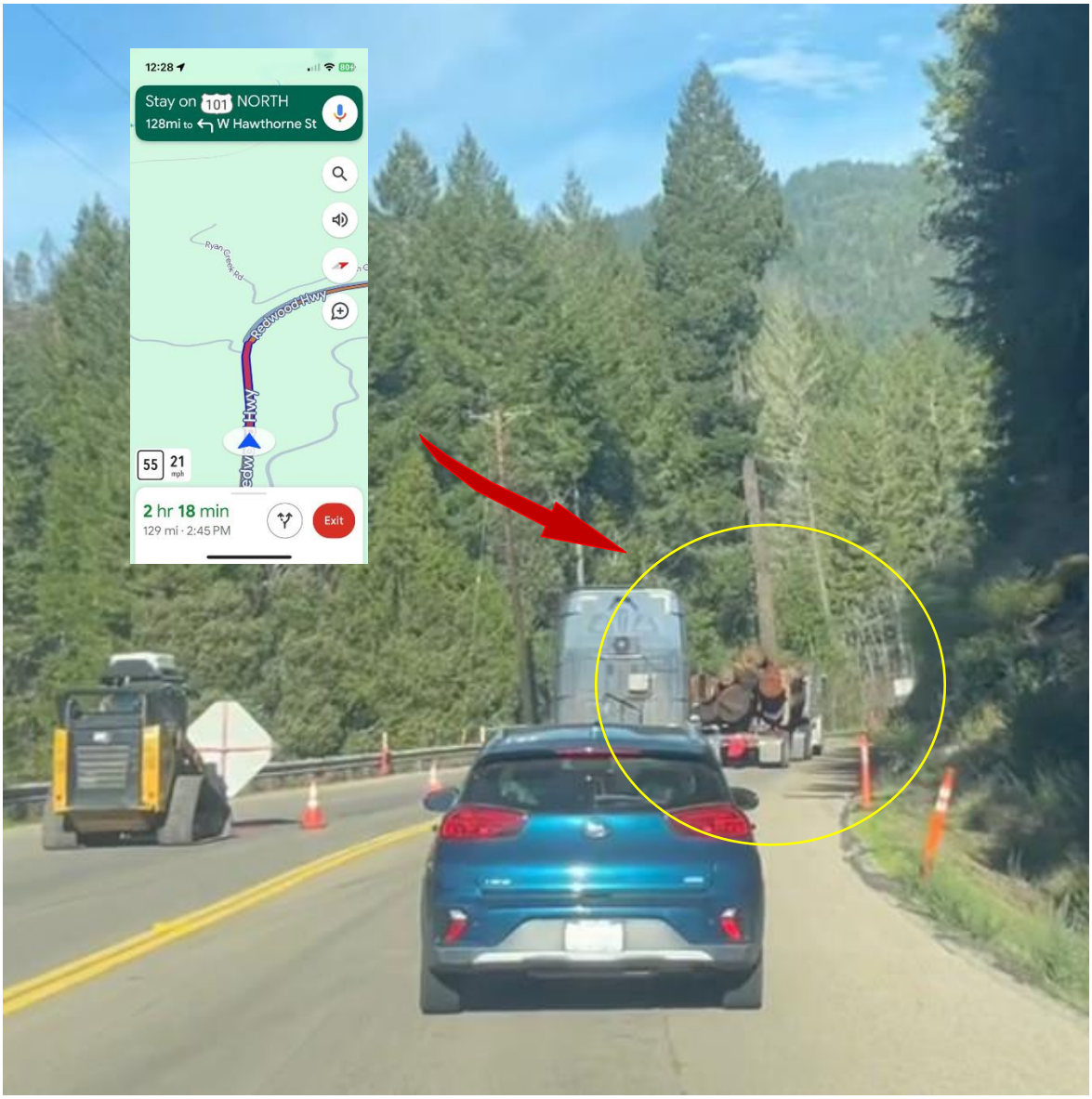


Figure 7: Hotel Marysville location on CA 70 (Source: Google Maps)

Driving to the north of US 101, congestion did show up at the work zone that was also encountered by the logging truck (see image below). A lane closure was observed during bridge work along US 101, as depicted in a screenshot from a video recorded while following a logging truck departing a sawmill in Ukiah. The lane closure caused delays for the truck. This is shown in Fig. 8.

An interesting event was also noted. After a few minutes of traveling in a single-lane stretch and upon reaching the end of the work zone, the logging truck pulled over to the shoulder to allow queued vehicles behind it to pass. Once the vehicles had passed, the truck re-entered the highway and resumed its journey.



While following a timber truck departing from a sawmill in Scotia, it was observed that, at several points north of Leggett on US 101, the vehicle had to navigate curves passing in close proximity to redwood trees, as illustrated in Fig. 5 below. Multiple such critical locations were identified along this stretch of US 101 and are highlighted on the map in Fig. 9.

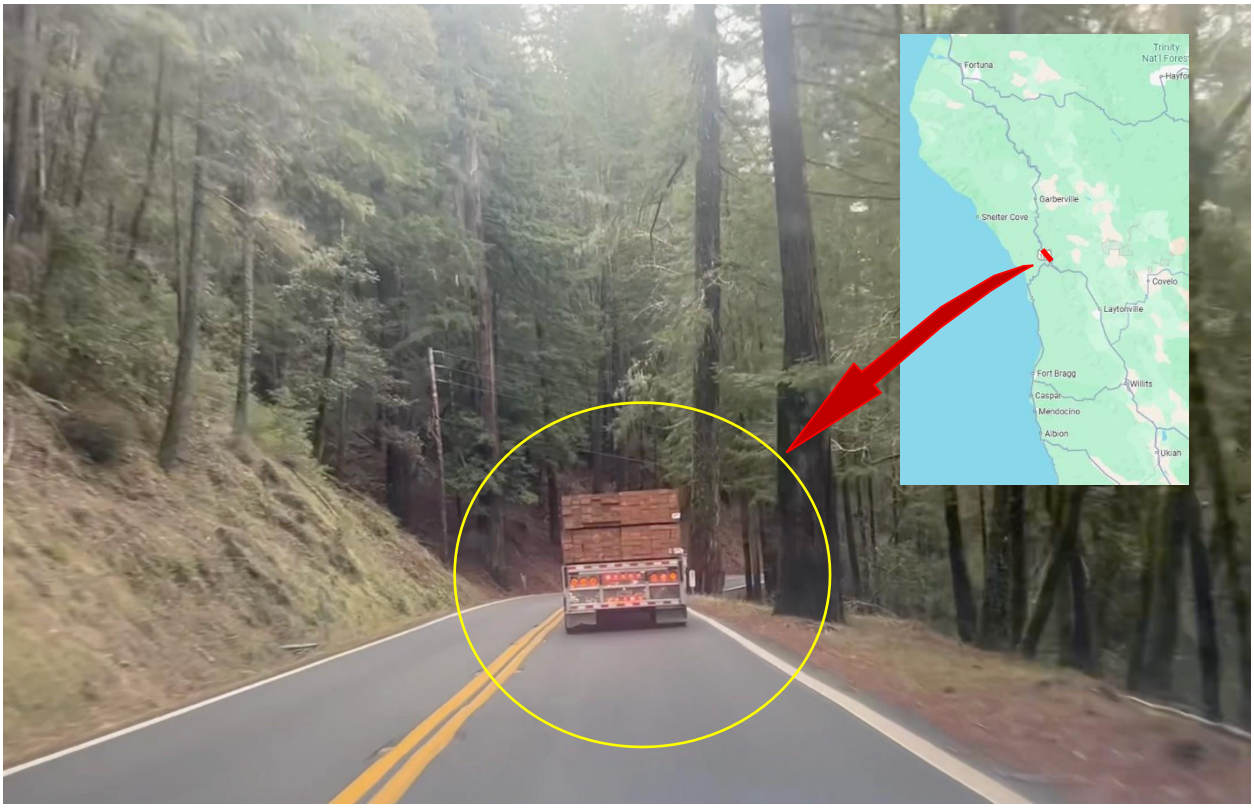


Figure 9: Truck carrying timber passing the curve on US 101

Discussions with truckers at a sawmill in Mendocino revealed that logging operations typically cover about 120 miles per trip, with trucks delivering up to 20 loads per day during winter. The truckers observed a drop in activity in 2023, followed by increased operations in 2024. The map in Fig. 10 shows the daily logging truck trips from the year 2022. The trip data were obtained from the FAF Highway Assignment Results, 2022).

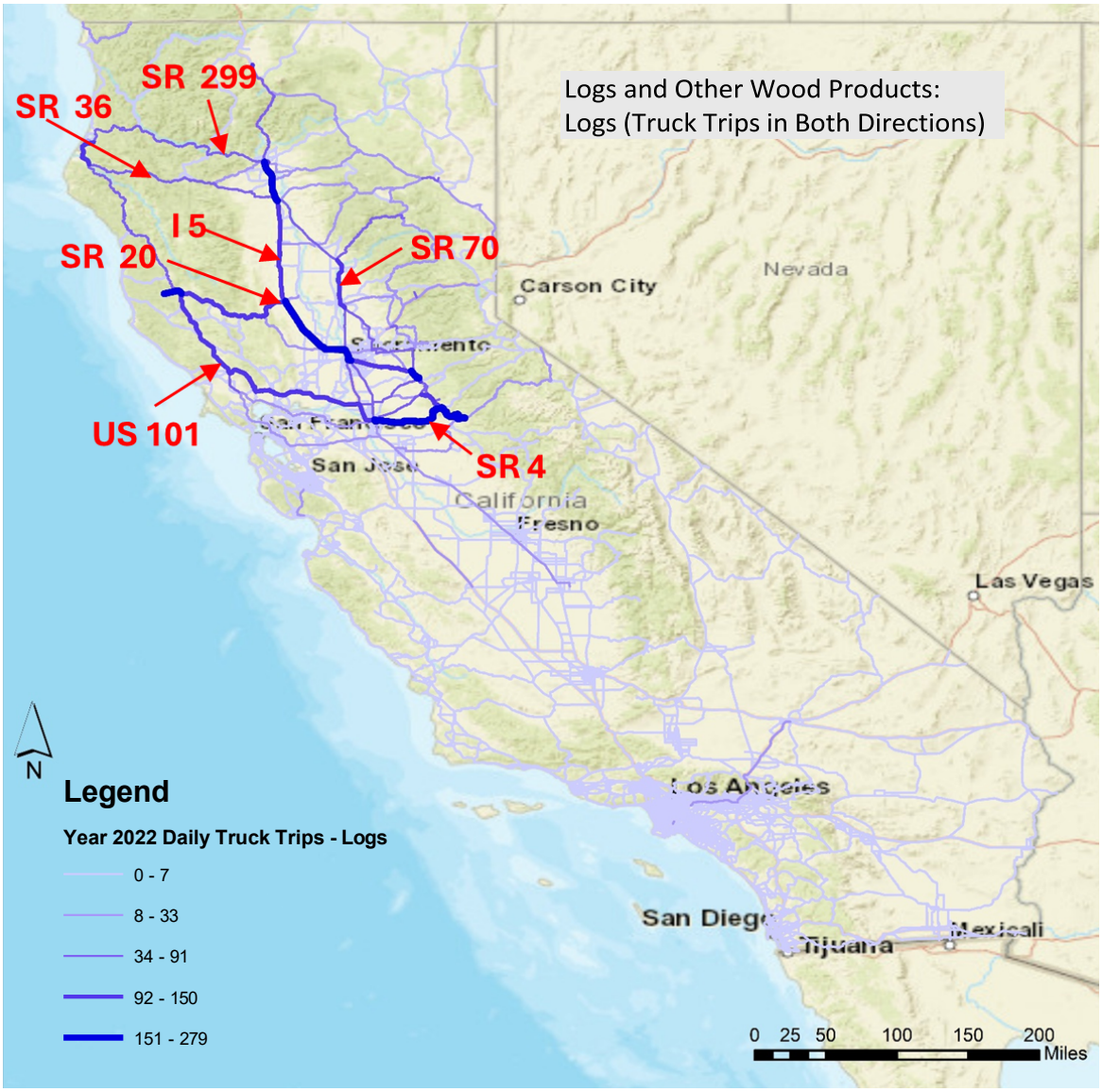
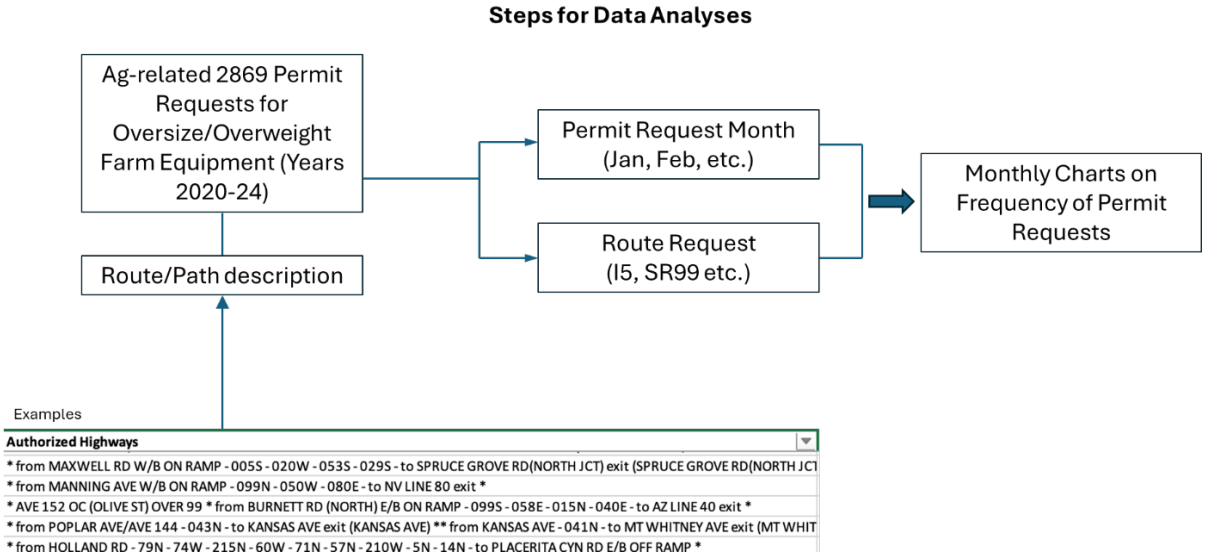


Figure 10: Distribution of logs and other wood products across California truck network

C. Critical routes and ramps for oversize/overweight farm vehicles

Major routes for oversize/overweight vehicle permit requests

Using the permit data for oversize/overweight farm vehicles, an analysis was conducted to determine the frequency of permit requests for various routes and ramps between 2020 and 2024. The data were provided by Caltrans. The flowchart/steps for the approach adopted for this analysis is presented below.



The monthly trends show that the Interstate 5 (I5) consistently receive the highest number of permit requests across the year, followed by other key routes such as SR99, I15, SR58, and I80. The permit requests reach peaks in specific months like September and October. The relevant findings are summarized in Table 4.

Table 4: List of major routes with frequency of permit requests for oversized/overweight farm vehicles by month

Month	Major Routes	Frequency of Permit Requests by Oversize/overweight Farm Vehicles (Years 2020-24)
January	I5	121
	I15	84
	SR99	84
	SR58	81
	I80	42
February	I5	112
	SR99	80
	I15	72
	SR58	64
	I10	44
March	I5	114
	SR99	75

	I15	59
	SR58	52
	I80	35
April	I5	88
	SR99	49
	I15	46
	I80	39
	SR58	38
May	I5	149
	SR99	73
	I15	67
	I80	60
	US101	59
June	I5	151
	I15	68
	SR58	64
	I80	60
	SR99	59
July	I5	144
	I80	58
	SR99	52
	I15	41
	SR58	34
August	I5	137
	I80	48
	US101	45
	SR99	44
	I10	33
September	I5	186
	I80	88
	SR99	79
	US101	66
	SR58	59
October	I5	165
	SR99	89
	I80	74
	I15	67
	SR58	60
November	I5	124
	SR99	74
	SR58	49

	I80	48
	I15	48
December	SR99	91
	I5	88
	SR58	61
	I15	60
	I40	36

The detailed permit request frequencies are depicted in the charts in Fig. 11a–l below.

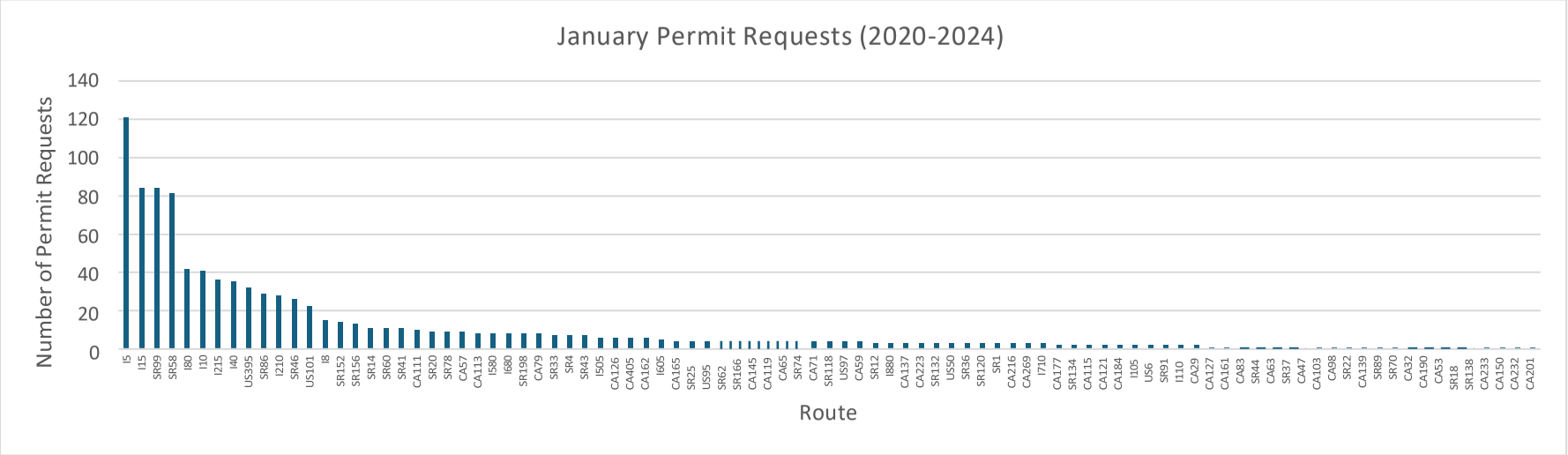


Figure 11a: Number of January permit requests for route usage by oversize/overweight farm vehicles

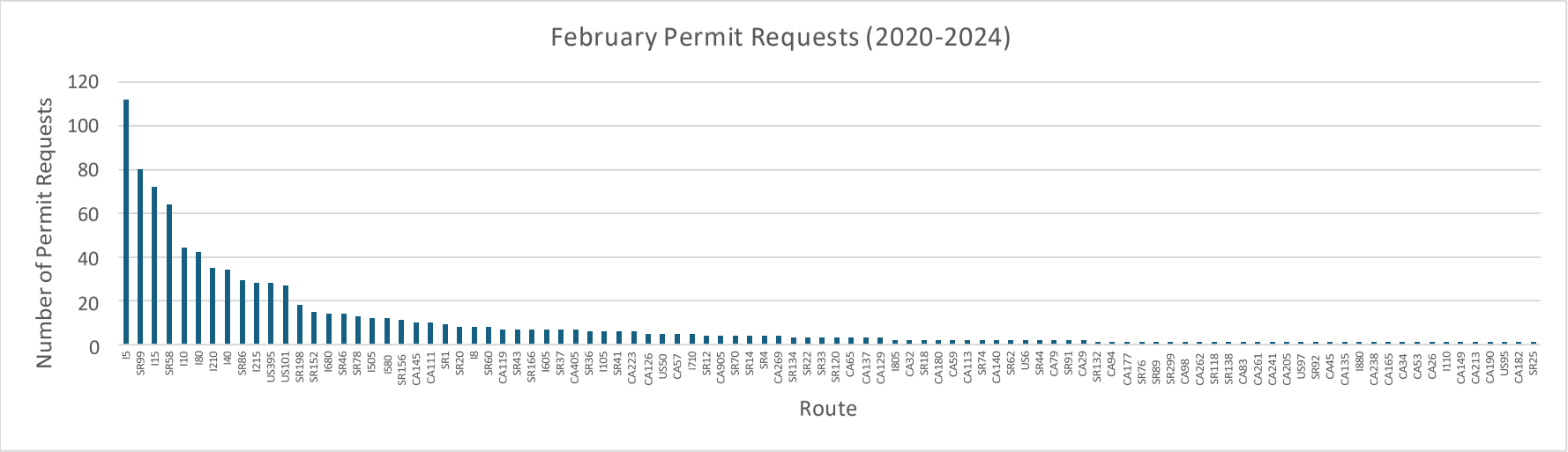


Figure 11b: Number of February permit requests for route usage by oversize/overweight farm vehicles

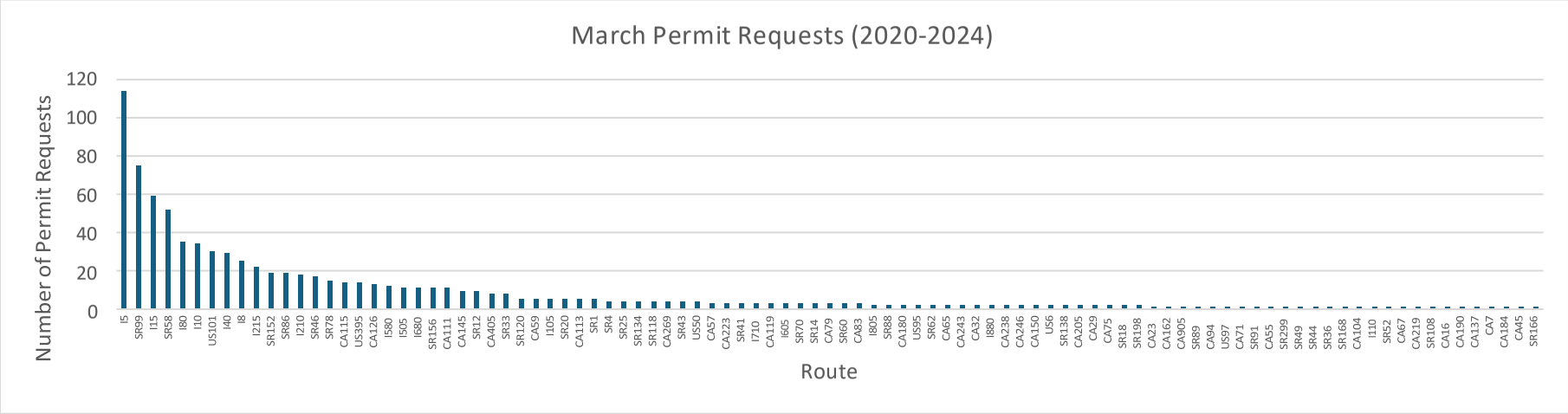


Figure 11c: Number of March permit requests for route usage by oversize/overweight farm vehicles

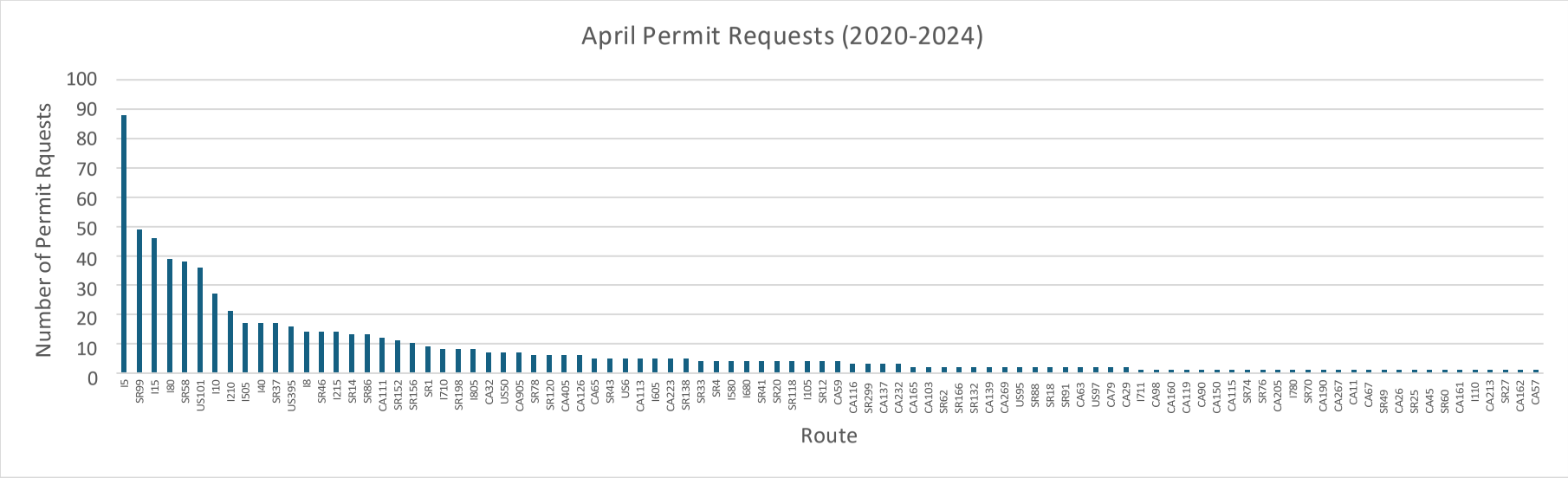


Figure 11d: Number of April permit requests for route usage by oversize/overweight farm vehicles

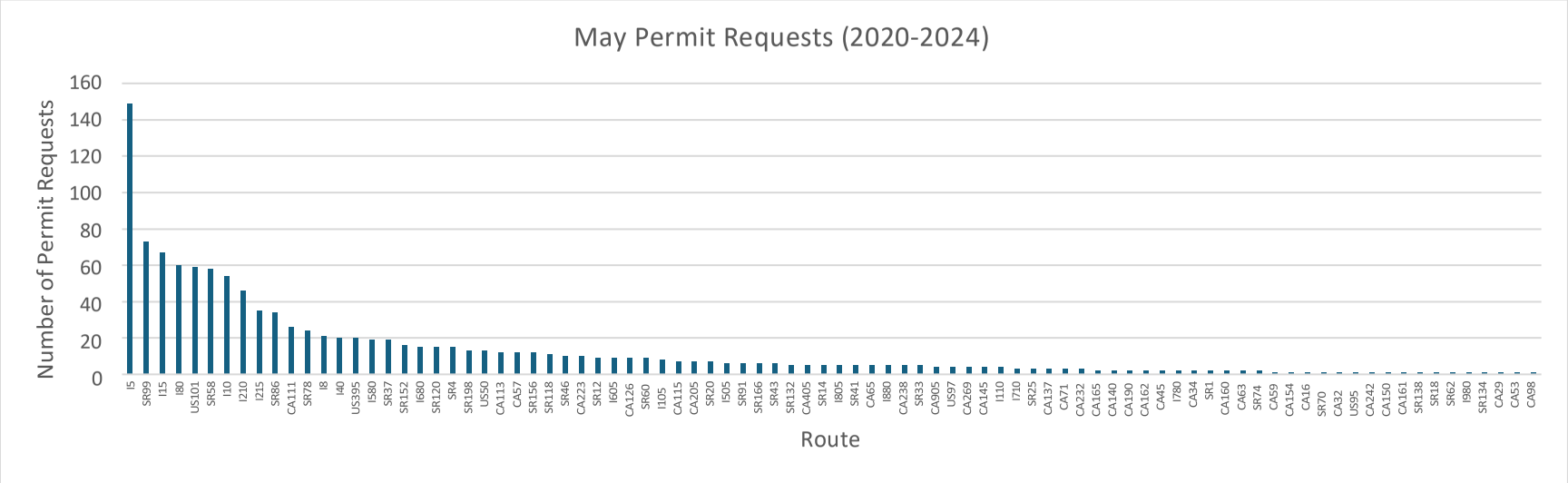


Figure 11e: Number of May permit requests for route usage by oversize/overweight farm vehicles

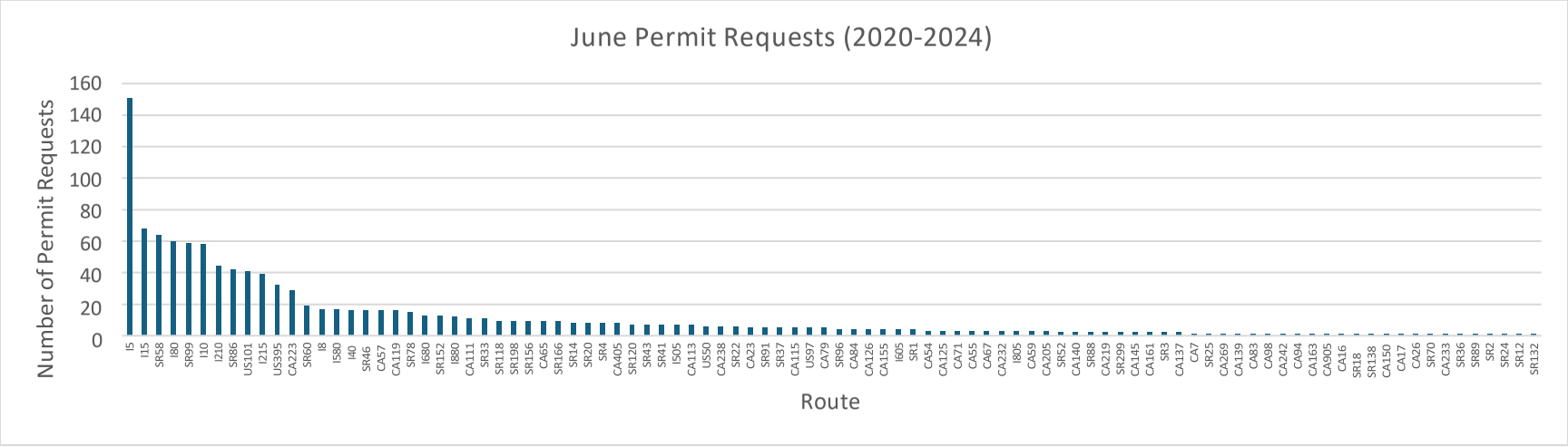


Figure 11f: Number of June permit requests for route usage by oversize/overweight farm vehicles

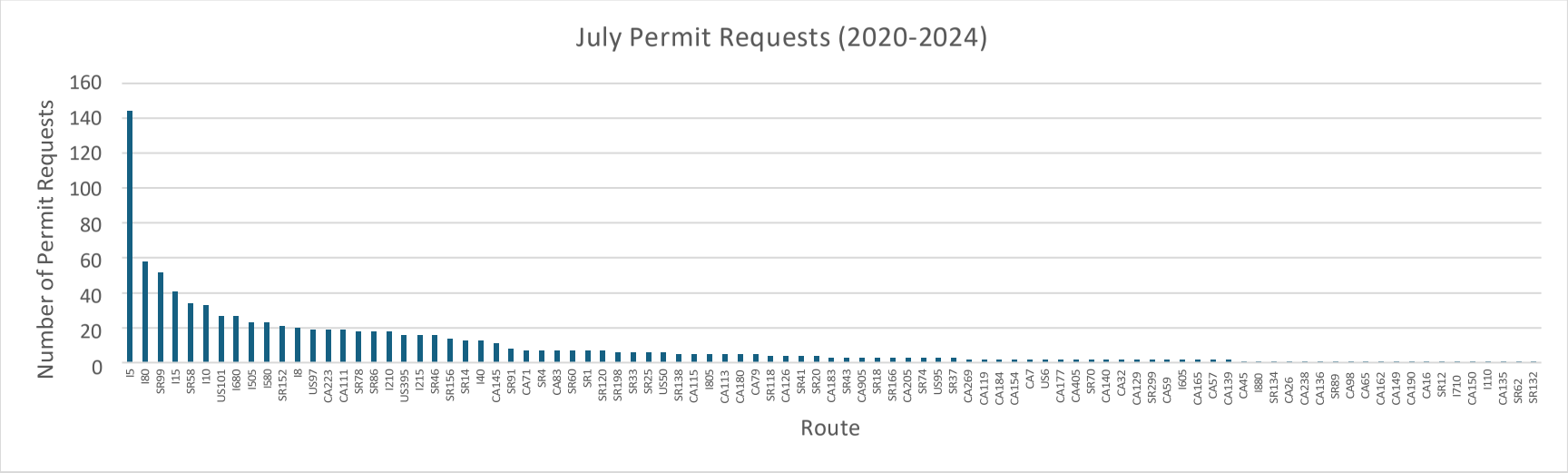


Figure 11g: Number of July permit requests for route usage by oversize/overweight farm vehicles

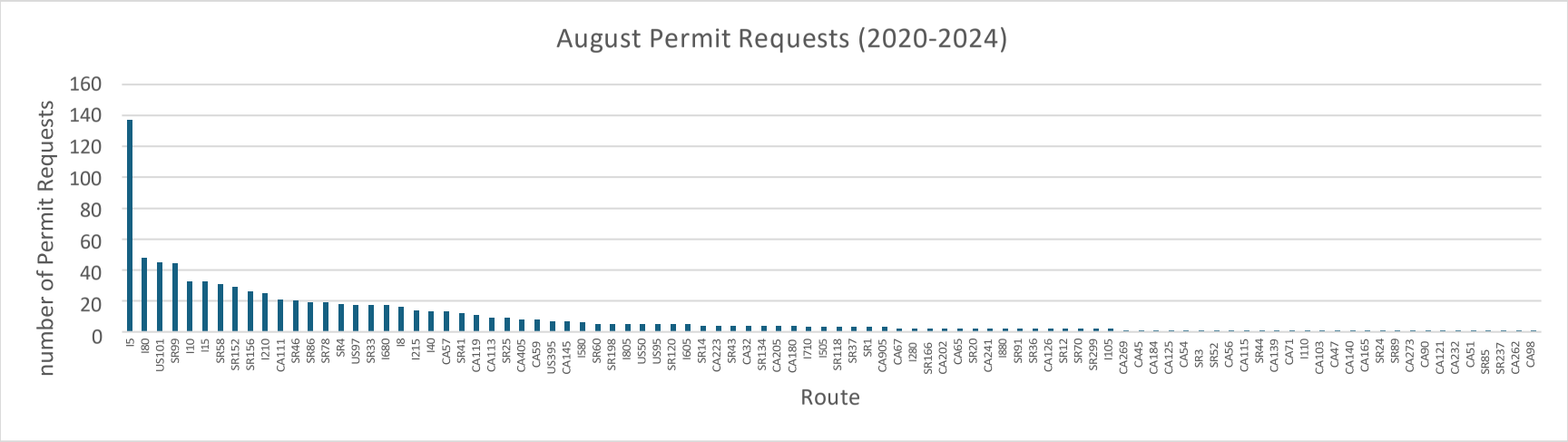


Figure 11h: Number of August permit requests for route usage by oversize/overweight farm vehicles

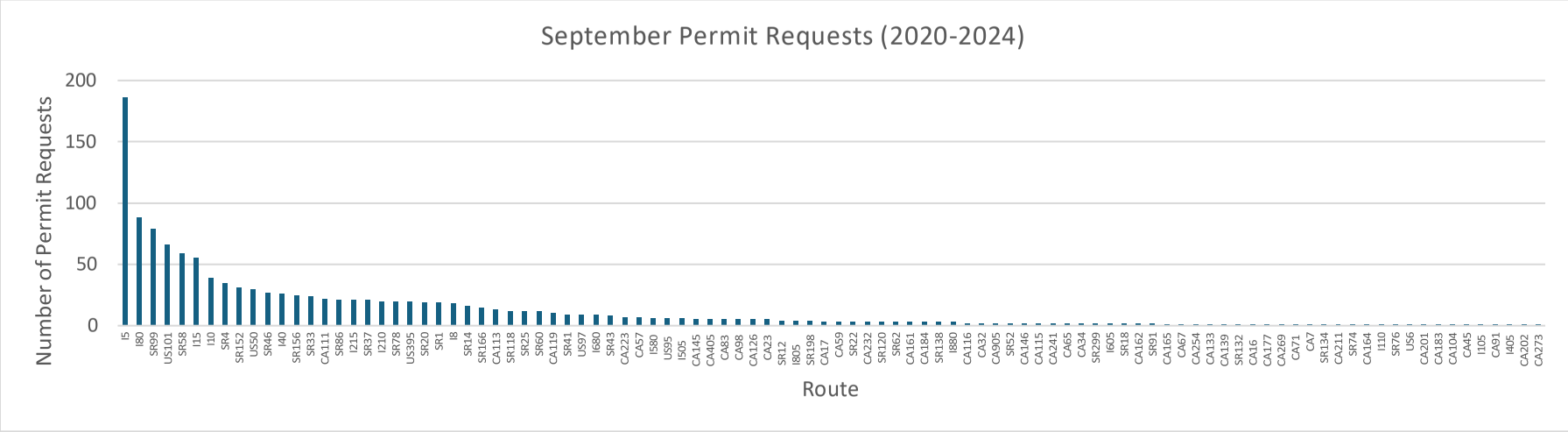


Figure 11i: Number of September permit requests for route usage by oversize/overweight farm vehicles

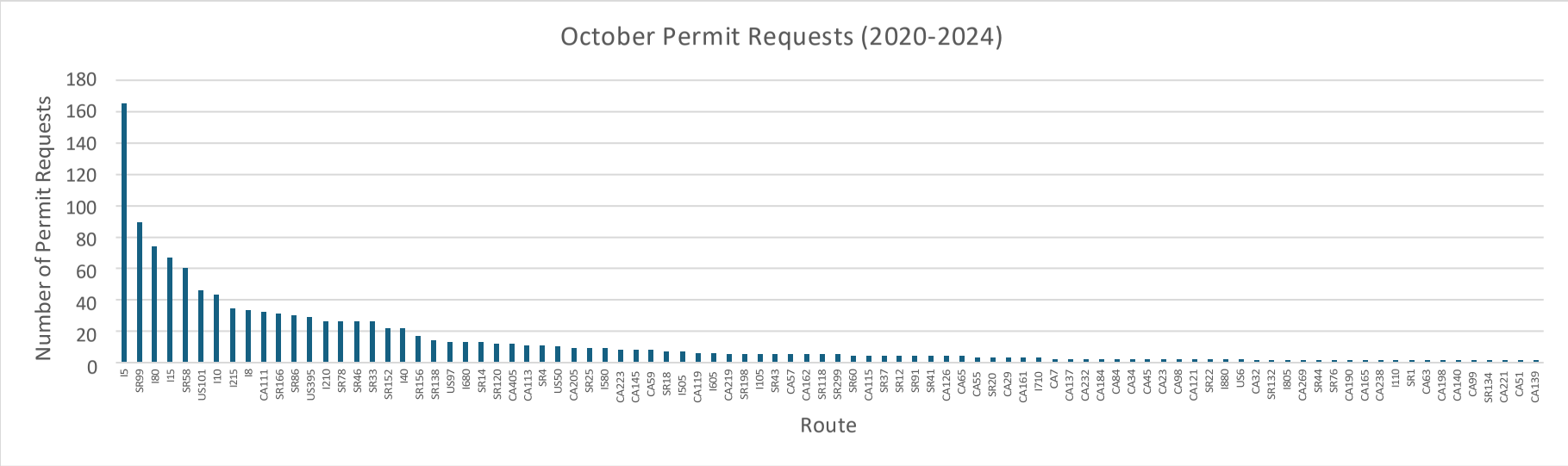


Figure 11j: Number of October permit requests for route usage by oversize/overweight farm vehicles

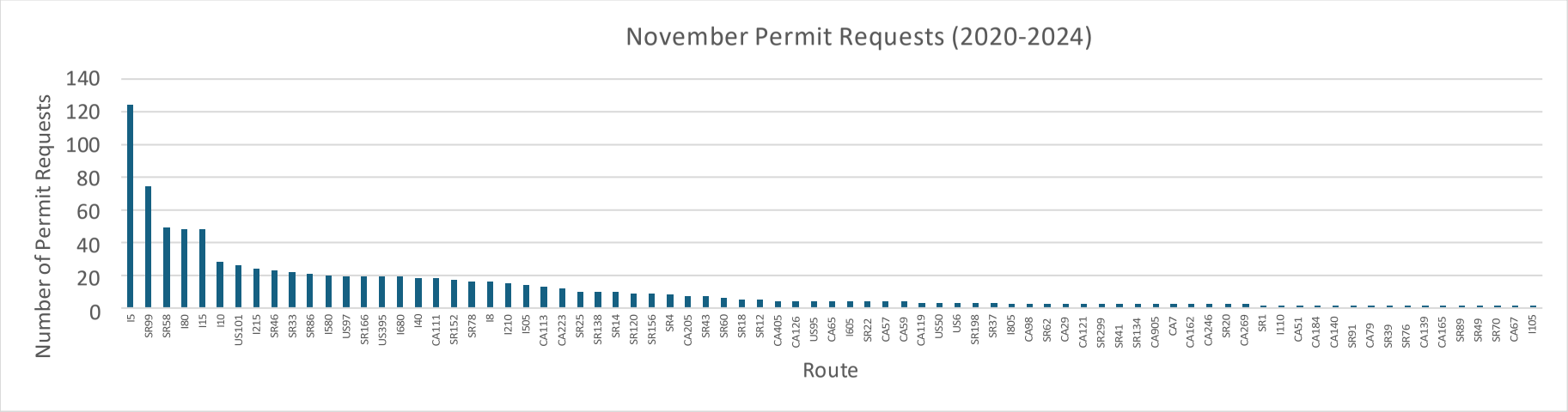


Figure 11k: Number of November permit requests for route usage by oversize/overweight farm vehicles

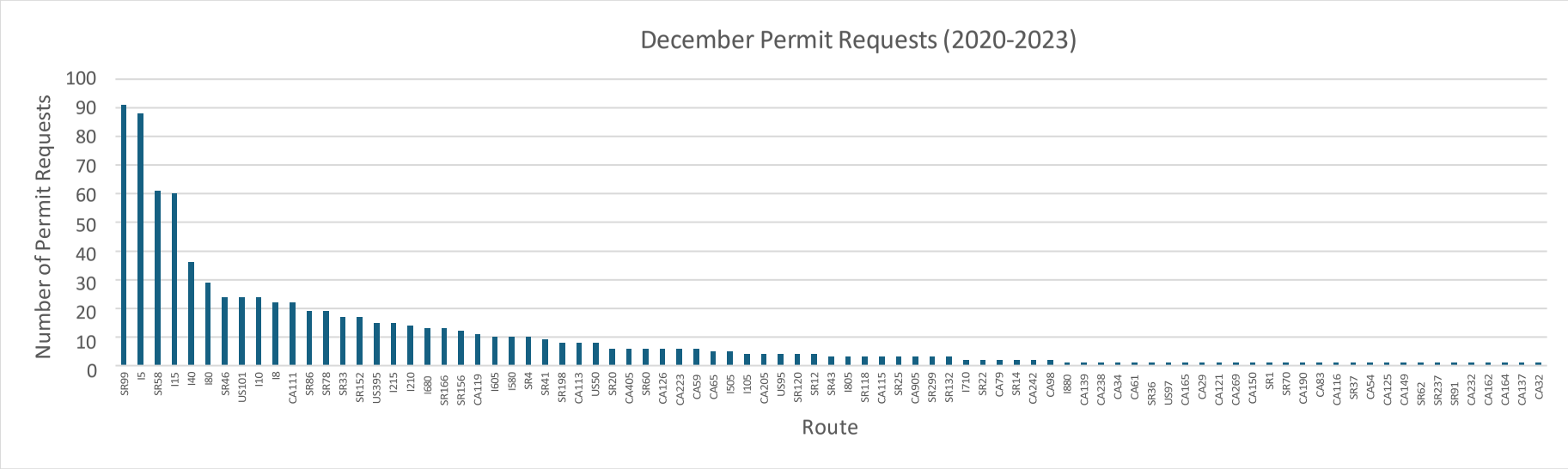


Figure 11l: Number of December permit requests for route usage by oversize/overweight farm vehicles

Further analysis shows that I-5, I-80, SR-99, I-15, and US-101 are the top five routes with the highest number of permit requests for oversize farm-related vehicles, as illustrated in Fig. 12 below. For overweight farm-related vehicle permits between 2020 and 2024, I-5, I-15, I-80, I-10, and SR-99 emerged as the top five routes (see Fig. 13).

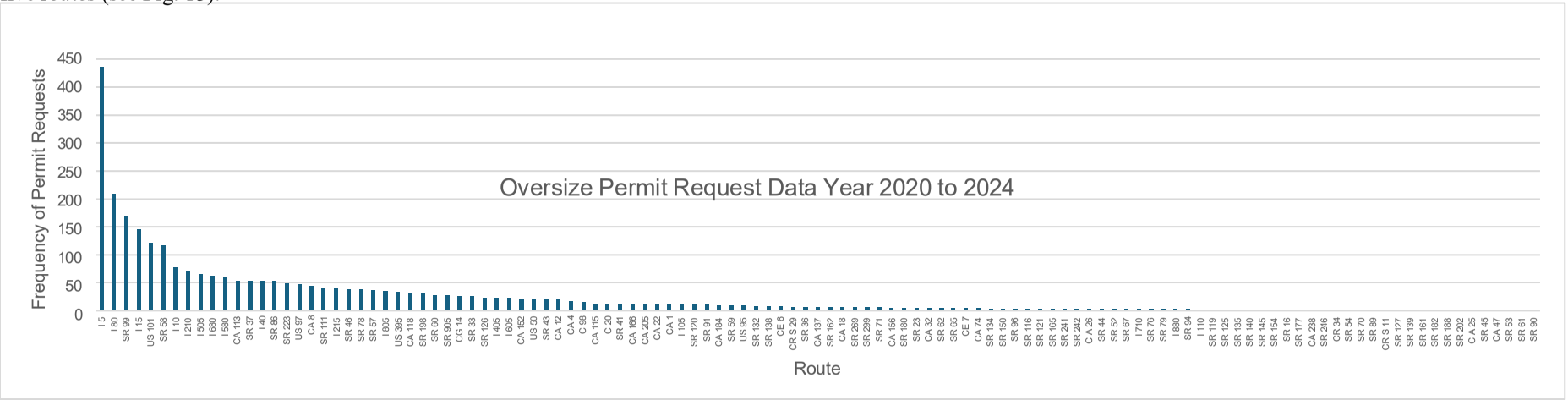


Figure 12: Number of permit requests for oversize farm-related vehicles

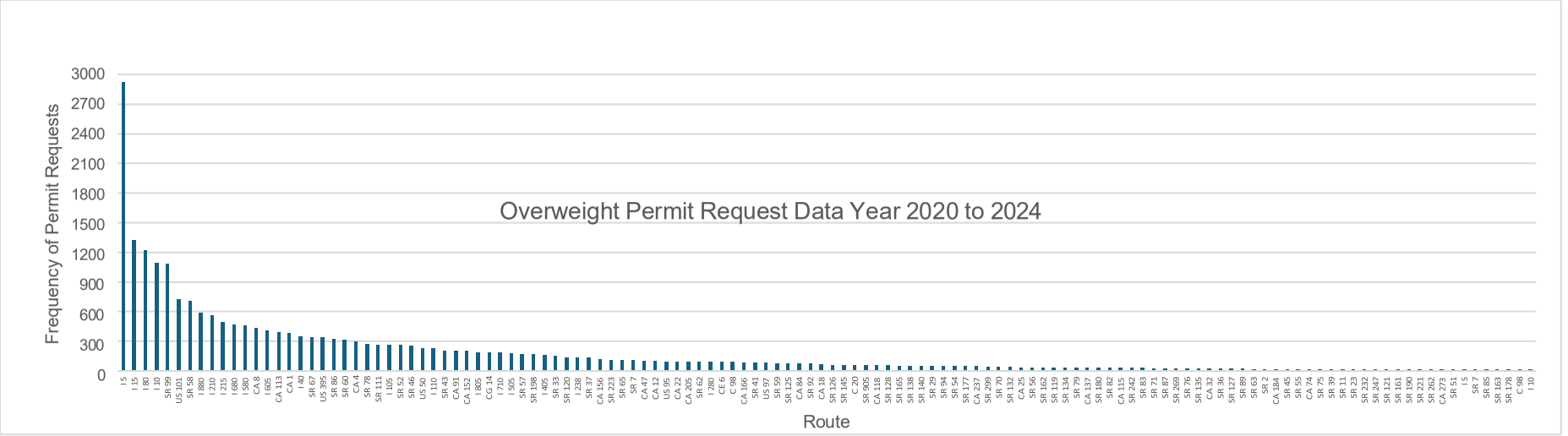


Figure 13: Number of permit requests for overweight farm-related vehicles

Critical Ramps for Oversize/Overweight Farm Vehicles

The table 5 below provides the top five frequencies of permit requests for oversized or overweight farm vehicles across various ramps and highways from 2020 to 2024. Each row in the table specifies a ramp and its associated highway, along with the annual frequency of permit requests. The Fairfax Rd S/B on-ramp SR-58E consistently appeared in earlier years (2020 and 2021), showing significant use in 2020 with 53 requests. Ramps such as Rohnert Park Expressway E/B on US-101S and Rowlee Rd ramps on I-5 feature prominently in multiple years, indicating their importance as critical routes. In later years (2023 and 2024), ramps like Lathrop Rd W/B on I-5N and Rohnert Park Expressway E/B on US-101S show higher frequencies, reflecting evolving traffic or operational priorities. Fig. 14 provides a spatial visualization of these ramps.

Table 5: Top-five frequency of permit requests for oversized/overweight farm vehicles across different ramps and highways

Year	Ramps of Authorized Highways	Frequency of Permit Requests
2020	FAIRFAX RD S/B ON RAMP SR-58E	53
	AVE `D` W/B ON RAMP SR-138W	11
	MT WHITNEY AVE E/B ON RAMP SR-145S	8
	ROHNERT PARK EXPRESSWAY E/B ON RAMP US 101S	8
	CATTLEMAN RD W/B ON RAMP US-101N	6
2021	FAIRFAX RD S/B ON RAMP SR-58W	11
	ROTH RD E/B ON RAMP I-5S	11
	7TH STANDARD RD E/B ON RAMP SR-99S	4
	COLLIER RD E/B ON RAMP SR 99N	4
	ROSAMOND BLVD E/B ON RAMP SR-14N	4
2022	ROHNERT PARK EXPRESSWAY E/B ON RAMP US-101S	11
	ROWLEE RD E/B ON RAMP I-5N	11
	ROWLEE RD W/B ON RAMP I-5N	11
	7TH ST W/B ON RAMP I-880S	7
	7TH STANDARD RD E/B ON RAMP SR-99S	7
2023	LATHROP RD W/B ON RAMP I-5N	13
	CHARTER WAY W/B ON RAMP I-5S	7
	LERDO HIGHWAY E/B ON RAMP I-5N	7
	SUTTERVILLE RD W/B ON RAMP I-5S	6
	TEMPLIN HIGHWAY E/B ON RAMP I-5S	4
2024	ROHNERT PARK EXPRESSWAY E/B ON RAMP US-101S	13
	BURNETT RD (NORTH) E/B ON RAMP SR-99S	5
	CO RD 33 W/B ON RAMP I-5S	5
	MATHEWS RD E/B ON RAMP I-5S	4
	OASIS RD W/B ON RAMP I-5N	4

Figure 14: Major ramps for oversize/overweight vehicle permit requests

Data Collection Concluding Remarks and Recommendations

While attempts were made to gather data through phone calls and emails, these efforts were unsuccessful, making in-person interviews the sole viable option for data collection. The stakeholders interviewed included truck drivers, safety managers and staff members at sawmills, totaling about 15 individuals. Through these interviews, the research team obtained insights on commodity movement and critical corridors and bridges supporting the agriculture supply chain in California.

The interviews highlighted that I-5 and SR 99 are essential highways for transporting agricultural produce, while US 101 plays a crucial role in the logging industry. However, information regarding the frequency and severity of past failures on these major agricultural corridors was limited due to inputs that were gathered from only a small number of stakeholders involved in the study.

To address these limitations, it is recommended that an extensive in-person data collection effort be conducted during the peak season for the transportation of specific agricultural commodities. This approach would enable the gathering of more comprehensive data on critical corridors and connections for the movement of agricultural goods.

Case Study: Identify, evaluate, and assess agricultural routes/intermodal connectors

An assessment to identify critical (key) corridors and intermodal connectors has been carried out using the Failure Mode and Effects Analysis (FMEA [59],[60]). The FMEA is a well-established methodology in supply chain failure analysis and applied to freight and transportation asset management plan for designing, constructing, and maintaining the heavy-vehicle agricultural network of California. The flowchart of the FMEA is presented below:

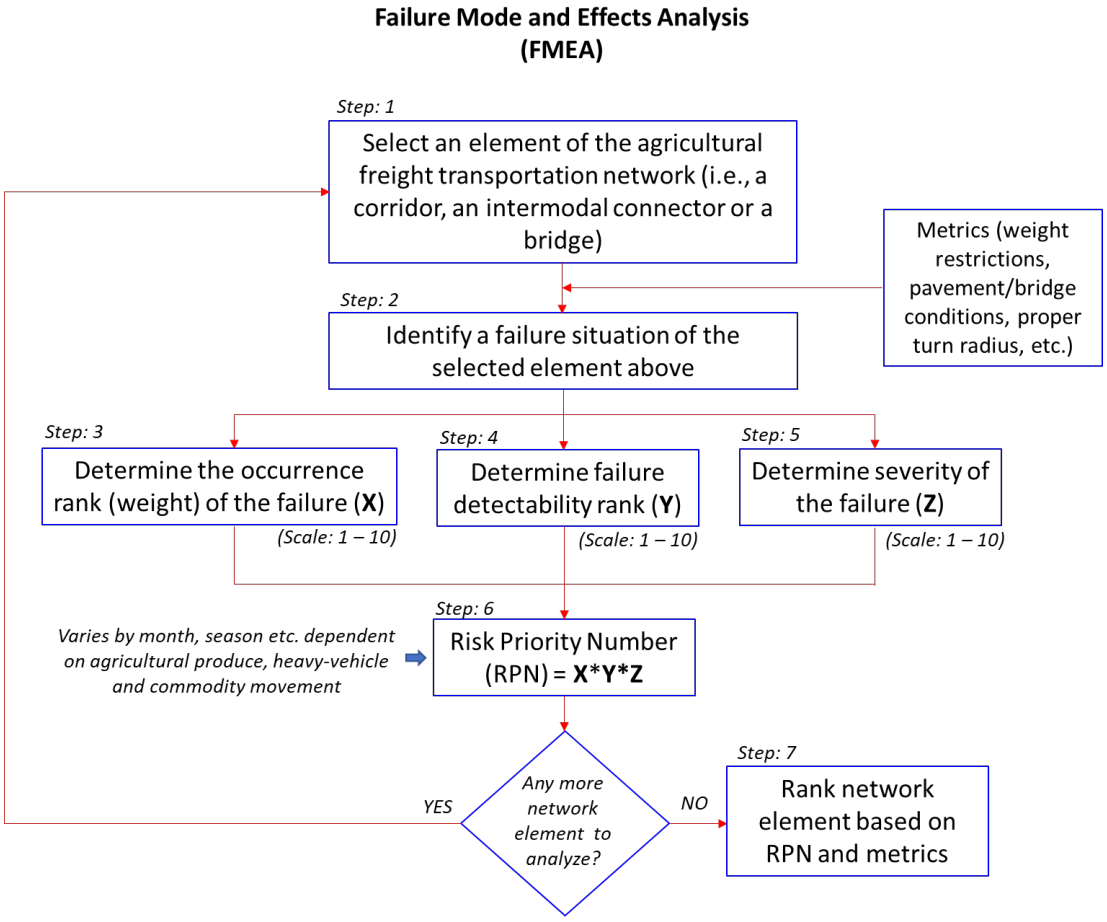


Figure 15: Flowchart for assessing critical (key) network components

The flowchart for FMEA shown above involves the use of various steps beginning with selecting a transportation network component (corridor, intermodal connector/facility or bridge) that facilitates movement of ag-related product, heavy equipment, etc., with the last step involving a list of network components ranked by risk priority number (RPN) – a product of the potential occurrence, detectability, and severity of the component failure.

With the information gathered using RPN, the primary components of the HVAN, namely, the ramps and bridges, in California have been identified.

A relatively high RPN indicates the element "failure" and the route on which the element is located is not suitable for heavy vehicles.

The goal of this part of this research was to identify, evaluate, and analyze key components of California's Heavy-Vehicle Agricultural Network (HVAN), including corridors, intermodal connectors, ramps, and bridges, which are critical for the safe and efficient transport of agricultural goods and heavy equipment. However, due to the lack of publicly available data on the role of intermodal connectors in agricultural freight truck movement, the analysis focused solely on ramps (linked to corridors) and bridges.

Risk Factor Evaluation using FEMA

Each component was assessed based on three risk factors - Occurrence, Detectability, and Severity - each scored on a scale of 1 to 10, as described below:

Occurrence (O)

This factor represents the likelihood of a component experiencing a failure condition. A score of 1 indicates a very low probability of failure, while a score of 10 signifies a high likelihood. Since all elements of the HVAN are assumed to have an equal probability of failure, the same occurrence score can be assigned to any component within the network. We assign an intermediate score of 5 for each component.

Detectability (D)

Detectability measures how easily failures can be identified upon their first occurrence. The scoring criteria differ for ramps and bridges:

For ramps: The detectability score is influenced by the number of permit requests by oversize/overweight farm vehicles. A higher number of permit-based ramp uses may lead to more frequent reports of potential ramp failures.

For bridges: The score is determined based on whether a bridge is already classified as being in poor condition. A structurally deficient bridge is considered more likely to be detected when it fails.

A score of 1 indicates the least likelihood of detecting a failure when it first occurs, while a score of 10 reflects immediate detection. Intermediate scores (ranging from 1 to 10) are assigned based on permit requests (for ramps) and the classification of bridges as poor along with their age. The oldest bridge with a poor rating is assigned a score of 10, whereas newer bridges receive proportionally lower scores.

Severity (S)

Severity reflects the impact of failure, with scores assigned based on the number of farm vehicle trips affected.

For ramps: The severity score is determined using the volume of agriculture-related (farm and logging) vehicle trips on the major roadway (truck route) to which the ramp connects.

For bridges: The score is based on the volume of agriculture-related vehicle trips on the roadway segment where the bridge is located.
A higher number of truck trips carrying farm products indicates a greater severity, resulting in a score closer to 10. A score of 10 is assigned to the component experiencing the highest volume of agricultural truck trips within the HVAN, while other components receive proportionally lower scores based on their truck traffic. Components with the lowest agricultural truck trips receive a score of 1, indicating minimal severity.

Calculation of Risk Priority Number (RPN)

The Risk Priority Number (RPN) for each network component is determined by multiplying the scores assigned to Occurrence (O), Detectability (D), and Severity (S):

$$RPN = 0 \times D \times S$$

Prioritization and Strategy Development

Once the RPN values are calculated for all network components, they are ranked accordingly. Higher RPN values indicate the most critical or vulnerable elements within the HVAN. Based on these rankings, strategic recommendations and performance metrics can be developed to enhance the design, construction, and maintenance of HVAN infrastructure.

Results

Risk Priority Numbers for On/off ramp Components

The map in Fig. 16 illustrates the RPN distribution for ramp-based corridors, using 2024 data from Caltrans on oversize/overweight farm vehicle movements. The RPN calculation for each ramp was integrated into the corresponding corridor it connects to. The map highlights the top five ramps with the highest frequency of oversize/overweight vehicle permit use and major agricultural corridors within the HVAN. Due to the large number of ramps associated with these permit requests, only those that ranked high in usage by oversize/overweight farm vehicles are displayed.

Notably, the major highways such as I-5, SR-99, and US-101 received the highest ramp-based RPN distribution, indicating their critical role in supporting the movement of oversize/overweight farm-related vehicles.

The chart in Fig. 17 illustrates the Risk Priority Numbers (RPN) for on/off ramp components associated with corridors designated for oversize/overweight vehicle permits across California. Certain corridors exhibit significantly higher RPN values compared to others, indicating a greater risk level for their on/off ramps. I-5, SR-99, US 101 and I-10 appear to have the highest RPN values, suggesting that ramps along these corridors experience heavy use by farm-related oversize/overweight vehicles and may be more vulnerable to structural or operational issues.

Figure 16: Spatial distribution of Risk Priority Numbers for on/off ramp components linked to corridors designated for oversize/overweight vehicle permits

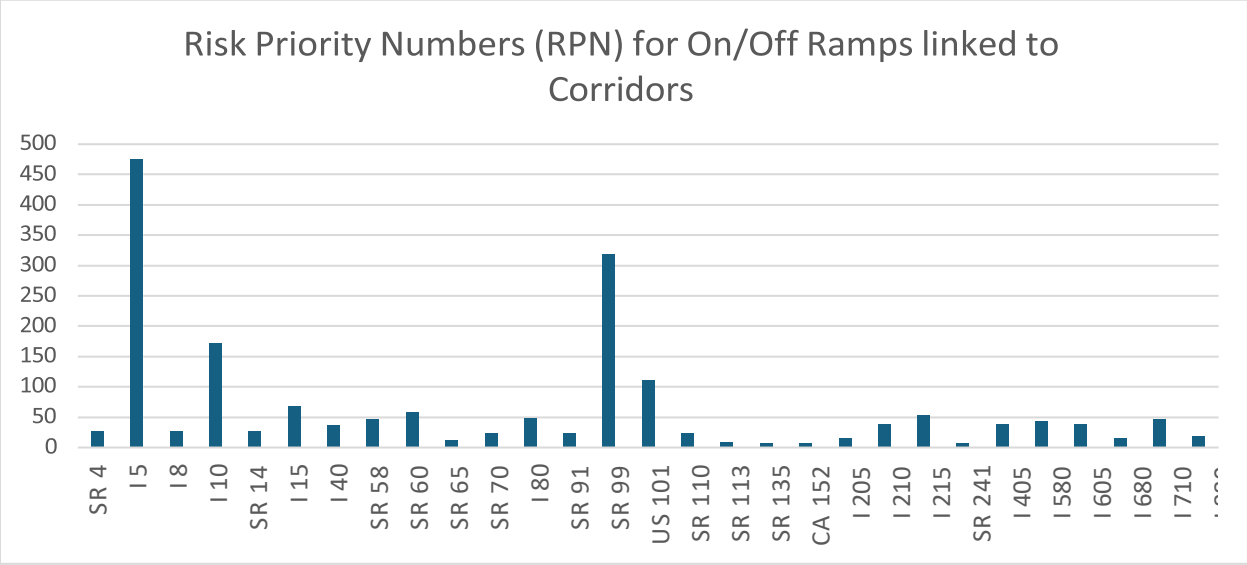


Figure 17: Risk Priority Number for on/off ramp components linked to corridors designated for oversize/overweight vehicle permits

Risk Priority Number (RPN) for Bridges

Farm Truck Trips: The spatial locations of bridges were obtained from the National Bridge Inventory dataset as of June 27, 2024, provided by the Federal Highway Administration (FHWA) 61. This dataset includes information on over 615,000 bridges across the United States, spanning public roads, Interstate Highways, U.S. highways, state and county roads, as well as publicly accessible bridges on Federal and Tribal lands.

Among these, 443 bridges on freight truck routes frequently used for farm-related trips in California were reported to be in poor condition. Similarly, approximately 210 bridges in poor condition were identified on freight routes primarily used by logging trucks.

The map in Fig. 18 illustrates the RPN distribution for bridges in poor condition that support farm truck trips across California. The distribution of RPN values is not uniform across the state; however, the highest RPN bridges tend to be concentrated along major agricultural freight corridors, including I-5 and SR-99, which experience significant farm truck traffic.

Bridges in poor condition with elevated RPN values are clustered along these key corridors, indicating a higher risk level due to factors such as heavy truck traffic and deteriorating bridge conditions. Consequently, corridors with high bridge RPNs face greater vulnerability.

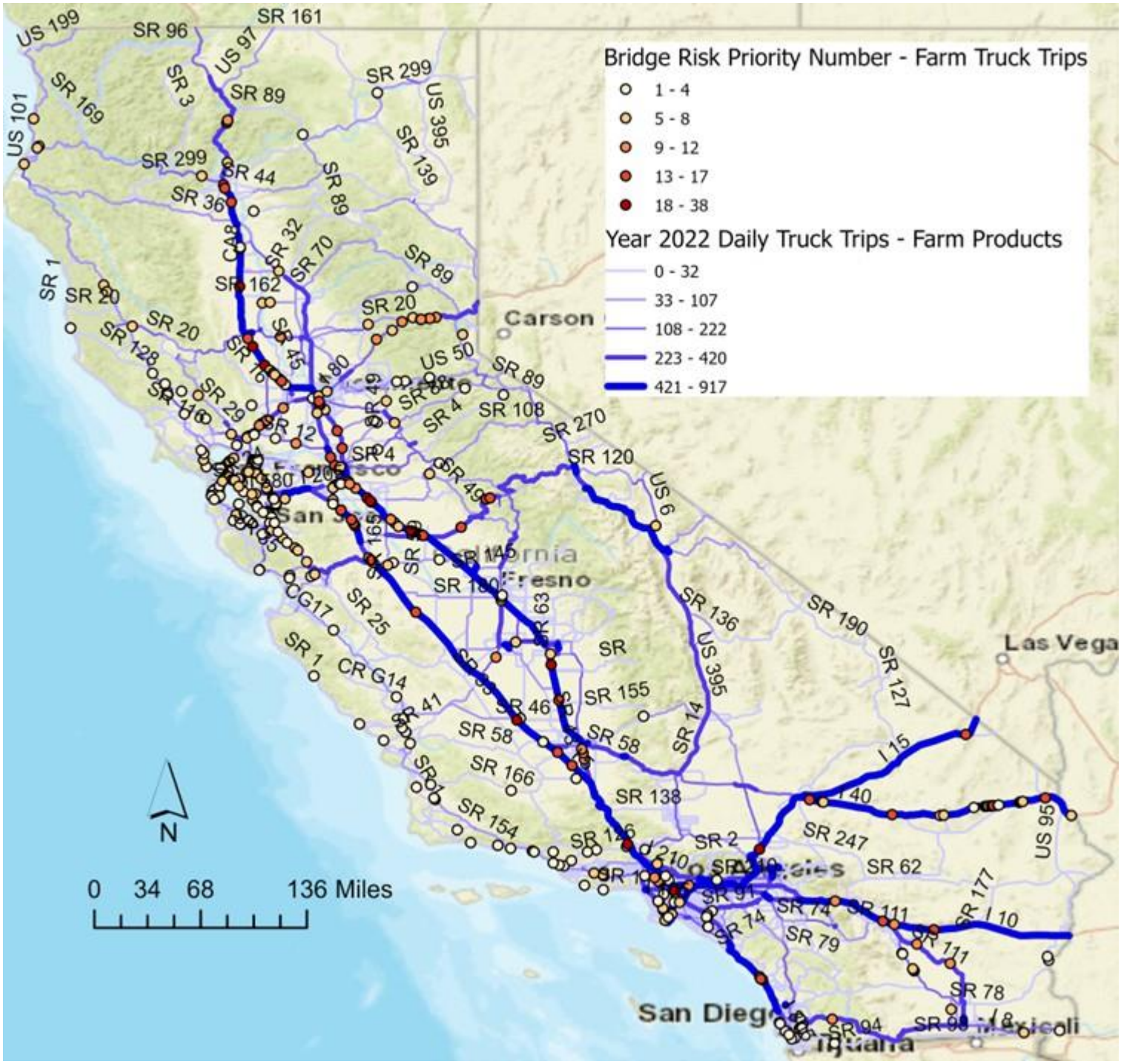


Figure 18: Spatial distribution of critical bridges across farm routes

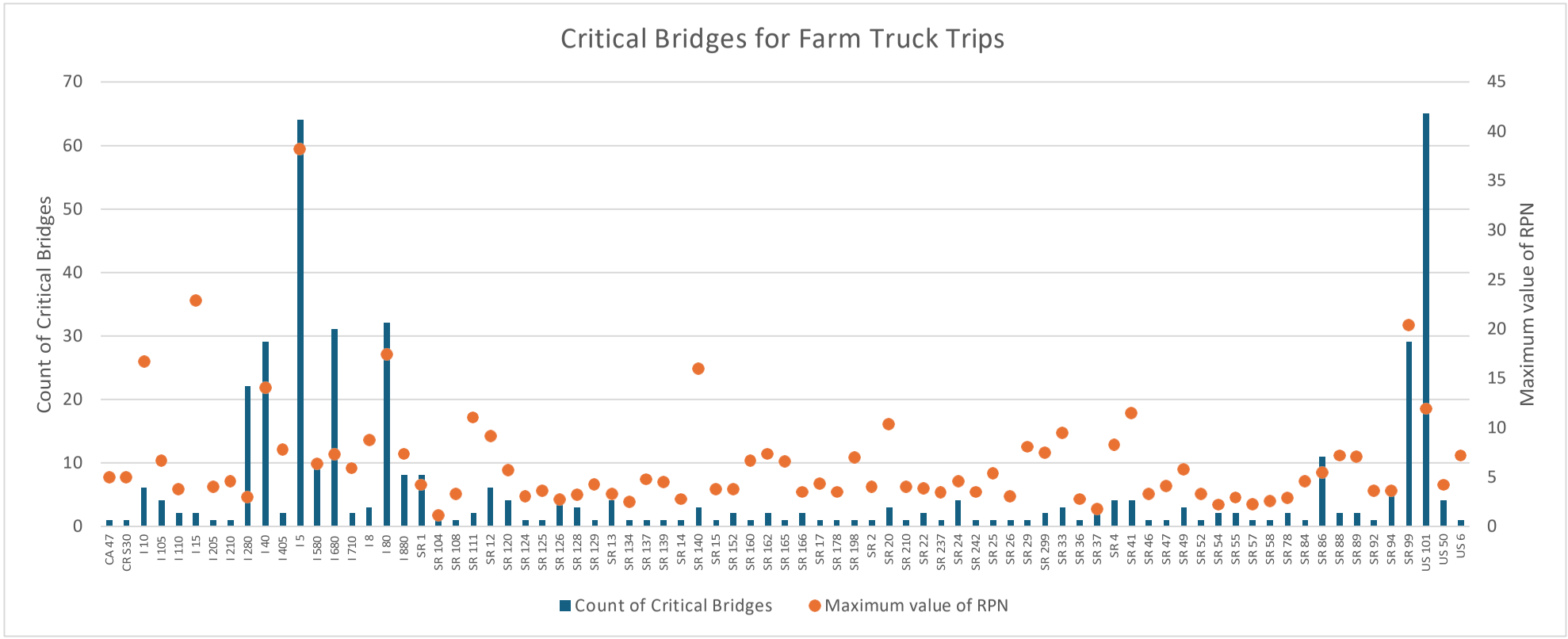


Figure 19: Distribution of critical bridges (based on RPN) across farm truck routes

The chart in Fig. 19 highlights 79 unique farm vehicle routes across California, emphasizing critical bridges along these routes. The accompanying table provides details on the number of critical bridges per route and their corresponding Risk Priority Number (RPN), which quantifies the risk level associated with each bridge - higher RPN values indicate greater risk. The following are the key findings:

- The average number of critical bridges per route is approximately 6.
- The minimum number of critical bridges on a route is 1, while the maximum is 65.
- Most routes have relatively few critical bridges, with a median value of 2.
- The top 25% of routes contain at least 4 critical bridges.
- US 101 has the highest number of critical bridges, with a total of 65.

The average maximum RPN of 6 per route suggests a moderate risk level across the network. However, the highest recorded RPN is 38, observed on I-5 in Los Angeles County, making it the most at-risk route.

Logging Truck Trips: The map in Fig. 20 presents the spatial distribution of Risk Priority Numbers (RPNs) for bridges in poor condition along various logging truck routes in California. Bridges with higher RPN values are concentrated in specific geographic regions, particularly in Northern California's mountainous terrain. This clustering suggests that factors such as high volumes of logging truck traffic, environmental stress, and aging infrastructure may contribute to the elevated risk of structural failure along these routes.

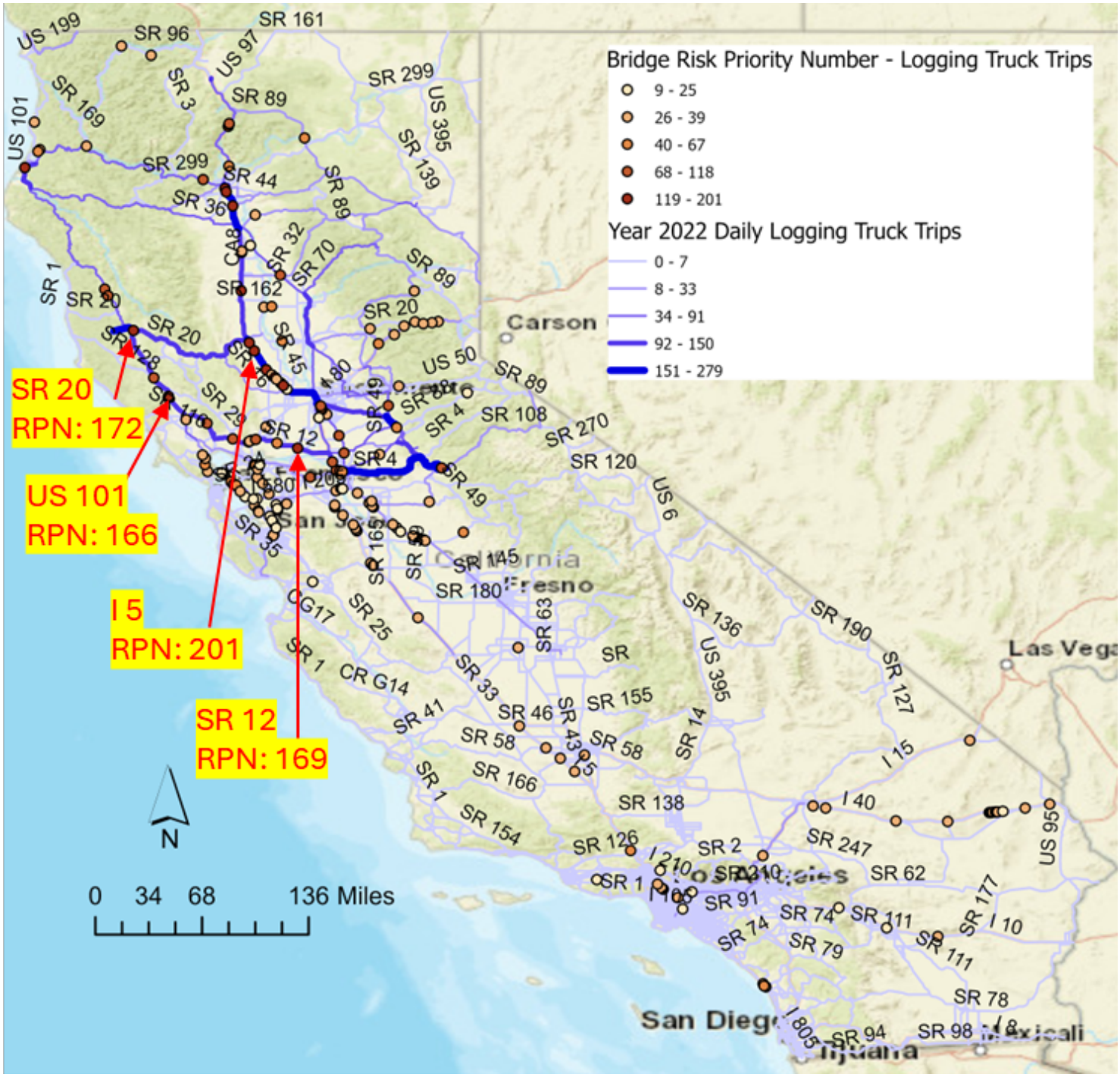


Figure 20: Spatial distribution of critical bridges with RPN for the logging trucks

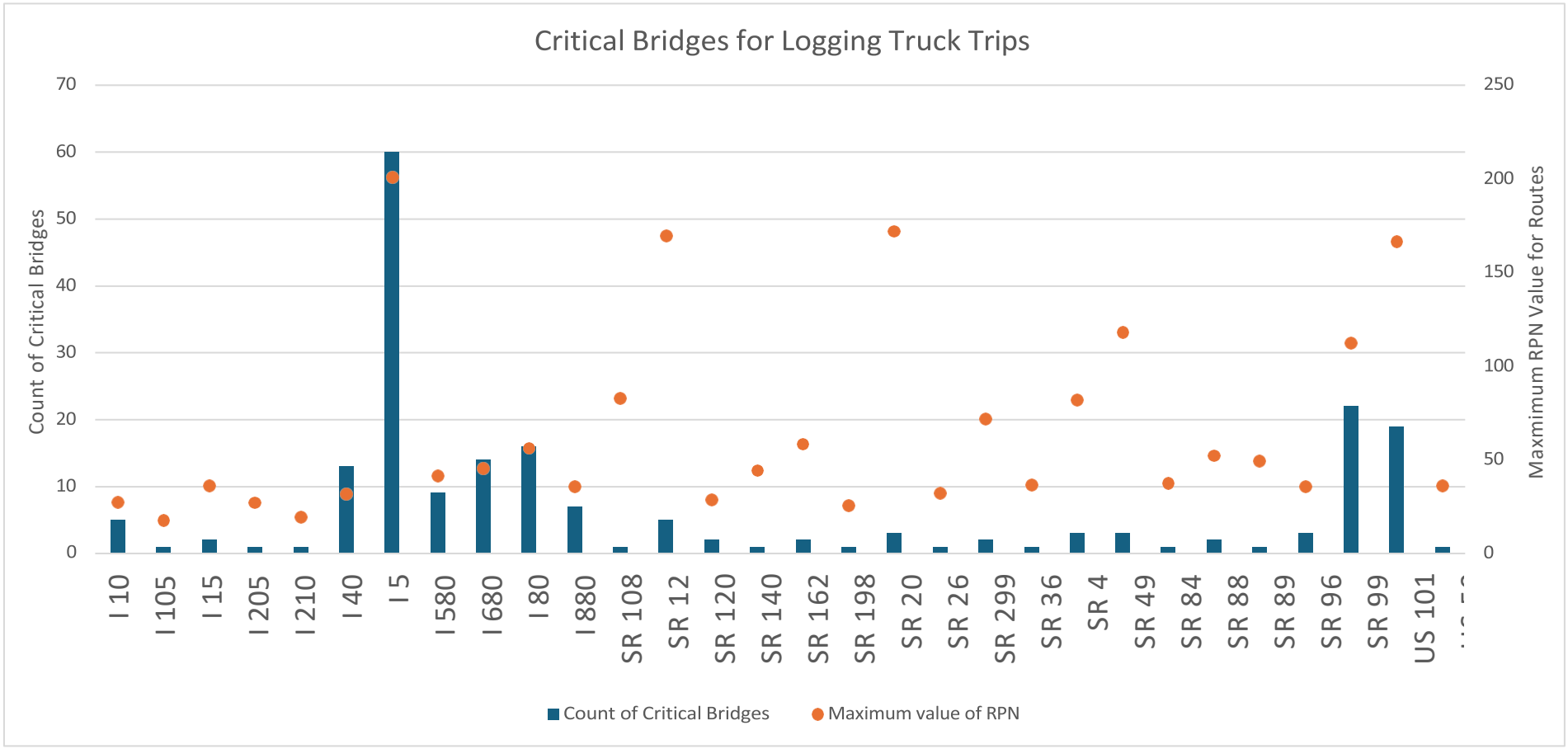


Figure 21: Distribution of critical bridges (based on RPN) across logging truck routes

The chart in Fig. 21 indicates that the average number of critical bridges per logging truck route is approximately 7, suggesting that most routes contain at least a few high-risk structures. The minimum number of critical bridges on any route is 1, while the maximum is 60. The I-5 corridor has the highest number of critical bridges (60), making it a key area for risk assessment and infrastructure management for logging truck routes.

RPN for the bridges are calculated relative to each other. The average maximum (relative) RPN per route is 65, which is notably higher than that observed for farm truck routes. The lowest recorded maximum RPN is 17, which, despite being the lowest, still represents a considerable level of risk. The highest recorded RPN is 201, observed along I-5 in Colusa County, identifying it as the most at-risk route for logging trucks. The highest RPNs for other at-risk routes on SR 20 is 172 (in Mendocino County), SR 12 is 169 (in Solano County), and US 101 is 166 (in Sonoma County).

A total of 13 bridges along US 101 in Northern California were identified as critical, with RPN values ranging from 24 to 166. One of these key bridge locations is highlighted in the map in Fig. 21, based on previous data collection efforts on logging truck movements.

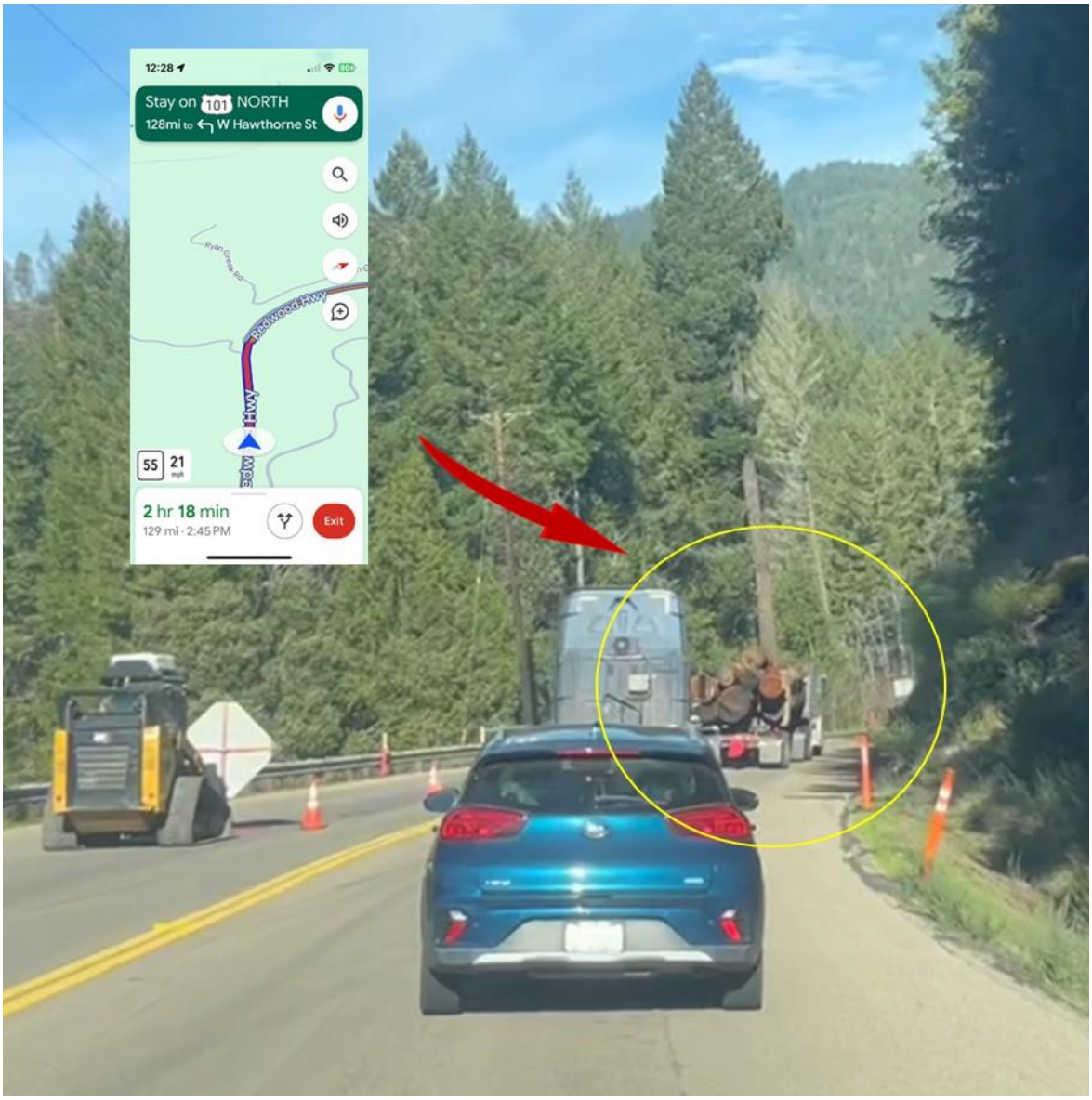


Figure 22: Logging truck passing through the work zone on US 101

It is notable that one of the critical bridges on US 101, with an RPN of 109, is currently under maintenance by Caltrans (Source: QuickMap app). The screenshot in Fig. 23 displays its spatial location on our bridge RPN map for US 101 along with its ongoing maintenance status. This alignment further validates our risk assessment approach.

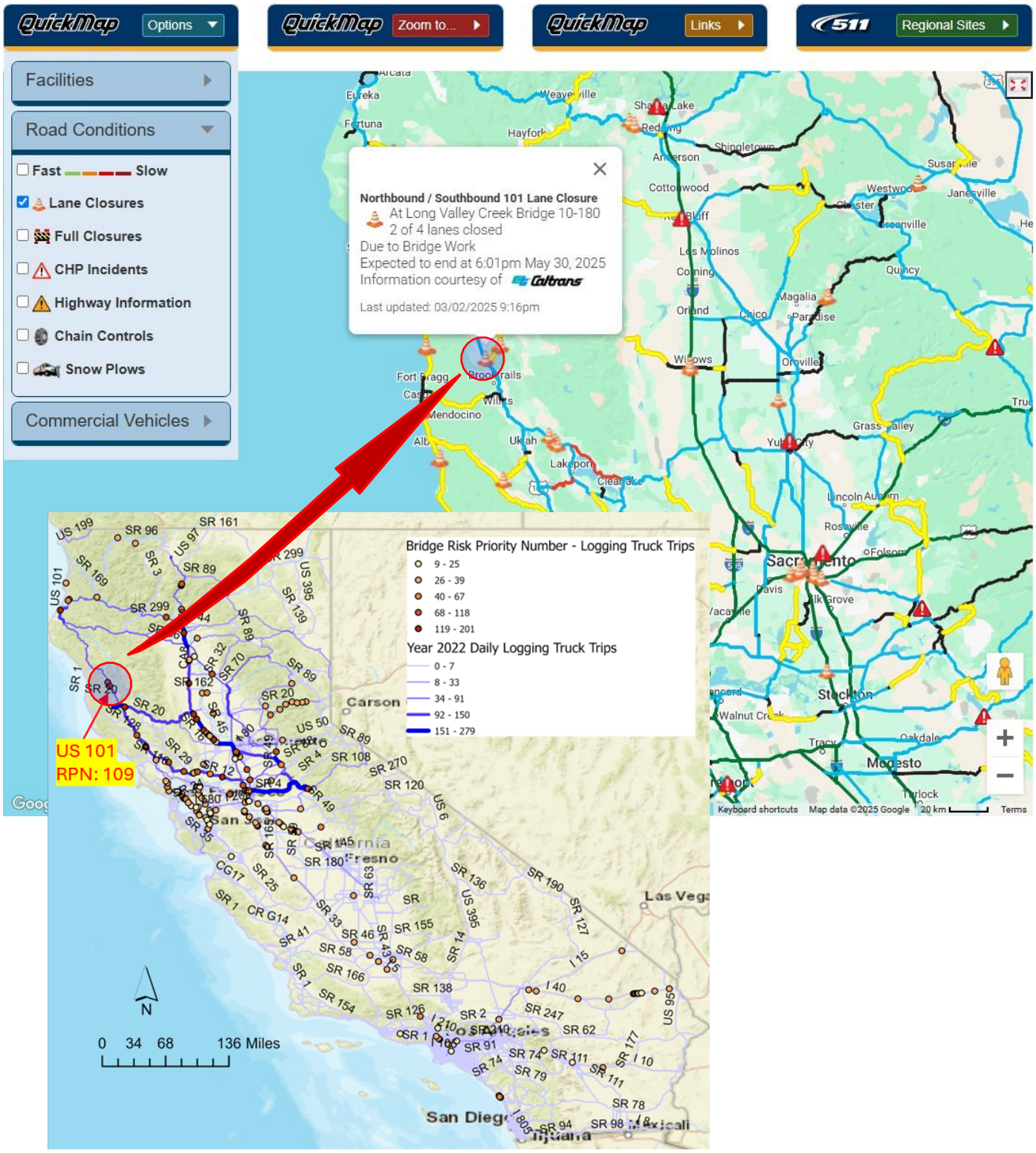


Figure 23: Critical bridge with RPN 109 on US 101 with on-going maintenance work (Source: QuickMap, Caltrans)

Case Study: Concluding Remarks

This study evaluates California's Heavy-Vehicle Agricultural Network (HVAN) using a Failure Mode and Effects Analysis (FMEA) framework to assess key transportation elements, namely ramps and bridges. By analyzing risk factors- Occurrence, Detectability, and Severity- the research computes a Risk Priority Number (RPN) for each component, thereby highlighting network vulnerabilities of agriculture supply chain in California – especially, for farm products and logging industry.

The spatial distribution of RPNs across major corridors such as I-5, US 101, and SR-99 is supported by data from Caltrans on oversize/overweight vehicle permits and the National Bridge Inventory on bridge conditions. This analysis not only identifies corridors with high-risk infrastructure but also highlights specific HVAN locations, such as on/off ramps and bridges with high RPNs, that require targeted maintenance and strategic improvements.

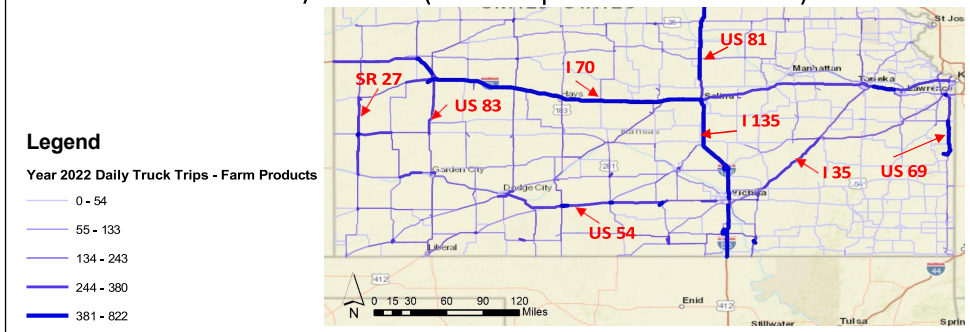
Future research could expand on this case study by incorporating several additional dimensions. For instance, future studies might include intermodal connectors once more comprehensive data become available, allowing for a more holistic assessment of the entire network. Moreover, integrating temporal dynamics- such as seasonal variations in traffic patterns and climate change impacts - could offer deeper insights into the evolving vulnerabilities of infrastructure, especially for the logging trucks and oversize/overweight farm-related vehicles. Advanced predictive modeling techniques, including machine learning algorithms, could also be employed to forecast potential failure scenarios and prioritize maintenance more effectively.

Appendix A

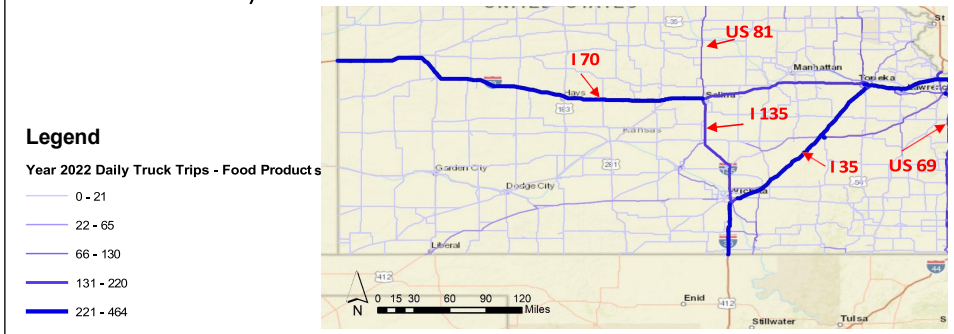
Spatial Distribution of Agricultural Product Movement: The maps below show estimated year 2022 freight analysis framework (FAF) truck trips – transported by all trucks in various states (Data Source: FAF Highway Assignment Results, 2022[62]). The truck trips were found to be correlated to the commodity tonnage.

Kansas

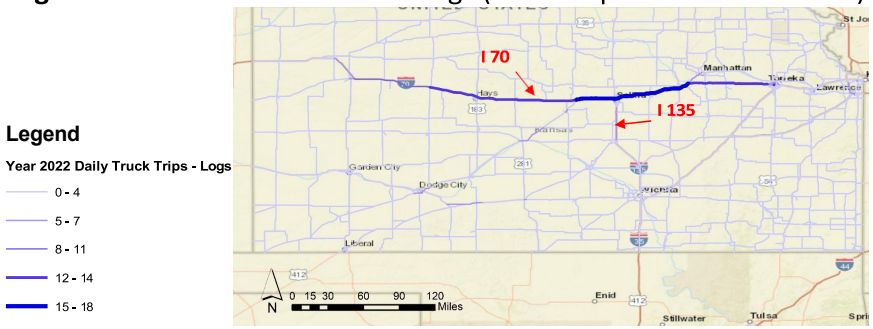
Farm Products: Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood (Truck Trips in Both Directions)



Food Products: Milled grain products, other foodstuOs, etc. (Truck Trips in Both Directions)

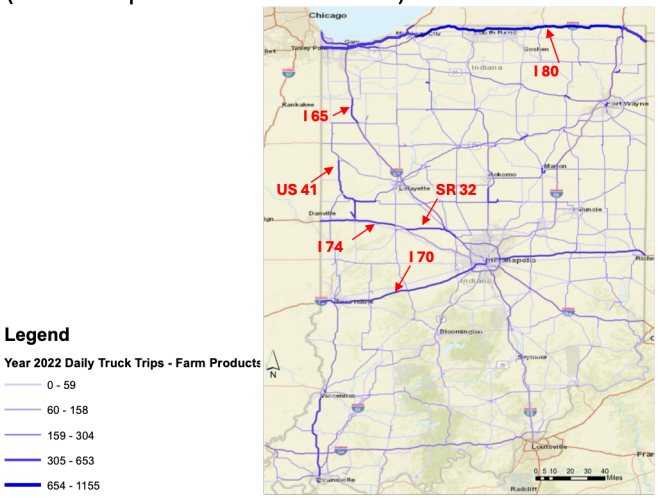


Logs and Other Wood Products: Logs (Truck Trips in Both Directions)

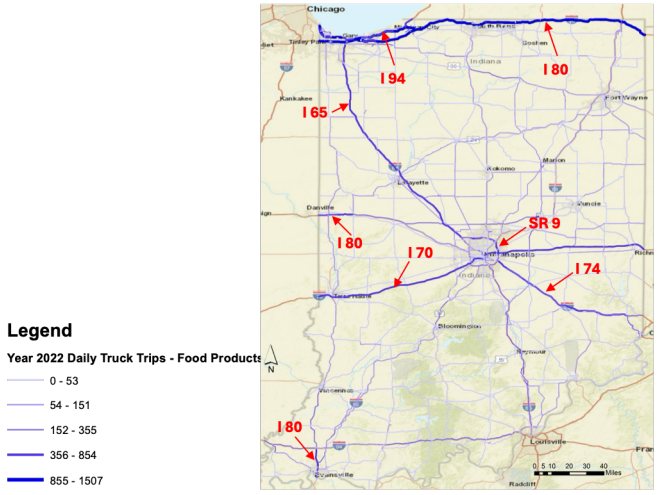


Indiana

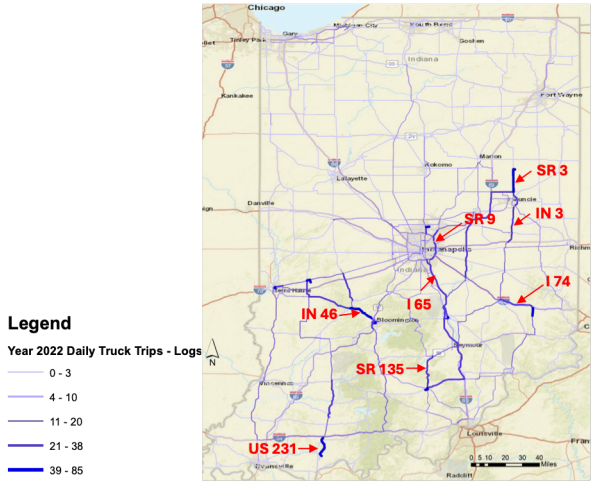
Farm Products: Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood (Truck Trips in Both Directions)



Food Products: Milled grain products, other foodstuOs, etc. (Truck Trips in Both Directions)

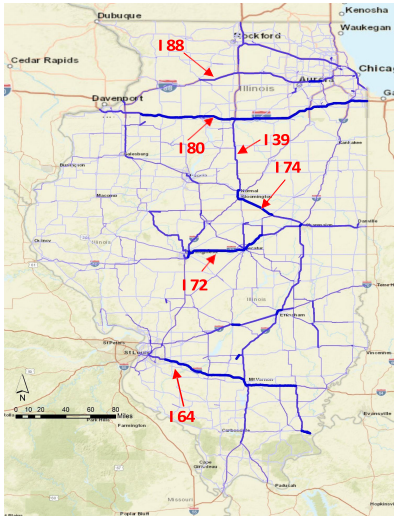


Logs and Other Wood Products: Logs (Truck Trips in Both Directions)



Illinois

Farm Products: Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood (Truck Trips in Both Directions)

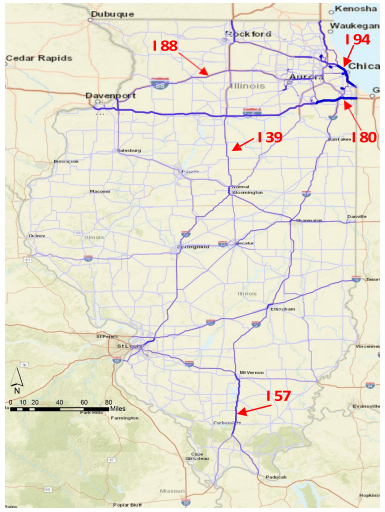


Legend

Year 2022 Daily Truck Trips - Farm Products

- 0 - 112
- 113 - 291
- 292 - 525
- 526 - 952
- 953 - 2683

Food Products: Milled grain products, other foodstuOs, etc. (Truck Trips in Both Directions)

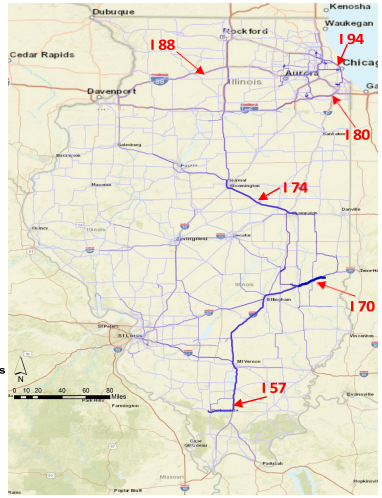


Legend

Year 2022 Daily Truck Trips - Food Products

- 0 - 119
- 120 - 331
- 332 - 620
- 621 - 1068
- 1069 - 1660

Logs and Other Wood Products: Logs (Truck Trips in Both Directions)



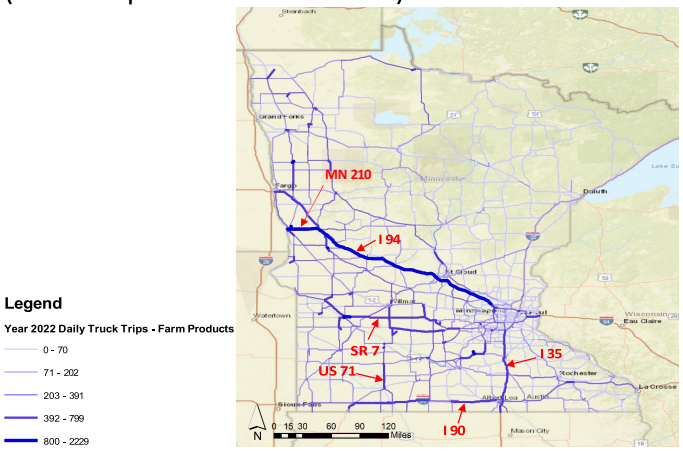
Legend

Year 2022 Daily Truck Trips - Logs

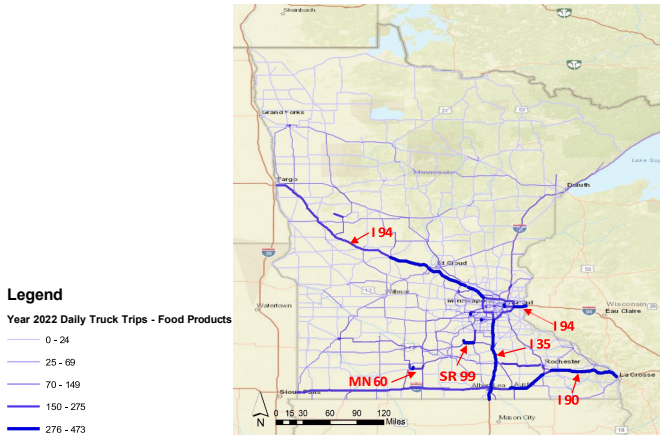
- 0 - 2
- 3 - 6
- 7 - 15
- 16 - 41
- 42 - 98

Minnesota

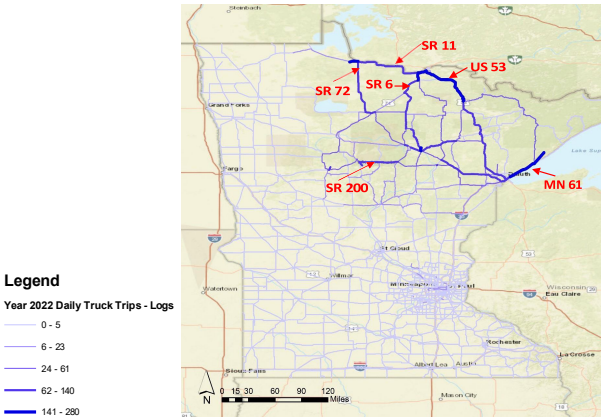
Farm Products: Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood (Truck Trips in Both Directions)



Food Products: Milled grain products, other foodstuOs, etc. (Truck Trips in Both Directions)

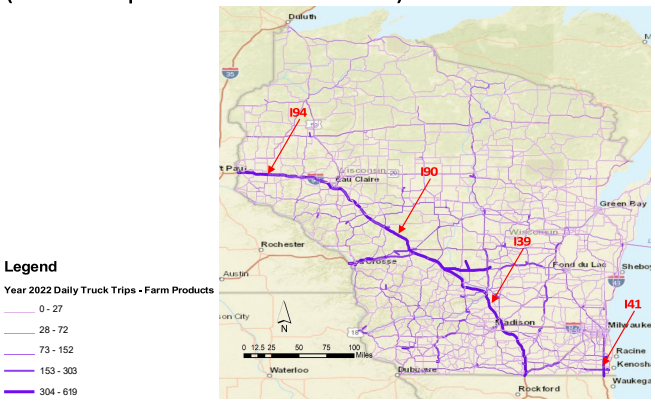


Logs and Other Wood Products: Logs (Truck Trips in Both Directions)

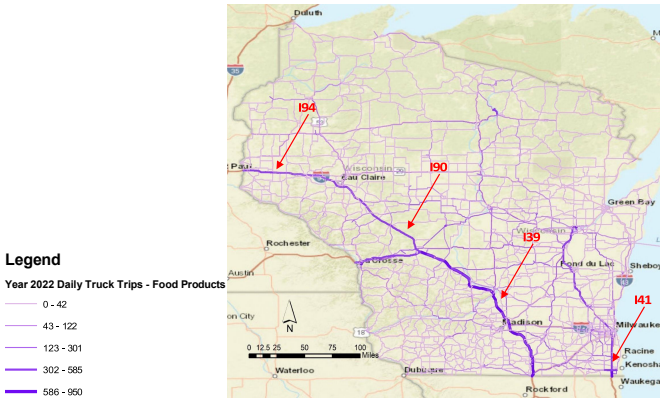


Wisconsin

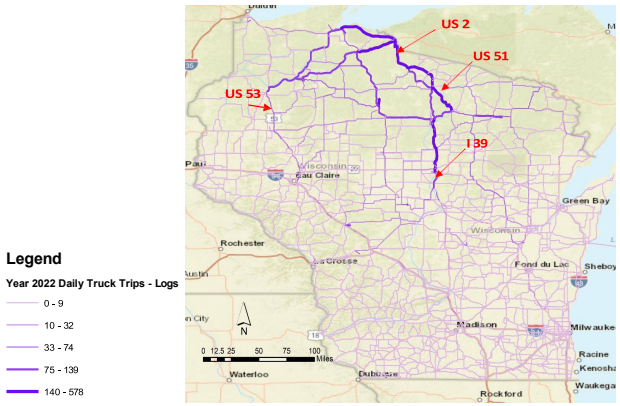
Farm Products: Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood (Truck Trips in Both Directions)



Food Products: Milled grain products, other foodstuOs, etc. (Truck Trips in Both Directions)

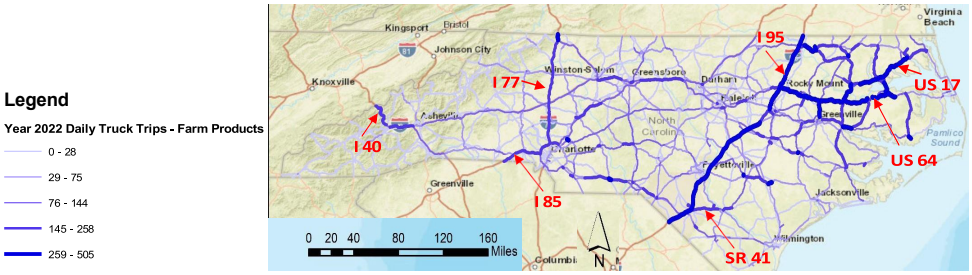


Logs and Other Wood Products: Logs (Truck Trips in Both Directions)



North Carolina

Farm Products: Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood (Truck Trips in Both Directions)



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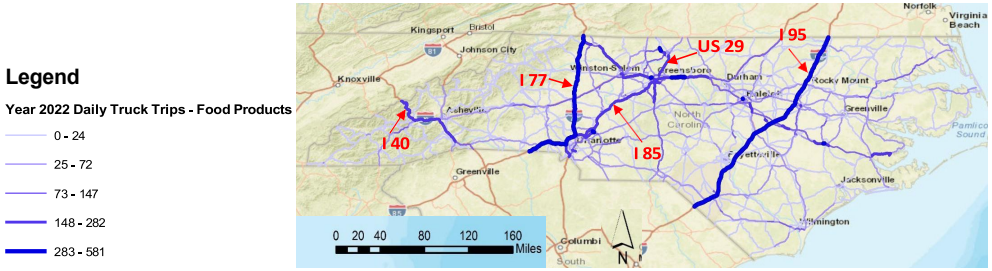
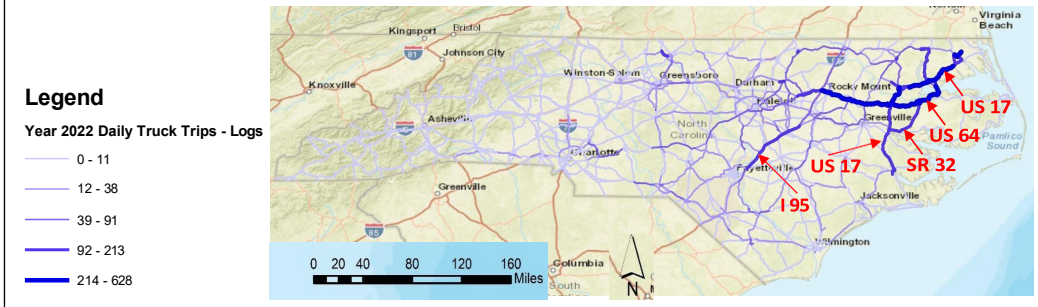
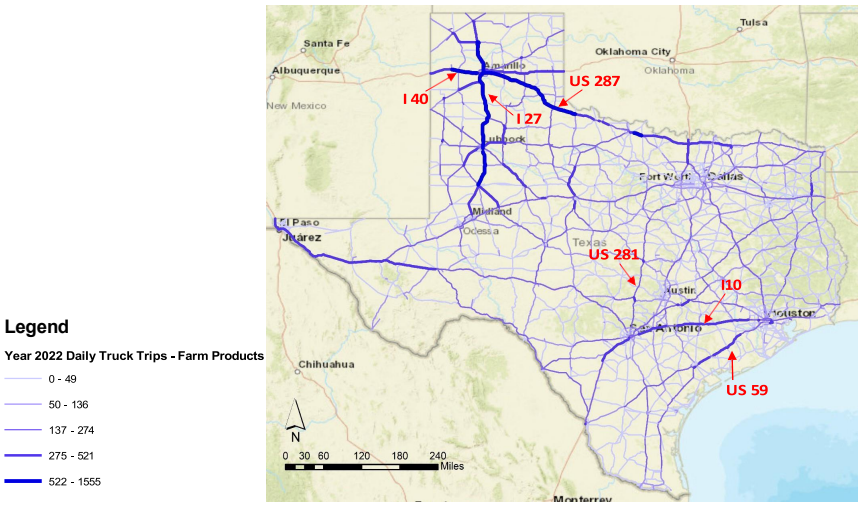


Logs and Other Wood Products: Logs (Truck Trips in Both Directions)

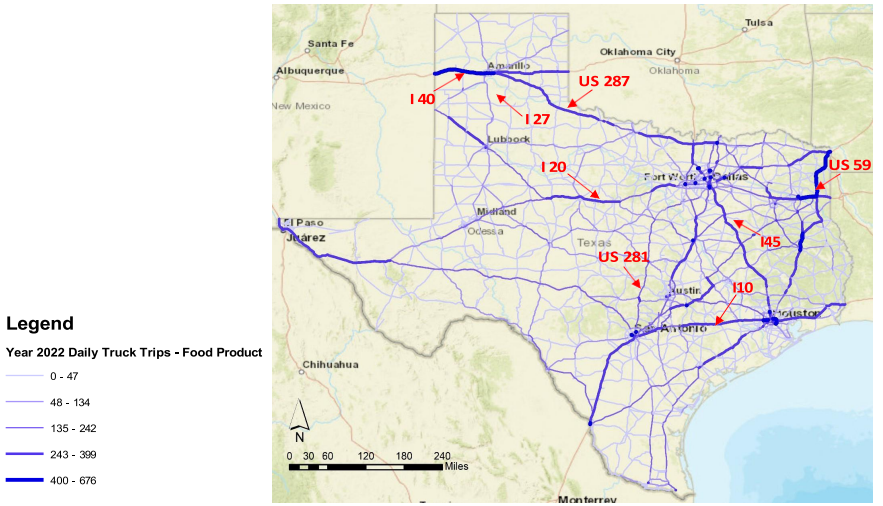


Texas

Farm Products: Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood (Truck Trips in Both Directions)



Food Products: Milled grain products, other foodstuOs, etc. (Truck Trips in Both Directions)



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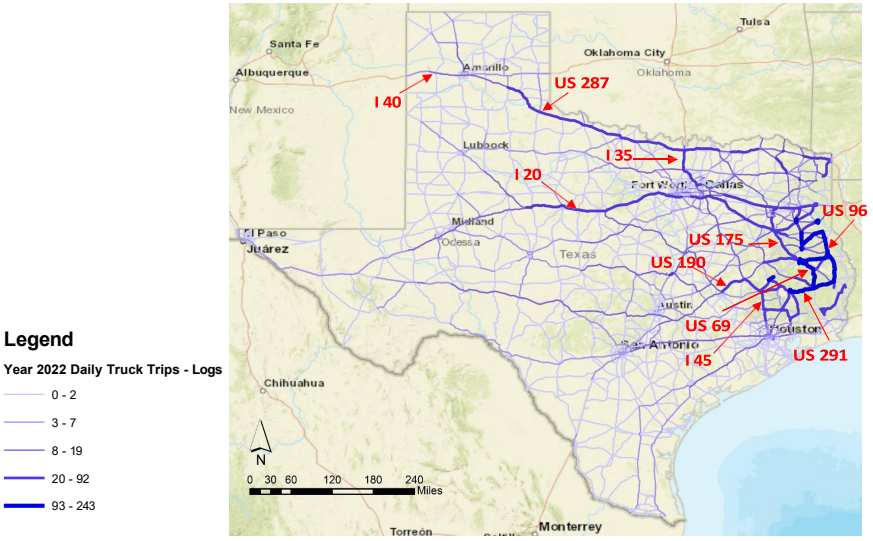
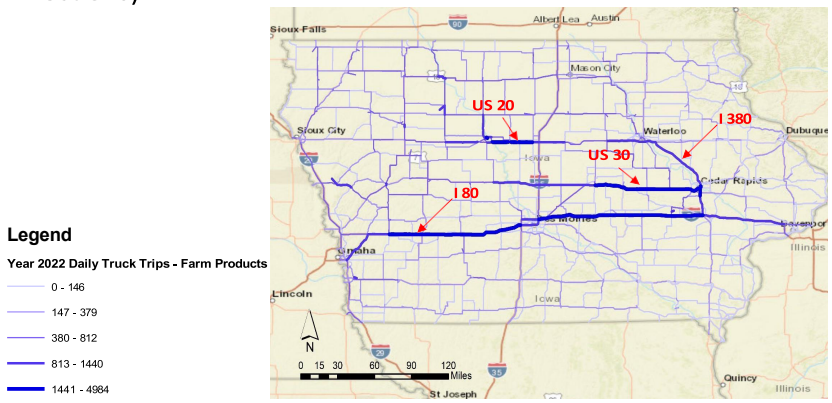
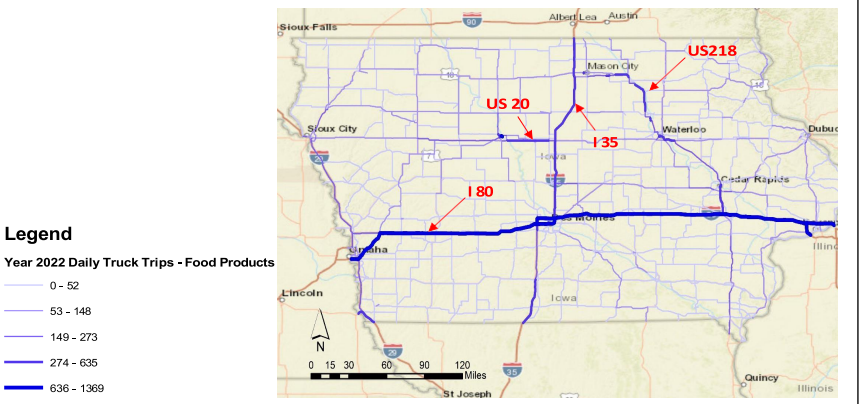


Iowa

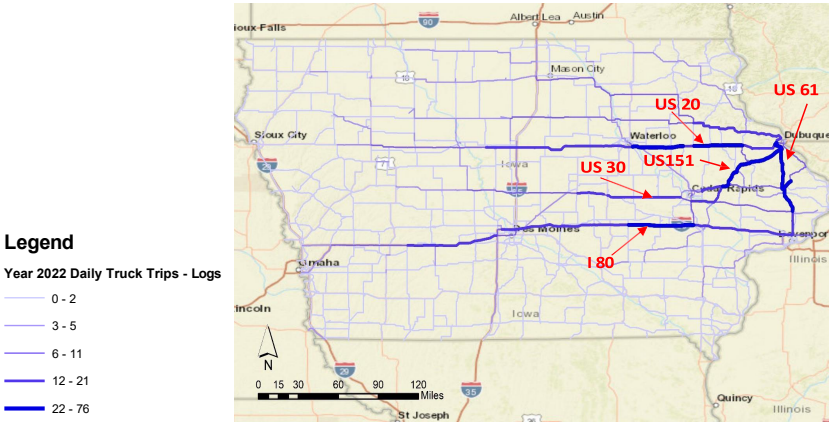
Farm Products: Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood (Truck Trips in Both Directions)



Food Products: Milled grain products, other foodstuOs, etc. (Truck Trips in Both Directions)

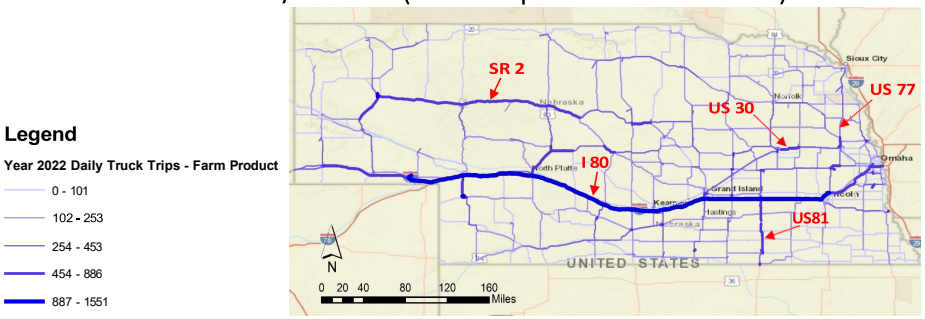


Logs and Other Wood Products: Logs (Truck Trips in Both Directions)

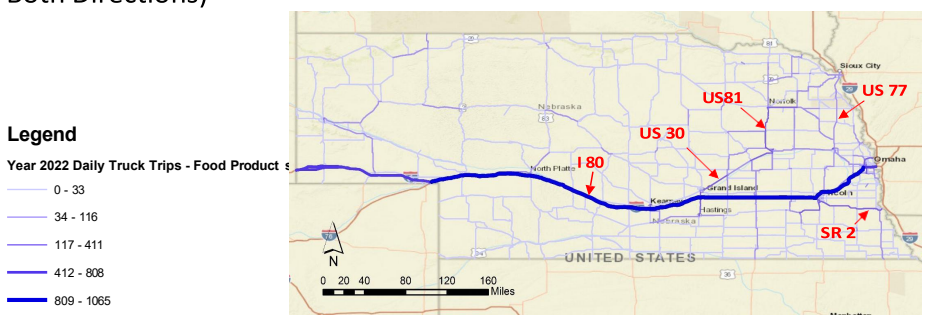


Nebraska

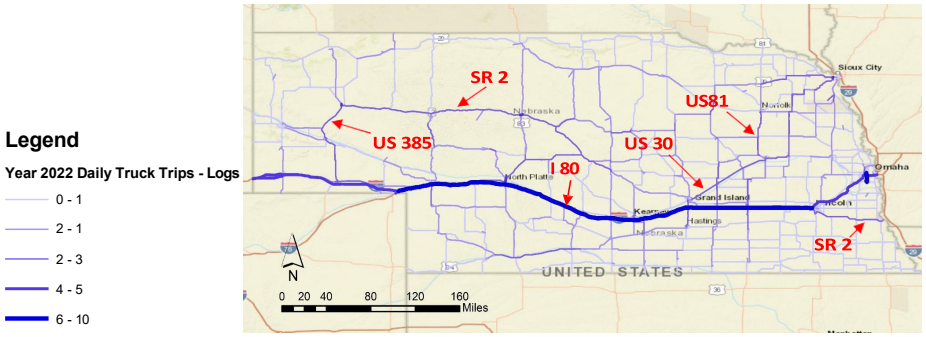
Farm Products: Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood (Truck Trips in Both Directions)



Food Products: Milled grain products, other foodstuOs, etc. (Truck Trips in Both Directions)

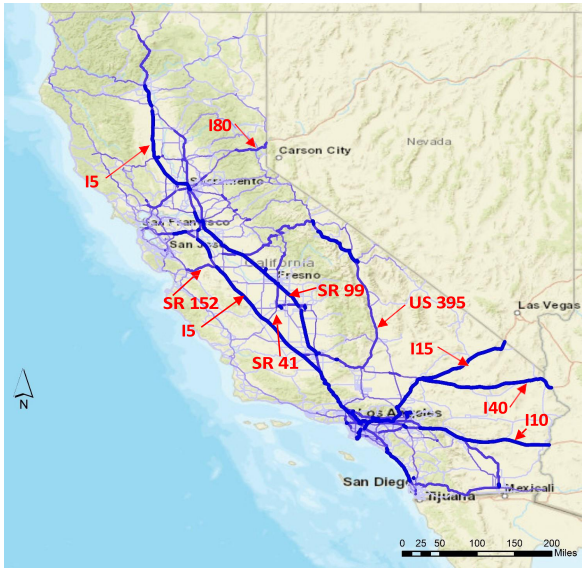


Logs and Other Wood Products: Logs (Truck Trips in Both Directions)

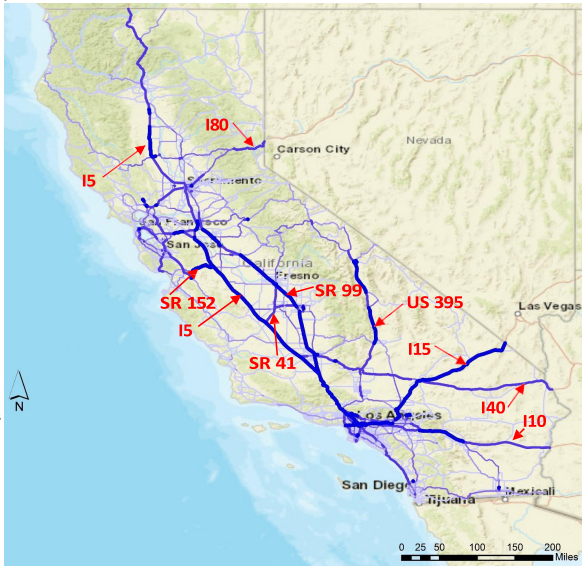


California

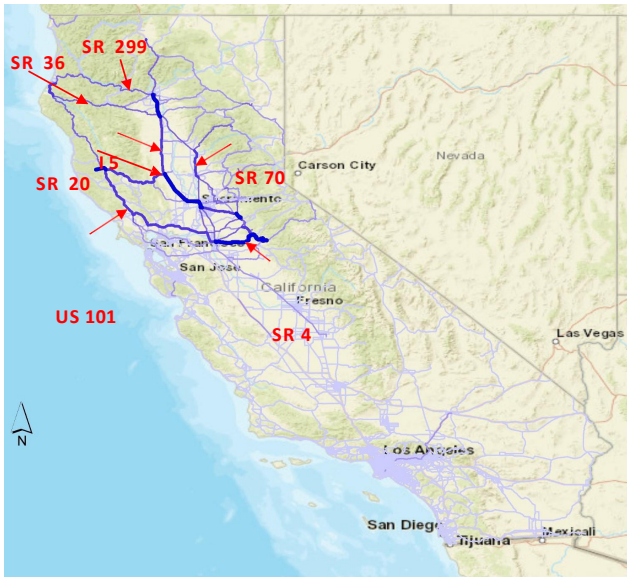
Farm Products: Live animals/fish, Cereal grains, Other ag products, Animal feed and Meat/seafood (Truck Trips in Both Directions)



Food Products: Milled grain products, other foodstuOs, etc. (Truck Trips in Both Directions)



Logs and Other Wood Products: Logs (Truck Trips in Both Directions)



Appendix B:

Survey Questionnaire

County of Operation:

1. **Which counties do you primarily operate in?**
   - ☐ Fresno
   - ☐ Kern
   - ☐ Tulare
   - ☐ San Joaquin
   - ☐ Other: _____

Stakeholder Information:

2. **Which category best describes your role?**
   - ☐ Farmer
   - ☐ Processor
   - ☐ Distributor
   - ☐ Transportation Authority Representative
   - ☐ Other: _____

Commodity or Equipment Transported:

3. **What type of commodity or equipment do you haul most frequently?**
   - ☐ Fresh Produce
   - ☐ Processed Goods
   - ☐ Heavy Machinery
   - ☐ Fertilizer or Agricultural Chemicals
   - ☐ Other: _____

Seasonality:

4. **During which months is your operation most active?**
   - ☐ January-March
   - ☐ April-June
   - ☐ July-September
   - ☐ October-December
   - ☐ Year-round

Truck Volume / Tonnage:

5. **What is the average weight of your typical haul?**
   - ☐ Under 10 tons
   - ☐ 10-20 tons
   - ☐ 20-30 tons
   - ☐ Over 30 tons

Route and Connection Details:

6. **Which routes or corridors are critical to your operations?**
   - ☐ Major Highways (e.g., I-5)
   - ☐ Regional Routes (e.g., SR-99)
   - ☐ Bridges or Flyovers (specify name or ID): _____
   - ☐ Other: _____

Route Performance Metrics:

7. **How would you rate the reliability of these critical routes?**
   - ☐ Excellent – No issues
   - ☐ Good – Minor delays occasionally
   - ☐ Fair – Frequent delays
   - ☐ Poor – Consistent issues impacting travel

Thresholds for Operational Impact:

8. **What range of delays (in minutes) causes significant operational impacts for you?**
   - ☐ Under 15 minutes
   - ☐ 15-30 minutes
   - ☐ 30-60 minutes
   - ☐ Over 60 minutes

Frequency of Route Disruptions:

9. **How often have you experienced route closures or major delays in the past year?**
   - ☐ Rarely (1-2 times)
   - ☐ Occasionally (3-5 times)
   - ☐ Frequently (6-10 times)
   - ☐ Very Frequently (over 10 times)

Severity of Route Failures:

10. **When route issues occur, how severe are the impacts on your operations?**
    - ☐ Minor – Minimal disruption
    - ☐ Moderate – Noticeable delays but manageable
    - ☐ Severe – Significant delays, operational rescheduling needed
    - ☐ Critical – Causes operational standstill or detours required

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