Assessing the Cost and Operational Impacts of State Practices for Minimum Quad Axle Weights Granted for Routine Over-Weight Permits

Final Report

Presented to

Specialized Carriers & Rigging Association

By

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In coordination with

Quetica, LLC

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Introduction

Member firms of the Specialized Carriers and Rigging Association (SC&RA) provide critical freight shipments to customers throughout North America. These shipments often require the utilization of different non-traditional vehicle configurations typically for non-divisible loads, i.e. those which cannot be easily dismantled or divided.

The laws and/or policies governing over-dimension and/or overweight (OS/OW) permit allowances for non-divisible loads fall exclusively into state jurisdiction. As a result, the policies, rules, and regulations governing the transport of oversize and overweight cargoes differ from state to state. A study of this issue by the Transportation Research Board (TRB) at the National Academy of Sciences, stated: "*This patchwork of regulations, permitting processes, and available information can result in inefficiencies in multi-state OS/OW transportation, which can lead to increased costs for carriers and shippers, as well as for the society more broadly.*"[1] That study also concluded that attempting broad scale changes across state jurisdictions to advance OS/OW harmonization, "*make this solution difficult, if not impractical as a singular focus in the short to medium term*."

Definition of a Non-Divisible Load

The Federal Highway Administration (FHWA) defines a non-divisible load as: "any load or vehicle exceeding applicable length or weight limits which, if separated into smaller loads or vehicles, would: (1) Compromise the intended use of the vehicle, i.e., make it unable to perform the function for which it was intended; (2) Destroy the value of the load or vehicle, i.e., make it unusable for its intended purpose; or (3) Require more than 8 work-hours to dismantle using appropriate equipment.

- Code of Federal Regulations, Title 23, Part 658.5 - Definitions

Many SC&RA members rely on the use of quad-axle trailers to haul divisible load shipments at weights exceeding typical tri-axle grouping. These specialized loads utilize state-issued OS/OW permits that allow loaded quad-trailers to transect the state on designated roadways. Seeking greater harmonization in how states regulate quad-axle configurations is the focus of this report.

Currently about one-half of the states routinely issue permits for quad axle groups weighing 80,000 lbs. (20,000 lbs. per axle). Five additional states will allow 80,000 lbs. on quad axles, subject to a review of the route by a state bridge engineer – a process that can significantly delay obtaining a permit. In addition, there remain nearly two dozen states that will not issue permits to truck configurations that load 80,000 lbs. on a quad-axle group. The map in Figure 1 shows the status of state regulations regarding 80,000 quad axle groups.

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[1] *Multi-State, Multimodal, Oversize/Overweight Transportation,* CPCS, Perkins Motor Transport Inc., and Portscape Inc.; National Cooperative Highway Research Program Report 830; Transportation Research Board (TRB); National Academies of Sciences. Washington D.C. 2016.

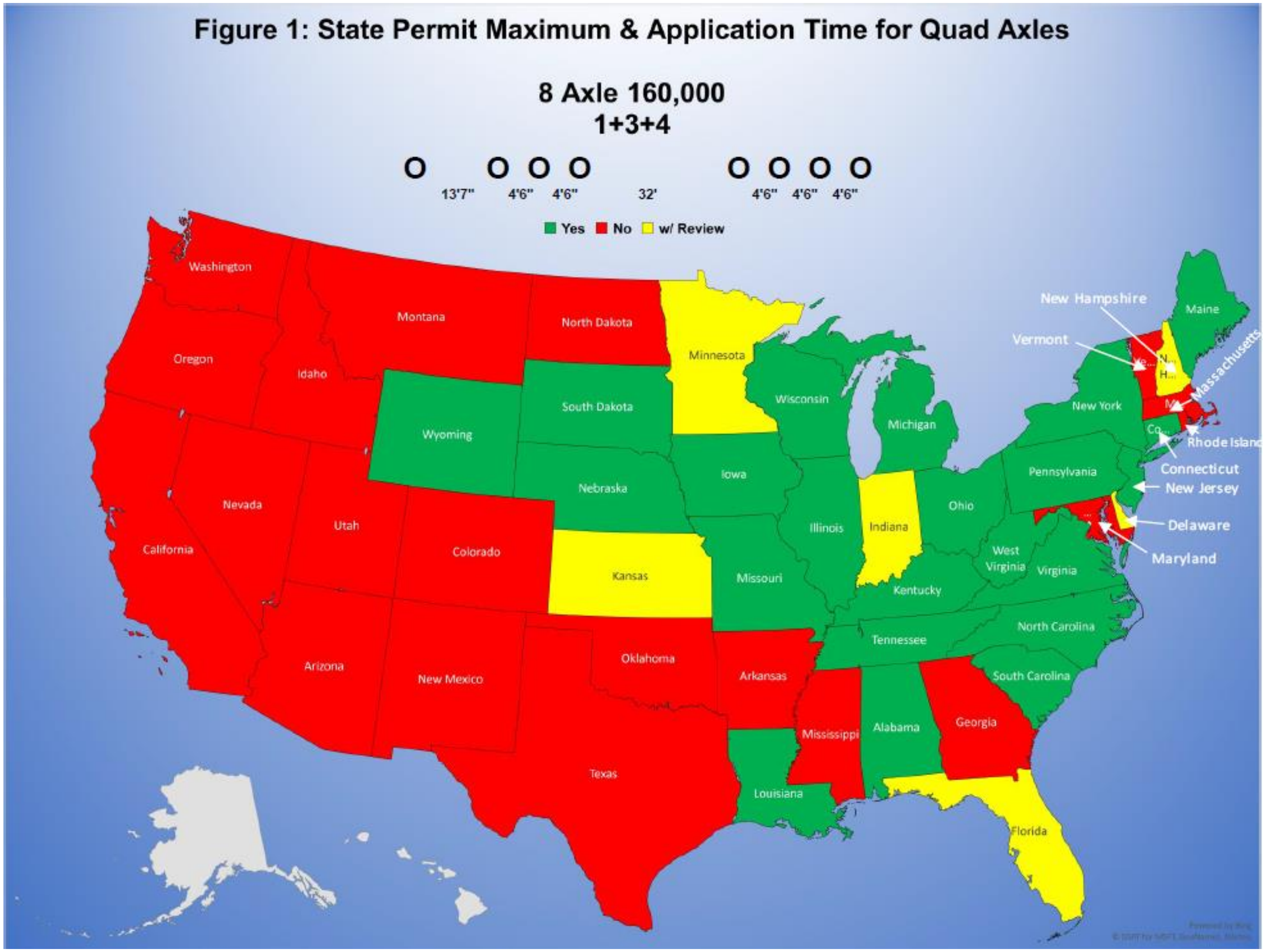

Figure 1: State Permit Maximum & Application Time for Quad Axles

Source: Source, Specialized Carriers and Rigging Association

In states where the quad-axle envelope vehicles are not permitted, specialized fleets must either re-route the trucks to states and roadways that do allow heavy quad axle groups or re-configure the tractor-trailer combination so that axle group weights meet state requirements. In both instances, serious time and expense may accrue to private industry while routing heavy loads in a circuitous manner imposes unnecessary pavement and bridge wear on infrastructure.

SC&RA contracted with a team lead by the American Transportation Research Institute (ATRI) to assess the costs associated with transporting loads that routinely permit quad-axle groups at 80,000 lbs., and compare the cost and operational impacts analysis with a) quad-trailer trips/loads that must re-route due to state restrictions on quad-axle groups, and b) loads that are require the vehicle configuration to be altered to meet state requirements. While this investigation focuses on heavy quad-axle groups, it is intended as a single case study of how state regulations for non-divisible loads often result in excessive transit time, unneeded infrastructure implications and a whole range of additional user and societal costs.

Study Approach

The approach to develop a broader understanding of the challenges facing the specialized carrier industry stemming from non-uniform standards for quad-axle permits involved five key tasks:

1. **Review existing literature and assemble a summary assessment of research and regulations impacting quad-trailer shipments**. For this task SC&RA provided summary information about state permitting practices regarding axle configurations and load limits. The research team conducted an online review of previous research and policy studies concerning quad-axle highway operations. The literature review was not intended as an exhaustive exercise on state policies or regulations. The intended outcome was to:

    - Identify previous studies that have examined the general scale of economic or infrastructure impacts resulting from state laws that do not routinely allow or prohibit the use of quad-axle configurations at a minimum of 80,000 pounds (lbs.);
    - Summarize the current state of understanding of quad axle load impacts on pavements and bridges; and,
    - Provide guidance on best practices and model approaches for utilizing quad-axle vehicle configurations for heavy non-divisible load movements.

2. **Develop an operational cost database for different vehicle configurations.** Since 2008 ATRI has conducted an annual industry survey to collect information about operating costs in the trucking industry. However, the loads handled by specialized carriers typically involve additional costs not always encountered by common carriers. For example, heavy or over-dimension loads often require:

    - Specially ordered tractors and trailers that are more expensive than the norm;
    - Specially trained and experienced drivers;
    - Permit applications and permit issuance;
    - Civilian or police escorts; and
    - Route surveys.

    To account for these differences, ATRI worked with SC&RA to collect data and develop operational cost metrics specific to moving oversize/overweight loads.

3. **Develop Operational Test Scenarios**. Working with SC&RA staff, the research team developed several hypothetical moves of heavy cargo for interstate permitted, overweight loads that examine routing scenarios due to non-uniform state regulations. The cargo routing scenarios were studied using Geographic Information Systems software and formed the basis for assessing the comparative costs for different loads/trips associated with quad-axle semitrailer trips.

4. **Develop Quad-Trailer Operating Costs**. Using the results of the specialized carrier cost data collection, ATRI developed specific cost metrics for operating specialized loads utilizing quad-axle semitrailers.

5. **Develop Final Report Summarizing Key Findings**. The results of the literature review, cost survey and scenario analysis are presented in this final report.

Existing Literature and Research

There has been an extensive amount of research conducted on issues related to commercial truck size and weight. In the U.S. alone, truck size and weight studies at the local, state and federal level on issues related to impacts on safety, pavements, bridges, geometrics and economics likely number in the hundreds. Even so, most major studies draw strong conclusions about specific vehicle configurations, especially specialized vehicle configurations that fall outside normal size and weight parameters.

For this study effort, 22 research and policy studies related to the impacts from truck size and weight on bridges, pavements and the economy were reviewed. The publications covered studies conducted over a 17-year period in three different countries.

MAP-21 Comprehensive Truck Size and Weight Study

One of the largest truck size and weight policy studies undertaken in the U.S. was the result of a Congressional directive in the Moving Ahead for Progress in the 21st Century Act (MAP-21). In 2012, MAP-21 directed FHWA to study U.S. truck size and weight limits "*addressing differences in safety risks, infrastructure impacts, and the effect on levels of enforcement between trucks operating at or within federal truck size and weight (TSW) limits and trucks legally operating in excess of federal limits*." Completed and submitted to Congress in 2016, the MAP-21 TSW Study included an extensive review of previous research, and sought to use the best, most current knowledge related to heavy truck impacts on bridge and pavement infrastructure. A primary objective of the MAP-21 TSW Study was to, "*Compare and contrast the potential safety and infrastructure impacts of alternative configurations (including configurations that exceed current federal limts) to the current federal truck size and weight law and regulations*…"[2] While Congress specifically called out tractor-trailer vehicle combinations with a tri-axle group, quad-axles were not an element of the alternative configurations studied. The MAP-21 TSW Study did an extensive "desk scan" which reconfirmed two long-established facts regarding the impact of truck weight on transportation infrastructure:

- **Wear and damage to highway pavements is most closely associated with indvidual axle weight.** That is, as axle weight increases so does the incremental damage to pavement structures. How much pavement damage is caused by a specfic type of truck or axle configuration has been the subject of countless studies and millions of dollars in research, although concrete conclusions are difficult to make. There are many variables that impact the amonut of wear caused by a particular vehicle or load: pavement variables such as material, thickness, subbase, weather, and moisture combine with vehicle factors such as weight of the load, load distribution, tire width, and tire pressure. Much of the existing research explores the details associated with these factors. For example, there are two main pavement types: asphalt and concrete. However, for each type there are an almost infinite number of mixes and combination of mix materials – including the trend of using more recycled materials.
- **Bridge life is most closely associated with the total or gross weight.** As with pavements there are many variables that affect the life of a bridge: design type, material, length or span, weather/environment, exposure to corrosive chemicals, as well as, vehicle and traffic factors like vehicle weight, and traffic volume. The easiest way to think of bridge forces is to picture a piece of wire: if the wire is repeatly bent or flexed – but only slightly – the wire will likely withstand a large number of bending

cycles before fatigue in the metal causes the wire to break or fail. The same piece of wire if bent or deflected sharply can usually be broken in just a few cycles. Bridge fatigue is one track of research that examines the number of repetitive bending cycles (bending moment) bridges can handle over time.

Performance Based Standard for Heavy Vehicles: Australia and New Zealand

The most in-depth and comprehensive research on the impacts of quad-axles has been conducted in Australia and New Zealand. In 2006, the Council of Australian Governments recognized the benefits associated with increasing mass for heavy vehicles and more efficient management of the national freight task. As a result, Australia and New Zealand adopted a radically different regulatory scheme for heavy trucks referenced as Performanced Based Standards (PBS). The traditional approach to vehicle size and weight regulation, including laws in the U.S., use prescriptive limits to regulate truck size and weight. Australia has long-established prescriptive regulations, and has also adopted 16 safety performance standards and four infrastructure performance standards that form the regulatory framework for assessing new vehicle designs that exceed traditional truck size and weight limits. New vehicle designs or configurations that meet the performance standards may be approved for use on one or more of the primary truck networks in Australia (Australia has established several road network categories). This lifting of prescriptive limits has been the catalyst for vehicle design innovations.

For example, the Austrailian federal government established a performance standard for axle groups that allows incrementally higher mass limits as the “section width of the tyres” increases. The upper limits of each standard may also change depending on the road network being traveled. New vehicle design or configurations that exceed prescriptive standards or meets or exceeds the performance standard can apply to operate legally.

Research in Australia compared the impacts on pavement of allowing general access for quad-axle groups operating at 24 metric tonnes (52,896 lbs.) versus a tri-axle group at 20 tonnes (44,080 lbs.), as well as higher limits on restricted routes with quad-axle groups at 27 tonnes (50,508 lbs.) versus tri-axle groups at 22.5 tonnes (49,590 lbs.). The results showed the quad-axle groups performed the same or better than tri-axles in several scenarios including an 11 percent reduction in pavement wear for single articulated vehicles and about eight percent for B-double vehicles. Overall, pavement wear reduction would be dependent on the number of vehicles that would utilize the quad-axle group: *The relative effects on pavements of the use of a quad-axle group in lieu of a tri-axle group were calculated for a fixed freight task. Due to the reduced standard axle repetitions (SAR) for a quad-axle group at 24 tonnes over a tri-axle group at 20 tonnes, road wear was reduced by 11 per cent for single articulated vehicles (A124) and about eight per cent for B-doubles (B1243). Net pavement wear reduction would depend on the uptake of vehicles fitted with the quad-axle group.*[2]

Quad-Axle Vehicle Approval under the Australian PBS Scheme

'Blueprint' designs for quad-axle semi-trailers and B-doubles have been pre-approved to Performance Based Standards and made available to the heavy vehicle industry. Operators can use these 'blueprints' to apply for access on PBS networks…If operators want to develop a different quad-axle group vehicle design, its safety and performance must be assessed under the PBS scheme. Other vehicle requirements include:

- dual tyres on quad-axle groups
- a steerable rear axle with at least +/- 12 degrees steering articulation and an effective centering mechanism (or another system acceptable to the registration authority)
- a load sharing system at least as effective as for a tri-axle group
- road-friendly certified suspension (refer Vehicle Standards Bulletin 11)
- (optional) 'lift axles' complying with ADR 43/04
- Accreditation under the National Heavy Vehicle Accreditation Scheme (NHVAS) or equivalent mass and maintenance accreditation.
- The Intelligent Access Program (IAP) as a potential tool for route compliance.

Source: National Heavy Vehicle Regulator https://www.nhvr.gov.au/road-access/performance-based-standards

The bridge engineering analysis performed in Australia concluded that quad axles with a load of 24 metric tonnes (52,896 lbs) would have additional impacts on some bridges: *The overstress factor method used to test simply supported bridges shows quad-axle groups produce stress results within the maximum permitted levels. Similar tests on continuous span bridges resulted in stress levels at the maximum permitted limit. However, testing the simply supported bridges using the T44 testing methodology resulted in quad-axle group*

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[2] *Review of Quad-Axle Groups,* National Transport Commission – Australia, March 2016. pp. 16

moments greater than the allowable limits by 12 per cent when tested at 24 tonnes. Bridges with spans between 4 and 9 meters are vulnerable. Bridges less than 4 m did not have sufficient span to hold the entire quadaxle group, while bridges over 9 m are sufficiently wide to distribute the load over the supports… Overall, the major constraint on replacing a tri-axle group with a quad-axle group is the impact on short-span, simply supported bridges. [3]

After researching quad axle groups, the Australian government adopted a quad axle group policy under the PBS scheme that was implemented on July 1, 2018. The policy allows up to 27 metric tonnes (59,524 lbs) on a quad axle group for some road networks, provided the axle group is equipped with dual tires and meets other vehicle performance standards for safety and manueverability.

The Australian research also found that as axle spacing is reduced, the less the axles in the group act as separate entities and the maximum deflection exerted on the pavement increases; however, maximum tensile stress can decrease. Thus, axle spacing and the associated impacts on pavement is complex and dependent on the nature of the pavement.[4]

NCHRP Report 830: Multi-State Multimodal, Oversize/Overweight Transportation[5]

This research funded through the National Academy of Sciences, Transportation Research Board was completed in 2016. The objective of the study effort was to: "*develop guidelines for use by states and other practitioners to improve the permitting process and to evaluate potential OS/OW freight movement solutions involving multi-state, multi-modal transportation corridors*.

The published report documents many of the regulatory differences among states regarding permitted Oversize and/or Overweight (OS/OW) loads. Regarding the impact on carrier operating costs associated with non-uniformity among states, the authors note: "*Carriers prefer to take the shortest path from origin to destination (referred to as the optimal route). In some instances, however, carriers will bypass a state to avoid having to comply with a particularly challenging or costly state requirement, making their journey longer as a result (referred to as the actual route)."*

The authors obtained information indicating that operating trailers with axle configurations exceeding quad-axle configurations can increase the per-mile operating

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[3] Ibid, National Transport Commission – Australia, 2016

[4] *Comprehensive Truck Size and Weight Study Volume 2 Chapter 6.* Federal Highway Administration; USDOT. https://www.fhwa.dot.gov/reports/tswstudy/Vol2-Chapter6.pdf

[5] Ibid, CPCS, Perkins Motor Transport Inc., and Portscape Inc.

costs. Most states also require civilian or police escorts for many over-dimension super loads:

> *"Police escorts are often required to accompany larger OS/OW loads, but related requirements often differ across states. From an operational perspective, carriers have to work around the hours police will work, plan with district offices, and plan for exchanges at jurisdictional boundaries, all of which contribute to delays and increased costs."* (NCHRP Report 830)

Together, higher equipment costs, and escort requirements can increase super load operating costs by three to 10 times over the cost of a routine OS/OW trailer. The study presented the following table of additional costs that can be occurred based on the industry acquired data:

Table 1: Per Mile Costs Associated with Escorts and Equipment for OS/OW Loads

Vehicle	Low (2013$)	High (2013$)
Escorts	$1.89	$3.23
Routine OS/OW Loads	$4.23	$4.26
Super loads	$6.45	$6.48

Literature Review Key Findings

A more detailed and thorough discussion of the research literature reviewed for this study is found as Appendix A to this report.

In general, most national level studies have failed to draw strong conclusions about infrastructure impacts from specialized vehicle configurations due to the large number of variables at play in bridge and pavement wear. Differing construction and maintenance policies at the state and local level are frequently cited in literature as factors limiting the ability to draw strong conclusions about impacts from changes in truck size and weight policy. The MAP-21 TSW Study concluded: "*It should be noted that States have different policies and procedures as they relate to bridge posting, rehabilitation, and preservation. It would be extremely difficult to reflect all of those policy differences in a national study."*

While Congress and FHWA have established design standards for the Interstate Highway System, even these national standards have evolved over time and some states have chosen to exceed standards to better accommodate heavy trucks. In addition, highway infrastructure can have very long life spans, especially in low volume rural areas.

Historically, bridges have tended to be the linchpin in adopting higher vehicle or axle load limits, in part due to their cost, but also due to potential loss of human life when bridges fail. However, the MAP-21 TSW research concluded in the summary analysis of the bridge section:

> *The findings generally indicated that relatively heavier axle loads, and axle groupings tend to negatively affect fatigue life when compared to the control vehicles. However, any overall reduction in bridge fatigue life depends on the number of relatively heavier trucks that are in the traffic stream. In general, fatigue-related costs in steel bridges are small compared to the total bridge program cost.*[6]

From a national perspective, assuming all bridges on the Interstate system are designed to carry the infrequent "*relatively heavier truck,*" a direct route between origin and destination that crosses fewer bridges than a circuitous route that results in crossing many more bridges will be less costly to all road users. A much older national review of federal truck size and weight policy undertaken by a special TRB Committee in 2002 concluded: *Present federal standards are for the most part the outcome of a series of historical accidents instead of a clear definition of objectives and analysis of alternatives."*[7] This statement may well sum up the current state by state permitting and regulation scheme applied to non-divisible heavy truck loads.

Developing Industry Costs Associated with Permit Load Operations

Leveraging ATRI's existing Operational Costs of Trucking data collection framework, ATRI developed a brief data collection form designed to collect the operational costs associated with operating a quad-axle truck configuration in 2017.[8] Data were collected on a per-mile basis for several key cost centers – driver pay and benefits, repair and maintenance, tires, fuel, insurance premiums, equipment lease/purchase payments, tolls, and permit and special license fees. The resulting data were then aggregated to calculate the average operational cost per mile for operating a quad-axle truck configuration.

The data collection form was disseminated to points of contact at eight specialized motor carriers provided by SC&RA. The key cost elements collected are shown in the table of Table 2. Of the eight carriers contacted by ATRI on behalf of SC&RA, four carriers provided usable cost data. The final data set was augmented with comparable

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[6] *Bridge Structure Comparative Analysis Technical Report;* Comprehensive Truck Size and Weight Limits Study, USDOT. June 2015. pp. ES-8 and 12.

[7] *Regulation of Weights, Lengths and Widths of Commercial Motor Vehicles, Special Report 267.* TRB, National Academy of Sciences, Washington D.C. 2002

[8] Hooper, A. and Dan Murray. "An Analysis of the Operational Costs of Trucking: A 2017 Update." American Transportation Research Institute. Arlington, VA. 2017.

data provided by five specialized motor carriers that participated in ATRI's 2017 Operational Costs of Trucking data collection.

Table 2: Cost Data Elements Collected by ATRI through Industry Surveys

Type of Pay
Pay per Mile • Include only base pay. Do not include benefits, incentives and bonuses.
Benefits per Mile • Include employer contributions to medical insurance, per diem and other financial benefits to the driver that are a standard part of employment. Do not include incentives and bonuses.
Expense Type
Repair & Maintenance • Include R&M costs for all trucks and trailer; do not include tire-related expenses.
Tires • Include all purchase, maintenance, re-treading, and replacement costs.
Fuel Costs • Include all transportation fuel. Do not include fuel surcharge revenue.
Truck Insurance Premiums • Include all liability, cargo, and excess liability policy premiums related to insuring the truck. Do not include workers compensation costs/insurance.
Truck and Trailer Lease or Purchase Payments • Include all payment costs, and interest and fees associated with the payments. Do not include depreciation tax benefits.
Tolls
Permits & Special Licenses • Include permits for oversize/overweight, HazMat, etc.

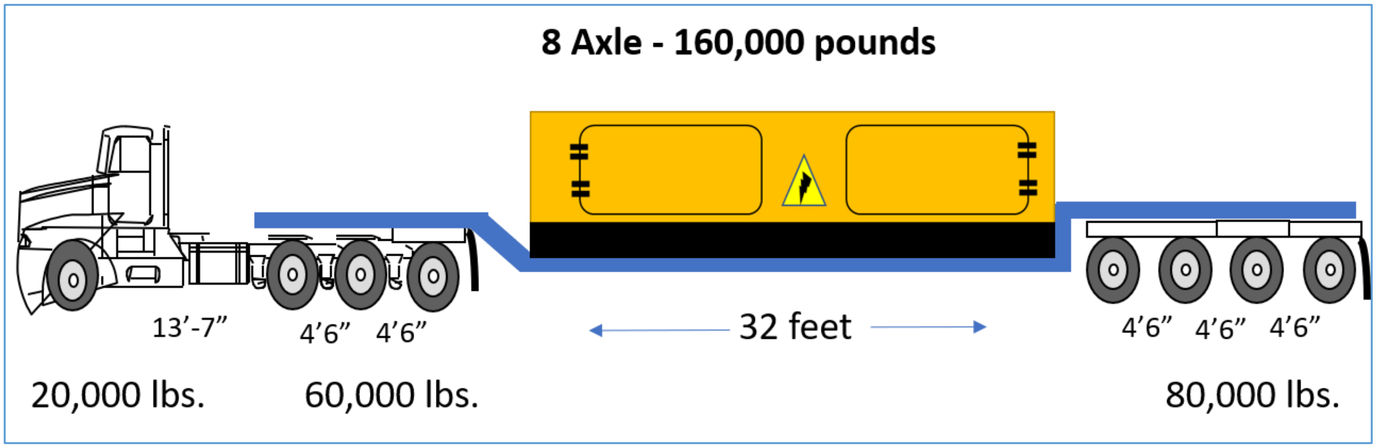
Developing Scenarios to Examine Quad-Axle Operations

The scenarios described in this section were used by the ATRI team to conduct an assessment of costs and other metrics associated with transporting loads that routinely permit quad-axle groups at 80,000 lbs., and juxtapose that cost and operational impacts analysis with: a) quad-trailer trips/loads that must re-route due to state restrictions on quad-trailer loads, and b) loads that are re-loaded on vehicle configurations that meet non-quad-trailer state requirements.

The scenarios will provide realistic and standardized assumptions to form the basis for assessing the comparative costs for different loads/trips associated with permissive versus restrictive quad-trailer trips. For the scenario analysis, a hypothetical over-weight, non-divisible load is moved between various origins and destinations in the U.S. The hypothetical vehicle and its load, a large generator, is shown in Figure 2. For the analysis, the travel time is based on the load traveling at an average of 50 mph to account for travel on non-interstate routes, load securement checks, and scales/weigh stations. The operating costs borne by specialized carriers to move the load are estimated based upon the operating and permitting rules in different state jurisdictions

(Figure 1). The route assignments do not account for time of day or other similar types of OS/OW restrictions.

Figure 2: Eight-Axle Scenario Configuration at 160,000 GVW



Source: Quetica

The cost data broken down by driver and vehicle operating categories collected specifically for this analysis are shown in Table 3.

Table 3: Average Trucking Costs Per Mile for General and Specialized Carriers

Key Cost Center	Specialized Carriers	ATRI 2016
Driver Pay	$0.683	$0.523
Driver Benefits	$0.226	$0.155
Repair & Maintenance	$0.240	$0.166
Tires	$0.067	$0.035
Fuel	$0.570	$0.336
Insurance	$0.077	$0.075
Lease/Purchase Payments	$0.244	$0.255
Tolls	$0.008	$0.024
Permits/Licenses	$0.122	$0.022

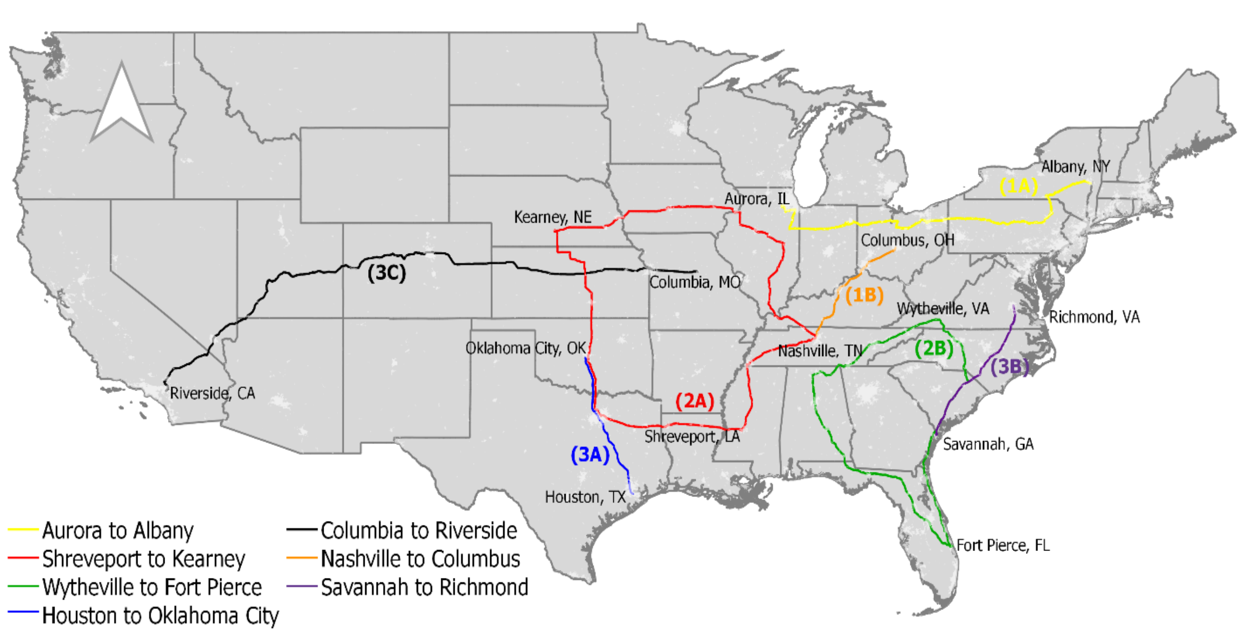
Scenario 1 (Baseline Scenario): Scenario 1 (A and B) provided origin-destination (O/D) pairs so that the load would pass through states which routinely issue a permit for

80,000 pounds on the quad-axle trailer shown in Figure 2. The first baseline O/D scenario is Aurora, Illinois and Albany, New York (Scenario 1A). The load routing (provided by SC&RA) is shown in Figure 3, and includes the following:

- Illinois: S-31, US-30, S-59, I-55, I-80, I-57, US-24
- Indiana: US-24, I-69, I-469, US-30
- Ohio: US-30, US-127, US-224, S-4, US-30, I-71, S-18, I-77, I-76, I-277, I-77, I-76, I-80
- Pennsylvania: I-80, I-81
- New York: I-80, I-88, US-20

Aurora, IL to Albany, NY along the route described above is approximately 856 miles. Driving at an average of 50 mph, the route takes about 17.12 hours to traverse from origin to destination. Utilizing the SC&RA operational cost per mile average, the total operational cost totals $1,915.21 (Table 4).

Figure 3: Origin-Destination Routes for Tested Scenarios.



A second baseline O/D pair (1B) is Nashville, TN and Columbus, OH. I-65 and I-71 provide a direct route, unlike the Aurora to Albany route, traveling through Tennessee, Kentucky, and Ohio constituting 379 miles, in about 7.5 hours, and operational costs of $847.97.

Table 4: Baseline Costs to Move a Non-Divisible Load Using an 8-Axle Quad

Scenario	Origin - Destination	Miles	Time	Operational Cost	Cost Differential
1A	Aurora, IL to Albany, NY	856	17hrs 7mins	$1,915.21	-
1B	Nashville, TN to Columbus, OH	436	8hrs 43mins	$975.50	-

After initial route scenarios were developed and reviewed by SC&RA, feedback from specialized carrier industry experts suggested that direct route miles are rarely achievable for permitted loads and quad axles due to a variety factors, such as bridge restrictions, access to parking, etc. SC&RA reviewed the route from Aurora, IL to Albany, NY in detail and provided specific routing that would be required, which exceeded the shortest path. For the other route scenarios, industry representatives suggested adding 15 percent to direct route miles to provide a more realistic estimate of true travel distance and time. For example, the shortest path Interstate route between Nashville, TN and Columbus, OH is 379 miles / 7.5 hours. When applying the suggested 15 percent real-world mileage factor, the trip increases to 436 miles/8.75 hours, and costs $975.50. For the remaining scenarios, the 15 percent factor is added in.

Scenario Two (Circuitous Routes): Scenario 2 (A and B) includes two O/D pairs that allowed analysts to assess the impacts on shipping costs and other metrics due to being unable to travel the most direct path from origin to destination.

Shipping OS/OW loads on a quad trailer with an 8-axle configuration between Shreveport, LA and Kearney, NE requires a circuitous route due to existing quad laws in Arkansas, Texas, Oklahoma, and Missouri. The circuitous path through the states of Mississippi, Tennessee, Kentucky, Illinois, and Iowa basically doubles the road miles when compared to the most direct route via I-35 through Texas, Oklahoma, and Kansas. Using the real-world mileage factor discussed previously, the circuitous route between Shreveport and Kearney is estimated to be 1,924 miles/38.5 hours versus 958 miles/19 hours and 10 minutes with a cost differential of $2,161.21 (See Table 5). The optimal and circuitous route segments are:

Optimal Route:

- Louisiana: I-20
- Texas: I-20, I-635, I-35E, I-35
- Oklahoma: I-35
- Kansas: I-35, I-135, US-81, US-24, S-128, US-36, S-8
- Nebraska: S-10, S-50A

Circuitous Route:

- Louisiana: I-20
- Mississippi: I-20, I-220, I-55
- Tennessee: I-55, I-240, I-24
- Kentucky: I-24
- Illinois: I-24, I-57, I-74, I-280
- Iowa: I-280, I-80
- Nebraska: I-80

Table 5: Cost Differential Based on Direct vs. Permitted Route for an 8-Axle Quad

Scenario	Origin - Destination	Miles	Time	Operational Cost	Cost Differential
2A Circuitous	Shreveport, LA to Kearney, NE	1,924	38hrs 29mins	$4,304.63	$2,161.21
2A Optimal	Shreveport, LA to Kearney, NE	958	19hrs 10mins	$2,143.42	-

The second O/D pair under this scenario (2B) is from Wytheville, VA to Fort Pierce, FL. The most direct route through the Carolinas and Georgia is not an option due to Georgia’s quad law. Instead, OS/OW loads must take a western route through Tennessee and Alabama. The circuitous route through Chattanooga and Nashville is roughly 55 percent longer in terms of both miles (1,324 versus 856) and travel time (26.54 hours versus 17 hours). The increased operating costs for moving this load increase over $1,000 as shown in Table 6.

Optimal Route:

- Virginia: I-77
- North Carolina: I-77
- South Carolina: I-77, I-26, I-95
- Georgia: I-95
- Florida: I-95, I-295E, I-95

Circuitous Route:

- Virginia: I-81
- Tennessee: I-81, I-40, I-75, I-24, US-72
- Alabama: US-72, I-565, I-65, I-85, S-271, US-231
- Florida: US-231, S-276, I-10, I-75, Florida Turnpike

Table 6: Cost Differential Based on Direct vs. Permitted Route for an 8-Axle Quad

Scenario	Origin - Destination	Miles	Time	Operational Cost	Cost Differential
2B Circuitous	Wytheville, VA to Fort Pierce, FL	1,324	26hrs 28mins	$2,961.52	$1,046.32
2B Optimal	Wytheville, VA to Fort Pierce, FL	856	17hrs 7mins	$1,915.21	-

Scenario Three (Additional Escort Costs): Scenario 3 (A, B, and C) includes three separate O/D pairs to show the cost differential between a routine OS/OW load and a superload due to additional costs from the requirement of escorts (Table 7). Scenario 3 utilizes typical weights found east of the Mississippi River derived from NCHRP Report 830 in relation to legal (up to 80,000 lbs.), routine OS/OW (120,000 lbs.), superload (greater than 120,000 lbs.), and megaload (case-by-case) load types[9], and an escort cost of $2.56 per mile – the midpoint between the reported low and high cost from Table 1.

Table 7: Cost Differential Based on Additional Escort Costs from Equipment Substitutions

Scenario	Origin - Destination	Miles	Time	Operational Cost	Cost Differential
3A	Houston, TX to Oklahoma City, OK	512	10hrs 14mins	$2,456.27	$1,310.72
3B	Savannah, GA to Richmond, VA	540	10hrs 48mins	$2,590.60	$1,382.40
3C	Columbia, MO to Riverside, CA	1,968	39hrs 21mins	$9,439.60	$5,037.20

The first O/D pair, Houston, TX and Oklahoma City, OK (3A), is a 445-mile direct route along I-45, I-30W, I-35E, and I-35. At an average of 50 mph, a truck can traverse the route in just under nine hours. If the mileage increases 15 percent to account for real world contingencies, the route is estimated at 512 miles and takes about 10.25 hours to travel. The different equipment results in cost differentials of $1,139.20 and $1,310.72.

Savannah, GA to Richmond, VA (3B) along I-95 through the Carolinas is a 466 mile/9.3-hour route resulting in a cost differential of $1,192.96 due to the equipment differences.

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[9] 9 Ibid, CPCS, Perkins Motor Transport Inc., and Portscape Inc.

Adding 15 percent to account for a non-straight route increases the miles to 540, drive time to 10.75 hours, and cost difference of $1,382.40.

The last O/D pair, Columbia, MO to Riverside, CA (3C) is a 1,711-mile route along I-70, I-15, and I-215 through Kansas, Colorado, Utah, and Arizona that takes roughly 34.2 hours to traverse, resulting in additional operating costs of $4,380.18. The additional mileage pushes the route miles to 1,968, hours to 39.35, and raises the operational cost difference to $5,037.20.

In summary, the analyses presented above represent the operational costs associated with various operating conditions for specialized carriers. The baseline scenario (Table 4) identified the need to adjust route mileage to represent specific routing that would be required beyond the most direct route between two locations. This analysis was extended to look at the operational cost differences between a permitted route relative to the most direct route (Tables 5,6). The added operational costs for the circuitous routes between the two Origin-Destination pairs examined were substantial. Similar results were found with the routes examined in Scenario 3 (Table 7), though this analysis does not account for additional equipment costs.

Public Sector Costs from Circuitous Routing

State and federal agencies have invested millions of dollars not only trying to understand the engineering dynamics associated with heavier loads, but also the best means of designing roadways and bridges to last longer. For many decades, state and local highway engineers relied on data from the pavement testing conducted in decades ago Ottawa IL. In the 1960s the American Association of Highway Officials (AASHO – today known as AASHTO) conducted what came to be known as the AASHTO Road Tests. A key outcome of these field tests was a pavement wear metric called the Equivalent Single Axle Load (ESAL). The ESAL metric converts wheel loads of various magnitudes and repetitions ("mixed traffic") to an equivalent number of "standard" or "equivalent" loads. The ESAL remains a widely used pavement load metric based upon an 18,000 lb. single axle load. Since the 1960s AASHTO has periodically modified the ESAL equation to reflect changes in pavement mixes, and additional field experiments. The ESAL approach to pavement design is based on past experimentation and observation and is therefore referred to as an empirical method.

Modern pavement design is trending toward what is known as mechanistic-empirical pavement design (MEPD). MEPD methods use data collected on a specific roadway corridor to essentially develop customized load factors for each highway, to account for differences in the physical environment, vehicle mix and load spectra. MEPD is considered a superior method for designing new pavement structures, however, the ESAL method is still widely used, especially when the extensive data collection required for MEPD approach is not available.

Calculating ESALs for a 160,000 Pound Quad Axle Configuration

In 2010, FHWA contracted for the development of a pavement cost calculation spreadsheet, called PaveDat designed to provide a sketch-level view of pavement costs associated with different vehicle types. The PaveDat spreadsheet was specifically designed to help state permit managers understand the pavement cost impacts associated with various vehicle configurations and axle loads. At the time the model was developed in 2010 it used the latest MEPD methods and was loaded with state-level vehicle counts and highway pavement types for 2010. The study team used the model to provide a sketch-level overview of pavement impacts caused by different vehicle types to gain an understanding of how circuitous routing caused by non-uniform permit policies increase the costs on public roadways. It should be noted however, that a significant limitation of the model is that it only includes load equivalency factors (LEF) for single, tandem and tridem axles. To overcome this limitation, the model was run substituting a tridem axle, plus a single axle for a quad axle group. The first model run was conducted to estimate the pavement impact from a standard 5-axle tractor-semitrailer (TST) loaded to 80,000 lbs. as shown in Figure 4.

Figure 4: Typical 5-Axle TST Loaded to the Federal Maximum GVW

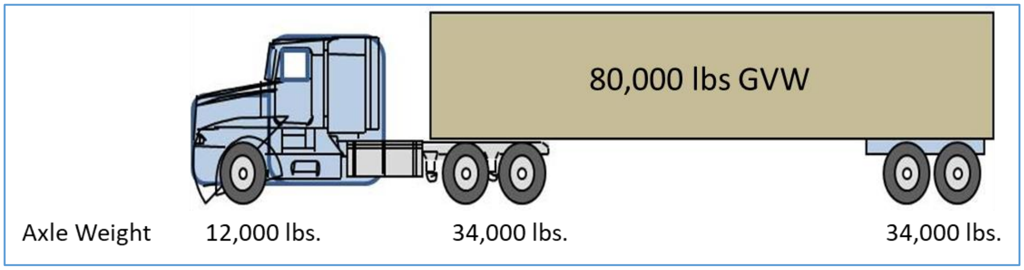
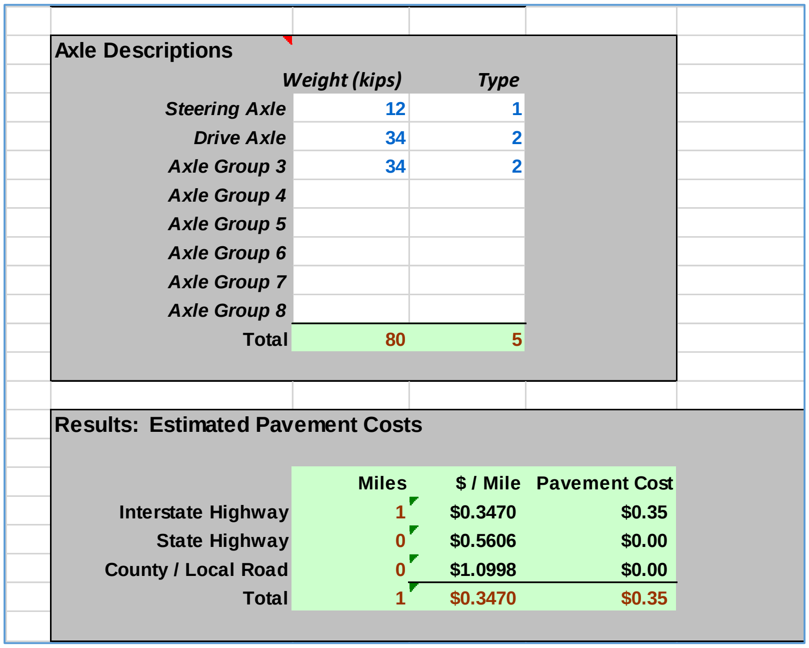


Figure 5: Screen shot of PaveDat Inputs for a 5-Axle TST



Axle Descriptions

	Weight (kips)	Type
Steering Axle	12	1
Drive Axle	34	2
Axle Group 3	34	2
Axle Group 4		
Axle Group 5		
Axle Group 6		
Axle Group 7		
Axle Group 8		
Total	80	5

Results: Estimated Pavement Costs

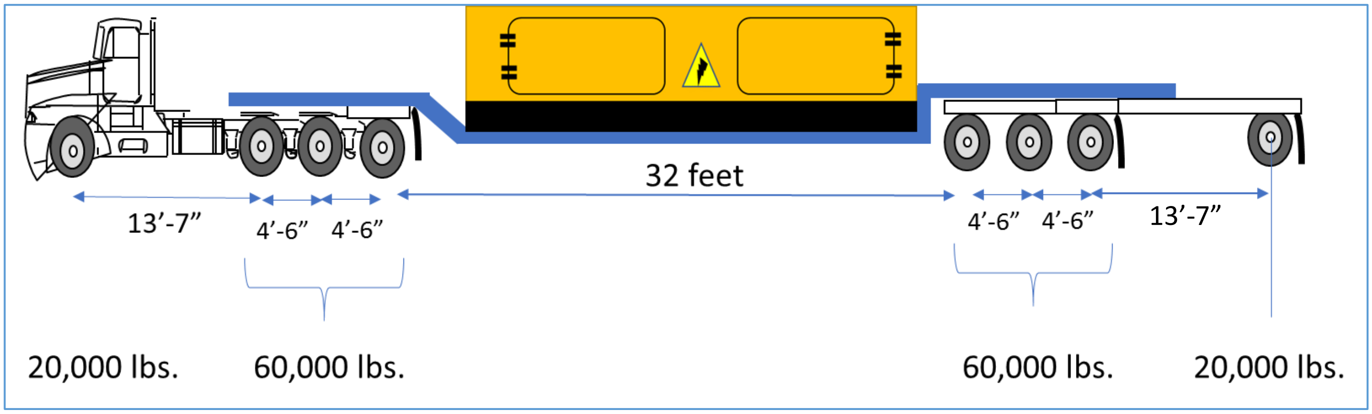
	Miles	$ / Mile	Pavement Cost
Interstate Highway	1	$0.3470	$0.35
State Highway	0	$0.5606	$0.00
County / Local Road	0	$1.0998	$0.00
Total	1	$0.3470	$0.35

TST

As the screen shot in Figure 5 shows, inputs to PaveDat can be used to estimate pavement costs for three highway categories: Interstate, State Highway and County/ Local Road. For Interstate highways, PaveDat estimates the pavement wear associated with the 80,000 lb. TST as $.3470/mile. (Note: The cost per mile estimates are provided as relative information. Specific estimates would depend on factors such as pavement type, thickness, etc.)

The next configuration entered into PaveDat is an alternative 8-axle configuration employing two tridem axles, and a single axle with a GVW of 160,000, as shown in Figure 6.

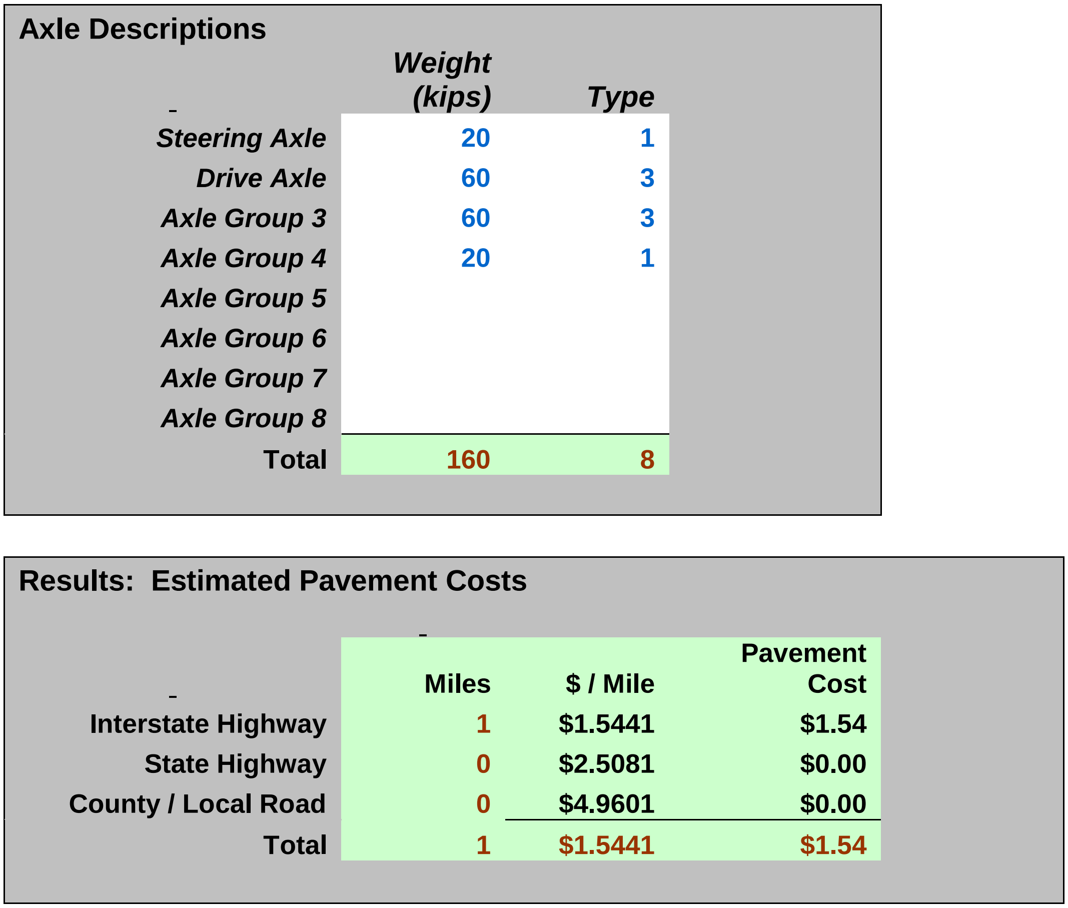
Figure 6: 160,000 GVW Configuration with Two Tridem Axles



Source: Quetica

The PaveDat output shown in Figure 7, shows that the estimated pavement cost associated with the eight-axle rig using two 60,000 lbs. tridem axles is $1.54/ mile. Since PaveDat is not programmed to generate costs estimates associated with quad-axles, the double tridem was substituted to examine the estimated public-sector pavement costs generated by circuitous routing. Table 8 shows the additional pavement costs associated with moving a non-divisible load of 160,000 under the scenario assumptions in 2A and 2B. In particular, the circuitous route connecting Shreveport with Kearney produces roughly an extra $1,490 worth of pavement wear, while the Wytheville to Fort Pierce circuitous route produces an extra $720 worth of wear. In total, the circuitous routes cost shippers approximately an additional $3,650 and $1,770.

Figure 7: Screen shot of PaveDat Inputs for an 8-Axle TST with Two Tridem Axles



Axle Descriptions

	Weight (kips)	*Type*
Steering Axle	20	1
Drive Axle	60	3
Axle Group 3	60	3
Axle Group 4	20	1
Axle Group 5		
Axle Group 6		
Axle Group 7		
Axle Group 8		
Total	160	8

Results: Estimated Pavement Costs

	Miles	$ / Mile	Pavement Cost
Interstate Highway	1	$1.5441	$1.54
State Highway	0	$2.5081	$0.00
County / Local Road	0	$4.9601	$0.00
Total	1	$1.5441	$1.54

Table 8: Pavement and Total Costs From Circuitous Routing 8-Axle 160K Truck

Scenario	Origin - Destination	Miles	Operational Costs	Pavement Costs	Total Cost Differential
2A Circuitous	Shreveport, LA to Kearney, NE	1,924	$4,304.74	$2,970.85	**$3,652.92**
2A Optimal	Shreveport, LA to Kearney, NE	958	$2,143.42	$1,479.25	
2B Circuitous	Wytheville, VA to Fort Pierce, FL	1,324	$2,961.52	$2,044.39	**$1,768.95**
2B Optimal	Wytheville, VA to Fort Pierce, FL	856	$1,915.21	$1,321.75	

Conclusions

The recent TRB-sponsored study of multi state OS/OW permit moves (NCHRP Report 830) identified the numerous differences in regulations for permit moves of non-divisible loads across states. There are differences in axle weight allowances on single, tandem, triple, and quad axle groups, as well as definitions for gross vehicle weight limits, with many of these differences stemming from decades old grandfathered exceptions. In addition, many states differ in defining what constitutes a super load. In the area of dimensions, there are a litany of differences regarding limits for width, height, and length. States also differ in their requirements for escort vehicle requirements of super loads.

The maze of rules and regulations that specialized carriers face in making interstate movements is truly overwhelming. As many states will attest, the basis for some of these regulations are extremely dated, not based on any empirical data or evidence. In 1989, Congress directed the Secretary of Transportation to request a study of federal regulations governing truck size and weight. That study drew an astounding conclusion: *present federal standards are for the most part the outcome of a series of historical accidents instead of a clear definition of objectives and analysis of alternatives.*[10] Special Report 267 went on to state that current truck size and weight regulations are poorly suited for the needs of commerce. While that study examined federal regulations, the same conclusion can be drawn about the myriad state regulations applying to permitted loads: they are often based on little science, and do not reflect current or future transportation needs for domestic commerce.

Congress took no action on the recommendations of the TRB Special Report, and since then has requested several more policy studies on truck size and weight issues. Still, Congress has failed to act on many of the recommended changes to truck size and

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[10] *Regulations of Weights, Lengths, and Widths of Commercial Motor Vehicles.* Special Report 267; Transportation Research Board (TRB); National Academies of Sciences. Washington D.C. 2002.

weight policy; instituting changes in special permitting policies at the state level has also proved challenging. The specialized carrier industry has sought greater uniformity in OS/OW regulations for decades, and while some progress has been made, much more needs accomplished. Indeed, the specialized industry continues to strongly advocate and recommend the following steps in addition to harmonization:

- 100% implementation of automated permit systems and raising the imposed issuance thresholds for dimension and weight issued under these systems gradually to acceptable levels.
- Alike pavement and structures analysis, in keeping with AASHTO standards, between states regarding dimensions and weights issued under permit.
- Adherence to regular, scheduled meetings from our four AASHTO regions, allowing critical industry input and exchange of ideas.
- Current and future bridge designs that recognize the industry's need to transport product more efficiently.
- Policies at the state-level that promote the analysis and study of traditionally prohibited configurations and weight allowances.

Because responsibility for heavy vehicle permitting policies falls to the states, there are also different institutional hurdles that specialized carriers must overcome. Permitting policies for specialized loads in most states are established by individuals or committees within the responsible agency. As a result, it is possible that there may be greater reluctance to implement change in an environment where the risk associated with a policy change falls to individuals.

However, the analysis of regulations across states conducted in this research demonstrate that the costs associated with these regulations are considerable. The added costs strictly due to circuitous permitted routes exceeded $1,000.00 for a haul from Wytheville, VA. To Fort Pierce Fla while these same costs amounted to nearly $2,200.00 for a trip from Shreveport, La. To Kearney, Ne. It is also important to note here that the cost of $2.24 per mile used to calculate the added costs strictly due to circuitous permitted routes may be understated. This per-mile cost figure does not include other peripheral costs, such as time constrains and poor driver and equipment utilization, which can be difficult to measure, but are nonetheless driven directly by these regulatory policies. Adding further to these costs are other considerations that OS/OW loads experience due to state laws requiring the use of nine or ten axle configurations for example. It is clear from this very limited research on the costs associated with differing regulations among the states for just one trailer axle configuration, that these extra costs are considerable and are ultimately borne by the consumers.

APPENDIX A: Literature Review

Purpose

SC&RA member firms provide critical freight shipments to customers throughout North America. These shipments often require the utilization of different non-traditional vehicle configurations typically for non-divisible loads, i.e. those which cannot be easily dismantled or divided. The laws and/or policies governing over-dimension or overweight permit allowances for non-divisible loads fall exclusively into state jurisdiction. Many SC&RA members rely on the use of quad-axle trailers to accommodate large non-divisible shipments at weights exceeding those typically allowed on tridem configurations. These specialized loads utilize state-issued OS/OW permits that allow loaded quad-trailers to transect the state on designated roadways.

Currently about one-half of the states routinely issue permits for quad axle groups weighing 80,000 lbs. (20,000 lbs. per axle). Five additional states will allow 80,000 lbs. on quad axles, subject to a review of the route by a state bridge engineer. However, there remain nearly two dozen states that will not issue permits to truck configurations that would load 80,000 lbs. on a quad-axle group.

In states where the proposed quad-axle envelope vehicles are not permitted for the minimum suggested weight of 80,000 pounds (lbs.) gross vehicle weight (GVW), specialized fleets must either re-route the trucks to states and roadways that do allow heavy quad axle groups, or re-configure the tractor-trailer combination so that axle group weight meets state requirements. In both instances, serous time and expense consequences may accrue.

SC&RA has contracted with a team lead by ATRI to assess the costs and other metrics associated with transporting loads that routinely permit quad-axle groups at 80,000 lbs., and juxtapose those cost and operational impacts analysis with a) quad-trailer trips/loads that must re-route due to state restrictions on quad-axle groups, and b) loads that are require the vehicle configuration to be altered to meet state requirements. While this investigation focuses on heavy quad axle groups, this is just one example of how inconsistent state regulations for non-divisible loads traveling under a special permit, can result in unnecessary user and societal costs.

The first step in this assessment is a review of research, studies and other literature on this or similar topics to understand lessons learned and provide a basis for the remaining analysis.

Literature Reviewed

The literature review undertaken for this analysis was not meant to be an exhaustive exercise on state policies, regulations or existing research. Rather, the three-fold outcome of this task is to:

- Identify previous studies that have examined the general scale of impacts resulting from state laws that do not routinely allow or prohibit the use of quad-axle configurations at a minimum of 80,000 lbs.
- Be able to summarize the current state of understanding about the impacts of quad axle loads on pavements and bridges.
- Provide some initial guidance on best practices and model approaches for utilizing quad-axle vehicle configurations for heavy non-divisible load movements.

Table 1 provides the list of reports reviewed for this exercise.

Table 1: List of Reports and Resources Utizlized in the Literature Review

Title	Year	Agency
PBS combinations fitted with quad-axle groups	2017	National Heavy Vehicle Regulator
Guide for Maximum Dimensions and Weights of Motor Vehicles	2016	AASHTO
Review of Quad-Axle Groups	2016	National Transport Commission
NCHRP Report 830: Multi-State, Multimodal, Oversize/Overweight Transportation	2016	NCHRP/TRB
Comprehensive Truck Size and Weight Limits Study: Bridge Structure Comparative Analysis Technical Report	2015	USDOT/FHWA
NCHRP Synthesis 476 Practices for Permitting Superheavy Load Movements on Highway Pavements	2015	NCHRP/TRB
Rate of Deterioration of Bridges and Pavements as Affected by Trucks	2013	South Carolina DOT and Clemson University
Long-Term Pavement Performance Pavement Loading User Guide (LTPP PLUG) - Part II- Guidelines for Developing Axle Loading Defaults	2013	FHWA
Preliminary Methodology for Estimating Cost Implications of Incremental Loads on Road Pavements	2012	Austroads
Impacts of Route Restrictions on the Movement of Oversize/Overweight Loads in Texas	2012	TRB
Directory of Significant Truck Size and Weight Research (NCHRP 20-07 Task 303)	2011	TRB: Requested by AASHTO SCOHT

Title	Year	Agency
A Synthesis of Overweight Truck Permitting	2010	FHWA JTRP
Impacts of Permitted Trucking on Ohio's Transportation System and Economy	2009	Ohio DOT
Characterising Pavement Surface Damage Caused by Tyre Scuffing Forces	2008	Land Transport New Zealand
A New Approach for Allocating Highway Costs	2007	Transportation Research Forum
Adoption of More General Use of Quad Axle Groups in Semi-Trailers and B-Doubles	2007	National Transport Commission
Pavement Impact on Quad Axle Vehicles	2005	ARRB Conference
Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures	2004	NCHRP
Equivalent Load for a Quad Axle	2003	National Road Transport Commission and Austroads
Comprehensive Truck Size and Weight Study Volume 2 Chapter 6	2000	FHWA
Effects of Truck Size and Weights on Highway Infrastructure and Operations: A Synthesis Report	2001	FHWA
The Impact of Heavy Vehicle Traffic on Road Pavements	N/A	RCA Forum

Overview

Research on issues related to commercial truck size and weight is extensive: In the U.S. alone, truck size and weight studies at the local, state and federal level on issues related to impacts on safety, pavements, bridges, geometrics and economics likely number in the hundreds. Even so, beyond a few generalities such as higher axle loads increase pavement wear, and higher gross vehicle weight increases bridge stress, few conclusions can be drawn about the impact of specific vehicle configurations, especially special vehicle configurations that fall outside regular size and weight parameters. Differences in state and local policies regarding bridge and pavement construction and maintenance is frequently cited in the literature as a factor for the inability to draw strong conclusions about the impacts from changes in truck size and weight policy.

While Congress and FHWA have established design standards for the Interstate Highway System, standards have changed over time and some states have chosen to exceed certain standards – for example bridge strengh, while others have not. Off of the Interstate System, the American Association of State Highway and Transportation Officials (AASHTO) has also established guidance standards, but states and local units of government are not required to adopt them, or adopt some standards while modifying others to maintain local autonomy.

Both pavements and bridges have many variables to consider when examining truck weight policies. For example, while there are two general categories of pavement type: Bitumous (black top) or concrete, there are many variations in mix of each material, and the depth of the pavement and underlying road bed are also prominent factors in pavement life. Bridges are usually constructed of either steel or concrete, but a recent federal study identified eleven bridge structure types. However, the overall design of the bridge, bridge length, total vehicle volumes, age and environment (e.g. exposure to deicing chemicals) are all variables that impact bridge stress and overall life expectancy. As a result, a recent federal study directed by MAP-21 concluded: *"It should be noted that States have different policies and procedures as they relate to bridge posting, rehabilitation, and preservation. It would be extremely difficult to reflect all of those policy differences in a national study."*

In 2012, Congress directed FHWA to undertake an extensive study of national truck size and weight policy. One objective of the MAP-21 Truck Size &Weight (TS&W) study was to "Compare and contrast the potential safety and infrastructure impacts of alternative configurations (including configurations that exceed current federal limts) to the current federal truck size and weight law and regulations…"[2] However, while Congress specifically called out tractor-trailer vehicle combinations with a tri-axle group, quad-axles were not an element of the alternative configuratinos studied. However, the MAP-21 TS&W did an extensive "desk scan" and also reconfirmed previous generalities as they relate to truck weight evaluations:

1. Most research and studies have found that heavier axle loads decrease pavement life.
2. The MAP-21 TSW Study points the difficulty of drawing specific conclusions about impacts on bridges due to weight policy changes, due to the many factors that can impact bridge life and safety: *While comparing the impacts of trucks with a GVW at or below current Federal limit of 80,000 pounds with trucks that operate above those limits, it is important to consider that GVW is not the sole, key consideration in conducting such a comparison. One study evaluated in the desk scan observed that traffic induced flexural stress does not necessarily increase with GVW but is highly related to axle weights and configurations. Another study noted that shorter spans show little correlation between GVW and moment effect. The study goes on to point out that the correlation improves as the span length increases. For example, the study found that when comparing truck induced moment on spans shorter than 60 feet, there is very little difference in the moments induced by 5-axle and 11-axle trucks. However, the study goes on to point out that for spans greater than 60 feet, as the span length increases the moments induced by 11-axle trucks are significantly higher than those induced by 5-axle trucks.*
3. The MAP-21 TSW study also points out that the most prevalent method of assigning costs associated with various vehicle configurations has been the

> “Federal Method” derived from the 1997 FHWA Highway Cost Allocation Study. The MAP-21 TSW study goes on to say: *To implement the Federal Method on a national scale would require a level of detail not available in a consistent format in the National Bridge Inventory System (NBIS) and potentially not available at all. The required information includes detailed structural data for each bridge, bridge-specific condition data, current detailed cost and expenditure data, and weigh-in-motion (WIM) data specifically applicable to bridges. It should be noted that States have different policies and procedures as they relate to bridge posting, rehabilitation, and preservation. It would be extremely difficult to reflect all of those policy differences in a national study.*

The most in-depth and comprehensive research as it relates specifically to quad-axles and the impacts of their use has eminated from Australia and New Zealand. In 2006, the Council of Australian Governments recognized the ‘increased mass benefits for heavy vehicles and the more efficient management of the national freight task. As a result, Australia and New Zealand adopted a radically different regulatory scheme for heavy trucks referenced as the Performanced Based Standards (PBS) scheme. While most countries, including the U.S., use prescriptive limits to regulate truck size and weight, Australia has adopted 16 safety performance standards and 4 infrastructure performance standards that form the regulatory framework. Vehicle configurations regardless of weight and/or size that can meet the standards may be approved for use on one or both of the primary truck networks in Australia. For example, the federal government has established a performance threshold for bridge stress that all vehicle configurations must meet. Any new vehicle design or configuration that meets or exceeds the performance standard can apply to operate legally. Shortly after adopting the PBS scheme, the Australian governemnt sought research to allow the “more general use of quad axle groups in semi-trailer and B-double configurations.”[11] The results of this research is reviewed under the pavement and bridge sections of this report.

Studies Examining Operating Cost Impacts Related to OS/OW Loads

Overall few of the studies examined under the literature review explicitly studied cost factors associated with quad-axles. That said, several studies did examine the impact to carriers and to the public from non-uniformity in regulations. These are the studies that are highlighted in the following section.

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[11] John Edgar Consulting; *Adoption of More General Use of Quad Axle Groups in Semi-Trailers and B-Doubles*. National Transport Commission. Melbourne, Australia. 2007.

Cost Impacts from Non-Uniformity in Permitting Regulations

Several studies used a case study approach to explore the impacts on carrier costs due to inefficient routing or circuitous route requirements stemming from non-uniform permitting regulations among states.

NCHRP Report 830: Multi-State Multimodal, Oversize/Overweight Transportation (TRB 2016)[12]
This research focused on documenting the regulatory differences among states regarding permitted Oversize and/or Overweight (OS/OW) loads. Regarding the impact on carrier operating costs associated with non-uniformity among states, the authors note: "*Carriers prefer to take the shortest path from origin to destination (referred to as the optimal route). In some instances, however, carriers will bypass a state to avoid having to comply with a particularly challenging or costly state requirement, making their journey longer as a result (referred to as the actual route).*" The authors obtained industry cost data which showed that superload trailers (trailers with additional axles) can increase per-mile operating costs. Most states only require civilian or police escorts for many over-dimension super loads:

> *"Police escorts are often required to accompany larger OS/OW loads, but related requirements often differ across states. From an operational perspective, carriers have to work around the hours police will work, plan with district offices, and plan for exchanges at jurisdictional boundaries, all of which contribute to delays and increased costs."*

Together, higher equipment costs and escort requirements can increase super load operating costs by three to 10 times over the cost of a routine OS/OW trailer. The study presented the following table of additional costs that can be occurred based on the industry acquired data:

Table 1: Per Mile Costs Associated with Escorts and Equipment for OS/OW Loads

Vehicle	Low (2013 $)	High (2013$)
Escorts	$1.89	$3.23
Routine OS/OW Loads	$4.23	$4.26
Superloads	$6.45	$6.48

The NCHRP study also examined social costs such as emissions, public facility costs, crashes, noise and unrecovered permitting costs resulting from deviations from inefficient (non-optimal) route miles resulting from non-uniform regulatory issues.

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[12] CPCS, Perkins Motor Transport Inc., and Portscape Inc.; National Cooperative Highway Research Program; Transportation Research Board; National Academies of Sciences. Washington D.C. 2016.

NCHRP Synthesis 476; Practices for Permitting Superheavy Load Movements on Highway Pavements[13]

This study sought to document the practices that states and provinces follow in issuing permits for overweight vehicles and super-heavy commercial vehicles (SHCVs). The researchers collected information using a literature review and survey of state and provincial permitting agencies. Once data had been collected the researchers used a Case Study approach to demonstrate the variation in fees associated with a particular move in different states and also understand the different types of route analyses that states perform for certain loads.

The author concludes that the findings of the study suggest that permitting practices for super-heaving commercial vehicles (SHCVs) could be improved by carrying out and implementing future research on: 1) Methodologies used for evaluating SHCV on pavements, and 2) The approaches for levying permit fees that cover pavement utilization.

Impacts of Route Restrictions on the Movement of Oversize/Overweight Loads in Texas (Texas Transportation Institute, 2012)[14]

In this analysis focused on the State of Texas, researchers examined the cost impacts on industry resulting from the need to reroute loads due to low overpass height restrictions, construction and other activities. The analysis used GIS tools to perform route analyses. Primary research objectives included: 1) developing criteria for assigning current and projected OS/OW groups to the future highway network, 2) Identifying strategic infrastructure improvements to remove barriers or impedances to OS/OW movements, and 3) Developing optimal routes for priority load groups between the most common origins and destinations. Using historical TxDOT permit data and mapping tools, researchers identified the primary OS/OW network in the state, and then analyzed barriers preventing a more efficient routing network.

The research concluded that infrastructure restrictions impose significant constraints on OS/OW routing and cause non-trivial additional costs for the associated industries...Using non-optimal routes due to the current route restrictions is causing an additional 103,775 miles of travel per year for the largest loads—those wider and taller than 16 ft.

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[13] A.T. Papagiannakis; *Practices for Permitting Superheavy Load Movements on Highway Pavements.* National Cooperative Highway Research Program; Transportation Research Board; National Academies of Sciences. Washington D.C. 2015.

[14] Middleton and Li, Texas Transportation Institute. *Impacts of Route Restrictions on the Movement of Oversize/Overweight Loads in Texas*. Paper Submitted to the Transportation Research Board. Washington D.C. 2012

A Synthesis of Overweight Truck Permitting (Purdue University, 2010)[15]
This study was jointly funded by the Indiana DOT and FHWA. It sought to document the revenue streams from the existing permitting process, and synthesize existing methods for quantifying the impacts of additional payloads on pavement deterioration and pavement repair costs. The researchers presented two case studies of the costs to permit two different OS/OW loads in the 8 states in the Midwest. In the first case study Multiple-trip permit fees ranged from a low of $19,200/yr in Minnesota to a high of $80,000/yr in Missouri. In the second case study, single trip permits for the same loads ranged from $1,400/year in Iowa to $152,475 in Wisconsin. The study found that Indiana collects on-average approximately $12 million/year in permit fees. While pavement cost impacts were not explicitly estimated, the authors conclude that permit revenue is insufficient to cover the additional costs to pavements citing previous ESAL research on pavement costs. As a next step the authors recommended conducting a cost allocation study to update load-damage relationships and overweight permit fee structures, to reflect current conditions in Indiana.

Studies Examining Overweight Loads Impact on Pavement

A number of topics and key concepts relating to overweight load impacts on pavements were common across the reviewed literature (shown in Table 2). These included: a direct comparison between quad- and tri-axle groups, measures of Equivalent Single Axle Load (ESAL) or Equivalent Axle Load (EAL) and Standard Axle Repetitions (SAR), impacts on different pavement designs/types, other factors regarding an overweight load's impact on pavement, how to allocate costs to overweight loads, and implications for transportation planners and engineers.

The literature's general consensus is that as the number of axle groups increases the impact on pavement is decreased when measured in equivalent single axle loads (ESAL) or equivalent axle loads (EAL). Data from Ohio's 2007 special hauling permits shows that the average rigid ESAL decreases as the number of axles and average gross vehicle weight increases.[16]

Researchers in Australia examined equivalent axle loads adopted by various road authorities throughout the world and various experimental and theoretical procedures for estimating equivalent loads for different axle groups across granular pavements with thin surface seals and bound pavements.[17] The research found that an interim

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[15] Bilal, M. K., M. Irfan, A. Ahmed, S. Labi, and K. C. Sinha. *A Synthesis of Overweight Truck Permitting*. Publication FHWA/IN/JTRP-2010/12. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University. West Lafayette, Indiana, 2010.

[16] Impacts of Permitted Trucking on Ohio's Transportation System and Economy. Ohio Department of Transportation. 2009

[17] Vuong, B., Jameson, G. *Equivalent Load for a Quad Axle.* ARRB Transport Research. Australia. 2003.

equivalent axle load for a quad axle of 22.5 metric tonnes (49,590 lbs.) was needed to cause equivalent damage to a standard axle.

Subsequent research in Australia compared the impacts on pavement of allowing general access for quad-axle groups operating at 24 tonnes (52,896 lbs) versus a tri-axle group at 20 tonnes (44,080 lbs.), as well as restricted higher mass limit access for a quad-axle group at 27 tonnes (50,508 lbs.) versus a tri-axle group at 22.5 tonnes (49,590 lbs.). The results showed the quad-axle group performed the same or better than tri-axles in a number of scenarios including an 11 percent reduction in pavement wear for single articulated vehicles and about eight percent for B-double vehicles. Overall pavement wear reduction would be dependent on the number of vehicles that would utilize the quad-axle group:

> *The relative effects on pavements of the use of a quad-axle group in lieu of a tri-axle group were calculated for a fixed freight task. Due to the reduced standard axle repetitions (SAR) for a quad-axle group at 24 tonnes over a tri-axle group at 20 tonnes, road wear was reduced by 11 per cent for single articulated vehicles (A124) and about eight per cent for B-doubles (B1243). Net pavement wear reduction would depend on the uptake of vehicles fitted with the quad-axle group*[18]

Beyond the load and axle groups, a number of other factors can influence the wear caused by an overweight load. By utilizing dual tires instead of single tires, Austroads assumes a 53 (kN) load supported by single axle with single tires is the equivalent of a 80 (kN) load supported by a single axle with dual tires; for a tandem axle, dual tires can support a 135 (kN) load versus a 90 (kN) load on single tires.[19] Land Transport New Zealand studied scuffing forces and found that single tires produce higher scuffing forces when compared to dual tires, axle groups with self-steering axles generate less scuffing forces than comparable non-steering axle groups, scuffing forces increase with increasing axle group spread, and the tighter the turn radius the higher the scuffing force.[20] Lastly, as axle spacing is reduced, the less they act as separate entities and the maximum deflection exerted on the pavement increases, but maximum tensile stress can decrease. Thus, axle spacing and the associated impacts on pavement is complex and dependent on the nature of the pavement.[21]

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[18] *Review of Quad-Axle Groups,* National Transport Commission – Australia, March 2016. pp. 16

[19] *The Impact of Heavy Vehicle Traffic on Road Pavements.* http://rcaforum.org.nz/sites/public_files/images/THE%20IMPACT%20OF%20HEAVY%20VEHICLE%20TRAFFIC%20ON%20ROAD%20PAVEMENTS.pdf

[20] Taramoeroa, N., dePont, J. *Characterizing Pavement Surface Damage Caused by Tyre Scuffing Forces.* Land Transport New Zealand Research Report 347. TERNZ Ltd, Auckland. 2008

[21] *Comprehensive Truck Size and Weight Study Volume 2 Chapter 6.* Federal Highway Administration; USDOT. https://www.fhwa.dot.gov/reports/tswstudy/Vol2-Chapter6.pdf

Table 2: Quad-Axle Impacts on Pavement

	Literature	**Cost Allocations**	**Quad- vs. Tri-Axle Comparison**	**Equivalent Single Axle Load (ESAL), Equivalent Axle Load (EAL)**	**Standard Axle Repetitions (SAR)**	**Multiple Pavement Design/ Types**	**Other Factors (i.e. number of tires, axle widths, other axle types, etc...)**	**Pavement Wear (horizontal and vertical forces)**	**Planning Implications (i.e. infrastructure design/strategic routing)**
1	Adoption of More General Use of Quad Axle Groups in Semi-Trailers and B-Doubles (2007)		x		x				x
2	Review of Quad-Axle Groups		x		x		x	x	
3	Characterising Pavement Surface Damage Caused by Tyre Scuffing Forces (2008)						x	x	
4	Impacts of Permitted Trucking on Ohio's Transportation System and Economy (2009)	x		x		x			x
5	The Impact of Heavy Vehicle Traffic on Road Pavements	x		x		x	x		x
6	Effects of Truck Size and Weights on Highway Infrastructure and Operations: A Synthesis Report (2001)	x			x	x	x		x
7	Comprehensive Truck Size and Weight Study Volume 2 Chapter 6 (2000)						x	x	
8	Long-Term Pavement Performance Pavement Loading User Guide (LTPP PLUG) - Part II- Guidelines for Developing Axle Loading Defaults (2013)		x					x	
9	Equivalent Load for a Quad Axel (2003)			x	x	x	x	x	
10	Pavement Impact on Quad Axle Vehicles (2005)		x			x	x	x	
11	Preliminary Methodology for Estimating Cost Implications of Incremental Loads on Road Pavements (2012)	x			x	x	x	x	
12	A New Approach for Allocating Highway Costs (2007)	x				x			x

	Literature	**Cost Allocations**	**Quad- vs. Tri-Axle Comparison**	**Equivalent Single Axle Load (ESAL), Equivalent Axle Load (EAL)**	**Standard Axle Repetitions (SAR)**	**Multiple Pavement Design/ Types**	**Other Factors (i.e. number of tires, axle widths, other axle types, etc...)**	**Pavement Wear (horizontal and vertical forces)**	**Planning Implications (i.e. infrastructure design/strategic routing)**
13	A Synthesis of Overweight Truck Permitting (2010)	x							
14	Impacts of Route Restrictions on the Movement of Oversize/Overweight Loads in Texas								x

Studies Examining Overweight Loads Impact on Bridges

State DOT Studies

The Ohio and South Carolina Departments of Transportation both studied the impacts of overweight trucks on bridges in order to allocate costs associated with the consumed fatigue life caused by overweight movements. [6 & 22] The Ohio study notes that impacts from overweight trucks on pavements have been studied in much more detail than on bridges, while the South Carolina study notes the lack of generalized findings results from the inability to replicate multiple variables such as specific bridge conditions, traffic patterns, truck fleets, and environmental conditions.

Both studies point out the non-linear relationship between bridge damage and truck weight, with bridge damage increasing exponentially for superloads -- those exceeding a state's routine permit limits. According to the Ohio DOT report, "In bridge design the vehicle characteristic of gross vehicle weight is the controlling characteristic. The heavier the largest vehicle expected to use the facility, the greater the structural requirements of that bridge." This is important because as the South Carolina DOT report mentions, an overweight truck may have load demands above the bridge's design load thereby producing a higher stress range and potentailly causing acclereated bridge deterioration, a reduction in service life, and fatigue failure. The overweight truck's impacts are amplified when bridge deterioration, such as cracks, is already underway.

Australia National Transport Comission

As noted previously, the National Transport Commission of Australia's *Review of Quad-Axle Groups* examined quad-axle impacts on pavement and bridges. Under Australia's PBS regulatory scheme, there are essentially two weight standards: General Mass Limits (GML), and Heavy Mass Limits (HML). GML limits apply to all trucks and roadway networks. HML apply only to vehicle configurations that have been accredited under the PBS scheme, and apply to only to the National Road Network. The research that was undertaken explored increasing the weight allowed on quad-axle groups in semi-trailers and B-doubles to operate at: 24 tonnes under general mass limits (GML) and, 27 tonnes under higher mass limits (HML) on suitable routes.

The bridge engineering analysis performed in Australia, employed the country's standard T44 and over-stress testing methodologies. The test used several load factors from 2, in essence placing twice the target load on the bridge to 1.6. Without getting

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[22] Chowdhury, M., Putman, B., Pang, W., Dunning, A., Dey, K., and Chen, L. *Rate of Deterioration of Bridges and Pavements as Affected by Trucks.* South Carolina Department of Transportation; Clemson University. Columbia, South Carolina. 2013.

into the engineering details, the report of the testing concluded, that quad axles with a load of 24 metric tonnes (52,896 lbs):

> *The analysis indicates that the deployment of quad-axle groups at higher mass limits will have an impact on some bridges. The overstress factor method used to test simply supported bridges shows quad-axle groups produce stress results within the maximum permitted levels. Similar tests on continuous span bridges resulted in stress levels at the maximum permitted limit. However, testing the simply supported bridges using the T44 testing methodology resulted in quad-axle group moments greater than the allowable limits by 12 per cent when tested at 24 tonnes. Bridges with spans between 4 and 9 m are vulnerable. Bridges less than 4 m did not have sufficient span to hold the entire quadaxle group, while bridges over 9 m are sufficiently wide to distribute the load over the supports. At the 4 m point the moments start to exceed the T44 maximum limits, peaking to 112 per cent at the 6 m point. There on, the moments start to reduce and go below the threshold at the 9 m point... Overall, the major constraint on replacing a tri-axle group with a quad-axle group is the impact on short-span, simply supported bridges. A key question for road authorities to consider is whether the impact of vehicles fitted with quad-axle groups on short-span bridges can be managed effectively.* [23]

MAP-21 Truck Size and Weight Study

As discussed previously, the most recent, major investigation of truck size and weight limits in the U.S. did not examine quad axles specfically. However,the structural analysis performed for the study did a comparative analysis using the AASHTOWare Bridge Rating® (ABrR) program to analyze the 490 bridges in eleven different bridge types (e.g. reinforced concrete slab, steel beam/grider simple span, etc) for the base case (GVW ≤ 80,000 lb.) and for the proposed alternative truck configurations in the six scenarios (alternative scenario, GVW >80,000 lb.):

> *…the results of this comparative analysis indicate that relatively higher axle loads and/or closely spaced axles negatively impact fatigue life when compared to the two 80,000 control vehicles. The number of stress cycles in a structure is proportional to the number of trucks that cross the bridge during its service life. The study team performed fatigue life evaluations based on the assumptions that each truck loading cycle causes some damage. The damage caused by each truck depends on the weight, the bridge's span length, and member section properties. In this area of the study, the study team investigated the effect of*

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[23] Ibid, National Transport Commission – Australia, 2016

> *trucks that exceed Federal weight limits) on bridge decks. One approach was to look at States that allowed heavier trucks in comparison to States that do not allow heavier than Federal legal limit trucks. Efforts in this area of the Study were not productive due to the reasons stated above—e.g., variations in States' approaches, allocators used, etc.—and because all States do issue overweight permits for loads heavier than the legal maximum. Furthermore, bridge deck thickness, girder or floor-beam spacing, and other general characteristics differ from one bridge deck to another.*

In summary the analysis concluded:

> *The findings generally indicated that relatively heavier axle loads and axle groupings tend to negatively affect fatigue life when compared to the control vehicles. However, any overall reduction in bridge fatigue life depends on the number of relatively heavier trucks that are in the traffic stream. In general, fatigue-related costs in steel bridges are small compared to the total bridge program cost.*[24]

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[24] *Bridge Structure Comparative Analysis Technical Report;* Comprehensive Truck Size and Weight Limits Study, USDOT. June 2015. pp. ES-8 and 12.