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Overweight Permit Fee Structure Development

Arizona Department of Transportation Research Center

ADOT

Overweight Permit
Fee Structure Development

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16. Abstract

Federal and state laws limit the legal maximum gross vehicle weight of commercial vehicles operated on a highway network. The operator of a vehicle wishing to operate above these weights must obtain a permit prior to travel from the jurisdiction(s) to be entered. For travel on state and US highways, state statutes and regulations govern the allowable weights, place restrictions on distribution of those weights across axles, and set travel restrictions. On the Interstate Highway System, however, federal law governs allowable weights. Current federal law limits gross vehicle weight on most interstate highways to 80,000 pounds when distributed across five or more axles. The objective of this report is to support the policy analysis of the Arizona Department of Transportation (ADOT) as to whether to allow overweight nondivisible loads in sealed shipping containers onto the Interstate Highway System between the Mariposa Port of Entry and the Port of Tucson (and in the reverse direction).

The project addressed three questions. First, was the estimated infrastructure cost due to damages that would be incurred by ADOT if it allowed heavier permitted vehicles in the study area in addition to the existing flow of permitted nondivisible vehicles. The research considers the expected infrastructure impacts to structures and pavements of a potential overweight nondivisible load permit for sealed shipping containers in intermodal travel utilizing the corridor between the border with Mexico at Nogales and Metropolitan Tucson on interstate highways. The second question was what fees would be necessary to recapture the cost of any infrastructure impacts. The third question was what would be the potential techniques and technologies for ensuring compliance in the study corridor should a permit program be implemented.

The project team calculated the cost of mitigating the resulting damage using ADOT-provided unit cost values. The estimated cost of mitigation was between $5.18 and $5.38 per equivalent single-axle load mile. In addition to the direct costs of the permit, additional items are important for determining the permit fee. This report addresses four of the most common costs considered in the fee setting process: project overhead, permitting technology, increases in enforcement, and increases in program administration.

The report recommends using four principles to govern the structure and compliance requirements of the permit: generally, that the origin or destination of the permitted vehicle be an intermodal facility; that the permit be used for a single trip; that the carrier provide information adequate to document compliance with federal policies; and that no additional permit be issued if the existing Mariposa Point of Entry permit can be issued for the trip.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ACRONYMS

Term	Definition
AADT	annual average daily traffic
AADTT	annual average daily truck traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
ADOT	Arizona Department of Transportation
ALF	axle load factor
CBP	US Customs and Border Protection
CTSWL	comprehensive truck size and weight limits
ESAL	equivalent single-axle load
EUAC	equivalent uniform annualized cost
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
GEF	group equivalency factor
GVW	gross vehicle weight
HCA	highway cost allocation
HMA	hot mix asphalt
HPMS	Highway Performance Modeling System
IRI	International Roughness Index
JPCP	jointed plan concrete pavement
LCV	longer combination vehicles
LTPP	long-term pavement performance
MAP-21	Moving Ahead for Progress in the 21st Century Act
MDR	material design reports
MR&R	maintenance, rehabilitation, and repair
NCHRP	National Cooperative Highway Research Program
NHS	National Highway System
OW	overweight
OSOW	oversize/overweight
PaveME	AASHTOWare Pavement ME software, v2.1
PCCP	portland cement concrete pavement
SCDOT	South Carolina Department of Transportation
SSC	sealed shipping container
TOT	truck only toll
TRB	Transportation Research Board
TRC	Texas Transportation Code
TSW	trucks size and weight
TxDOT	Texas Department of Transportation
US	United States
USDOT	United States Department of Transportation
VMT	vehicle miles traveled
WIM	weigh-in-motion

EXECUTIVE SUMMARY

INTRODUCTION

Federal and state laws limit the legal maximum gross vehicle weight of commercial vehicles operated on a highway network. Before traveling, the operator of a vehicle wishing to operate above these weights must obtain a permit from the jurisdiction(s) to be entered. For travel on state and US highways, state statutes and regulations govern the allowable weights, place restrictions on distribution of those weights across axles, and set travel restrictions. On the Interstate Highway System, however, federal law governs allowable weights. Current federal law limits gross vehicle weight on most interstate highways to 80,000 pounds when distributed across five or more axles, according to what is known as the "federal bridge gross weight formula."

The Arizona Department of Transportation (ADOT) is considering the policy question of whether to allow overweight nondivisible loads in sealed shipping containers onto the Interstate Highway System between the Mariposa Port of Entry and the Port of Tucson (and in the reverse direction) on Interstate 19 and Interstate 10. This project examines the estimated infrastructure cost that ADOT will incur by allowing heavier permitted vehicles in the study area in addition to the currently permitted nondivisible vehicles. The research considers the expected impacts to structures and pavements of issuing an overweight nondivisible load permit for sealed shipping containers in intermodal travel on the interstate highways between the Mexican border at Nogales and Metropolitan Tucson. The project also considers the fees necessary to recapture the cost of any infrastructure impacts. Finally, the project considers potential techniques and technologies for ensuring compliance in the study corridor should a permit program be implemented.

The study corridor includes the entire length of I-19 as well as the portion of I-10 between Exit 260 (I-19) and Exit 269. The intermodal terminal connecting the highway with the Union Pacific railroad at the Port of Tucson is at the northern end of the study corridor.

RESEARCH CHALLENGE

Given federal truck size and weight laws and regulations, and the unique geography around I-19 (where there are no other parallel non-interstate highways between Exits 40 and 48), I-19 would have to be used for travel in the region. As a result, the only nondivisible loads that ADOT could permit under federal law would be Customs-sealed international shipping containers exceeding legal weight and used in intermodal moves.

An operator would be required to obtain an ADOT permit for the type of movement being evaluated. This permit would not replace the current permit available for a 25-mile zone around the Mariposa Land Port of Entry. A carrier could hold both permits: the existing permit for travel within the 25-mile zone and the new permit for travel between the Mariposa Port of Entry (or the 25-mile zone) and the Port of Tucson (in either direction).

The cost recovery question has three parts, as shown in Figure 1:

- The total damage affects the permit fee needed if one is to recapture the damage costs;
- The permit fee affects the demand for the permit; and
- The permit utilization affects the total damage.

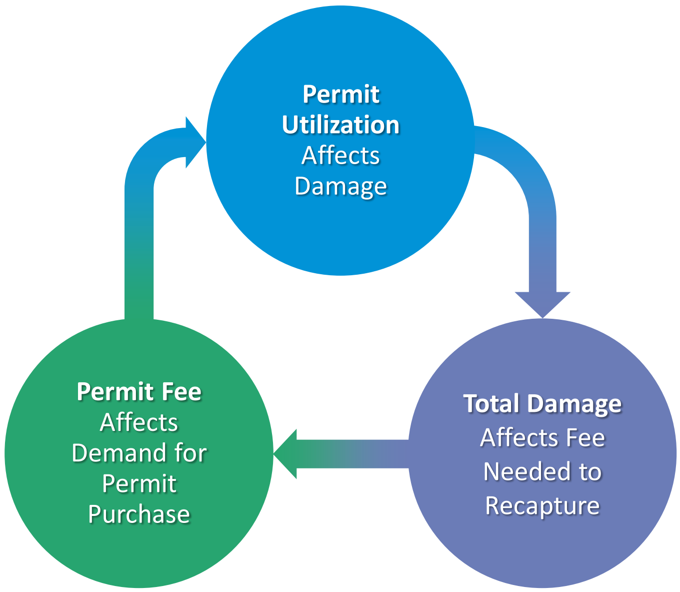

Figure 1. Relationship Among Cost Components

RESULT

The demand for the permit would be based on three factors: the need for international, intermodal container travel, the types of commodities that are currently not utilizing the entire container due to the weight limit, and the permit cost.

The analysis initially considered four scenarios for vehicle configuration. Only one scenario, a vehicle with total gross weight of 90,800 pounds over five axles, had sufficient demand for trips to warrant cost calculations. The other scenarios involved heavier loads, for which carriers would have to make capital equipment investments or required truck/rail connections, and stakeholders stated that the demand was insufficient to justify such investments or operational changes.

An estimate of 100 existing trucks per day was used to estimate infrastructure damage. This estimate was based on analysis of available commodity data, customs data, and anecdotal comments made by potential shippers, manufacturers, and carriers. In each scenario, the existing trucks were replaced by a correspondingly smaller number of permitted vehicles with heavier weight, keeping a similar total amount of cargo shipped but shifting the axle weight distributions used in the engineering analysis.

METHODOLOGY

The analysis for this study used four primary inputs, as shown in Figure 2:

- The expected total truck traffic along the study corridor for commodity shippers likely to purchase a permit for overweight loads, if it were made available.
- Total traffic along the study corridor, so that the infrastructure software can be properly configured.
- Inventory data about structures and pavement sections.
- Cost data about projects necessary to either rehabilitate or replace structures and pavement sections when weight-based damage occurs.

Similarly, the study involved four primary calculations:

- An estimate of the number of current vehicles for which carriers will purchase a permit.
- Inputs to infrastructure models (pavement and structures) about the new mix of traffic across the infrastructure when the permit is implemented.
- Increased infrastructure damage from the new traffic mix.
- The appropriate fee to recapture the cost of projects to rehabilitate or replace the infrastructure due to the newly increased damage.

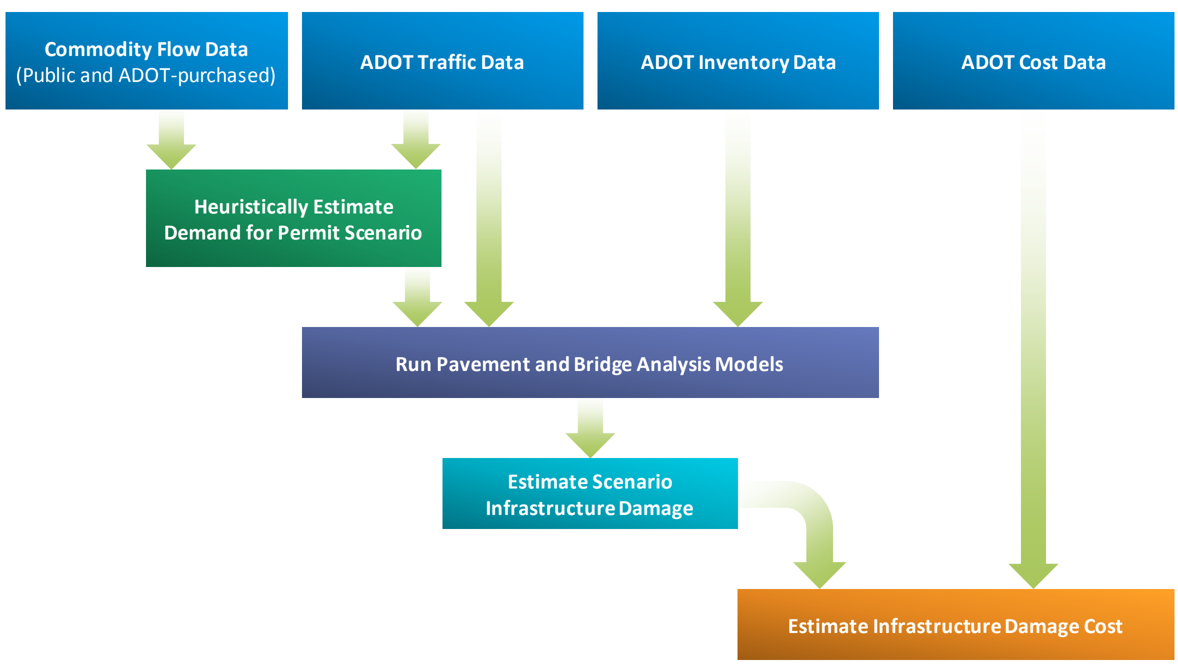

Figure 2. Schematic of the Analysis Methodology

The study assumes that each opportunity to purchase a permit will cause an existing truck and its associated axle weights to be replaced either by a new truck with higher axle weights or by no truck (because the cargo has been shifted to other permitted containerized trucks).

TOOLS AND DATA

The study used ADOT's existing tools for structural and pavement analysis. Structures and pavement sections were categorized, and representative samples were used in damage and cost calculations. Eight structure categories and five pavement categories were used. The analyses were conducted in 2016 and the first three months of 2017 using current data.

LITERATURE REVIEW AND STAKEHOLDER INPUT

In parallel with the start of the data acquisition effort, the project involved a literature review and stakeholder interviews. The research team identified relevant literature to provide guidance on the state of the practice in related areas of research. No literature was found to reject the team's analysis methodology or any of the processes currently used by ADOT.

Stakeholder input was gathered at a series of meetings in the study area and was augmented by follow-up conversations by teleconference. Stakeholder sentiment was mixed in both the public sector and industry, with some stakeholders pointing to the need for intermodal rail movement as a limiting factor.

FINDINGS

The cost calculated in this study is the cost of the expected infrastructure damage from allowing the new permit. It is not the cost of the permit itself, the pricing of which must consider other factors.

The project team calculated the cost of mitigating the resulting damage using ADOT-provided unit cost values. The tabulated cost of mitigation was between $5.18 and $5.38 per equivalent single-axle load (ESAL) mile. The variability in the data, however, and especially the demand data, leads the research team to posit that the cost of mitigation may be as high as $7 per ESAL-mile.

CHAPTER 1. OVERVIEW

Federal and state laws limit the legal maximum gross vehicle weight of commercial vehicles operated on a highway network. Before traveling, the operator of a vehicle wishing to operate above these weights must obtain a permit from the jurisdiction(s) to be entered. For travel on state and US highways, state statutes and regulations govern the allowable weights, place restrictions on distribution of those weights across axles, and set travel restrictions. On the Interstate Highway System, however, allowable weights are governed by federal law.

Current federal law limits gross vehicle weight on most interstate highways to 80,000 pounds when distributed across five or more axles, according to what is known as the “federal bridge gross weight formula” (23 USC §127; 23 CFR §658). The majority of states, including Arizona, may issue permits for travel on interstate highways at higher weights only when the load is considered nondivisible, meaning that the load cannot be reduced in size or weight without compromise of the vehicle’s intended use, destruction of the load or vehicle’s value, or the need to perform more than eight work hours to dismantle (Federal Highway Administration 2018). A further clarification of nondivisibility was made by the US Federal Highway Administration (FHWA) in the early 1980s, to the effect that goods transported in Customs-sealed international intermodal containers could, at the state’s option, be treated as nondivisible. This policy clarification is often referred to as the “Barnhart Letter,” referring to a 1984 letter from a former FHWA administrator to the state agency that requested the clarification.

In Arizona, Customs-sealed international shipping containers exceeding legal weight had not previously been allowed to travel on interstate highways. The Barnhart Letter says that states may, but are not required to, allow these movements if a permit has been issued. As a result, a patchwork of states allows such moves on some or all of the Interstate system.

This report summarizes the activities and findings of SPR-735, the Overweight (OW) Permit Fee Structure Development project. The project considers the expected infrastructure impacts to structures and pavements of a potential overweight nondivisible load permit for sealed shipping containers (SSC) in intermodal travel on the interstate highway corridor between the border with Mexico at Nogales and Metropolitan Tucson. The project also considers the fees necessary to recapture the cost of any infrastructure impacts. Finally, the project considers potential techniques and technologies to ensure compliance in the study corridor should a permit program be implemented.

The entire length of I-19 is in the study corridor, as is the portion of I-10 between Exit 260 (I-19) and Exit 269. The intermodal terminal at the Port of Tucson is at the northern end of the study corridor; there is an intermodal connection to the Union Pacific railroad at the Port.

An operator would be required to obtain an Arizona Department of Transportation (ADOT) permit for the type of movement being evaluated. This permit would not replace the current permit available for a 25-mile zone around the Mariposa Land Port of Entry. Part of the research’s goal is to determine the effective characteristics of the permit, such as the number of trips for which the permit would be valid. The research statement also considers the implications of goods movement and network distances associated with the permits for compliance and enforcement strategies to ensure that only vehicles with truly intermodal and international movements utilize the permit.

The research indicated that the appropriate permit would be for a vehicle of five axles and a gross vehicle weight of up to 90,800 pounds. This permit would allow carriers to maximize container weight for double-stack rail operations to fulfill the intermodal component of the trip requirements under federal law. After analyzing commodity flow data, the research team anticipates that a maximum of 100 vehicles per weekday would be suitable candidates for such a permit, yielding 80 corresponding permit vehicles (as the permit would allow consolidation of travel).

TECHNICAL METHODOLOGY

The research considers how to use data about current traffic on I-19, primarily either into or out of Mexico, to extrapolate the infrastructure damage that would be caused by vehicles issued new permits. The research uses information about current international goods movement in the study corridor to estimate the likelihood of converting the goods movement to heavier permitted loads. The methodology to attain this result has three components:

- Understand the goods and commodities currently moving in the study corridor, and make assertions as to the percentage of traffic that would benefit from higher weights for both a SSC and an intermodal transfer. For example, raw materials delivered by ship from Asia to Mexico via the Port of Long Beach are already in containers, and today they would be broken into smaller legal truckloads either in California or in Tucson.
- Estimate the infrastructure damage to a sample of bridges and pavements, presuming that the carriers for that percentage of traffic could obtain a permit that was completely free, and calculate the contribution per vehicle trip over a planning horizon.
- If necessary, reduce the projected demand based on the initial cost, as the extra cost per ton of product moved may prevent some types of carriers from purchasing the permit, and iterate.

This approach, illustrated in Figure 3, shows that the cost recovery question has three related components:

- The total damage affects the permit fee needed if one is to recapture the damage costs.
- The permit fee affects the demand for the permit.
- The permit utilization affects the total damage.

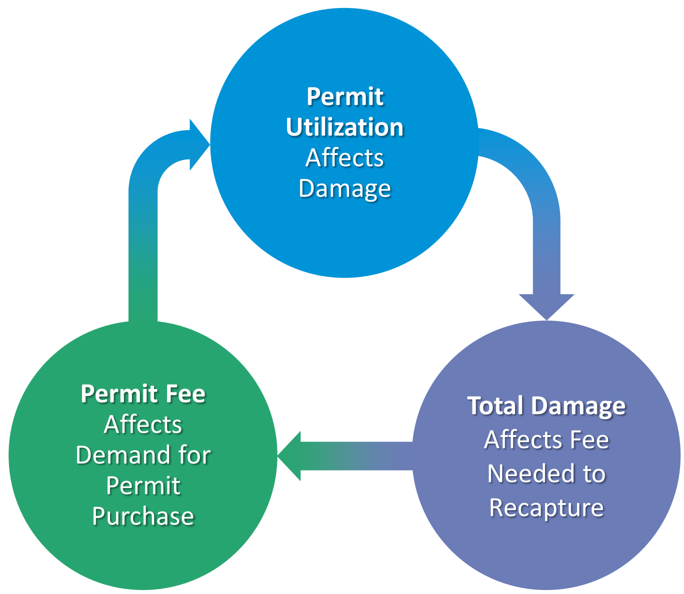

Figure 3. Relationship Among Cost Components

The infrastructure damage portion of the cycle is based on an understanding of changes in the traffic load on bridges and pavement that will result from the issued permit. Figure 4 illustrates the methodology for estimating the cost of infrastructure damage.

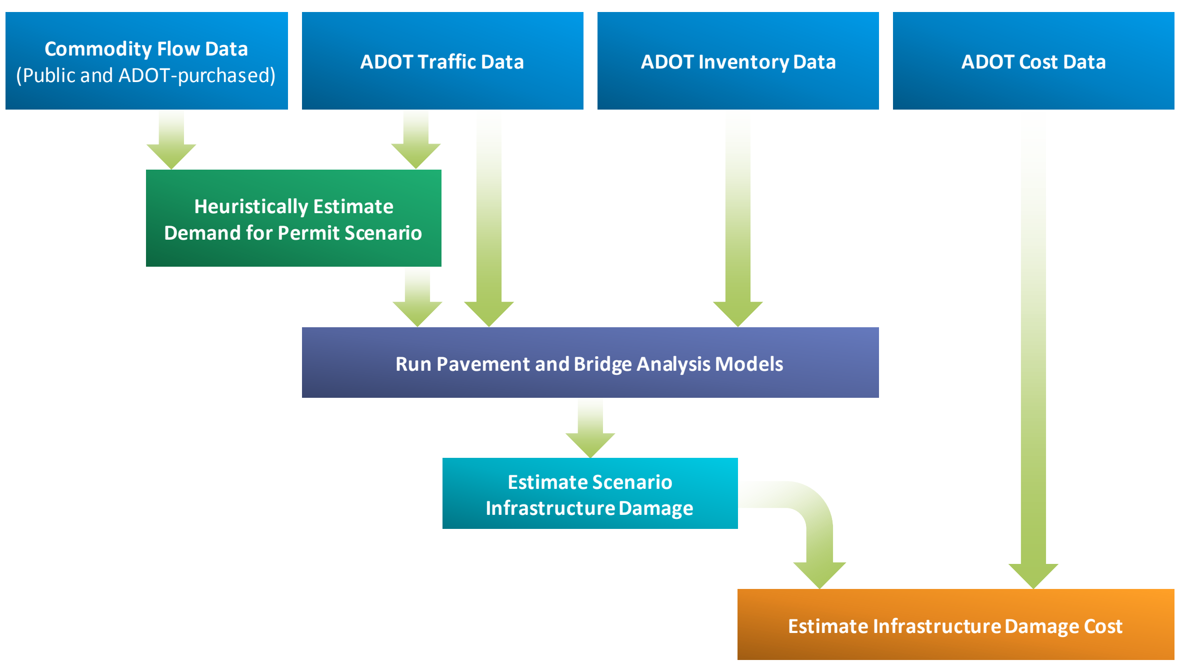

Figure 4. Schematic of the Analysis Methodology

There are four primary data inputs to the methodology:

- The expected total truck traffic along the study corridor for commodities likely to use a permit for OW loads if a permit were made available.
- Total traffic along the study corridor, so that the infrastructure software can be properly configured.
- Inventory data about structures and pavement sections.
- Cost data about projects needed to either rehabilitate or replace structures and pavement sections when weight-based damage occurs.

Similarly, the methodology makes four primary calculations:

- An estimate of the number of current vehicles for which carriers will purchase a permit.
- Inputs to pavement and structure infrastructure models about the new mix of traffic across the infrastructure when the permit program is implemented.
- Increased infrastructure damage from the new mix of traffic.
- The appropriate fee to recapture the cost of projects to rehabilitate or replace the infrastructure due to the increased damage.

Each opportunity to issue a permit will cause an existing truck and its associated axle weights to either be replaced by a new truck with higher axle weights or be replaced by no truck because the cargo has been shifted to other permitted containerized trucks. Figure 5 illustrates a typical shift of axle loads, where the red line represents the traffic axle weight distribution before the permit and the blue line represents the traffic axle weight distribution after the permit. In this example, the permit is for a 90,800 pound gross vehicle weight on five axles. (The various permit configurations that were studied are discussed in Chapter 4.) The 90,800-pound permit on five axles is denoted as Scenario 1.

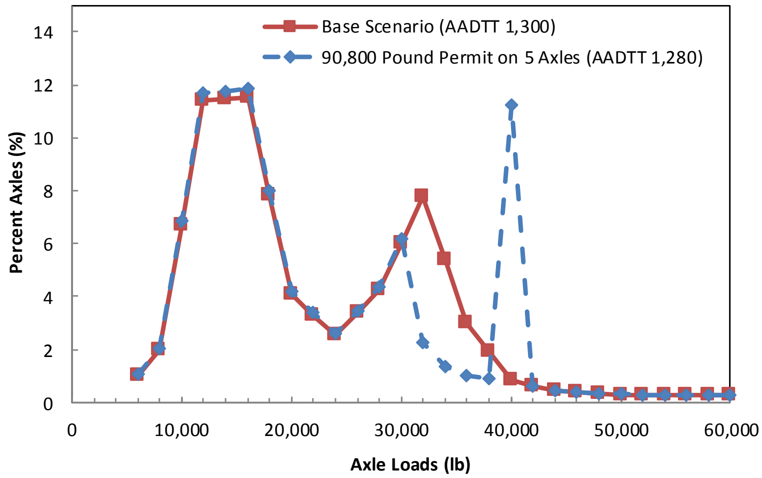

Figure 5. Application of Permit Scenario to Existing Traffic Distribution

Once the new traffic axle weight distribution is known, the appropriate ADOT engineering software can be used to compare the impacts on the bridges and pavement sections in the study corridor. A sample of bridges and pavement sections was used to represent both the length of I-19 and the small section of I-10 in the study corridor, and the results were extrapolated to the overall study area according to the characteristics of the remaining bridges and pavement sections.

An initial estimate of permit utilization was obtained through a mix of stakeholder interviews and analysis of available northbound freight commodity data. Commodity data were obtained from both the US Customs and Border Protection (CBP) and ADOT, which supplied data previously purchased for use in its statewide freight plan. The number of permits to be purchased that was estimated from the data sets was much lower than the number indicated in the feedback of stakeholders. As a result, the estimated number of potential permits was increased to ensure the analysis included sufficient sensitivity in the engineering software to generate meaningful results that could be prorated to a per-permit basis. If the lower number of permits were to be used, a low benefit would be difficult to differentiate between the vehicles not causing damage or there simply not being enough vehicles.

The fee calculation was based on the total infrastructure damage over an estimated life span of the structure or pavement. The research anticipated 20 years of permit purchases, but the damage calculations were tabulated as needed for the entire remaining lifespan of the infrastructure. The damage calculated was then tabulated and prorated across the permit volume. The specific methods for calculating damage to bridges and pavement sections were slightly different because of the inputs to the software packages used to calculate the infrastructure damage.

REPORT ORGANIZATION

This report is divided into seven chapters, representing the methodology of sequencing the research activities. Chapter 1 provides an overview of the report and the context of the project. Chapter 2 summarizes a review of available literature on the topic. Chapter 3 summarizes a review of collected information, including information and data available from ADOT, information gathered through outreach with stakeholders in the study region, and a review of information about international SSC travel available from the other states that border Mexico. Chapter 4 presents the results of the research team's analytical processes, including analysis of eight representative bridges and five representative pavement sections, and an analysis of data representing potential traffic in the study area where an international SSC permit may be relevant. Chapter 5 describes the permit frameworks that ADOT can consider given the analysis results and the corresponding fees that would be needed to recapture the infrastructure costs. Chapter 6 describes the compliance policies and approaches available to ADOT to ensure that transport of goods using an international SSC permit is lawful and meets the spirit of the Barnhart Letter; this chapter also describes how a pilot process could be used to test such approaches. Finally, Chapter 7 presents conclusions and recommendations.

CHAPTER 2. REVIEW OF LITERATURE

INTRODUCTION

The research team identified relevant literature about the state of the practice in areas of research related to OW permits. While the literature on the topic of overweight commercial traffic is growing, this literature review is based on materials freely available during the beginning of the study period (summer 2015).

The literature review was designed around categories of literature. The project team originally identified 34 items of potential interest. After consultation with ADOT, the project team performed detailed reviews of 15 items and found that three items were not relevant to the findings. The remaining 12 items are summarized in this chapter.

FINDINGS

All of the permit fee studies reviewed included assumptions about fleet mixes, potential vehicle configurations, and adoption rates; however, the reviewed literature did not identify overall cost to the trucking industry associated with new vehicle purchases, changes in operating schedules or routes, or increased wages or other factors associated with transporting heavier loads. Nothing in the reviewed literature conflicted with the team's methodology or any of ADOT's current processes.

With respect to cost calculation methodology, the literature confirmed the applicability of the federal method for bridge deterioration modeling. The National Cooperative Highway Research Program (NCHRP) "Report 495: Effect of Truck Weight on Bridge Network Costs" (National Cooperative Highway Research Program 2003) presents a methodology that is superior to alternate methods for generating cost information for Arizona infrastructure and provides an adequate framework for this analysis. The methodology allows for scenarios where a new travel pattern includes loads that would exceed the operating rating threshold of the bridges, while providing a framework for capturing costs for bridges with smaller changes to the operating rating threshold. The NCHRP 495 methodology was designed to support network analysis. Even though the study area is a single highway, the methodology is suitable for ADOT to utilize in other future policy analyses, as the single highway case can be extrapolated to the broader network approach.

The methodology estimates bridge network costs resulting from changes to truck weight limits by using four cost impact categories:

- Fatigue of existing steel bridges.
- Fatigue of existing reinforced concrete decks.
- Deficiency due to overstress for existing bridges.
- Deficiency due to overstress for new bridges.

These categories are chosen because their cost impact is generally quantifiable when based on current available data. Earlier, Transportation Research Board (TRB) Special Reports 225 and 227 ("Truck Weight

Limits: Issues and Options" and "New Trucks for Greater Productivity and Less Road Wear: An Evaluation of the Turner Proposal") had noted that trucks produce significant damage to highway bridges (TRB 1990a, 1990b). A truck's gross weight, axle weights, and axle configuration (collectively referred to as "truck weight" in this study) directly affect the useful life of highway bridge superstructures. Building on this information, the team also explored critical issues associated with stakeholder outreach, market penetration, factors that encourage load diversion, and the general environment for overweight permitted operations in the study corridor.

Although Project 495 was focused on bridges, the team asserts that a similar general approach is appropriate for pavement analyses. The specific categorizations and calculations—for example, a pavement section's base thickness and material type instead of steel versus concrete bridges—may differ, but the approach shown in Figure 4 utilizes the Project 495 concepts in an asset-independent framework.

LITERATURE SELECTIONS

The remainder of this chapter describes in greater detail selected literature reviewed for this project and its application in the context of the current study. These reviews are intended to offer observations as they relate to the potential permit that is the focus of this research project.

1. Costs and Revenues Associated with Overweight Trucks in Indiana (Ahmed et al., 2012)

Summary. This study estimated highway pavement and bridge costs for overweight trucks for the State of Indiana and analyzed the adequacy of permit revenues to cover these costs. The overall additional cost to the trucking industry for hauling overweight loads was not mentioned in this report.

For both pavements and bridges, models/strategies of cost incurrence for maintenance, rehabilitation, and repair (MR&R) were used to estimate the costs, along with replacement cost. For flexible pavements, for example, one model/strategy was to apply thin hot mix asphalt (HMA) overlay every 20 years and crack sealing every three years. The total life cycle cost estimate was then based on the agency's unit costs for these activities, distributed by Equivalent Single-Axle Load (ESAL)-mile. The overweight truck fee for pavement was recommended accordingly. It was estimated as ranging from $0.006 per ESAL-mile on interstate highways to $0.218 per ESAL-mile on non-interstate national highways for the Indiana Department of Transportation.

This study also conducted a sensitivity analysis of the pavement damage cost with respect to the pavement life-cycle length, discount rate, rest period, effectiveness of rehabilitation treatments, and cost of pavement reconstruction and rehabilitation treatment. The results suggested that the pavement cost estimates are highly sensitive to pavement life-cycle length, although the life-cycle length used in the study is not based on historical data. Such a sensitivity analysis is plausible because data used in these types of estimations may not be reliable or available. This basic analysis can help decision makers understand how reliable the final results can be. In our study, data are insufficient to measure the sensitivity effectively because of the challenges in identifying permit demand.

While the approach for pavement cost estimations appears reasonable given the accepted theory about pavement deterioration as a material fatigue process, the same approach applied to bridges is questionable because bridge deterioration has not been accepted or formulated as a fatigue-related (i.e., a load-time interacting) process, except for steel member fatigue.

In summary, this study may be acceptable for broad planning purposes. It is not possible to verify or confirm the estimated results because of the assumptions used.

2. MAP-21 (Moving Ahead for Progress in the 21st Century Act) Comprehensive Truck Size and Weight Limits Study (US Department of Transportation 2015)

Summary. This is the most recent report of the USDOT on the broader subject of truck size and weight impacts for various load configurations. The study examined six scenarios of new truck configurations and estimated cost impacts relating to pavements and bridges, along with other impacts. Cost impact to the trucking industry was not analyzed, however.

For bridge costs, the FHWA study team reviewed numerous reports and studies including federal- and state-sponsored studies as well as those conducted in other countries. In particular, concepts and information from the previously mentioned NCHRP Report 495, "Effect of Truck Weight on Bridge Network Costs" (2004), was considered for use in developing a methodology to estimate bridge costs and needs. The report stated, "The most prevalent method used in the United States in the past decade (1997–2012) has been the 'Federal Method,' as described in the 2003 NCHRP Report 495–Effect of Truck Weight on Bridge Network Costs."

The cost impact estimation in the report for strength-related categories followed the federal method, which is a departure from previous federal truck size and weight studies. A sample of 490 bridges was used to represent the population of 88,945 bridges on the National Highway System (NHS). The total cost for the population was then projected using the sample bridges' data to estimate the costs of either rehabilitation or replacement, depending on cost effectiveness.

This report did not include cost impact estimates for fatigue-related consumption of bridge components (neither steel component fatigue nor reinforced concrete deck fatigue); nevertheless, the report did include a review of these two topics, largely referring to NCHRP Report 495. The two examples included in NCHRP Report 495 show that additional cost for steel fatigue due to overweight trucks can be very low, mainly due to the low cost of repair (compared with the costs of bridge replacement due to inadequate strength); however, additional reinforced concrete deck fatigue due to overweight loads can become expensive to fix if axle load magnitude is not well controlled/enforced.

In summary, the latest federal comprehensive truck size and weight limits (CTSWL) study has accepted and adopted the methodologies developed in NCHRP Report 495.

For pavement cost impact estimation, typical flexible and rigid pavement sections were selected using the long-term pavement performance (LTPP) database. In addition, the sites included in the field calibration studies represent four geographically diverse states in the United States. These sites were selected to serve as a starting point in determining the impact of different truck traffic levels.

Using the FHWA 2012 Highway Performance Modeling System (HPMS) data as a reference, the report identified pavement cross sections corresponding to low-, medium-, and high-volume highways. In doing so, the report explored a number of alternative cross sections in order to ensure that the selected cross sections encompass the range of pavements in the NHS from a standpoint of both layer thicknesses and expected performance.

The load and load volume information was gathered using weigh-in-motion (WIM) data and annual average daily truck traffic (AADTT) of sites. It was not clearly stated how the focused new truck scenarios were considered under different truck axle load distributions and truck traffic volumes. These elements are expected to change the cost of maintaining the pavement service and performance. NCHRP Report 495 developed a method for predicting such changes as the input to decision making models for design and maintenance. Allowing heavier gross vehicle weight (GVW) can reduce pavement cost (i.e., can incur a negative cost impact) if the total payload remains unchanged and the axle load is maintained because of fewer trips. When axle loads remain the same, each axle load's damage to the pavement remains the same, while the number of loadings (proportional to the number of trips) is reduced. As a result, pavement consumption can be reduced under such overweight load scenarios.

3. A Practical Approach for Determining Permit Fees for Overweight Trucks (Banarjee et al. 2015)

Summary. This paper presents an approach for setting permit fees for overweight trucks based on consumption of the service life of highways. Permanent deformation, load-related fatigue damage, and roughness scores were used as descriptors to estimate service life consumption for flexible pavements and punchouts, and roughness measures were used to estimate service life consumption for rigid pavements. The experiment included flexible and rigid pavement sections with varying structural numbers and slab thicknesses, spread across the State of Texas to account for climatic and geographical differences.

The behaviors of each of the pavement sections were simulated under different loading conditions to reflect the full spectrum of axle weights that are characteristic of single, tandem, tridem, and quad axles. Group equivalency and axle load factors (GEF and ALF) were developed for individual axle groups. The determination of axle-specific parameters made it possible to adopt a modular approach to determine gross load equivalencies for any truck category without any restriction on axle weights or configuration.

Service life consumption was calculated as "the additional pavement structure that would be required to accommodate OW traffic in excess of the design truck volume while ensuring the same terminal distress condition." The cost of providing additional pavement structure to offset the reduced service life was assigned to "the responsible truck fleet in proportion to the marginal load equivalency over the legal GVW and axle weight tolerances."

The report considered a scenario in which the total number of ESALs owing to the OW truck fleet equals the number of ESALs for the design truck volume. Designing the pavement structure to exclusively cater to OW truck volume was not considered, however, as the highway facility was designed for the design truck traffic; therefore, the additional structure necessary to accommodate the OW truck traffic (in addition to the design traffic volume) was determined, and the associated costs were apportioned on the basis of the marginal additional structure necessary. In the case of flexible pavements, these costs were estimated using each of the three primary distress mechanisms discussed earlier: rutting, cracking, and roughness. In the case of rigid pavements, costs were assessed using punchout and roughness (functional deterioration of pavement).

An important part of the procedure involved obtaining reliable estimates for construction costs. Unit costs were multiplied by the total quantity of required material to determine the construction costs per lane mile under the damage calculations. The authors determined the apportioned fee in $/mile/ESAL: $0.037/mile/ESAL for asphalt concrete pavement (AC) and $0.029/mile/ESAL for portland cement concrete pavement (PCCP).

4. 129,000-Pound Pilot Project, Report to the 62nd Idaho State Legislature (Idaho Transportation Department 2013)

Summary. In 2003, the Idaho Legislature passed House Bill 395, creating a pilot project to test the effect of increasing the legal truck weights on state highways. Trucks configured to increase GVW from 105,500 pounds to 129,000 pounds were permitted on 16 specified routes. In 2005 and 2007, an additional 19 routes were included for a total of 35 specified routes. This report to the Idaho legislature measured the effect of the pilot project, particularly with respect to highway safety and cost impacts on pavements and bridges.

The Idaho Transportation Department did not observe any significant effect of the 129,000-pound pilot project trucks on pavements, bridges, or roadway safety. This conclusion was reached by comparing data generated before and after the implementation of the pilot project, for pilot routes, most highly utilized pilot routes (State Highway 24, State Highway 25, and State Highway 78), and non-pilot routes. The data included crash rates, pavement rutting depths, pavement cracking indices, pavement roughness indices, and bridge condition ratings.

The cost to participating carriers of acquiring or changing equipment to be able to operate at higher weights was not calculated. Significant savings of millions of dollars were reported by participating truck companies in this pilot project. Follow-up conversations indicated that most carriers participating in the pilot did not purchase new equipment but merely added weight to existing configurations.

NCHRP Report 495, which developed the federal method referred to in the latest report for the USDOT Comprehensive Truck Size and Weight Limits Study (Item 3 above), included Idaho as one of the two application examples. The scenarios covered in that example are based on an earlier pilot project for years 1998 to 2000 and for two routes only (as opposed to years 2003 to 2013 and for 35 routes as mentioned above). One of these two routes in the earlier pilot project is SH 25, which was also identified in this Idaho report as one of the three most utilized pilot routes. As in NCHRP Report 495, very insignificant cost impact was identified. This Idaho report thus offers a verification of NCHRP Report 495 and its federal method, although the scenarios are not identical to each other or to the single-route scenario used in this SPR-735 research. To the best of this research team's knowledge, NCHRP Report 495 represents the only research effort relevant to cost impact estimation for overweight trucks that has been verified by results in practice.

5. Rate of Deterioration of Bridges and Pavements as Affected by Trucks (Chowdhury et al. 2013)

Summary. This report estimates pavement and bridge costs for overweight trucks in South Carolina. The study assumed that 8.3 percent of the trucks in each truck category were loaded up to or over the maximum limit. This 8.3 percent figure was based on WIM data collected at the St. George WIM station on I-95. This assumption was used for both pavement and bridge damage cost estimations. This percentage appears to be high, compared with percentages reported in other literature. For example, Indiana reported that less than one percent of the entire truck population is overweight in that state. While differences can be expected in certain commodities or geographic locations, the larger percentage of overweight loadings seems high in this study. Furthermore, WIM data does not represent vehicle miles traveled (VMT).

For pavements, the analysis focused on flexible pavements "because asphalt is the predominant paving material used in South Carolina from a system perspective (i.e., all functional classes)." All pavements were assumed to have the same HMA Surface Course, HMA Intermediate Course, and Graded Aggregate Base Course thicknesses. The thickness of the HMA Base Course varied depending on the pavement design.

Using the unit cost of flexible pavements of South Carolina Department of Transportation (SCDOT), the analysis estimated the cost impact on pavements due to overweight trucks as the difference between the scenarios of no-overweight traffic and total traffic with overweight trucks. The overweight trucks' configurations were modeled by increasing current legal trucks' axle loads without changing the axle distances and the number of axles. This assumption increased ESALs for overweight trucks. This approach is consistent with the approach utilized in this SPR-735 analysis.

For South Carolina bridges, four archetype bridges were used to represent the entire population of 9,271 bridges—one reinforced concrete slab bridge and three prestressed concrete beam bridges of various span lengths. Detailed modeling of these bridges using the finite element method was done in order to find the stress levels used for fatigue analysis and in turn to estimate cost impact.

The total cost impact for South Carolina bridges was estimated as the sum of fatigue cost and maintenance cost. The former was estimated through the finite element method, and the latter was based on the expenditures of SCDOT.

This approach estimated a total bridge cost of $8,800,119 attributed to overweight trucks, out of which $35,351 (0.4 percent) was due to maintenance and $8,764,769 (99.6 percent) was due to fatigue damage. Given the fact that SCDOT's operation does not explicitly maintain a record of expenditure for correcting fatigue damage other than maintenance cost, the results are not useful to include in this study, as the fatigue cost constitutes almost 100 percent of the total cost.

6. Oversize/Overweight Vehicle Fees Study (Prozzi et al. 2012)

Summary. The Texas Legislature directed the Texas Department of Transportation (TxDOT) to conduct a study on road damage caused by oversized and overweight (OSOW) vehicles and to provide recommendations for permit fee and fee structure adjustments. TxDOT commissioned the Center for Transportation Research at the University of Texas and the University of Texas at San Antonio to evaluate the damage that OSOW vehicles (including exempt vehicles) cause to the transportation infrastructure (including pavements and bridges), along with direct costs imposed by OSOW vehicles on highway appurtenances (such as signs, traffic signals, and light poles) and other costs that other state agencies and local jurisdictions accrue from OSOW enforcement or management.

A methodology was developed to quantify pavement and bridge consumption rates per mile. The consumption rates were calculated for multiple axle loads and axle configurations and are independent of commodity. Per-mile fees for bridges were also calculated for non-routed loads. The researchers used this information to develop a new fee schedule that considers costs associated with oversized, overheight, or overlength vehicles across 34 rate categories. These new fees also incorporated VMT calculations.

Using the new permit fee structure, the research team conducted a revenue analysis by comparing projected revenue under the new structure to FY 2011 permit sales numbers and associated revenue. In FY 2011, the Motor Carrier Division sold 574,578 OSOW permits that generated just over $111 million in permit fee revenue, for an average cost of just over $193 per permit. These permits are for a wider set of vehicle configurations than those in international intermodal container transport, and this value is representative of costs beyond infrastructure damage. The revenue based on the new pavement and bridge consumption and operational and safety impact fees is an estimated $521.4 million—an increase of $410 million over FY2011 permit fee revenue. As a result of the study, the permit fee structure was changed and now includes a $10 administrative fee for each permit sold and a new TxDOT Base Fee of $40 for all permits sold to help fund costs that are not currently recovered by existing permit fee revenues.

7. A Synthesis of Overweight Truck Permitting (Bilal et al. 2010)

Summary. This study documented the state of truck weight permitting practices in the State of Indiana in comparison with those of its neighboring states. The truck permitting practices and policies of eight Midwestern states were documented, assessed, and compared with respect to the ease of the permitting process for the permit applicant, the permit fee amounts, and the permit fee structure or basis for fees (per vehicle, per vehicle-mile, per ton-mile, etc.).

The study determined that while the upper thresholds (dimensions and weights) for legal trucking operations are generally the same across states, those for extra-legal operations vary considerably. From the perspective of overweight and oversize thresholds and associated permit fees, it was observed that a number of states are generally more favorable to trucking than others because they have relatively higher upper thresholds for defining an overweight truck and/or relatively lower fees for overweight trucking operations.

The study also discussed the issue of revenue neutrality: highway agencies that have switched from a single-trip permit system to an annual permit system report that they benefited from cost savings due to reduced monitoring efforts of each single trip but lost significant revenue overall. These findings are not useful to include in this study.

8. Truck Size and Weight Enforcement Technologies—State of the Practice of Roadside Technologies (Krupa and Kearney, 2009)

Summary. This article studies increases in the efficiency and effectiveness of truck size and weight enforcement using near-term planning with different combinations of roadside technologies. It reviews the general goals of combining WIM data with other technologies for data collection, informed placement of future WIM, preselection of potential offenders, intervention with specific companies that have a history of continuous violations, and, ultimately, direct enforcement. While the authors do not offer technical specifics for each of these solutions, they describe the properties and function of WIMs, the use of high-speed WIMs for general screening, and the use of low-speed WIMs for a higher degree of sorting. The idea behind using WIMs with traditional static weigh stations is not to identify potential offenders and catch them, but to avoid forcing obvious non-violators through the static weigh stations, thus relieving congestion at weigh stations. The data collected from WIMs are extremely useful to increase awareness of locations, days, and times that tend to have more illegally overweight vehicles. This information is used to schedule mobile enforcement teams. These data also help decision makers make informed decisions about where to place future WIM sites.

Preselecting can be done through mobile screening at WIM sites or through virtual weigh stations. The mobile screening process can include one or two police officers, depending on traffic volume, and requires a roadside processor, connectivity via Wi-Fi to the officer's car, and a WIM site. If the vehicle does not comply with requirements at the WIM site, the officer is notified on his or her computer. If there is only one officer, the notified officer then intercepts the vehicle to weigh it with a portable scale. If there are two officers, the officer by the WIM notifies an officer downstream of the physical description of the potential violator and the downstream officer intercepts. This method is used more often in areas with high traffic volumes.

Virtual WIM sites are the same as the WIM sites used for the mobile screening process but include digital imaging systems at the very least. A virtual weigh station is meant to mimic a static weigh station by sending real-time information to one officer downstream who intercepts the potential violator(s). Some drivers avoid weighing by taking the freeway exit prior to the weigh station. These can be intercepted using the virtual WIM, which takes a picture of all trucks exiting before the weigh station and then entering after. If images of an exiting and re-entering truck match, then that truck may have avoided the weight station and can be intercepted downstream.

Overall, this article discusses WIM and types of WIM data. It describes what can be done with specific WIMs rather than what technology is needed for certain weight enforcement scenarios. The technologies described are relevant to potential compliance strategies, but the costs of acquisition and operation must be considered and compared to the impact of OW carriers traversing the study corridor without having purchased a permit.

9. Wisconsin Truck Size and Weight Study (Adams et al. 2009)

Summary. This project was intended to assess potential changes in Wisconsin's truck size and weight (TSW) laws that were perceived to benefit the Wisconsin economy while protecting roadway and bridge infrastructure and maintaining safety. The project investigated six possible scenarios involving new truck regulations. This review focuses on the part that dealt with possible cost impacts on pavements and bridges. The cost impact to the trucking industry was not considered in the study or mentioned in the report. The report was a network-based study of potential changes to state truck size and weight limits, as opposed to an analysis of the impact of any particular policy on a particular set of highways.

For pavements and bridge decks, the impact of additional ESAL miles was estimated as the difference between the base case and each of the scenarios considered. Cost impact was then estimated as the product of the additional ESAL miles and the cost per ESAL mile. While the ESAL concept is well known and documented for pavement deterioration/damage/consumption, its application to bridge decks has never been mentioned in the literature.

For bridges, Wisconsin happened to have an overweight load regulation in place—a GVW of 190,000 pounds—that was much more severe than the regulation for the six considered scenarios. The 190,000 pound amount was greater than any of the scenario specifications requested in the study. As a result, the report concluded that "Implementation of TSW loading has little or no effect on the overall design cost." This finding is not useful to this study.

For load-carrying capacity of bridges, the study covered only the state-maintained bridges in Wisconsin. A sample of 85 bridges was used to represent the population of state-maintained bridges (6,361) for detailed analysis. The bridges that would be required to be posted, inspected, and/or replaced under the new scenarios of overweight load were identified and their costs estimated. The study then projected these results to the entire population of state-maintained bridges and then to all bridges in Wisconsin.

Note that this approach to estimating cost impact is identical to the one developed in NCHRP Report 495. This category of cost impact for replacing inadequate bridges is shown in NCHRP Report 495 as the dominant contributor to total cost impact for the two illustrative examples of Michigan and Idaho.

10. Estimating the Cost of Overweight Vehicle Travel on Arizona Highways (Straus and Semmens, 2006)

Summary. This report attempted to quantify state highway damage based on the impacts of overweight vehicles. The researchers used qualitative information such as surveys of personnel in various states and provinces along with an analysis based on WIM data. Only pavement costs were considered. While the report is intriguing because it focuses on Arizona highways, the lack of available data, the lack of bridge methodology, and the presence of newer studies all mitigate the study's potential impact on current research methodology.

11. Economic and Financial Feasibility of Truck Toll Lanes (Holguin-Veras et al. 2003)

Summary. This report analyzed the economic and financial feasibility of heavy-truck toll lanes. The research expanded the line of inquiry of previous researchers by analyzing toll lanes for exclusive use by heavy trucks (i.e., large size and capacity). Implementation of such a toll system was studied relative to productivity changes, toll-lane fees, users' travel time and vehicle operating cost savings, and impact on infrastructure costs. The economic benefits were estimated using the Highway Design and Maintenance Standards Model developed by the World Bank. The analyses, complemented by sensitivity analyses of important variables, indicate that heavy-truck lanes are economically and financially viable.

This article notes the benefits that arise with truck-only toll (TOT) roads. The idea is to have designated toll roads for trucks that are built to support larger weights and longer combination vehicles (LCVs) than regular roadways. The ability to increase the weight and length of the trucks has proven to be beneficial to the carriers and therefore the economy, as seen in USDOT's 2000 "Truck Size and Weight Study" (FHWA 2000). The net savings would accumulate to between 10 billion to 40 billion dollars per year. The idea is that the carriers would pay a toll up to one half of the net gains they receive from increased carrying capacity and more reliable pathways. The removal of trucks from the regular highways would increase safety and alleviate congestion. Certain policy changes must be implemented to accommodate this new infrastructure, but it could prove to be the solution to many congestion, safety, and infrastructure consumption issues with which the United States is struggling.

USDOT's "Highway Cost Allocation Study" acknowledges that what the trucks pay is not proportional to highway costs (FHWA 1997). Trucks pay 80 percent of the cost they impose on highways, while regular vehicles pay 110 percent of the costs they impose. The study provides a Toll Truckway Feasibility Analysis, which covers pavement design, productivity analysis, and feasibility analysis.

12. A Road Pricing Methodology for Infrastructure Cost Recovery (Conway and Walton, 2010)

Summary. The purpose of this research is to provide a theoretical framework for charging commercial vehicle users using real-time vehicle weight and configuration information collected using WIM data systems. This work provides an extensive review of mechanisms and technologies employed for charging commercial and passenger vehicle-users worldwide.

Existing structures for charging commercial vehicle users use only broad vehicle classifications to distinguish between vehicles for the purpose of user fee pricing. The methodology proposed employs highway cost allocation (HCA) methods for developing an "Axle-Load" toll structure. A theoretical case study, based on information obtained from TxDOT, was performed to explore the equity improvements that could be achieved by implementing user fees. Some sensitivity analysis is also performed to examine the potential revenue impacts due to uncertainties in different data inputs under existing and proposed structures.

This study provides a useful methodology for determining and allocating costs, as presented in Figure 6. The research team was able to develop a simplification of this approach suitable for the research topic and the level of available data at hand.

The study showed that nearly half (49 percent) of trucks with heavier loads would pay additional tolls under a scheme allocating costs across the trucking operations.

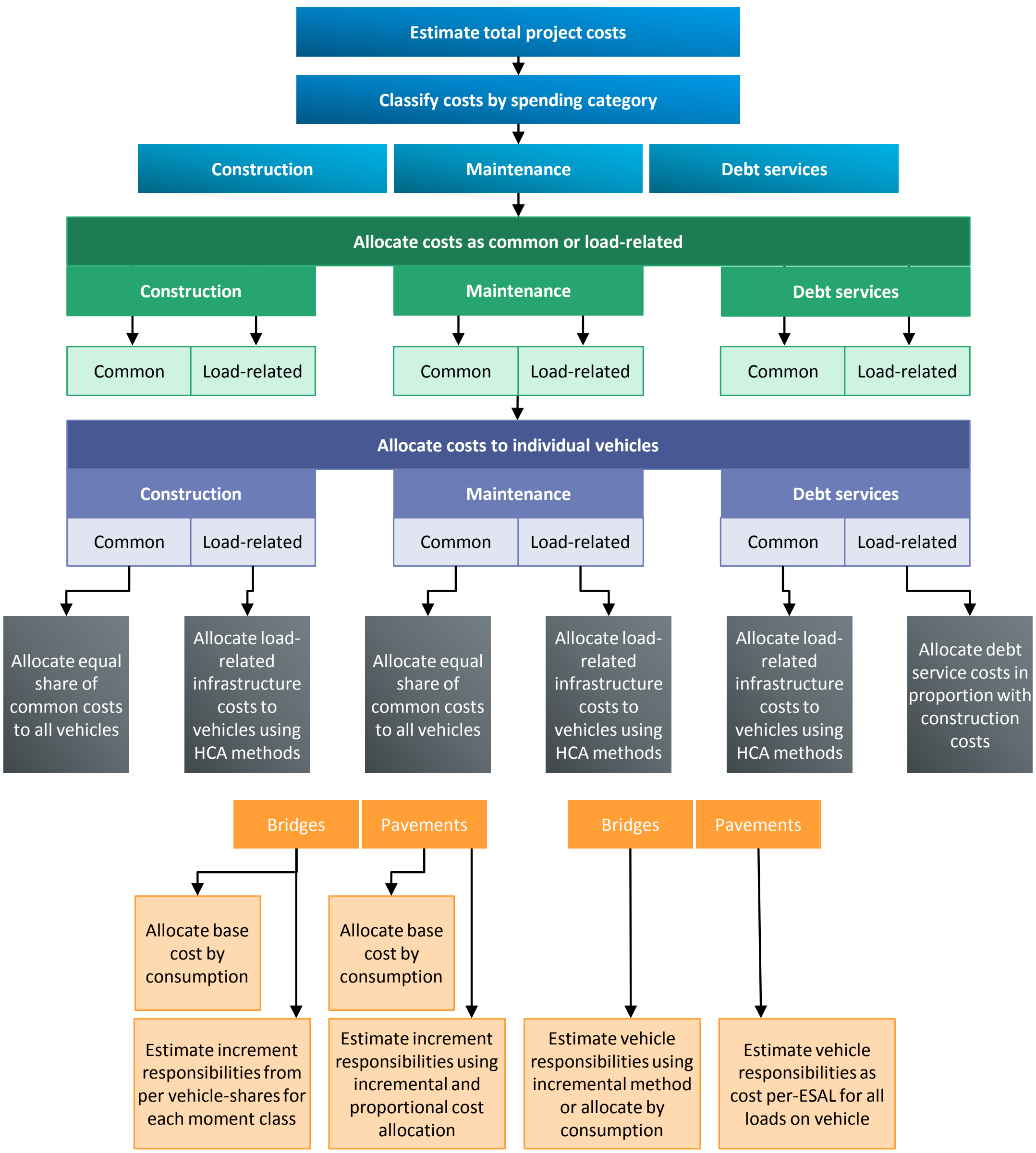

Figure 6. Cost Determination and Allocation (from Conway and Walton, 2010)

CHAPTER 3. OTHER COLLECTED INFORMATION

The research methodology for evaluating the cost of infrastructure damage due to permitted vehicles considers the interaction between infrastructure damage and permit utilization to develop an estimate of the damage impact of each utilized permit. To properly consider such an interaction, many factors must be accounted for prior to any detailed engineering analysis. These factors include the relevant guiding laws, including those laws in competing states, the perspectives of a variety of relevant stakeholders, and the infrastructure for which the permit is being evaluated. This section summarizes the relevant information as part of the analysis process.

LAWS GOVERNING INTERNATIONAL TRANSPORT OF SEALED SHIPPING CONTAINERS

The transport of SSCs between the United States and Mexico in either direction is governed by a mix of federal, state, and local laws, depending on the jurisdictions and the owners of the roads traversed. This section reviews the laws applicable in the study corridor as well as laws applicable in the three other states bordering Mexico.

Federal Laws and Regulations

Section 658 of Title 23 of the US Code of Federal Regulations guides the discussion of legal weight on the Interstate Highway System from a federal perspective (23 USC §127; 23 CFR §658). As the study corridor cannot be traversed in its entirety without entering I-19, Section 658 is of relevance here. Specifically, Section 658.17 contains provisions regarding the weight of vehicles that may travel on the interstate system, while Section 658.5 contains relevant definitions. To understand the impact of these sections, we must consider three items:

- The limits for the weight of divisible loads on the interstate system.
- The definition of "nondivisible."
- The ability of states to define SSCs moving internationally as nondivisible.

Weight Limits on the Interstate Highway System

Section 658.17 establishes several parameters for weight, including the following items of relevance to this research:

- Section 658.17(f) states that "except as provided herein, States may not enforce on the Interstate System vehicle weight limits of less than 20,000 pounds on a single axle, 34,000 pounds on a tandem axle, or the weights derived from the Bridge Formula, up to a maximum of 80,000 pounds, including all enforcement tolerances. States may not limit tire loads to less than 500 pounds per inch of tire or tread width, except that such limits may not be applied to tires on the steering axle. States may not limit steering axle weights to less than 20,000 pounds or the axle rating established by the manufacturer, whichever is lower."
- Section 658.17(h) states that "states may issue special permits without regard to the axle, gross, or Federal Bridge Formula requirements for nondivisible vehicles or loads."

- Section 658.17(i) states that “the provisions of paragraphs (b),(c), and (d) of this section shall not apply to single-, or tandem-axle weights, or gross weights legally authorized under State law on July 1, 1956. The group of axles requirement established in this section shall not apply to vehicles legally grandfathered under State groups of axles tables or formulas on January 4, 1975. Grandfathered weight limits are vested on the date specified by Congress and remain available to a State even if it chooses to adopt a lower weight limit for a time.”

Section 658.17 and the federal FAST Act Legislation (Public Law 114-94, Fixing America’s Surface Transportation Act) identify sections of the interstate network that are exempt from these restrictions. No interstate highways in Arizona meet these criteria. Transport exceeding 80,000 pounds in gross vehicle weight may not occur on Arizona's interstate highways, including in the study area of this research, unless the load is deemed to be nondivisible.

Defining a Nondivisible Load

Section 658.5 defines nondivisible as "any load or vehicle exceeding applicable length or weight limits which, if separated into smaller loads or vehicles, would:

“(i) Compromise the intended use of the vehicle, i.e., make it unable to perform the function for which it was intended;

“(ii) Destroy the value of the load or vehicle, i.e., make it unusable for its intended purpose; or

“(iii) Require more than 8 workhours to dismantle using appropriate equipment. The applicant for a nondivisible load permit has the burden of proof as to the number of workhours required to dismantle the load."

Given the definition of the term "nondivisible," many commodities cannot generally be transported in vehicles where the gross vehicle weight exceeds 80,000 pounds. Examples of such commodities include produce, electronics and machinery, consumer household products packaged for retail, and raw materials such as copper. Putting less material into a vehicle's storage unit does not compromise the intended use of the vehicle (Subsection i), nor does it require dismantling (Subsection iii). As a result, the only avenue for consideration of transport of such loads over 80,000 pounds of gross weight is the question of destruction of value of the load.

The Barnhart Letter and International Intermodal Shipping Containers

When goods are transported across national borders into the United States, they are subject to a Customs process by CBP. (A summary of the process is provided by CBP at https://www.cbp.gov/border-security/ports-entry/cargo-security/csi/sealing-policy.) A SSC of containerized cargo is typically sealed when transported to maintain the integrity of the contents. When CBP inspects a vehicle, it places another seal on the container to "preserve the integrity of containerized cargo leaving CBP possession."

USDOT has been asked whether breaking the seal of a SSC before its final destination, in order to divide the contents across multiple trips to meet the Federal 80,000-pound limit, "destroys the value of the load" under Section 658.5(ii). In 1984, FHWA administrator Ray Barnhart provided guidance on this question in a letter known as the “Barnhart Letter,” regarding international intermodal transport via the state of South Carolina. Additional clarifications to the letter have not been provided by the FHWA in the intervening years (Brown 2012).

More than 20 states have chosen to interpret the 1984 federal guidance to determine circumstances in which SSCs can travel on interstate highways in their states as part of international intermodal transport. As of the inception of the research project summarized in this report, the State of Arizona had not made such an interpretation.

Summary of Federal Impact on the Research Statement

Federal law and regulations provide the State of Arizona the option to determine that SSCs may travel on the study corridor with a permit to exceed federal interstate weight limits if the container is sealed and the load is part of international shipping. General freight may not travel on the study corridor with a permit to exceed federal interstate weight limits. As a result, only a subset of vehicles carrying freight on the study corridor in either direction is eligible for a permit. For a vehicle to be permitted with a divisible load, three things must all be true:

- The cargo must be in a SSC.
- The container must be used in international shipping.
- The contents of the container must not be divided at an intermediate point between its overall origin and overall destination. (Otherwise, the point regarding the value of the load becomes moot, because there is no justification for not dividing the load prior to entering the interstate.)

The federal guidance is silent as to the countries of origin and destination of the SSC. Three permutations are theoretically possible, assuming the trip is intermodal:

- Originating in the United States and terminating outside the United States.
- Originating outside of the United States and terminating inside the United States.
- Transiting the United States while traveling from one foreign country to another foreign country.

Arizona Laws and Regulations

Vehicle size and weight on Arizona’s highways, and related permitting of extralegal vehicles, are generally covered in Arizona law and regulation as follows:

- Arizona Revised Statues, Title 28, Section 18, defines vehicle size, weight, and load and establishes the authority to issue special permits.
- Arizona Revised Statutes, Title 28, Section 19, defines envelope permits for nonspecific and nonreducible vehicles or cargo.
- Arizona Administrative Code, Title 17, Section 6, defines the ability of ADOT to issue oversize and overweight special permits.

One of the special permits that can be issued by ADOT is the Single Trip Overweight Border Permit. This permit enables a motor carrier to transport goods from Mexico into a 25-mile region from one of the participating International Ports of Entry (including the Mariposa port in the study region) if it has a gross vehicle weight of up to 90,800 pounds on five axles. The permit program started in Nogales in 2010, and ADOT currently shares revenue from these permits with the City of Nogales and Santa Cruz County. As a result, permittees in the research study corridor who are traveling only in the 25 miles closest to the Mexican border would not need the permit considered by this study unless they were applying for a permit at a gross vehicle weight of greater than 90,800 pounds.

Scenarios in Other States Bordering Mexico

State Highway System Permits. The research team researched scenarios where SSC traffic crossing the border between the United States and Mexico in either direction wished to operate at a weight greater than 80,000 pounds. The three other states bordering Mexico (California, New Mexico, and Texas), all have similar programs for the general issuance of oversized and/or overweight permits for travel on both state and interstate highways.

While states in other parts of the country have permits for international travel for SSC when utilizing the Interstate Highway System, neither California, New Mexico, nor Texas have such a permit for the Interstate highway network:

- California explicitly declares an aversion to such permits as part of Section 35580 of the California Vehicle Code.
- New Mexico allows a border permit at Santa Teresa similar to Arizona's 25-mile border permit, but for 12 miles and in a region with no interstate highways in New Mexico.
- Texas allows divisible loads on state-maintained roads, but not on the interstate highway network. Loads are available up to 89,600 pounds for agricultural products or 88,000 pounds for other products. At the time of this report, the Texas Legislature is considering legislation to allow permits for operations in a 30-mile radius from some port locations, excluding the interstate system.

Local Highway Jurisdictions with Overweight Divisible Load Permits

The Texas Transportation Code (TRC) authorizes the Texas Transportation Commission, which oversees the Texas Department of Transportation, to contract with seven designated third parties to issue single trip permits for overweight vehicles on specified state-maintained roadways. While these permits are not specifically targeted at regulating sealed containers, they could theoretically be used for such containers if the loads being transported met all other permit requirements. Three third-party organizations currently issue overweight permits to transport divisible loads on state-maintained roadways: the Port of Brownsville, Hidalgo County, and the Port of Freeport.

The Port of Brownsville has issued permits for more than a decade and issues between 30,000 and 40,000 permits annually. Single trip permit fees are $30, with fee collections of more than $380,000 annually. While the port is authorized to charge up to $80 per single trip permit, fees were originally set at $30 and have not been increased since the program's inception.

Hidalgo County, which started a permit process in 2014, issued 9,600 permits in its first full year of operations. Single trip permit fees are $80, with collections of $770,000 annually. Load descriptions provided by a county representative in a telephone interview were exclusively produce, with mangos comprising 20 percent and tomatoes and general produce comprising 16 percent each. Given its proximity to Reynosa, San Antonio, and the Ports of Corpus Christi and Brownsville, Hidalgo County has the potential to expand its market share of the Mexican produce industry as well as expanding into other Mexican imports/exports.

The Port of Freeport began issuing overweight permits in March 2015 and issued 170 permits through August 2015. The single trip permit fee is $80, with $13,000 collected. All permits were issued to one customer to transport polyvinyl chloride resin.

STAKEHOLDER PERCEPTIONS

The research team interviewed stakeholders in order to understand their perspectives on the utilization of shipper and carrier resources. The team sought to better understand the potential effectiveness of a permit in improving operations in the region, especially when the framework of the permit is limited to a specific type of movement of sealed containers, i.e., international and intermodal moves. These interviews posed the following questions:

- What is the mix of industries for which a containerized vehicle permit could even be feasible based on the physical nature of what is being shipped? In general, lower-density products and commodities would be less relevant because their manufacturers may currently be shipping full containers at or under the current legal weight, and providing them with additional weight allowances for a fee would be of no operating value.
- For industries shipping relatively dense goods, which industries have business processes that are well suited to long-distance multimodal container movements? As discussed later in this section, some industries with relatively dense goods already have business processes that rely on distributing commodities across vehicles at a local distribution center.
- For the remaining industries, what are the general issues beyond price that would either assist or impede the use of extralegal weight in sealed containers?
- What are the implications of the nature of the permit under consideration as applicable to an international movement versus an intermodal movement?
- How could the permit be abused? A security seal is relatively inexpensive, so enforcement resources would have to be diverted from other programs should abuse be widespread.
- What are the perceptions of the local government agencies in the study area regarding potential benefits and costs of changing the traffic mix in the study corridor by allowing higher permitted container weights?
- Are the shippers' savings from heavier loads sufficient for carriers to consider capital investments in six- and seven-axle vehicles?

These issues are important, because the percentage of potential operators that can be expected to actually purchase and use a permit affects the estimated future traffic mix and thus affects the structural and pavement engineering analyses. The results of these interviews were used to estimate various ranges of permit purchase percentages for different commodity groups based on the characteristics of various potential vehicle configurations, directions of traffic, and ability to coordinate with intermodal activities.

Government Agency and Non-Governmental Organization Perspectives

Metropolitan Tucson Agencies. A group interview was held at the Tucson Chamber of Commerce and included representatives from a variety of agencies from the metropolitan Tucson area, including the City of Tucson, several suburbs, Pima County, and the metropolitan planning organization. Representatives were generally positive about the concept of a containerized vehicle permit and believed anecdotally that the market share of containerized shipments both to and from Sonora (which included metropolitan Tucson) could only increase as a result. In addition, the idea was proffered by one of the Tucson-based stakeholders that such a permit would enable metropolitan Tucson to attract manufacturing and distribution businesses focused on the Sonoran market. Representatives were also interested in the potential development of intermodal rail shipments via the Port of Tucson.

One item that was considered both a concern and an opportunity was the integration of a containerized permit with local permitting in the metropolitan Tucson area. New highways under development in Tucson may be well suited to a similar permit, but for divisible loads on a specified network. On the other hand, the potential impact of carriers traveling on local roads, including during interstate construction or other high traffic events, could be a problem, since it would not be easy for local enforcement to identify overweight vehicles.

Metropolitan Nogales Agencies. A group interview at the Nogales (Arizona) City Hall included executives from the City of Nogales and representatives from Santa Cruz County and the metropolitan planning organization. Unlike the Tucson-area stakeholders, the Nogales-area stakeholders were uniformly opposed to an expanded permit for the study area. The Nogales region currently has the previously described 25-mile regional permit, for which there is revenue sharing between ADOT and the region; this permit has encouraged development of a variety of businesses related to industries that ship via containerized trucks. The stakeholders' position was that any change from the status quo would have a negative effect on the Nogales economy, regardless of the fee charged to offset infrastructure damage.

Depending on the structure of the permit for the study area, the study area permit could cannibalize the local permit, with carriers seeing a benefit in simply buying the state permit. Although carriers with overweight loads are asked for permits when crossing into Arizona at the Mariposa Port of Entry, there would be no way to determine whether the carrier is indeed heading to Tucson or simply stopping in Nogales.

The larger issue stated, however, was the amount of investment in the Nogales region around the relevant industries. An anecdotal example was provided of another "waiver zone" for passenger vehicles coming into Arizona from Mexico: the zone extended into shopping areas in the southern portion of the Tucson metropolitan area, and retail business was transferred from Nogales to Tucson. The stated position was that a containerized permit extending into metropolitan Tucson would cause pressure on distribution centers, motor carriers, and ancillary businesses to move their operations further north, out of the Nogales area, with negative implications for the regional economy. To address this issue, effective enforcement is critical. If the intermodal spirit of the move is violated and the permit becomes a mechanism to simply conduct truck-to-truck shipping via a distribution center, then the issue becomes more critical.

Industry Perspectives

Produce Companies. In its solicitation for this research project, ADOT identified the produce industry as potential users of an overweight permit. A group interview was held at the offices of the Fresh Produce Association, with participants representing both the association and individual produce companies.

The participants were uniform in their position that an overweight permit for the study area was not of any use to their industry. They cited a number of reasons, most notably the following:

- The approach that the retailers of produce, such as supermarkets, use for distribution of Sonoran-grown produce involves mixed truckloads of commodities from various producers. Customs seals are irrelevant because very few retailers would order, for example, an entire sealed container of tomatoes.
- Unlike other products that are manufactured or mined, produce has more variability in characteristics and quality, and purchasers wish to set guidelines on what is accepted. The earlier in the supply chain that unacceptable produce is removed, the lower the cost to the chain.
- Produce is subject to safety and security issues at a higher level than are many other commodities being shipped out of Sonora. Business processes are currently in place to protect produce safety and security.
- A test of watermelons shipped by rail via the Port of Tucson was considered a failure due to spoilage and time delays. (Note that this is contrary to the opinion of the Port of Tucson stakeholders for the same shipment, as described later).
- The produce industry has made significant capital investments in its facilities in metropolitan Nogales, and shifting business processes to allow containers to flow later in the supply chain (to an intermediate point such as Tucson, to regional distribution centers, or to ocean shipments in locations such as the Port of Long Beach) would be problematic.

Smaller produce companies without capital investment may take a contrary position to the above assertions. The Port of Tucson identified produce companies that, they claim, have an interest in intermodal shipments via Tucson. Shipments of produce from Mexico via the west coast ports to Asia may be more suitable to containerized transport to a rail facility than shipments of other commodities. Overall, however, interviews suggest that only a small portion of the industry could be expected to use a permit that is truly intermodal in nature. This point is consistent with the discussion with the Nogales government units, which noted that a potential side effect of a permit would be sealed containers being split and then shipped by truck instead of rail from Tucson-area distribution centers, even if the emphasis were placed on truck-rail intermodal moves.

Manufacturers. The research team conducted interviews with Sonoran manufacturers ("maquilas") or logistics companies in person in Tucson and Nogales, and by telephone. Several interviewees were members of the Association of Maquiladoras of Sonora.

Some interviewees had current operations at the Port of Tucson, while others did not. Regardless of their current use of rail, industry members were uniform in their conviction that, if the pricing of both the permit and the rail segment were appropriate, there would be interest in purchasing permits. A need for permits was identified for both finished products being shipped northbound and raw materials heading southbound.

Several anecdotal examples indicated that the southbound shipments of raw product would generate a higher demand. One example was the manufacture of automated garage door opening units. A finished product would be packaged, be protected from damage, and have a lower density per cubic foot than its raw components. By comparison, the substantially denser metal chain used as a component of the opening unit is produced in Asia and shipped to either California or the Mexican port of Guaymas. Inbound shipments of this chain do not fill an entire shipping container because of the weight limitations.

While the stakeholder interviews with manufacturers were quite positive, several research challenges in interpreting their opinions arose:

- The way in which the association members thought about their manufacturing did not line up directly with the way commodity flow data structures typically represent the products (either inbound or outbound).
- Many companies manufactured products across sectors with widely different densities, so estimating permit volume had to be considered at a product level, not a manufacturer level.
- The discussion frequently centered on the potential cost of the permit as a barrier to acceptance. This caused a circular reference in logic, in that the manufacturers would vary traffic volume and mix by permit price, but the cost of the permit is likely to be related to the infrastructure damage that, in turn, may be highly sensitive to variations in traffic volume.

Mineral Producers. We were unable to interview specific producers of minerals during our initial interviews. The presence of large-scale mining operations, however, was mentioned in several interview sessions. 68% of domestic copper production is from Arizona mines, including locations near the study corridor (Arizona Geological Survey 2018). Given the international nature of the container permit, only shipments of copper and other Arizona-mined minerals from Arizona out of the country would be appropriate to consider in this research.

Port of Tucson. We interviewed representatives of the Port of Tucson on two occasions, once at their facility and once in a group meeting at the Tucson Chamber of Commerce. Several businesses with distribution center operations or truck-rail intermodal shipments at the port also attended the latter meeting. We also were provided with a tour of the port, including their intermodal operations. The port's rail connection to Union Pacific's Southern Corridor Main Line utilizes a variety of equipment including hoppers, box cars, tankers, and containers. Intermodal containers are not available on all rail shipments but are shipped out to the California ports five days per week. The port is currently conducting drayage operations for domestic clients.

The port staff were enthusiastic about an overweight container permit. They stated that their internal research through their sales processes indicated sufficient demand for higher-weight transport on I-19 to potentially enable additional rail service from the Union Pacific, especially but not limited to traffic to Long Beach and Los Angeles. Given that the port conducts drayage operations, it could safely be assumed that the port itself would be a purchaser of permits for those operations as it competes for drayage business that has crossed the border.

For traffic into points east of the Mississippi River, the port staff discussed their pilot shipment of watermelon from Sonora. Unlike the Fresh Produce Association, the Port staff thought that the basic concept had been proven via the test, and the port staff asserted that produce companies without capital-intensive distribution operations in metropolitan Nogales would have interest in exploring these types of intermodal movements.

The port has the ability to weigh containers, as it must abide by Union Pacific's rules for weight limits for double stack operations. The ability to weigh containers at the intermodal transfer point may have an impact on the design of compliance processes. Similarly, the port may have data suitable for use by ADOT in ensuring that a trip permit is used exactly once for a specific container.

Motor Carriers. The research team met with several motor carriers and freight brokers who had operations in Nogales, Arizona, that specialize in cross-border operations, including containerized freight, as well as with the Safe Border Trucking Association. Motor carriers in the region are often owned by holding companies, with a Mexican carrier and a United States interstate carrier both owned by the same holding company. A transfer of the container is then made within the Nogales operating zone for the Mexican carrier. This operation works in both directions into and out of Mexico. The team was unable to meet with carriers currently conducting cross-border operations beyond the 25-mile region.

One of the key points raised is that the split of the transport between the Mexican and United States carriers has virtually nothing to do with the commodity being transported. A variety of operating reasons were cited by participants, including differences in duty rules, the variability of the border crossing timings at the Mariposa Port of Entry, and the volume of inspections performed at border crossings and their impact on USDOT/Federal Motor Carrier Safety Administration (FMCSA) safety ratings for companies (and thus their potential impact on insurance rates).

Another key point raised is that for shipments being sent from Mexico to Asia, the sequencing of the manufacturing processes with both the rail schedule and the port schedule has a substantial impact on permit utilization. It may be highly inefficient to purchase a permit for only a fraction of a company's shipments if the rail service is not frequent enough to support on-time deliveries to a port (or vice versa for inbound shipments of raw materials). Therefore, a company with higher volumes may in fact purchase fewer permits, while a company that takes a week to fill a container headed to an oceangoing vessel on a monthly route may be able to purchase permits for its entire inventory.

Another topic discussed with the motor carriers involved capital purchases of power units and the viability of six- and seven-axle configurations. Carriers were uniform in their assessment that the subset of industries under consideration was insufficient to justify an investment in equipment with more axles.

The double stack weight limits are also sufficiently low that the total gross vehicle weight for a truck-rail move would not exceed 91,000 pounds. Exceeding the double stack limit would mean that the container would in essence be taking two spaces on the train, lowering the effective capacity instead of raising it. If the study area had an ocean component and there were a truck-ocean move, higher weight limits would be more feasible.

Findings

The stakeholder interviews yielded additional insights; the information obtained appears to be relevant, and perspectives differ on the viability and usefulness of an overweight permit for international intermodal containerized travel.

Southbound traffic of raw manufacturing components into Mexico appears to have the highest potential demand for permits because of the isolation of individual commodities and the ability to select permits for the densest ones. Manufacturing processes, including food processing, appear to have a greater potential demand for permits than the produce industry.

The hierarchy of demand for a containerized permit appears to be as follows:

- High demand
    - Southbound high-density commodities used in manufacturing processes, such as bicycle chains from Asia and grains from the Midwestern United States (highest).
    - Northbound high-density finished products, especially those with minimal needs for packaging.
- Medium demand
    - Southbound medium-density components.
    - Northbound medium-density finished products.
    - Minerals produced in Arizona and being shipped to Asia.
- Minimal demand
    - Northbound produce.
- No demand
    - Low-density products and components.
    - Southbound produce.

Nearly all of the discussions assumed substitution of existing travel; for example, a carrier with multiple truckloads at 80,000 pounds using permits to reduce the total number of trips to carry the same amount of goods. There were some discussions about route choice between Sonora and Long Beach (via Tucson or via Mexicali), but no discussion of route choice between Nogales and Santa Teresa.

A five-axle configuration of roughly 91,000 pounds was the stated preference of stakeholders in the meetings.

The issue of previous capital investment in various locations along the study area or in Mexico was raised in multiple sessions, in multiple contexts:

- Stakeholders with existing capital investments in metropolitan Nogales were against the permit, regardless of whether they were in the private or public sector.
- Motor carriers were generally neutral to slightly favorable, in that they would opportunistically purchase the permit if the shipper had a heavier load that qualified for it, but their investments would be made regardless of whether the permit ever came to pass.
- Stakeholders with capital investment either in metropolitan Tucson or in Mexico were generally positive about the potential demand for a permit.

Finally, the role of compliance was a recurring theme. For research purposes, the assumptions are clear in terms of the types of movements that "qualify" for permit demand. The stakeholder concerns about compliance are compelling, however, and affected the approaches described in later chapters of this report regarding compliance and data management. An example of a compliance concern was ADOT's ability to track whether a particular permitted trip was indeed part of an international, intermodal trip and the ability of law enforcement to verify the veracity of the information provided by the carrier.

In these situations, operating at heavier weights without the permit (or above the permitted weight) is the relatively minor issue, as we know it occurs at some level today and will likely occur at some level in the future. Serious concerns were raised by stakeholders about the ability to manipulate the permit to move anything at a higher weight simply by putting a seal on the container and claiming that the move is indeed intermodal and international. If this scenario were indeed to occur in large volumes without suitable compliance countermeasures, the overall infrastructure impacts being evaluated will be underestimated.

DEVELOPING SAMPLE STRUCTURES AND PAVEMENT SECTIONS

The research team interviewed staff from ADOT and obtained information about the highway infrastructure on I-19 and I-10 in the study region. The team used this information to select sample structures and pavement sections for use in the analysis process described in Chapter 4 of this report.

Structures Inventory

With respect to structures, the infrastructure damage due to overweight loads is generated only for bridges over which permitted traffic would travel, as opposed to those trips in which permitted traffic would pass under the bridge. As a result, the collection of inventory was limited to structures where traffic passes over the structure on the mainline of the interstate highways (I-19 and I-10) in the study area.

There were 192 structures associated with the study corridor at the time of the analysis. Structures at exits where traffic would cross the bridge only when exiting, and structures on the frontage roads of I-19, were excluded from the collection process because of the expected lack of substantial volume (and, possibly, the preclusion of exiting completely if the highway is a locally maintained road). While permitted vehicles might travel over these bridges, and the design mix of these bridges might differ from those over which trucks will be passing on the mainline, the relatively low percentage of vehicles that would both obtain a permit and also travel over these bridges places them at the margin of the analysis. A permit for such a load would not be likely to allow a carrier to leave I-19 to use a service station or food outlet, for example, because the vehicle would have to travel on a local road. Similarly, heavier containerized loads could cause additional impacts on frontage road bridges in an emergency detour situation. The tiny likelihood of an emergency situation causing any vehicles to detour over these frontage road bridges renders the analysis to be of negligible relevance with respect to sample selection.

One exception to the above guidelines is the ramps between I-19 and I-10. There are bridges on two relevant ramps, one ramp between northbound I-19 and eastbound I-10 and one ramp between westbound I-10 and southbound I-19.

Sampling Considerations

In the research methodology's sampling approach, eight bridges in the study corridor are to be analyzed, and the results are to be extrapolated to similar bridges in the region. Four criteria were identified for selecting the eight sample bridges to be used in the analysis:

- Focus on older bridges that are not built to current ADOT standards, and then extrapolate a reduction of impacts to bridges with newer design standards.
- Focus on bridges with lower current ratings, including in the areas of operating, inventory, and sufficiency. Again, impact reductions can be extrapolated from bridges with higher ratings.
- Select a mix of structure types where the structure type affects how the overweight load impacts the structure itself. Steel bridges and concrete bridges should be considered, and within concrete bridges a mix of slab, T-beam, and prestressed/post-tensioned bridges should be considered.
- Consider a mix of bridges so that traffic in all directions is captured.

Structures Identified for Engineering Analysis

Based on the above criteria, the research team analyzed the available inventory. Within the decision tree of the first three criteria, various structures emerged as appropriate for sampling. For example, the structure at milepost 11.97 northbound on I-19 was a slab bridge built in 1951, one of the oldest structures in the inventory and thus potentially prone to substantial impacts.

Table 1 presents the selections for analysis structures based on the above criteria and on consultation with ADOT engineering staff.

Table 1. Sample Structures Identified for Overweight Load Analysis

Bridge Sample No.	ADOT Structure No.	Milepost of Structure	Structure Name	Year of Construction	Structure Type Material	Structure Type Design	No. of Spans	Maximum Span Length	Inventory Rating	Operating Load Rating	Sufficiency Rating	Bridge Type
1	353	11.97	Agua Fria Canyon Br NB	1951	2	01	4	25	34	56	84.34	Slab Bridge
2	1735	17.75	Arroyo Angulo Agudo NB	1978	6	02	3	67	39	66	96.35	P/S AASHTO Girder
3	1737	18.19	Tumacacori TI OP NB	1978	5	06	1	150	47	80	97.32	PT Box Girder
4	1354	40.65	Esperanza Blvd TI NB	1969	2	04	4	49	35	60	92.72	RC Tee Girder
5	1572	45.80	El Toro Rd OP NB	1971	4	02	4	95	36	55	91.63	Steel Girder
6	1303	49.62	Pima Mine TI OP NB	1968	5	02	4	61	33	77	93.00	P/S AASHTO Girder
7	1243	56.80	Santa Cruz River Br NB	1967	4	02	5	114	42	70	92.73	Steel Girder
8	2531	62.67	I-19 Ramp W-S	2004	6	06	2	109	54	99	86.19	PT Box Girder

Pavements Inventory

Several types of data about the pavement in the study corridor were collected in consultation with the ADOT Roadway Engineering Group:

- ADOT Material Design Reports (MDR).
- Pavement core logs.
- Pavement management section database summary information.
- Record drawings for specific projects.

The MDRs, in conjunction with the pavement core logs, were used to estimate AC layer thicknesses. For older pavement sections, MDRs or core logs were not available in ADOT records, especially for PCCP sections. In these cases, ADOT’s pavement management section database files were used to identify initial project information, and record drawings were then reviewed in collaboration with the ADOT Roadway Engineering Group to obtain PCCP section thickness data.

Sampling Considerations

To identify pavements to be considered for engineering analysis, researchers first categorized pavement sections as follows (as explained in more detail in the Appendix):

1. Pavement layer thickness.
2. Base layer thickness.
3. Subgrade soil type.
4. Truck traffic level.

Pavement Sections Identified for Engineering Analysis

The research team initially considered the percentage of corridor length represented by a pavement section in determining a candidate pool of pavement sections for engineering analysis. In making the final decision, the aforementioned engineering categories were evaluated for the sections representing the highest percentage of study corridor length. In some cases, pavement sections were selected even though they represented a smaller percentage of the study corridor than sections that were not selected. This decision was based on engineering judgement considerations, specifically, the expected performance under heavier truck loads. Table 2 presents the breakdown of pavement sections along the study corridor along with those identified for engineering analysis.

Table 2. Selection of Pavement Sections

Pavement Layer	Base Thickness	Subgrade Type	Annual Average Daily Truck Traffic	% of Study Corridor Length	Identified for Engineering Analysis?
<7 inches asphalt concrete	<12 inches	A-4	<1500	0%	No
	>12 inches	A-4 / A-6	>4000	6%	Yes
7-10 inches asphalt concrete	<12 inches	A-2-4	<1500	29%	Yes
	>12 inches	A-2-4	1500-4000	2%	No
		A-4	<1500	8%	Yes
>10 inches asphalt concrete	<12 inches	A-2-4	<1500	20%	Yes
		A-4	<1500	2%	No
	>12 inches	A-2-4	<1500	5%	No
			1500-4000	8%	No
9 Inches portland cement concrete	<12 inches	A-1	>4000	7%	No
		A-2-4	1500-4000	2%	No
		A-4 / A-6	1500-4000	7%	Yes
13 inches portland cement concrete	<12 inches	A-1	> 4000	4%	No
15 inches portland cement concrete	> -12 inches	A-2-4	1500-4000	1%	No

SUPPORTING DATA

Commodity Flow Data

One of the challenges identified in the discussions with stakeholders is the wide variety of products produced in the Sonora region for export and the equally wide variety of raw materials and components shipped through Arizona into Sonora to support the manufacturing process. We used data from three

sources to evaluate the potential for motor carriers in the study region to purchase OSOW permits for sealed shipping containers in international intermodal transport:

- Traffic classification data from ADOT were used to identify the traffic volumes on various pavement sections throughout the corridor. These data are a blend of northbound and southbound data on I-19 (and eastbound and westbound data on I-10) but contain detailed information about single-axle and tandem-axle weights. The data, however, do not distinguish between containerized truck traffic and other types of truck traffic.
- ADOT provided the research team with access to proprietary commodity flow data purchased by the agency for a different freight-related study. This data, IHS Markit TRANSEARCH 2013 (TRANSEARCH), provided estimates of current and future commodity flows from Mexico to various destinations, provided the flows traveled through Arizona. TRANSEARCH provides data in units.
- Publicly available data collected by CBP were obtained from USDOT's Bureau of Transportation Statistics regarding vehicle border crossings into Arizona at the Mariposa Port of Entry. Units are not reported, only tonnage and value.

The latter two data sources were available only for northbound traffic. No reliable data source for southbound container traffic was found.

Enforcement Data

Truck inspection data are available from ADOT, as ADOT transmits this information to the FMCSA. The lack of a fixed domestic port of entry on I-19, however, means that the volume of inspections is relatively low. As a result, we did use utilize specific enforcement records or annual summaries in our research methodology, but we describe methods to incorporate enforcement effectively in Chapter 6 of this report.

CHAPTER 4. ANALYSIS OF POTENTIAL INFRASTRUCTURE IMPACTS

INTRODUCTION

This chapter describes the team's analysis of how the switch from a legal weight vehicle to a permitted OSOW vehicle for international intermodal container traffic would affect the representative bridge and pavement sections identified in Chapter 3. The following activities are covered:

- Defining scenarios for potential permits, basing the definitions on literature and industry feedback.
- Using publicly available and ADOT-purchased data to estimate the amount of traffic traversing the study region that will be entitled to purchase a permit and will have reason to do so.
- Applying this information to models for pavement and bridge analyses based on software used by ADOT and the information about the permit demand.

Figure 2 illustrated the methodology used for estimating potential infrastructure impacts. Four sets of data were used in the methodology:

- Commodity flow data, including both data previously purchased by ADOT for other freight planning purposes and data publicly available from CBP.
- ADOT data regarding traffic volumes, numbers of axles, and axle weight distributions in the study region.
- ADOT data regarding each of the bridges and pavement sections being analyzed.
- ADOT cost data regarding bridge and pavement maintenance and replacement (to be used in the cost calculations discussed in Chapter 5).

CANDIDATE VEHICLE SCENARIOS

Four possible permit scenarios were identified for comparison with the base case for the study corridor. One scenario mimics the gross vehicle weight allowed on a typical class of Arizona nondivisible permit, while the other three scenarios were obtained from the reviewed literature and from stakeholder feedback. Two of the scenarios utilize a five-axle configuration commonly found in truck operations: a front axle on the power unit and two tandem axles. The other two scenarios require the motor carrier to add a sixth axle at the rear of the vehicle, changing the rear axle from a tandem to a tridem configuration.

The estimation of demand in the study corridor for each scenario is controlled by the commodities to be transported and practices regarding intermodal movements on rail. The engineering analyses of the scenarios, however, are transferable to a broader spectrum of situations within Arizona. Selecting a wider range of configurations enables consideration of the impacts of potential changes in federal law and policy, and, to a lesser extent, changes in neighboring states' laws and policies.

Base Case: 80,000 Pounds on Five Axles

Our starting point for comparison is the vehicle configuration for which carriers are most likely to desire to purchase a permit to operate at a higher GVW. This vehicle would have a GVW that includes the vehicle, container, and cargo of 80,000 pounds, which is the maximum divisible load weight allowed by federal law on the interstate network in Arizona.

Table 3 presents the "axle weights," which refers to the allowable vehicle load on each axle, and a typical set of "spacings," which refers to the distances between the centers of each successive pair of axles.

Table 3. Details of the 80,000-Pound Gross Vehicle Weight Container Vehicle

Axle	1	2	3	4	5
Weights (pounds)	12,000	17,000	17,000	17,000	17,000
Spacings (feet)	16	4	27	4	

Scenario 1: 90,800 Pounds on Five Axles

The primary scenario is derived from a similar configuration permitted in Arizona for nondivisible loads. The gross vehicle weight is set at 90,800 pounds. This weight is similar to gross vehicle weights for oceangoing container permits in many other states. For example, the State of Tennessee allows 90,000 pounds for an oceangoing container permit. Stakeholder feedback, supplemented by analysis of rail operations, indicated that this scenario would have the highest demand for truck-to-rail (or rail-to-truck) operations in the study corridor and thus should be considered as the primary scenario for our analyses. Table 4 presents a typical set of axle weights and spacings for the vehicle in this scenario.

Table 4. Details of the 90,800-Pound Gross Vehicle Weight Container Vehicle

Axle	1	2	3	4	5
Weights (pounds)	13,620	19,295	19,295	19,295	19,295
Spacings (feet)	16	4	27	4	

When the research team interviewed stakeholders, Scenario 1 was identified as the preferred configuration for travel in the study corridor if an intermodal connection to or from rail is required. It is also the scenario for which the current distribution of commodity flows in the study region supports a demand for permits.

Scenario 2: 97,000 Pounds on Six Axles

The second scenario is derived from the MAP-21 Comprehensive Truck Size and Weight Limits Study reviewed as Selection 2 in Chapter 2 of this report. As the federal report was considering a wider variety of vehicles, it considered a mix of single-trailer and double-trailer configurations. The double-trailer configurations are inappropriate for this study because of the divisibility of the cargo. As a result, we considered the principal heavier configuration from the report as our second scenario, which adds an additional axle, at an additional 17,000 pounds of weight, to be consistent with the other non-drive axles. Table 5 presents a typical set of axle weights and spacings for a containerized vehicle at this gross vehicle weight.

Table 5. Details of the 97,000-Pound Gross Vehicle Weight Container Vehicle

Axle	1	2	3	4	5	6
Weights (pounds)	12,000	17,000	17,000	17,000	17,000	17,000
Spacings (feet)	16	4	23	4	4	

Scenario 3: 98,000 Pounds on Five Axles

The third scenario increases the Scenario 1 weight and is more typically considered for truck-to-ocean movements on state and local highways. Table 6 presents a typical set of axle weights and spacings for a containerized vehicle at this gross vehicle weight. The need for a rail connection to make the permit feasible in Arizona reduces demand for this scenario to nearly zero.

Table 6. Details of the 98,000-Pound Gross Vehicle Weight Container Vehicle

Axle	1	2	3	4	5
Weights (pounds)	14,000	21,000	21,000	21,000	21,000
Spacings (feet)	16	4	27	4	

Scenario 4: 120,000 Pounds on Six Axles

The fourth scenario considers a much heavier vehicle and load. Much of the analysis of permit loads in the State of Texas' "Rider 36" study, reviewed as Selection 6 in Chapter 2 of this report, considered analysis loads up to this weight, regardless of destination. This scenario is provided primarily to consider the sensitivity of the infrastructure damage to escalating weights. Demand for containerized cargo will be extremely rare, but any changes in federal law or federal interpretation of divisibility could stimulate additional demand beyond the scope of our analyses. Furthermore, if the study corridor contained contiguous state-maintained non-interstate routes traversing the length of the corridor, this permit configuration would be suitable for transport of bulk commodities from industries such as mining, timber, and certain kinds of agriculture. Table 7 presents a typical set of axle weights and spacings for a containerized vehicle at this gross vehicle weight. Note that the tridem spacing inputs vary slightly from Scenario 1 because of the need to properly fit the container onto the vehicle.

Table 7. Details of the 120,000-Pound Gross Vehicle Weight Container Vehicle

Axle	1	2	3	4	5	6
Weights (pounds)	15,000	22,500	22,500	20,000	20,000	20,000
Spacings (feet)	18	4	37	5	5	

ANALYSIS OF CARGO CAPACITY AND VEHICLE SUBSTITUTION RATES

For each scenario, the next step in the analysis process involves analyzing the cargo capacity of each configuration. Once the cargo capacities are identified, substitution rates can be calculated to translate a volume of trips of vehicles in the base scenario into a corresponding number of trips of vehicles in other scenarios for which a permit must be purchased.

Estimate of Weight of Typical Unloaded Vehicle and Container

The analysis of the vehicle cargo capacity considers several factors:

- The weight of the power unit, also known as the “bobtail.”
- The weight of the chassis that carries the container and connects to the power unit.
- The weight of an empty container.
- The weight of the fuel when the fuel tank is fully loaded.
- The extra weight incurred when a sixth axle is added to the vehicle to convert the rear axles into a tridem configuration.

For each of these items, the specific weights vary slightly from vehicle to vehicle. For example, a carrier may choose to have a larger fuel tank if traveling in rural areas with a low density of service stations. The values in Table 8, however, represent industry norms for each component and show the resulting unloaded vehicle weight of the five-axle and six-axle configurations.

Table 8. Details of a Typical Unloaded Containerized Vehicle for Five and Six Axles[a]

Component	Component Weight (pounds)
Power unit	20,000
Chassis	6,700
Empty Container	8,250
Fuel (Diesel)	1,100
Total for Five Axle Configuration:	**36,050**
Sixth Axle	1,000
Total for Six Axle Configuration:	**37,050**

[a] Examples retrieved from the following vendors:

- http://www.midwestenergysolutions.net/cng-resources/energy-volume-weight; Chart Industries, NexGen Fueling Division, On-Board Fueling Systems, Tank Specifications.
- http://www.talinternational.com/equipment/chassis.
- https://www.tracintermodal.com/wp-content/uploads/2015/03/TRAC_Chassis_Brochure_2015.pdf.
- Triton International, http://www.talinternational.com/equipment.
- Container Technology, Inc., http://containertech.com/container-specifications/.

Cargo-Carrying Capacity

Based on the unloaded weights and scenario weights previously identified, Table 9 presents the typical cargo-carrying capacity of each scenario. Table 9 also presents the substitution ratio of one base scenario trip into a fractional trip for each subsequent scenario.

Table 9. Available Cargo Capacity for Each Scenario

Scenario	Gross Weight (Pounds)	Axles	Unloaded Weight (Pounds)	Available Cargo Capacity (Pounds)	Equivalent Number of Scenario Vehicles for One Base Scenario Vehicle
Base	Legal weight	5	36,050	43,950	1.000
1	90,800	5	36,050	54,750	0.803
2	97,000	6	37,050	59,950	0.733
3	98,000	5	36,050	61,950	0.709
4	120,000	6	37,050	82,950	0.530

For any specific shipper, however, the equivalent number of scenario vehicles will be the next higher integral number for total cargo being transported at that time. Consider a shipper with an amount of cargo to ship at a point in time that is equal to precisely 2.7 base scenario vehicles (118,665 pounds). Table 10 illustrates this example. In the base scenario, three trips are taken, with two at maximum weight for the base scenario. In some of the candidate scenarios, one of the trips taken is at a legal weight less than the base scenario, so no substitution is actually made for that trip. The impact of this rounding factor is that shippers with lesser amounts of commodity to ship via container at a particular point in time may sometimes buy permits for only some trips, because the benefits of the extra weight cannot be utilized on every single trip. The more total product a shipper has motor carriers transport at a particular point in time, the more likely that the full equivalences from Table 9 will in fact be reached.

Table 10. Example of Actual Equivalent Scenario Permits for a Shipper with 2.7 Base Scenario Vehicles' Volume of Cargo to Ship

Scenario	Available Cargo Capacity per Vehicle (Pounds)	Cargo Carried in Vehicle Trip #1 (Pounds)	Cargo Carried in Vehicle Trip #2 (Pounds)	Cargo Carried in Vehicle Trip #3 (Pounds)	Required Number of Permits
Base	43,950	43,950	43,950	30,765	N/A
1	54,750	54,750	54,750	9,165	2
2	59,950	59,950	58,715	N/A	2
3	61,950	61,950	56,715	N/A	2
4	82,950	82,950	35,715	N/A	1

ANALYSIS OF POTENTIAL PERMIT VOLUME

Data Sources

As described in Chapter 3, the research team analyzed data from three sources to understand the potential for motor carriers in the study region to purchase OSOW permits for sealed shipping containers in international intermodal transport:

- Traffic classification data from ADOT were used to identify the traffic volumes on various pavement sections throughout the corridor.
- Proprietary commodity flow data, purchased by the ADOT for a different freight-related study, were also used. This data, "IHS Markit TRANSEARCH 2013" (TRANSEARCH), supplied estimates of current and future commodity flows from Mexico to various destinations, provided that the flows traveled through Arizona. TRANSEARCH provides data in units.
- Publicly available data collected by CBP were obtained from USDOT's Bureau of Transportation Statistics regarding border crossing data into Arizona at the Mariposa Port of Entry. Units are not reported, only tonnage and value.

The latter two data sources were available only for northbound traffic. No reliable data source for southbound container traffic was found. To compensate, the number of trucks purchasing permits was increased slightly for the infrastructure analysis.

Limitations of Truck-to-Rail Intermodal Capacity

A key limitation to the feasibility of utilizing permits for international intermodal container transport in the study area is the ability of the containers to be transported by rail once they have reached Tucson. Two situations should be considered: one where a container is transported by rail with no other container on top of it, and another where two containers are transported by rail with one on top of the other, in a "double stack." The load weight limit for a single container on the Union Pacific railroad traversing the north end of the study region in Tucson is 65,000 pounds (Union Pacific Railroad 2018).

The Interaction Between Mexican versus American Motor Carriers

Chapter 3 of this report discussed the differentiation between carriers authorized to operate in Mexico and the radius around the Mariposa Port of Entry (referred to as "MX" carriers) and carriers authorized to operate throughout the United States (referred to as "MC" carriers). If a shipper decides to utilize an MX carrier to traverse the Mariposa Port of Entry and then transfer the container to an MC carrier, two permits would theoretically be needed, because permits are issued to the motor carrier, not to the owner of the load. If the MX carrier has one of the existing 25-mile radius permits for greater Nogales, however, the MX carrier would not need to purchase a permit in any of the scenarios being considered. Only the MC carrier would purchase a permit covered by one of the scenarios. The same situation would apply for traffic in the southbound direction from Tucson into Mexico.

Characteristics of Likely Permit Purchases

As the trip being considered must be both intermodal and international, every truck for which a set of permits has been purchased must travel the entire length of the study corridor from the Mariposa Port of Entry to the rail facilities in metropolitan Tucson or vice versa. As a result, the maximum number of vehicles that could possibly purchase a permit can be identified by the lowest travel volumes on I-10 and I-19 in the study region.

According to ADOT truck classification data, the lowest truck volume is approximately 1,300 trucks per day, corresponding to the I-19 corridor.

Not all of the owners of those trucks would be in a position to purchase a permit, however, for one or more of four reasons:

- The transport is not containerized.
- The transport is not currently reaching the weight limits.
- The transport is not international, with the cargo being transported either crossing the Mexico/United States border or leaving the United States by ocean vessel or both.
- The transport origin or destination is not realistically accessible by rail from Tucson.

These four potential reasons yield two constraints on demand that must be considered. The first constraint is the least difficult constraint to overcome. While other kinds of trailers may be more suitable for certain commodities, and containers were originally designed for ocean shipping and then adapted for rail and truck transport, there is little functional reason to believe that a container could not be used for various kinds of transport.

The second constraint is that there must be enough cargo being transported to even consider the benefits of operating at higher weights. While none of the available data show the sequencing of traffic by an individual shipper, a study of truck classification data can identify some general constraints.

The American Association of State Highway and Transportation Officials (AASHTO) Pavement ME (PaveME) software (version 2.1) used by ADOT requires truck weights to be distributed into specific axle load categories and reported as a percentage of total axles of each specific truck class. Figure 7 presents an example of axle load distribution for a section of I-19. The base scenario shows the current distribution of axle loads, with the peak tandem axle load occurring near the current legal tandem axle limit of 34,000 pounds. In comparison, Scenario 1 represents the shifted axle load distribution to account for the higher axle weights of the permitted trucks with a tandem axle load of 40,000 pounds.

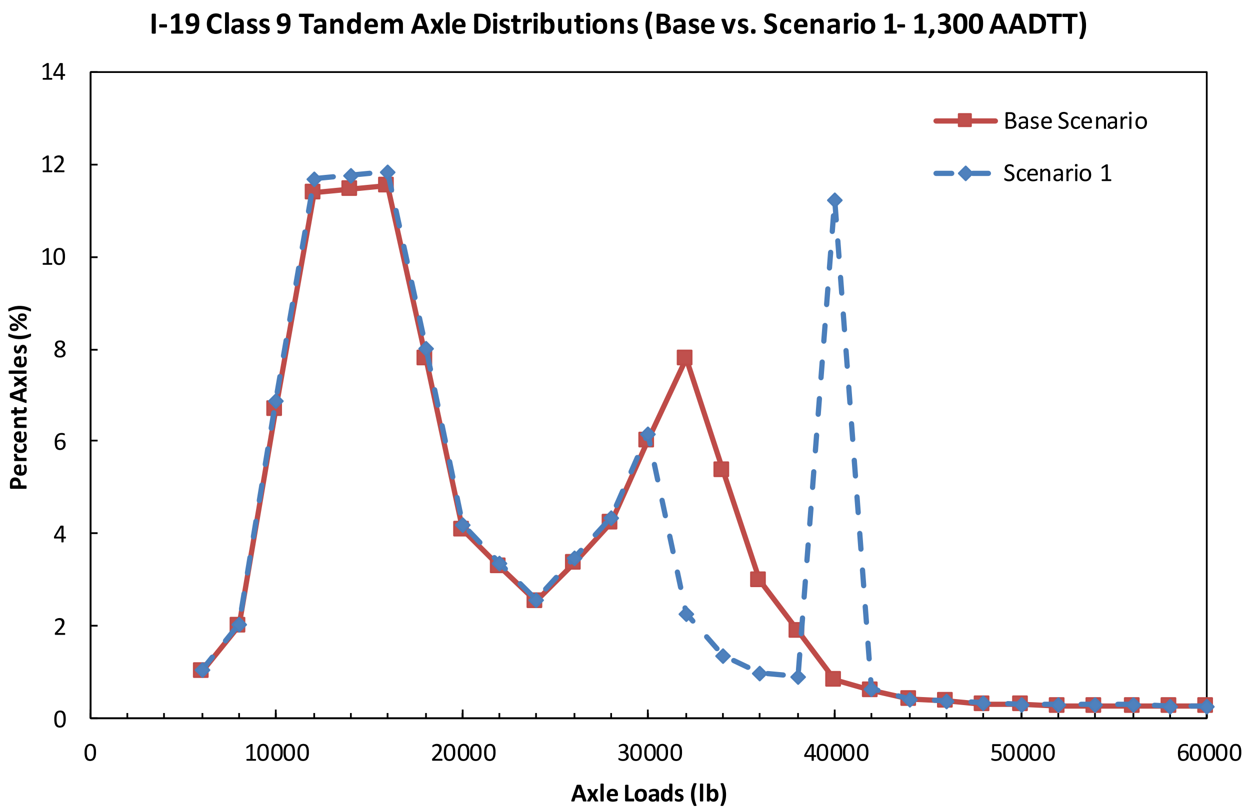

Figure 7. Distribution of Axle Loads for a Low AADTT Location on I-19

Source: ADOT traffic classification data.

Figure 8 shows the same data, but the vertical axis reflects the cumulative percentage of tandem axle distribution. Three potential situations are considered:

- The trucks with a tandem weight below 34,000 pounds still likely have space for additional cargo without exceeding the weight limit. They have no need for a permit.
- The trucks with a tandem weight greater than 38,000 pounds are either already permitted (and thus have some other type of nondivisible load) or are operating illegally without a permit. It is unlikely that any of these trucks would purchase a permit under one of our four scenarios.
- At 34,000 pounds per tandem, the vehicle is most likely weight-constrained by law. To account for errors in loading vehicles, differences in densities of bulk commodities, and similar situations, the team extended the benefit of the doubt to the carriers with trucks up to 38,000 pounds. These are the carriers who are likely to purchase a permit under one of our four scenarios, if they have additional product to transport as in the example shown in the "Results of Pavement Analysis" section.

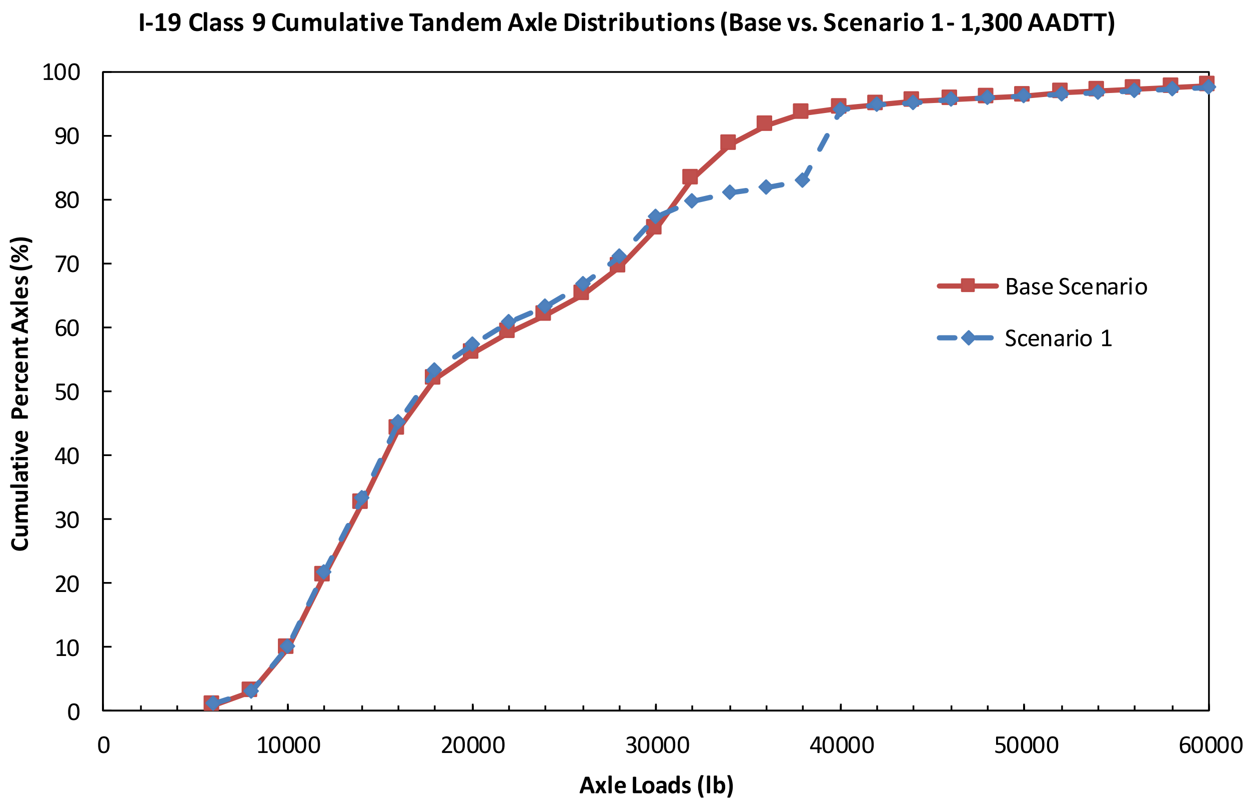

Figure 8. Cumulative Distribution of Axle Loads for a Low AADTT Location on I-19

Source: ADOT traffic classification data.

Given this set of conditions, it appears highly unlikely that more than 300 trucks per day could theoretically be transporting enough cargo to purchase a permit under one of the four scenarios.

Trip and Commodity Characteristics: Analysis of Commodity Flow Data

The research team analyzed both the TRANSEARCH data provided by ADOT and the publicly available CBP data. Both data sets contained information only about northbound traffic from Mexico into the United States through Arizona.

One challenge is that import truck volumes at Mariposa are much higher in the CBP data than in the TRANSEARCH data. Table 11 compares the two data sets. The CBP data capture much more truck traffic than the TRANSEARCH data do. Only the TRANSEARCH data, however, capture units. As a result, the research team conducted the detailed analysis with the TRANSEARCH data but then adjusted the results to mimic the total CBP volumes.

Table 11. Comparison of Truck Volumes (2013)

Source	Tons (Millions)
CBP Data	
Goods bound for all US destinations by truck from Mexico from all ports of entry	37.7
Port District of Nogales: Goods bound for destinations other than Arizona	1.6
Port District of Nogales: Goods bound for Arizona destinations	2.6
TRANSEARCH	
Traffic from all Mexican origins associated with Arizona	7.4
Traffic from only Sonora and Sinaloa, most likely to enter at Nogales	0.6

Sources: US Customs and Border Protection, IHS Global Insight.

The TRANSEARCH data for the Mariposa Port of Entry organizes the entries into the United States by destination. Given the network characteristics of the Union Pacific rail line traversing Tucson, the research team isolated traffic for two broad zones of destinations.

To address the travel constraints, one zone was broadly defined as all destinations in the United States east of the Mississippi River. These trips were of a distance where rail transport typically provides distance-based benefits while excluding travel to states such as Texas and New Mexico where other truck-based routes through Mexico exist. It also includes all of the Atlantic and eastern Gulf of Mexico deep water ports for ocean shipping.

The other zone was defined as Southern California. Service exists between Tucson and Metropolitan Los Angeles, including the Ports of Los Angeles and Long Beach. Other parts of the country were excluded, as trips would either be too circuitous by rail or would most logically travel by truck through ports of entry east of Nogales.

The TRANSEARCH data is organized by major commodity groups. Table 12 presents the volumes for each commodity group between the Mariposa Port of Entry and the two zones for which travel by rail would be realistic. The research team did not include transport with equipment not traditionally used in intermodal rail service, such as auto carriers, tanks, and flatbeds.

Table 12. Distribution of Customs and Border Patrol-Tracked Shipments to the United States East of the Mississippi River and Southern California Zones (2013)

Commodity Category / Commodity Name		US East Zone		Southern California Zone	
		Tons	Units	Tons	Units
01	Farm Products	1	0	314	23
09	Fresh Fish and Marine Products	2,924	126	4,926	212
10	Metallic Ores	641	25	7	0
14	Nonmetallic Minerals	80,263	3,351	3,740	154
20	Food and Kindred Products	43,854	4,665	5,899	406
22	Textile Mill Products	230	11	218	10
23	Apparel and Other Finished Textiles	1,740	106	2,716	167
24	Lumber and Wood Products, Exc. Furniture	254	20	381	14
25	Furniture and Fixtures	4,704	313	303	20
26	Pulp, Paper, and Allied Products	1,364	56	121	5
27	Printer Matter	426	24	140	8
28	Chemicals and Allied Products	2,726	343	2,219	394
30	Rubber and Miscellaneous Plastic	2,566	367	871	138
31	Leather and Leather Products	51	3	21	1
32	Stone, Clay, Glass and Concrete Products	8,826	0	344	0
33	Primary Metal Products	4,665	373	1,019	81
34	Fabricated Metal Products	5,233	408	377	29
35	Machinery, Except Electrical	14,652	2,131	904	131
36	Electrical Machinery, Equipment, and Support	27,438	2,050	927	77
37	Transportation Equipment	4,696	448	984	101
38	Instruments, Photo and Optical	8,025	857	308	35
39	Misc. Products of Manufacturing	128	7	289	15
Total		**215,407**	**16,605**	**27,030**	**2,051**

Source: HIS Markit 2013 data provided by ADOT.

Data about shipments are aggregated by the commodity types above. For each commodity and zone, the average tons per shipment, rounded to the nearest thousand pounds, is shown in Table 12.

The research team makes the following assertions regarding the likelihood of permit purchase under Scenario 1:

- Commodities with an average of more than 20 tons can be expected to leverage purchasing the permit every time.
- Commodities with an average of 18 through 20 tons can be expected to leverage purchasing the permit roughly three-quarters of the time. Some loads will be heavier; some will be lighter.

- Similarly, commodities with an average of 15 through 17 tons can be expected to leverage purchasing the permit roughly one-half of the time.
- Finally, produce and perishable agriculture commodities would have been limited to 10 percent usage of the permit, based on the stakeholder feedback described in Chapter 3, but the average tons per unit is less than 15 tons for the most relevant commodity. It is unlikely that even 10 percent of the produce would use the permit.

For Scenarios 2 and 3, the threshold for fully utilizing the permit is much higher; thus, the following assertions are made about utilization:

- Commodities with an average of more than 23 tons can be expected to leverage purchasing the permit every time.
- Commodities with an average of 20 through 23 tons can be expected to leverage purchasing the permit roughly one-half of the time.
- Similarly, commodities with an average of 15 through 20 tons can be expected to leverage purchasing the permit roughly 10 percent of the time.

The right column of Table 10 tabulated the estimated number of current base scenario trips for which a permit is predicted to be purchased if an intermodal move is utilized. The translation into the number of annual trips at the higher weights is found in Table 13. Note that traffic is not calculated for Scenario 4, as the cargo weight exceeds the maximum rail container weight. Also, commodities from Table 12 that do not have any share in Scenario 1 are omitted from Table 13.

Table 13. Estimated Maximum Permits Likely to be Purchased by Commodity Type

Commodity Category / Commodity Name		Average Tons/ Shipment	Total Units Shipped	Scenario 1 Total Share	Scenario 2-3 Total Share
09	Fresh Fish and Marine Products	23	339	338	338
22	Textile Mill Products	21	21	20	10
23	Apparel and Other Finished Textiles	16	273	136	0
25	Furniture and Fixtures	15	333	166	0
26	Pulp, Paper, and Allied Products	24	61	61	61
27	Printer Matter	18	32	15	3
31	Leather and Leather Products	15	5	2	0
32	Stone, Clay, Glass and Concrete Products	16	949	474	0
33	Primary Metal Products	16	454	227	0
34	Fabricated Metal Products	16	437	218	0
36	Electrical Machinery, Equipment, and Support	15	2,127	1063	0
39	Misc. Products of Manufacturing	19	22	16	2
Total Annual Vehicles Transferring to Permit Loads (TRANSEARCH 2013)				**2,736**	**414**
Estimated Growth Rate 2013-2017 (8.24%)				**225**	**34**
Annual Estimate after CBP Reconciliation				**20,727**	**3,136**
Daily Estimate (250 business days)				**82.9**	**12.5**

Growth Rate over Time

The TRANSEARCH data analyzed were for calendar year 2013. As a result, a growth rate of two percent per year has been assumed. Accordingly, the results in Table 13 were multiplied by a compounding of two percent, for an 8.24 percent adjustment to reflect 2017 volumes.

Adjusting the Estimate to Account for Southbound Traffic

In our stakeholder interviews described in Chapter 3, the prevailing sentiment was that the traffic from Tucson to Nogales might have greater potential for permit traffic, depending on the ability to transfer raw materials from Asia to Nogales via a rail connection between the Ports of Los Angeles and Long Beach to Tucson and then via a permitted vehicle to Nogales. Unfortunately, the relevant data is highly anecdotal in nature.

The research team determined that a higher permit volume than 82.9 permits per day was required for the engineering analysis to account for the lack of the southbound data, as stakeholders had indicated that the commodity mix heading southbound into Mexico (more raw commodities) was more conducive to permit purchase than the northbound commodity mix (more finished products). As a result, a figure of 100 permit vehicles per weekday was chosen to capture the uncertainty and variance in the available data sets.

ANALYSIS OF IMPACTS ON PAVEMENT SAMPLE SECTIONS

Methodology

Pavement analysis was performed using version 2.1 of the AASHTOWare PaveME software in conjunction with the Arizona local calibration factors listed in the ADOT SPR 606 Report, *Calibration and Implementation of the AASHTO Mechanistic-Empirical Pavement Design Guide in Arizona* (Darter et al. 2014). The overall approach to analyzing the impacts of overweight vehicles followed the methodology of the 2015 MAP-21 Comprehensive Truck Size and Weight Limits Study, reviewed in Chapter 2, where the pavement structure was considered new for analysis purposes (US Department of Transportation 2015). The only exception was that once the initial rehabilitation activity occurred (based on PaveME analysis), a rehabilitation interval was assumed for subsequent activities as follows:

- A 12-year rehabilitation interval was assumed for the base scenario traffic. This is a common rehabilitation interval on Arizona highways and the same interval assumed for all traffic scenarios in the 2015 FHWA Study.
- An 11-year rehabilitation interval was assumed for Scenario 1 traffic to capture the effect of accelerated deterioration due to overweight (permitted) axle loads.

The Appendix presents a detailed discussion of the pavement analysis approach and PaveME analysis.

Results of Pavement Analysis

The results of the pavement analysis (Table 14) indicate that the marginal infrastructure damage on the pavement sections caused by the transfer of the vehicles from the base scenario to Scenario 1 (the 90,800-pound permit) on I-19 is minimal. For example, one pavement section has its initial service life reduced from 22.9 to 22.8 years (0.4 percent) in Scenario 1; the result is similar across the other I-19 asphalt concrete sections. The asphalt concrete section on I-10 shows a reduction in initial service life of two years, and the concrete sections exhibit a 1.5-year decrease in initial service life. The increased reduction in service life for the overweight scenario on the I-10 pavement sections is likely due to the fact that overall truck volumes are much higher (compared to I-19) and the existing pavement structure is not of adequate thickness (based on available ADOT records) to handle future traffic volumes. Thus, the PaveME analysis shows that overweight vehicles produce more damage to the pavement on I-10 when combined with accelerated damage (compared to I-19) from the higher truck volume.

Table 14. Results of PaveME Analysis

Pavement Section	Route	Truck Scenario	Description	Time to Critical Distress (Years)		
				Asphalt Concrete		
				IRI	Rut	AC Fatigue (Bottom Up)
1	I-19	0	Base/STAA 80000/5	36.8	22.9	32.9
		1	Permit 90800/5	36.7	22.8	32.1
2	I-19	0	Base/STAA 80000/5	37.9	32.9	>40
		1	Permit 90800/5	37.9	32.8	>40
3	I-19	0	Base/STAA 80000/5	37.0	26.8	>40
		1	Permit 90800/5	37.0	26.7	>40
5	I-10	0	Base/STAA 80000/5	36.4	10.8	24.9
		1	Permit 90800/5	36.1	8.8	22.9
Pavement Section	**Route**	**Truck Scenario**	**Description**	**Time to Critical Distress (Years)**		
				PCC		
				IRI	**Faulting**	**Slab Cracking**
4 - PCC	I-10	0	Base/STAA 80000/5	30.5	29.5	11.9
		1	Permit 90800/5	27.6	26.8	10.4

Note: PCC analysis assumes 1.25" dowels for the analysis to output logical values.

ANALYSIS OF IMPACTS ON BRIDGE SAMPLES

Table 15 presents the eight sample structures identified in Chapter 3. While all eight structures are in the northbound direction, several of these structures are dual bridges with similar characteristics in the southbound direction.

Table 15. Sample Structures Identified for Overweight Load Analysis

Bridge Sample No.	ADOT Structure No.	Milepost of Structure	Structure Name	Year of Construction	Structure Type Material	Structure Type Design	No. of Spans	Maximum Span Length	Inventory Rating	Operating Load Rating	Sufficiency Rating	Bridge Type
1	353	11.97	Agua Fria Canyon Br NB	1951	2	01	4	25	34	56	84.34	Slab Bridge
2	1735	17.75	Arroyo Angulo Agudo NB	1978	6	02	3	67	39	66	96.35	P/S AASHTO Girder
3	1737	18.19	Tumacacori TI OP NB	1978	5	06	1	150	47	80	97.32	PT Box Girder
4	1354	40.65	Esperanza Blvd TI NB	1969	2	04	4	49	35	60	92.72	RC Tee Girder
5	1572	45.80	El Toro Rd OP NB	1971	4	02	4	95	36	55	91.63	Steel Girder
6	1303	49.62	Pima Mine TI OP NB	1968	5	02	4	61	33	77	93.00	P/S AASHTO Girder
7	1243	56.80	Santa Cruz River Br NB	1967	4	02	5	114	42	70	92.73	Steel Girder
8	2531	62.67	I-19 Ramp W-S	2004	6	06	2	109	54	99	86.19	PT Box Girder

The five truck vehicle configurations assumed for the load analysis were assessed for their impact on the eight sample structures. These vehicle configurations were selected to provide a range of potential load impacts.

Methodology

The eight sample structures were subjected to a load rating analysis based on the Load Factor Method for the five vehicle configuration scenarios using the LEAP ConBox (from Bentley Systems) and AASHTOWare Bridge software programs. ConBox was used for the structures with post-tension box girders, while the AASHTOWare Bridge program was used for the other structures. Data for each sample structure were obtained from ADOT. Unlike the pavement analysis, which loads the entire traffic distribution onto the infrastructure, the structural analysis considers the individual vehicle.

The load rating analysis determines impacts to structures using inventory and operating load rating factors. The following definitions guide the analysis and interpretation of the results:

- The ***inventory load rating*** measures how much load can safely utilize the structure for an indefinite period of time.
- The ***inventory load rating factor*** is the ratio of the inventory rating load the structure is designed to handle without adverse impacts compared to the inventory rating load of the assumed vehicle configuration scenario.
- The ***operating load rating*** is the maximum permissible live load that can be placed on the structure.

- The ***operating load rating factor*** is the ratio of the operating rating load the structure is designed to handle without adverse impacts compared to the operating rating load of the assumed vehicle configuration scenario.

Inventory and operating load rating factors below 1.0 indicate the structure will suffer adverse impacts from adding the vehicle to the structure.

Since none of the bridges in question had been "posted" to only allow travel at legal weights at the time of the analysis, the inventory and operating load rating factors are presumed to be greater than 1.0. The specific amount above 1.0 is irrelevant; for example, results of 1.03 and 1.11 both indicate that there are no adverse effects. A permit scenario will have adverse effects if the scenario vehicle causes a rating factor of less than 1.0.

Table 16 presents the findings from the load ratings analysis. Ratings under 1.0 are shown in bold.

Table 16. Load Ratings Analysis Findings

Bridge Sample No.	ADOT Structure No.	Structure Name (Bridge Type)	Rating Type	Current Base Scenario (80,000 & 5)	Scenario 1 (90,800 & 5)	Scenario 2 (97,000 & 6)	Scenario 3 (98,000 & 5)	Scenario 4 (120,000 & 6)
1	353	Agua Fria Canyon Br NB (Slab Bridge)	Inventory	1.15	1.01	1.15	0.93	0.77
			Operating	1.91	1.68	1.91	1.55	1.28
2	1735	Arroyo Angulo Agudo NB (P/S AASHTO Girder)	Inventory	1.52	1.33	1.37	1.24	1.13
			Operating	3.13	2.75	2.85	2.54	2.34
3	1737	Tumacacori TI OP NB (PT Box Girder)	Inventory	1.15	1.01	0.95	0.94	0.89
			Operating	2.14	1.89	1.77	1.75	1.66
4	1354	Esperanza Blvd TI NB (RC Tee Girder)	Inventory	1.08	0.95	1.10	0.88	0.77
			Operating	1.80	1.58	1.84	1.47	1.28
5	1572	El Toro Rd OP NB (Steel Girder)	Inventory	1.11	0.97	1.05	0.90	0.88
			Operating	1.85	1.62	1.75	1.50	1.46
6	1303	Pima Mine TI OP NB (P/S AASHTO Girder)	Inventory	1.36	1.19	1.22	1.11	0.92
			Operating	3.08	3.08	3.08	2.51	2.07
7	1243	Santa Cruz River Br NB (Steel Girder)	Inventory	1.52	1.34	1.45	1.24	1.23
			Operating	2.54	2.23	2.43	2.07	2.06
8	2531	I-19 Ramp W-S (PT Box Girder)	Inventory	1.58	1.40	1.28	1.29	1.28
			Operating	3.42	3.01	2.82	2.77	2.69

In a typical situation for an overweight nondivisible permit where the vehicle causes an inventory rating of less than 1.0, a carrier might be asked to take precautions when traveling over a bridge, such as slowing down to a crawl. Given the potential volume of permit vehicles traveling on I-10 and I-19 in the study area on any particular day, these types of measures do not appear feasible.

CHAPTER 5. DAMAGE COST AND FEE CALCULATION

INTRODUCTION

Given the estimated infrastructure damage, the next analysis step is to translate the results from the analysis of permit volumes and infrastructure damage to a per-permit cost to mitigate the infrastructure damage. For example, if mitigation of the damage required an ongoing activity at a cost of $8,000 per weekday and 100 current trucks would be replaced by 80 permitted trucks each day, the mitigation cost for the infrastructure damage would then be $100 per permit.

Given the characteristics of the network in the study area and the lower levels of damage in cases for which infrastructure replacement is not an option, we used a simplified approach from network-level models found in the literature and focused on the maintenance and rehabilitation options available to alleviate the expected damage from the permitted trips.

Our analysis incorporated inputs from our previous research steps and inputs from ADOT on treatment options and relevant costs. Only Scenario 1 (a permit for a vehicle weighing 90,800 pounds on five axles) was used for the cost calculation, as the number of trips expected for Scenarios 2 through 4 appeared highly unlikely to generate enough demand to enable the rail portion of the intermodal trip.

The methodology below calculates the estimated direct costs of structural and pavement damage based on the purchase of permit vehicles. That is ***not*** the same as the actual cost of the permit, as permit costs implicate additional factors beyond infrastructure damage. Several examples of additional cost components to be considered when setting permit fees are outlined at the end of this chapter.

METHODOLOGY

Our approach considers the rehabilitation costs to keep the infrastructure at the level of the "no-permit" option through additional highway projects. These projects would be scheduled according to standard ADOT procedures. The projects could be in either of two categories:

- Projects conducted in addition to the normal sequence of events for the infrastructure
- Projects already anticipated that would be conducted earlier than otherwise expected because of the damage impacts of the permits

Our methodology utilized six steps in sequence:

1. Review results of engineering analysis of sample sections and identify appropriate treatment(s). Project team staff met with ADOT technical staff and mutually agreed upon the appropriate treatment option(s) for each sample infrastructure unit. When multiple potential options were identified, they were to be applied proportionately to the unit.
2. Identify direct costs on a per unit basis. Direct costs are the actual costs of activities required to restore the infrastructure to the condition to be expected if the permitted trips did not occur. If the activity would have been undertaken eventually and now was being undertaken earlier, the appropriate percentage of the total direct costs was allocated to the permitting process. Direct

costs for either a square-foot basis or a lane-mile basis (depending on the treatment) were obtained from ADOT.

3. Calculate costs for each sample of structure and pavement. For each sample unit, the direct cost of appropriate treatment was budgeted against the unit to obtain a total direct cost for the sample unit.
4. Expand these costs to all corresponding infrastructure associated with each sample. In Chapter 3, the total inventory in the study area was categorized based on the sample units identified. Either lane-miles or square footage was applied to the cost per unit. Calculations were done individually for the north-to-east and the west-to-south directions of travel.
5. Add up costs for the entire trip length. While it is possible that some trips will not traverse the entire 68-mile length of I-19 and I-10 in the study area, the vast majority of trips are expected to cover the entire study region. If there were a broader network of distribution centers and intermodal facilities, a more complex set of assumptions would be needed for this step.
6. Amortize across the number of single-trip permits to be issued (not the number of trips diverted, as that is a higher number). In Chapter 4, we indicated that the value of 100 legal-weight truck-loads used in the engineering analysis would translate to 80 to 81 permits issued, for 250 days per year.

Table 17 summarizes the general inputs to the methodology. Additional inputs are specific to the analyses of structures module and are summarized in Table 20.

Table 17. Cost Analysis Methodology Inputs Common to Both Structures and Pavement Methodologies

Methodology Input	Input Source
Infrastructure samples	Chapter 3 analysis identified samples
Translation of costs to remaining infrastructures	Chapter 3 analysis identified relationships
Damage to be mitigated	Chapter 4 analysis
Appropriate treatment(s) to utilize	Discussion with ADOT technical staff regarding current practice
Direct costs of treatments on a per-unit basis	ADOT technical staff
Number of permits to be issued	Chapter 4 analysis

Pavement Engineering Methodology

The pavement analysis approach generally parallels the structures analysis approach. The central metric is the elapsed time for a pavement type to reach a specified distress level (for example, time for asphalt concrete to reach a critical level of fatigue cracking, rutting, and/or International Roughness Index [IRI] and how the time to critical distress level changes in the permit scenario). Pavement analysis was performed using version 2.1 of the PaveME software in conjunction with the Arizona local calibration factors listed in the ADOT SPR 606 Report, “Calibration and Implementation of the AASHTO Mechanistic-Empirical Pavement Design Guide in Arizona” (Darter et al. 2014). In the Appendix, the analysis process and the method for estimating changes in time to fatigue, rutting, and IRI are described.

To mitigate the accelerated distresses, typical ADOT pavement rehabilitation approaches were utilized, as summarized in Table 18. Then, for each pavement sample, the relevant rehabilitation activities were identified and the costs tabulated for both the no-permit scenario and the 90,800-pound permit scenario. Each activity was assumed to last for a shorter amount of time (one year) in the permit scenario, and additional rehabilitation activities continue to be applied until the end of the 50-year life cycle analysis period. Table 19 shows an example of these tabulations.

After adjusting value to 2017 dollars, the present value was amortized across the appropriate number of purchased permits to obtain a per-permit cost. Once the sample pavement sections per-permit costs were identified, the results were extended to the entire study area, with individual tabulations in the north-to-east and west-to-south directions.

Table 18. ADOT Loaded Construction Costs for Typical Asphalt Concrete Rehabilitation Treatments

ADOT Method ID	Type of Work	Loaded Construction Costs (in $1000 per Lane Mile)
100	RR (5”TL, 3” PL) + FR	359
101	RR 4” AC + FR	359
102	RR (4” TL, 3” PL) + FR	330
103	RR (4.5” TL, 2.5” PL) + FR	326
104	RR (3.5” TL, 2.5” PL) + FR	301
105	RR 3” AC + FR	300

Source: ADOT
TL – travel lane
PL – passing lane
RR – remove (mill) and replace asphalt concrete
FR – asphalt concrete friction course (open graded)
AC – asphalt concrete

Table 19. Mitigation Cost Comparison Example Between Base and Permit Scenarios

Activity	Base Scenario (80,000 Pounds on 5 Axles)	Permit Scenario (90,800 Pounds on 5 Axles)	Treatment Applied
Failure Mode	Rutting	Rutting	
Activity 1 (yrs)	22.9	22.8	102
Cost for Activity 1	$660,000	$660,000	
Activity 2 (yrs)	34.9	33.8	104
Cost for Activity 2	$602,000	$602,000	
Activity 3 (yrs)[a]	46.9	44.8	104
Cost for Activity 3	$155,517	$284,582	

[a] Cost of this activity was prorated based on an analysis period of 50 years.

Structural Engineering Methodology

The structural engineering cost analysis follows the general methodology identified in NCHRP Report 495, described in Chapter 2 of this report. A simplified version of the methodology was used for two reasons. First, the infrastructure damage does not cause the Operating Rating of any of the sample structures to fall below 1.0. As the Operating Ratings remain above 1.0, there is no loss of function of the structures or need for considering bridge replacement. Second, the trip is considered a single route and not a complex network. As a result, many of the nuances in the NCHRP 495 process can be simplified.

The general theme of NCHRP 495, however, is retained. The AASHTOWare Bridge Management software is utilized to calculate the relative difference in bridge deck life between the no-permit option and the permit option for each sample structure analyzed in Chapter 4. The yearly difference in life is then multiplied by the square footage of all structures similar to the sample structure and the cost of the replacement or rehabilitation function. By tabulating these values in each direction, we obtain a total annual cost in 2017 dollars. Dividing the total cost against the expected number of permits yields a per-permit cost in 2017 dollars.

Additional data is needed beyond the inputs from the NCHRP report. As enumerated in Table 20, ADOT provided several inputs, and other inputs were derived from the results of analyses described in earlier chapters of this report.

Table 20. Structural Engineering Inputs to the Cost Model

Source	Input Variables
NCHRP 495, Section 3.4	• Wheel load and deck interaction • Safety, reliability, uncertainty, and model correction factors
ADOT Bridge Data	• Age • Traffic volumes and lane distributions • Default factors for AASHTOWare Bridge software parameters
Previous Chapters	• Number of vehicles replaced • Number of permit vehicles added • Weight and spacing information per axle

ADOT Bridge Group provided the cost per square foot of typical bridge deck rehabilitation, deck replacement, superstructure replacement, and total bridge replacement. A 1.9 percent discount rate was assumed. The standard base case trucks were assumed to be replaced by the heavier trucks 250 days out of the year.

COST RESULTS

Structural Engineering Results

Table 21 summarizes the changes in the deck lifespan for the eight sample structures. In all cases, the change in deck lifespan is ***less than one half of one day per year***.

Table 21. Difference in Time to Deck Fatigue for the Sample Structures

Structure Sample Type	Current Deck Lifespan (Years)	Change in Lifespan (Days)
Slab	35.8	0.35
PS AASHTO-1	35.2	0.37
PS AASHTO-2	39.3	0.05
PT Box-1	32.9	0.35
PT Box-2	47.0	0.07
Tee Girder	21.2	0.13
Steel Girder-1	15.4	0.10
Steel Girder-2	34.8	0.09

While these values are minimal and likely within the variances of the AASHTOWare Bridge Manager methodology when it comes to precision and significance, the project team did carry the analysis of the direct costs through the cost methodology process. The direct costs assumed an even mix of deck replacement ($150 per square foot) and deck rehabilitation ($100 per square foot) projects.

Results of Bridge Cost-Impact Analysis

The results of the bridge cost-impact analysis presented in Tables 22 and 23 indicate that the infrastructure damage on the bridge structures caused by the transfer of the vehicles from the base case scenario (80,000-pound truck) to Scenario 1 (the 90,800-pound truck) is minimal. The steel fatigue's remaining safe life is reduced by approximately 0.58 years. The reduced service life of the reinforced concrete decks from the deck fatigue analysis is essentially none. Finally, the deficiency due to overstress of existing bridges is not a factor. With the four cost-impact categories from NCHRP 495, the additional cost of the damage caused by the Scenario 1 overweight truck permit is approximately $0.03.

Table 22. Steel Superstructure Fatigue per Truck Cost Analysis

Bridge Superstructure Type	Years of Service Life of Sample Bridge Deck	Current Age of Sample Bridge Deck in Years	Remaining Years of Life of Sample Bridge Deck	Remaining Years of Life of Sample Bridge Deck	Total Deck Area for Same Bridge Type (NB/EB)	Total Construction Cost for Same Bridge Type (NB/EB)	Total Deck Area for Same Bridge Type (SB/WB)	Total Construction Cost for Same Bridge Type (SB/WB)
	Sample Bridge				**All Bridges in the Network**			
Steel Girder -2	133.69	49	84.68864	84.10903	63,976	$18,393,100.00	59,466	$17,096,475.00
					PV (Base) =	$3,735,892.47		$3,472,530.04
					PV (Scenario 1) =	$3,776,871.87		$3,510,620.59
						NB/EB		**SB/WB**
					Total PV (Base) =	$3,735,892.47		$3,472,530.04
					Total PV (Scenario 1) =	$3,776,871.87		$3,510,620.59
					Difference in PV =	$40,979.40		$38,090.55
					EUAC =	$1,276.83		$1,186.82
Directional Deck Fatigue Cost of Overweight Trucks (90,800 lb Scenario) on a Per Truck Basis:								
					$/Truck (365 days/yr.) =	$0.0437		$0.0406
					$/Truck (250 days/yr.) =	$0.0300		$0.0278

Table 23. Deck Fatigue per Truck Cost Analysis

Bridge Superstructure Type	Years of Service Life of Sample Bridge Deck	Current Age of Sample Bridge Deck in Years	Remaining Years of Life of Sample Bridge Deck	Remaining Years of Life of Sample Bridge Deck	Total Deck Area for Same Bridge Type (NB/EB)	Total Construction Cost for Same Bridge Type (NB/EB)	Total Deck Area for Same Bridge Type (SB/WB)	Total Construction Cost for Same Bridge Type (SB/WB)
	Sample Bridge				**All Bridges in the Network**			
Slab	90.04	65	25.03822	25.03822	53,236	$7,652,675.00	52,574	$7,557,512.50
					PV (Base) =	$4,776,877.53		$4,717,476.13
					PV (Scenario 1) =	$4,776,900.98		$4,717,499.29
PS AASHTO-1	50.51	38	12.50737	12.52143	37,245	$5,353,968.75	37,004	$5,319,325.00
					PV (Base) =	$4,230,953.84		$4,203,576.74
					PV (Scenario 1) =	$4,229,834.65		$4,202,464.80
PS AASHTO-2	50.49	48	2.49124	2.49123	47,331	$6,803,831.25	48,563	$6,980,931.25
					PV (Base) =	$6,492,167.41		$6,661,154.97
					PV (Scenario 1) =	$6,492,168.30		$6,661,155.89
PT Box-1	51.21	38	13.20652	13.20636	52,848	$7,596,900.00	56,467	$8,117,131.25
					PV (Base) =	$5,924,939.55		$6,330,675.93
					PV (Scenario 1) =	$5,924,956.61		$6,330,694.16
PT Box-2	50.45	12	38.44539	38.44529	46,776	$6,724,050.00	130,400	$18,745,000.00
					PV (Base) =	$3,261,153.74		$9,091,295.69
					PV (Scenario 1) =	$3,261,159.36		$9,091,311.36
Tee Girder	50.10	47	3.09853	3.09851	23,714	$3,408,887.50	23,980	$3,447,125.00
					PV (Base) =	$3,215,768.26		$3,251,839.54
					PV (Scenario 1) =	$3,215,769.17		$3,251,840.46
Steel Girder-1	50.37	47	3.37270	3.37269	19,955	$2,868,531.25	19,955	$2,868,531.25
					PV (Base) =	$2,692,095.65		$2,692,095.65
					PV (Scenario 1) =	$2,692,096.27		$2,692,096.27
Steel Girder-2	51.49	49	2.48616	2.48615	63,976	$9,196,550.00	59,466	$8,548,237.50
					PV (Base) =	$8,776,121.79		$8,157,447.46
					PV (Scenario 1) =	$8,776,123.18		$8,157,448.74
						NB/EB		**SB/WB**
					Total PV (Base) =	$39,370,077.77		$45,105,562.12
					Total PV (Scenario 1) =	$39,369,008.52		$45,104,510.97
					Difference in PV =	-$1,069.25		-$1,051.15
					EUAC =	-$33.32		-$32.75
Directional Deck Fatigue Cost of Overweight Trucks (90,800 lb Scenario) on a Per Truck Basis:								
					$/Truck (365 days/yr.) =	-$0.0011		-$0.0011
					$/Truck (250 days/yr.) =	-$0.0008		-$0.0008

Pavement Engineering Results

Table 24 summarizes the changes in the lifespan of the five sample pavement sections. Unlike the structures, the pavement sections are susceptible to more variability in permitted vehicles' effects on the time to critical rutting. As a result, Table 25 shows corresponding variability in the total project costs for the study area for each pavement type. Permitted vehicle impacts on fatigue cracking and IRI are not presented here, since rutting was the critical distress to trigger rehabilitation in asphalt pavements. Similarly, faulting and IRI for concrete pavements are not presented here, since slab cracking was the critical distress to trigger rehabilitation. Tabulating the project costs across all pavement sections, applying a discount rate to future activities, and adding in a multiplier for overhead costs yields an estimated total cost for pavement impacts of slightly over $5 in each direction per permitted truck.

The AASHTOWare software utilizes the same traffic volumes each day unless detailed day-by-day traffic volumes are available. The ADOT data are aggregated and averaged, so day-by-day data were not available. As a result, permit volumes had to be assumed for 365 days of the year instead of the more likely estimate of 250. On the other hand, the costs incurred were also divided by a similarly larger number of permits. While the resulting costs can be expected to be marginally higher when considering 365 days per year of permit traffic, the variation is also expected to be negligible compared to the overall precision and accuracy of the traffic data.

Table 24. Difference in Time to First Major Rehabilitation for the Pavement Sections

Pavement Group (Route)	Base Case Lifespan (Years)	Scenario 1 Lifespan (Years)
Asphalt 1 (I-19)	22.9	22.8
Asphalt 2 (I-19)	32.9	32.8
Asphalt 3 (I-19)	26.8	26.7
Concrete 4 (I-10)	11.9	10.4
Asphalt 5 (I-10)	10.8	8.8

Table 25. Cost of Mitigating Accelerated Pavement Damage

Pavement Sample Group	Total Lane Miles NB/EB Direction	Annual Direct Cost of Mitigation NB/EB Direction (in 2017$)	Total Lane Miles SB/WB Direction	Annual Direct Cost of Mitigation SB/WB Direction (in 2017$)	Cost per Lane Mile (in 2017)
1	25.9	$52,843.42	17.2	$35,086.95	$2040
2	23.0	$28,316.72	28.5	$35,084.62	$1231
3	5.8	$6,227.48	9.0	$9,675.22	$1075
4	5.1	$31,027.86	5.1	$31,027.86	$3027
5	4.5	$16,660.29	4.5	$16,660.29	$3702
6[1]	6.6	$9,280.90	6.6	$9,280.90	$1406
7[1]	2.9	$11,883.87	3.2	$13,019.53	$4069
Total Annual Cost (in 2017$)		**$156,231.54**		**$149,835.37**	
Per-Permit Direct Cost		**$5.35**		**$5.13**	

[1] Represents an additional pavement section not analyzed in project scope. Damage cost estimates were extrapolated from costs for similar analyzed sections.

Cost Summary

The structural and pavement damage costs can be combined into a single total cost, as shown in Table 26. Given the range of results and the relative accuracy and lack of precision of the analyses, $5-$7 appears to be an appropriate preliminary estimate of direct infrastructure costs due to increased damage.

Table 26. Summary of Damage Costs by Component

Cost Component	Structural Damage	Pavement Damage	Total Damage
Direct Costs of Treatment (per permit)	$0.03	$5.13 to $5.35	$5.16 to $5.38

ADDITIONAL ITEMS TO CONSIDER WHEN SETTING PERMIT FEES

As discussed earlier, a direct cost of just over $5 does not mean that the corresponding permit fee should be set at $5. Decision makers should consider a variety of additional agency costs as part of the fee-setting process. Four of the most common costs are project overhead, permitting technology, increases in enforcement, and increases in program administration.

Project Overhead Costs

Any rehabilitation or replacement of decks or pavement sections has project costs beyond the basic physical activity at the infrastructure component in question. Project planning and traffic mitigation are examples of these types of overhead costs. In consultation with ADOT staff, we assumed a planning factor of approximately 260 percent of direct costs to represent the project costs in aggregate.

In the engineering calculations above, however, planning costs can be added only if the change in traffic mix from the associated action (in this case, the introduction of a permit) will result in a new project during the planning horizon. If the time of the activity merely shifts without requiring a new project, then the overhead costs do not change in a meaningful way.

To illustrate, consider a hypothetical infrastructure element with a base case lifespan to rehabilitation of seven years. In a 20-year planning horizon, the element would involve two projects at most. If the permit action changed the lifespan to 4.5 years, a third and even a fourth project would be possible in the later years of the 20-year horizon. Therefore, it would be appropriate to add the preliminary damage costs.

In our scoped permit scenario, however, there will generally be no change in the number of projects. The bridge deck lifespan is changing by a matter of days, and the first pavement activity time is changing by a matter of months. The only infrastructure element scenario that even potentially would incur a project overhead cost is the “Asphalt 5” sample, and even then, a conservative estimate tabulates the additional effect at less than 11 cents per permit.

Permitting Technology and Staff Costs

The permit described in this report has an underlying business logic that is slightly different from the logic underlying permits currently issued by ADOT. Additional questions and validation requirements will arise about the trip as well as about the vehicle load as consideration of the program evolves. The actual permit credential document may have additional wording, information for the intermodal facility to note information (should the permit trip originate at a rail facility), and additional printed restrictions.

As a result, one can reasonably expect that the current agency permit system would be modified to accommodate what is in essence a new single-trip type of permit. The specifics of the implementation depend on the internal system architecture. At a minimum, there would have to be additional system configuration of internal data of the set of permits, design of the printed permit credential, and changes to the user interface for requesting a permit would be necessary. Other potential changes might include changes to standard workflows and database structures. Additional regression testing would be required to ensure that system changes to implement this permit do not inadvertently affect other parts of the permit system.

If implemented, the new permit program would require at least a fractional amount of weekly staff time to monitor compliance, as well as financing of up-front costs for setting up the program, including training and outreach.

Additional Roadside Enforcement and Deskside Compliance Costs

In Chapter 6, we will discuss the enforcement process and how it is affected by these permits. If additional enforcement costs (in the form of either labor or technology investment) are incurred to ensure compliance with this new permit, then those costs should be amortized across the expected permit volume. Given the nature of the permit and the volume of permits expected to be issued, we do not anticipate significant enforcement labor costs on the roadside. Additional labor costs may be incurred in the form of “deskside compliance” costs for staff required to review compliance of carriers, however.

It is possible that additional WIM or virtual weigh station technologies will be implemented either solely or partially to improve weight compliance on the study route. If so, these costs may be fully or partially amortized across the expected permit volume.

CHAPTER 6. PERMIT CHARACTERISTICS, COMPLIANCE, AND ENFORCEMENT

The permit under consideration is for the transport of customs-sealed containerized cargo as part of an international trip. Figure 9 illustrates the specialized nature of this permit. In the figure, a Venn Diagram shows the intersection of the three primary components of the permit as required for compliance with FHWA opinion via the Barnhart Letter discussed in Chapter 1:

- The permit must be part of an international trip.
- The permit must be part of an intermodal trip.
- The cargo can be defined as nondivisible if it is in a Customs-sealed container.

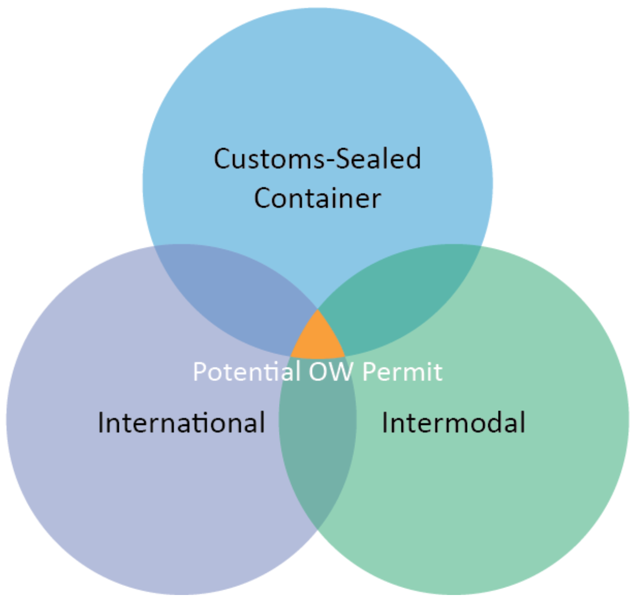

Figure 9. Relationship Among Permit Vehicle Elements to Adhere to the Barnhart Letter

The intersection of these three circles in the Venn Diagram identifies the conditions pursuant to which the permit in question can be issued. This permit is not intended to be a replacement or extension of the existing 25-mile radius permit from the Mariposa Port of Entry; it is intended to leverage the definition of nondivisibility from the Barnhart Letter to allow interstate travel to or from an intermodal facility.

The permitted vehicles in question would be of legal size. The permit should not be issued to any vehicle with dimensions in excess of currently legal dimensions. As a result, permitted vehicles will not be required to have either private or police escorts and can follow standard ADOT procedures regarding time-of-day and day-of-week restrictions for travel.

Varying degrees of difficulty are encountered in defining permit conditions in the project area to ensure compliance with federal criteria. As discussed in Chapter 3, most shipments crossing the border currently use two carriers for reasons having little to do with the absence or presence of a permit. These reasons can include the carrier's organizational structure, variability in border crossing time, inspection processes, and FMCSA safety score preservation. The presence of two carriers involved in one shipment, plus at least one intermodal segment, makes compliance with the "international" and "intermodal" permit conditions more challenging.

GUIDING PRINCIPLES

We recommend that the following four principles be used to govern the structure and compliance requirements of the permit:

- The permit is intended to connect to an intermodal movement; therefore, either the origin or the destination of the permitted vehicle shall be an intermodal facility unless the carrier can provide documentation of an intermodal trip segment before the permit trip segment.
- The permit shall be issued for a single trip.
- The permittee must provide enough information to allow for verification that the trip meets the provisions of the Barnhart Letter.
- The permit shall not be issued if the current 25-mile radius permit around Mariposa Point of Entry can be issued for the trip.

The first item is consistent with the Barnhart letter. It is theoretically possible to issue a permit for a trip not involving an intermodal facility, but not without disrupting the chain of information: a carrier may believe that a trip is indeed intermodal or international in nature when in fact it is not, and the next carrier will take the load in a different direction or break the load at an intermediate point. By specifying an intermodal facility as either the origin or destination, ADOT will be able to ensure that the intermodal facility indeed takes possession of the container. Exceptional situations, such as a train derailment or weather event blocking the rail line, may occasionally prevent the intermodal trip and require that the cargo be shifted into two legal-size loads for over-the-road transport. These situations, however, are expected to be rare.

The second principle also involves the ability to both enforce the permit program and properly track the volume of permits purchased and match these purchases against infrastructure fatigue. Each permit applies to a specific, individual cargo container that is uniquely identified in the permit application process. Issuance of a multi-trip permit, such as a monthly permit, would make it impossible to identify which containers are being transferred. For example, a permit could be created that would allow a drayage company to operate for a full calendar day on a single permit for a single power unit. Given the 70-minute drive between Nogales and Tucson, a carrier could theoretically transport 16 loads per day with multiple drivers. To ensure that the intermodal and international constraints are present, the carrier would have to submit information for each container. Given the low demand for such a permit, we find this scenario unreasonable and unlikely to be utilized.

The third principle also facilitates compliance with Figure 9. We recommend that the permit application (most likely made online using the state's permit system) include sections requiring information about the three main components required to satisfy the permit program requirements (in addition to the typical permit information):

- International — the point of entry into or exit from the United States, such as the Port of Long Beach or the Mariposa Port of Entry.
- Intermodal — information about the rail portion of the trip, including the rail facility utilized (at this point, only the Union Pacific line at the Port of Tucson would be available, but that could change over time) and the expected train on which the container will be placed.
- Containerized — information about the waybill and the container itself.

The fourth principle involves the existing permit process that is in place for businesses around Nogales. A new permit to simply supersede an existing permit type is not needed. Trips fully within the 25-mile radius of the Mariposa Port of Entry would continue to use the existing permit type. The following trips, however, are examples of trips where the new permit type would be appropriate:

- From Mariposa to the Union Pacific terminal at the Port of Tucson, or vice versa.
- From Mariposa to a distribution center in Tucson, provided the container arrived in Mexico by ship or traveled in Mexico by rail before arriving at Mariposa.
- From a distribution center in Nogales to the Port of Tucson, provided the carrier can document that the container did cross at Mariposa (possibly driven by another carrier) or will leave the United States as part of its trip.
- From the Union Pacific terminal at the Port of Tucson to a distribution center in Tucson, provided that the carrier can document where the container entered the United States.

ADDITIONAL COMPLIANCE-RELATED PERMIT PROCESS CHARACTERISTICS

Each printed permit should state that the permit is valid only for sealed containers involved in international, multimodal transport between the origin and destination indicated on the permit. Similarly, permit application or verification requirements specific to this permit should be incorporated into relevant statutes, rules, or policy as appropriate to facilitate compliance and aid enforcement actions.

The research team recommends that ADOT require that a Bill of Lading (a document issued by a carrier acknowledging receipt of cargo for shipment) be submitted with the permit application to ensure that the trip is an international one. Ideally, this could be submitted as an attachment to the online application, if feasible, or as an e-mail to a specified address within the Permit Office to be reconciled as needed.

Similarly, the research team recommends that ADOT require the US Customs and Border Patrol seal number be included in the permit application and printed on the permit for verification.

ADDITIONAL ENFORCEMENT PROCESSES AND TECHNOLOGY NEEDS

The challenge for roadside enforcement staff is simple to explain and difficult to mitigate: it is virtually impossible to tell the difference between a base case (80,000 pounds) and a permit case (90,800 pounds) vehicle load for vehicles carrying intermodal containers. A trained roadside officer may be able to detect subtle changes in how the vehicle looks in travel, but at highway speeds these are challenging distinctions to make. As a result, simply asking roadside enforcement staff to "find the overweight containers which are not permitted" is a losing proposition without technological assistance.

With technologies such as virtual weigh stations, however, it is more feasible for roadside staff to identify potential violators carrying containerized cargo over legal weight without a permit. A virtual weigh station utilizes in-ground WIM devices with camera and license plate reader technology for vehicle identification. By tying such devices into the state's Innovative Technology Deployment (formerly known as Commercial Vehicle Information Systems and Networks) program and linking permit purchases to the vehicles traveling on I-19, a member of the enforcement staff at the roadside can discern which containerized vehicles do and do not have permits for the 90,800- pounds I-19 permit. As of the date of the analysis in late 2016, ADOT had elements of this technology available southbound on I-19 at Canoa, but not northbound.

The challenge, however, is implementing such technology in a cost-effective manner. The analysis of Chapters 4 and 5 can be applied to characterize the infrastructure-related benefits of roadside enforcement investments. Specifically, on this section of the ADOT highway network, the benefit of identifying and stopping a vehicle whose owner did not purchase a permit for the same size and weight as the permitted load is only a little over $5.00. That is to say that the shift from 90,800 pounds on five axles to 80,000 pounds on five axles saves only as much infrastructure damage as is caused by a legally permitted vehicle. Assuming even a $100/hour cost of roadside enforcement labor and technology, 14 vehicles per hour would have to be stopped to justify the enforcement cost. There is not nearly enough freight demand on I-19 for this result to be feasible.

At a broader level, reversing the methodological flow solved in Chapters 4 and 5 can be applied to estimate the enforcement benefits of mitigating direct infrastructure damage. Successful enforcement takes heavier, illegal tandem axles off the road and replaces them with lighter, legal tandem axles and additional fractional vehicles to carry the cargo. As a result of imposing the enforcement treatment, there are a "base" and a "treatment" set of tandem axle distributions (as described in Chapter 4) and a concomitant increase in time before the next infrastructure MR&R action. The methodology in Chapter 5 can then be used to translate the difference in time into a corresponding dollar amount and derive a benefit of reduced infrastructure damage.

This does not suggest that roadside enforcement is generally not viable to prevent weight violations. In fact, a substantial portion of federal policy is based on the opposite point of view. Instead, the research team simply asserts that this particular permitting scenario on I-19 does not appear to be one where additional enforcement resources will provide cost benefits with respect to infrastructure damage savings.

IMPACT ON ADOT'S PERMIT SYSTEM

ADOT has a relatively new permit system that went into service in 2016. Some of the information that would be needed in the OW permit application does not exist in other ADOT permit applications. As a result, some systems modifications are likely needed to enable proper capture of application data. Additional modifications may be needed for either the printed permit and/or reporting features within ADOT.

THE ROLE OF THE RAIL TERMINAL OPERATOR IN COMPLIANCE

It would be theoretically possible to weigh permit vehicles in real time utilizing a virtual weigh station approach. The WIM sensor would be able to weigh the vehicle, while a license plate reader would identify the vehicle and link the vehicle to a specific permit. The technological downside of this approach is that the container information would not be available, so that multiple permits purchased by drayage companies for the same vehicle on the same day could not be distinguished from one another. (Drayage companies are those that transport goods over a short distance, typically between stops in the supply chain, like intermodal facilities to warehouses.)

A similar objective can be met, however, by requiring that rail terminal operators that are either valid origins or valid destinations for the permit document the activity of the permitted vehicles and the corresponding containers at their facilities and transmit this information on a periodic basis (most likely weekly) to ADOT for review and potential compliance action. We recommend that the following information be tracked and reported:

- The permit number provided by the driver when entering the terminal.
- The presence of a customs seal, or preferably the custom seal number.
- The specific train on which the container departed (tracking specific containers arriving via rail and departing via truck is unrealistic).
- The weight of the container.

SUMMARY

The international, intermodal, containerized permit is involved in a complex transaction. Multiple transportation operators are involved, and the ability for ADOT to track them to ensure that all constraints are properly observed is impossible without additional documentation and processes. The approaches described above recognize the federal interpretation of nondivisible containers on the interstate network, respect the rationale behind other existing ADOT permits, and balance the burden on carriers and rail terminal operators with the need for increased information.

CHAPTER 7. FINDINGS AND RECOMMENDATIONS

The research achieved the goal of estimating the cost of repairing the expected infrastructure damage from a potential new permit for intermodal overweight sealed shipping containers in the study area between the Mariposa Port of Entry and the Port of Tucson. The cost identified was $5.38 per ESAL-mile in the northbound direction, and $5.16 in the southbound direction, with all but a few pennies of the cost due to pavement damage. The short portion of I-10 had a disproportionate amount of the damage compared to the long portion of I-19. This cost is not the cost of the actual permit itself, which must account for other factors.

The research developed a methodology whose process is transferable to other similar policy analyses on Arizona's highway network, both for permitting and enforcement. The raw numerical results from the study area cannot be utilized elsewhere in Arizona because of the uniqueness of the network and the constraints on the permit vehicle due to federal laws and regulations governing the Interstate Highway Network. The methodology, however, can be applied to similar data in other parts of Arizona.

ADDITIONAL FINDINGS ABOUT THE PERMIT FEE ESTIMATION METHODOLOGY

In regard to the methodology for estimating permit fees, the research team made the following findings:

- The methodology enables practitioners to calculate the effects of changes in traffic volumes and axle weight distributions on a particular highway route for commercial vehicles as a result of policy, regulatory, or legal changes. Both the potential implementation of a permit as well as the potential for adjustments in size and weight enforcement techniques cause a shift in truck patterns. For a new permit, the resulting traffic distribution can be expected to consist of fewer trucks, but some trucks with higher axle weights. For enforcement activities, the resulting traffic distribution can be expected to consist of the same or slightly more trucks, but fewer trucks with axle weights above legal limits.
- The existing software products used by ADOT for both structure and pavement evaluation were the products used in current best practices through our literature review. The two products address permit demand differently: the structural analysis is concerned with the single permitted vehicle, and the pavement analysis considers the mix of traffic and how it changes through the implementation of a permit. As a result, the pavement analysis is more sensitive to the estimate of the number of permits to be purchased (or, for enforcement, the number of drivers convinced to carry legal loads as opposed to illegal overweight loads).
- The approach to sampling infrastructure for our analysis was appropriate. For most infrastructure analyzed, the infrastructure impacts were minimal. The need for sampling is important because larger study areas would have an exceptionally high amount of calculation and a smaller amount of available and accurate traffic count data.
- In executing the methodology, commodity flow data were the most difficult item to obtain and utilize. The border crossing data and the commodity flow data previously purchased by ADOT yielded different findings and had to be blended together heuristically to yield meaningful results. The lack of available southbound data reduced the precision of our estimate of the infrastructure impacts.

ADDITIONAL FINDINGS ABOUT THE STUDY REGION

In regard to the study region, the research team made the following findings:

- The unique geography of I-19 in the study area limited the permit's availability to truck movements in support of international, intermodal movements of containerized goods. This is a significant limitation, as it limits demand to only those products or commodities whose supply chain is heavily influenced by such moves.
- While pockets of stakeholders expressed substantial desire for a permit in the corridor, the potential demand was not evident when analyzing northbound data. Average commodity tonnage crossing the border at the Mariposa Port of Entry yielded few commodities for which a demand is evident. The customs data, however, reflects broad categories of commodity and thus may not reflect individual manufacturers. For that reason, as well as that several stakeholders did mention that southbound traffic would have a higher use for the permit, the research team utilized a much higher design volume (100 trucks being replaced by 80 permitted trucks, each weekday) to reflect the impacts of a potentially higher demand. A lower permit volume would cause less damage on the pavement sections, as the expected time reduction for rehabilitation actions and the impact on infrastructure costs would be minimal.
- Over 90 percent of the total infrastructure damage identified by the research team is in the small section of I-10 connecting I-19 with the exit for the Port of Tucson. Different highways built in different eras with different design standards yielded different results for a small number of vehicles purchasing permits. Therefore, the overall results for the study area cannot be converted into a per-mile cost for interstate highways across Arizona for this type of permit load.
- ADOT's current permit system is sufficient to implement a permit for the study region for international, intermodal, containerized goods. As with any new permit, some programming and configuration changes would be necessary to implement the user interface and underlying permit logic and rules.
- Only structures and pavement sections on interstate highways were considered. No assertions are made about how the results would change if a similar permit were issued on a mix of non-interstate highways, including a mix of state and local highways.
- Under federal truck size and weight law and under the interpretation of the Barnhart Letter, the move must be intermodal in nature for the permit to be valid; consequently, enforcement is needed to ensure that shippers are indeed implementing an intermodal trip. The ability of an intermodal facility to accept higher-weight containerized traffic needs to be balanced with the need for reporting by the intermodal facility to ensure that shipper compliance is not compromised.

RECOMMENDATIONS FOR TRANSFERABILITY OF THE METHODOLOGY AND FINDINGS

In regard to the transferability of this project's methodology and findings to other areas, the research team makes the following recommendations:

- ADOT has most of the data and all of tools needed to conduct analyses for other weight-related commercial vehicle policy issues using the methodology developed in this study. However, granular commodity flow data at the origin/destination level is lacking. As a result, while this methodology could be applied in large study areas, it will have more impact in study areas closer to or smaller than this project's study area, or for narrower sets of explicitly identified commodities. For example, reviewing the impacts of a commodity-specific exemption would presumably imply that the commodity movements are known and can be modeled.
- While the methodology was developed to review permitting policy, the methodology also has value in evaluating potential changes in truck size and weight enforcement. Both manpower and technology improvement ideas can be analyzed for their pavement and structural impacts. Combining this approach with knowledge of "at-risk" infrastructure on ADOT-owned highways will provide ADOT with the ability to develop return-on-investment metrics for targeted enforcement investments.

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APPENDIX: PAVEMENT ANALYSIS METHODOLOGY, INPUT DATA, AND COST ANALYSIS

PAVEMENT ANALYSIS METHODOLOGY

This section presents the methodology used in analyzing the effects of overweight vehicles on the pavement sections on the I-19 corridor and the portion of I-10 within the study limits. Input data, pavement analysis approach, analysis assumptions, and software input parameters are presented herein.

Overview

Pavement analysis was performed using Version 2.1 of the AASHTOWare Pavement ME (PaveME) software in conjunction with the Arizona local calibration factors listed in the ADOT SPR-606 Report "Calibration and Implementation of the AASHTO Mechanistic-Empirical Pavement Design Guide in Arizona" (Darter et al., 2014). These Arizona-specific calibration factors are provided herein. The following distress criteria were considered in the analysis:

- Flexible Pavement (asphalt concrete) – rutting, bottom-up fatigue cracking, international roughness index (IRI).
- Rigid Pavement (portland cement concrete) – slab transverse cracking, joint faulting, IRI.

For flexible pavements, thermal cracking or top-down cracking distresses were not considered as a failure criteria because of the models' poor correlation to Arizona conditions. However, it is important to note that thermal cracking is an input to the international roughness index (IRI) model and, in that respect, its influence is unavoidable.

The following provides a general overview of the pavement analysis procedure:

1. Review as-constructed project records and other relevant information provided by ADOT.
2. Identify representative pavement sections (based on the overall study corridor) to be included in the analysis task.
3. Conduct a pavement performance analysis.
    a. Build input files for AASHTOWare Pavement ME (PaveME) software.
        i. Analyze traffic data and finalize traffic inputs (base case and overweight case).
        ii. Determine pavement structure inputs.
    b. Simulate pavement performance using PaveME.
4. Compile and analyze PaveME results.
    a. Summarize results.
    b. Determine incremental pavement infrastructure damage due to overweight trucks.
5. Conduct a cost analysis of potential pavement infrastructure damage.

Representative Pavement Sections

To begin identifying pavement sections along the study corridor, each route was first divided into milepost (MP) sections that corresponded to the latest major rehabilitation such as asphalt concrete (AC) mill and overlay or AC overlay. The unbound layer thicknesses were extracted from the ADOT pavement management section (PMS) database; however, none of these data sources provided material properties of the unbound base layers or subgrade soil. Long-Term Pavement Performance (LTPP) section information along I-19 (Table A.1) and a soil mapping utility (Zapata and Cary, 2012) were used to identify the subgrade soil types in the region that corresponded to milepost ranges along the study corridor. LTPP sections have significant historical information related to material properties, pavement distress, and pavement section information. Additional information contained in the LTPP database provided a potential source for a more reality-based representation of material properties for the subsequent pavement analysis. Tables A.2 and A.3 present the pavement section categories for I-10 and I-19, respectively. These tables also show the percentage of the routes represented by the different pavement sections; asphalt concrete (AC) and jointed plain concrete pavement (JPCP).

Table A.1. Locations of LTPP Sections along I-19

Route	Direction	LTPP Section	MP	AASHTO Soil Classification
I-19	NB	046060	14.88	A-2-6
		041017	32.98	A-2-6, A-2-4
	SB	046054	52.25	A-2-4
		041018	36.2	A-2-4, A-6
		041016	24.17	A-2-4
		041015	18.33	A-2-7

Table A.2. Pavement Section Categories on I-10

Dir.	Milepost		Thickness (Inches)		Base Thickness (Inches)	Soil Classification	AADTT	% of Route
	Beginning	Ending	AC	JPCP				
EB	259.92	260.5	-	13.5	4	A-1	7809	4.6%
	260.35	262.7	-	13	4	A-1	7261	18.8%
	262.4	267.5	1	9	9	A-1	5630	40.7%
	267.5	272	6.5	-	22	A-4 / A-6	4728	35.9%
WB	272	267.5	6.5	-	22	A-4 / A-6	4728	35.1%
	267.5	262.4	1	9	9	A-1	4630	39.8%
	262.73	260.05	-	13	4	A-1	7261	20.9%
	260.44	259.91	-	13.5	4	A-1	7809	4.1%

Table A.3. Pavement Section Categories on I-19

Dir.	Milepost		Thickness (inches)		Base Thickness (Inches)	Soil Classification	AADTT	% of Route
	Beginning	Ending	AC	JPCP				
NB	0	0.3	5	–	10	A-4	1033	0.5%
	0.3	6.08	9.4	–	16-23	A-4	1272	9.3%
	6	8.56	10.1	–	11	A-4	1312	4.1%
	8.56	9.41	10.1	–	9	A-2-4	1312	1.4%
	9.41	16.17	10.1	–	13	A-2-4	1189	10.8%
	16.2	21.1	12.7	–	8-11	A-2-4	1161	7.9%
	21.1	25.3	8.3	–	9	A-2-4	1167	6.7%
	25.3	31.88	9	–	5	A-2-4	1178	10.5%
	31.88	42.5	8.4	–	6-12	A-2-4	1404	17.0%
	42.5	47	7.8	–	10	A-2-4	1466	7.2%
	47	50.24	10	–	16	A-2-4	1535	5.2%
	50.1	54.76	11.1	–	29	A-2-4	1687	7.5%
	54.76	58.5	1	9	10	A-4 / A-6	1832	6.0%
	58.5	59.7	1	9	10	A-4 / A-6	1832	1.9%
	59.7	60	1	9	9	A-4 / A-6	1832	0.5%
	60.86	62.25	1	9	9	A-2-4	2413	2.2%
	62.25	63.09	–	15	4 (AC)	A-2-4	2599	1.3%
SB	63.09	62.25	–	15	4 (AC)	A-2-4	2599	1.3%
	62.25	60.86	1	9	10	A-2-4	2413	2.2%
	60	59.7	1	9	10	A-4 / A-6	1832	0.5%
	59.7	58.5	1	9	9	A-4 / A-6	1832	1.9%
	58.5	54.76	4.5	9	9	A-4 / A-6	1832	6.0%
	54.76	50.1	11.4	–	29	A-2-4	1687	7.5%
	50.2	47	9.3		16	A-2-4	1535	5.1%
	47	42.5	10.5	–	10	A-2-4	1466	7.2%
	42.5	31.88	8.6	–	6-12	A-2-4	1404	17.0%
	31.88	25.3	9	–	6	A-2-4	1178	10.5%
	25.3	21.1	10.9		9	A-2-4	1167	6.7%
	21.1	16	12.1	–	8-11	A-2-4	1161	8.2%
	16	6	10	–	9-13	A-2-4	1312	16.0%
	6.08	0.3	9.9	–	16-23	A-4	1272	9.3%
	0.3	0	5	–	10	A-4	1033	0.5%

Pavement sections presented in Tables A.2 and A.3 can be further subdivided into three AC and three JPCP categories. Of the three JPCP sections, only the 13-inch category included dowels. The scope of the study included the entire 63 miles of I-19 and approximately 12 miles of I-10. Table A.4 provides a summary of the distribution of bound layer (AC and JPCP) pavement thicknesses along the I-19 and I-10 study corridor.

Table A.4. Percent Distribution of Bound Layer Thicknesses along the I-19 and I-10 Study Corridor

Route	Direction	% of Mileage (Each Route, Direction)					
		AC Thickness (Inches)			JPCP Thickness (Inches)[a]		
		< 7	7 - 9.99	10-13	9 - UD	13 – D	15 - UD
I-19	NB	0.5%	36.8%	50.8%	10.6%	–	1.3%
	SB	0.5%	41.9%	45.6%	10.6%	–	1.3%
I-10	EB	35.9%	–	–	40.7%	23.4%	–
	WB	35.1%	–	–	39.8%	25.1%	–

[a] UD: un-doweled JPCP; D: doweled JPCP.

The percent distribution of bound layer types was similar for both directions on the I-19 and I-10 corridors; this similarity is consistent with the practices of constructing or reconstructing both directions of interstate during a construction project.

Traffic Data to Support Pavement Selection

The two most recent available years of traffic data were obtained from ADOT's Multimodal Planning Transportation Data Management System site [12] for 41 total sites, including 24 on I-19 and 17 on I-10 within the study corridor. I-19 sites included one weigh-in-motion (WIM) site and one axle classifier, with the remainder of the sites providing counts only. I-10 sites included one WIM and three axle classifiers. Annual average daily traffic (AADT) was available for all sites, with only the WIM and axle classifier sites providing the percentage of trucks. Annual average daily truck traffic (AADTT) was calculated for the sites where truck traffic data were available and was estimated for the remaining sites through a linear data fit between AADT and AADTT. On the basis of the available traffic data, the following three categories were considered:

- <1,500 AADTT
- 1,500 – 4,000 AADTT
- >4,000 AADTT

Selection of Pavement Sections for Engineering Analysis

In selecting representative pavement sections for analysis, the research team considered the following five categories:

1. Percent representation of study corridor pavements
2. Asphalt or concrete layer thickness
3. Base/subbase layer thickness
4. Subgrade soil type
5. Traffic

To begin the selection process, the research team first considered the percent representation of pavement sections by length along the study corridor as a key factor in determining the pavement sections to be analyzed. Table A.5 shows the breakdown of pavement sections along the study corridor along with the percent length representation of the study corridor. The “Ranking” column provides the numerical ranking of the top five pavement section combinations (based on pavement thickness, unbound base layer thickness, subgrade, and AADTT) that represent the highest percent length within the study corridor.

Table A.5. Percent Length Representation, Ranking, and Selection of Pavement Sections

Pavement Layer	Base	Subgrade	AADTT	% of Length	Ranking	Selection
<7 inches AC	<12 inches	A-4	<1500	0%		
	>12 inches	A-4 / A-6	>4000	6%		5
7-10 inches AC	<12 inches	A-2-4	<1500	29%	1	1
	>12 inches	A-2-4	1500–4000	2%		
		A-4	<1500	8%	4	3
>10 inches AC	<12 inches	A-2-4	<1500	20%	2	2
		A-4	<1500	2%		
	>12 inches	A-2-4	<1500	5%		
			1500–4000	8%	3	
9 Inches JPCP (UD)	<12 inches	A-1	>4000	7%		
		A-2-4	1500–4000	2%		
		A-4 / A-6	1500–4000	7%	5	4
13 inch JPCP (D)	<12 inches	A-1	>4000	4%		
15 inch JPCP (UD)	>12 inches	A-2-4	1500–4000	1%		

Review of this ranking posed a concern from a pavement engineering standpoint. The outcomes of the selection process did not include the thinnest AC section (<7 inches) with the greatest truck traffic

(>4,000 AADTT) on the weakest subgrade material (A-4/A-6). This section, while representing only 6 percent of the total corridor, represented a pavement that may experience the most damage from overweight vehicles and thus have a large economic cost to the agency due to additional maintenance and early rehabilitation. Therefore, the research team revised the rankings (last column of Table A.5) and considered the remaining categories (thickness, soil type, and traffic) to determine the five pavement sections for engineering analysis.

PAVEME SOFTWARE INPUT DATA

Overview of Required Data

PaveME required numerous input parameters in order to best simulate pavement performance at a specific location. Required inputs fall into the following categories:

- Truck traffic data and truck properties
- Climatic information
- Pavement structure and material properties
- Performance criteria
- Model calibration coefficients

Default values for a majority of the required input properties are available within PaveME; however, use of local model calibration coefficients and site-specific information yields more realistic performance output. In this study, ADOT calibration coefficients and design methodology were used, along with any site-specific traffic and pavement information available from ADOT.

Traffic Input Data

ADOT's Multimodal Planning Transportation Data Management System (TDMS) site (ADOT 2016) provided a key source of traffic data for PaveME analysis. The major traffic inputs to the PaveME software include AADTT, vehicle class distribution, growth rate, axles per truck, and axle load distributions (i.e., single, tandem, tridem, and quad). Traffic inputs were developed from the TDMS data from WIM stations on I-19 at MP 8.3 (ID 100455) and on I-10 at MP 269.89 (ID 100166).

According to the TDMS, I-19 has two lanes in the design direction, 85% of the trucks in the design lane, and a posted speed limit of 75 miles per hour. I-10 also has two lanes in the design direction, 82% of the trucks in the design lane, and a posted speed limit of 75 miles per hour. Note that I-10 transitions from three lanes to two lanes at MP 262.7, but a very short portion of the I-10 corridor in the study has three lanes; thus, two lanes were considered in the analysis. Table A.6 provides a summary of general traffic input values to PaveME based on ADOT standard practice.

Table A.6. General Traffic Inputs to Pavement ME

Traffic Input	Input Value
Average axle width	8.5
Dual tire spacing	12
Tire pressure	120
Tandem axle spacing	51.6
Tridem axle spacing	49.2
Quad axle spacing	49.2
Mean wheel location	15
Traffic wander standard deviation	10
Design lane width[1]	12
Average spacing of short axles	12
Average spacing of medium axles	15
Average spacing of long axles	18
Percentage of trucks with short axles	11
Percentage of trucks with medium axles	17
Percentage of trucks with long axles	72

[1]Value was verified in the inventory data tables of LTPP sections.

Vehicle Class Distribution—Base Case

Table A.7 shows the average vehicle class distribution of trucks on I-19 (WIM ID 100455) based on the average daily traffic (ADT) of each vehicle class from 2012 to 2016. An unusually high number of Class 10 and Class 13 vehicles was observed in 2015 and 2016. However, counts of the other classes in 2015 and 2016 seemed reasonable. Class 9 trucks (a class likely to purchase an overweight permit) seemed to fluctuate between 980 and 1,600 (ADT). ADT for Class 5 vehicles appeared to steadily decrease over time. Average vehicle class distribution input to PaveME for Class 4 to Class 13 trucks was represented by the average vehicle class distribution over the years from 2012 to 2016.

Table A.7. I-19 Vehicle Class Distribution for PaveME

Class	ADT 2012	ADT 2013	ADT 2014	ADT 2015	ADT 2016	Average	Percent
4	81	71	72	80	105	81.8	3.7%
5	592	482	486	200	177	387.4	17.5%
6	119	80	99	121	147	113.2	5.1%
7	21	28	33	14	8	20.8	0.9%
8	175	119	137	72	90	118.6	5.4%
9	1674	1083	1537	984	1446	1344.8	60.7%
10	3	7	5	221	135	74.2	3.4%
11	30	33	27	39	46	35.0	1.6%
12	3	2	1	37	26	13.8	0.6%
13	0	1	1	81	42	25.0	1.1%

Table A.8 presents the average vehicle class distribution of trucks on I-10 at WIM ID 100166 based on the ADT of vehicle class from 2013 to 2016. The number of Class 5 and Class 9 trucks steadily increased over this period. All other vehicle classes appeared to have slight or no significant increases. As with I-19 data, the average vehicle class distribution input to PaveME for Class 4 to 13 trucks was represented by the average vehicle class distribution over the years from 2012 to 2016.

Table A.8. I-10 Vehicle Class Distribution for PaveME

Class	ADT 2013	ADT 2014	ADT 2015	ADT 2016	Average	Percent
4	391	396	396	404	396.8	4.5%
5	1780	1777	1808	1907	1818.0	20.4%
6	259	294	294	274	280.3	3.1%
7	5	7	9	11	8.0	0.1%
8	565	449	390	405	452.3	5.1%
9	5232	5372	5667	5891	5540.5	62.3%
10	54	56	63	64	59.3	0.7%
11	152	158	172	178	165.0	1.9%
12	166	157	171	183	169.3	1.9%
13	8	11	10	12	10.3	0.1%

Traffic Growth Rate

Figure A.1 shows the AADT trends on I-19 at Location ID 100455 from 1990 to 2015. There was a linear growth of approximately 4.6% up until 2006, but it appears that the traffic growth rate declined in later years without any increase to highway capacity. The traffic input for PaveME was chosen as a 2.2%

growth rate, derived from the average growth over the last 15 years (2001 to 2015). In comparison, Figure A.2 provides I-10 AADT at WIM Location ID 100166 from 1992 to 2016. There was a linear growth of approximately 9.8% up until around the mid-2000s, but traffic growth rate declined in recent years. The traffic input for PaveME was chosen as 1.5%, derived from the average growth over the last 15 years (2001 to 2015).

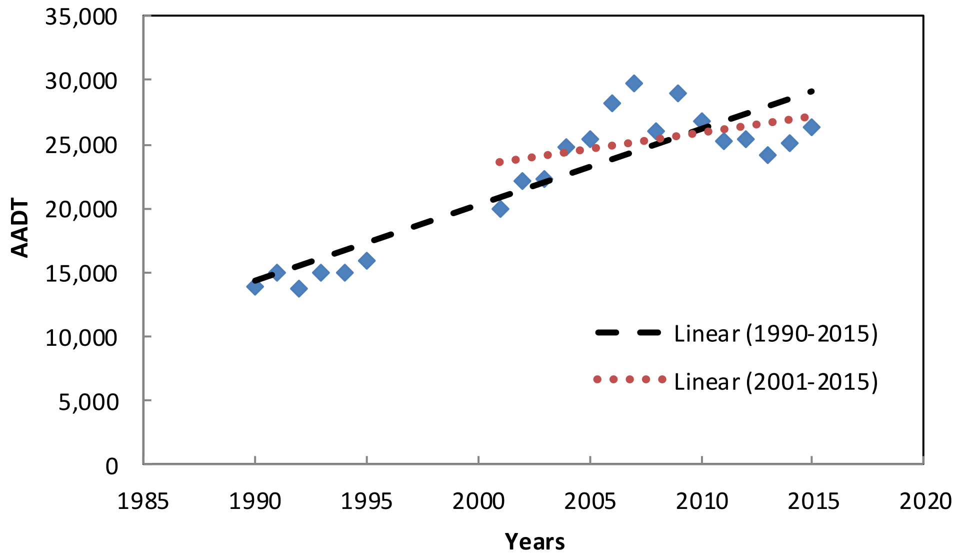

Figure A.1. AADT Trend from ADOT TDMS for WIM Location ID 100455 (I-19)

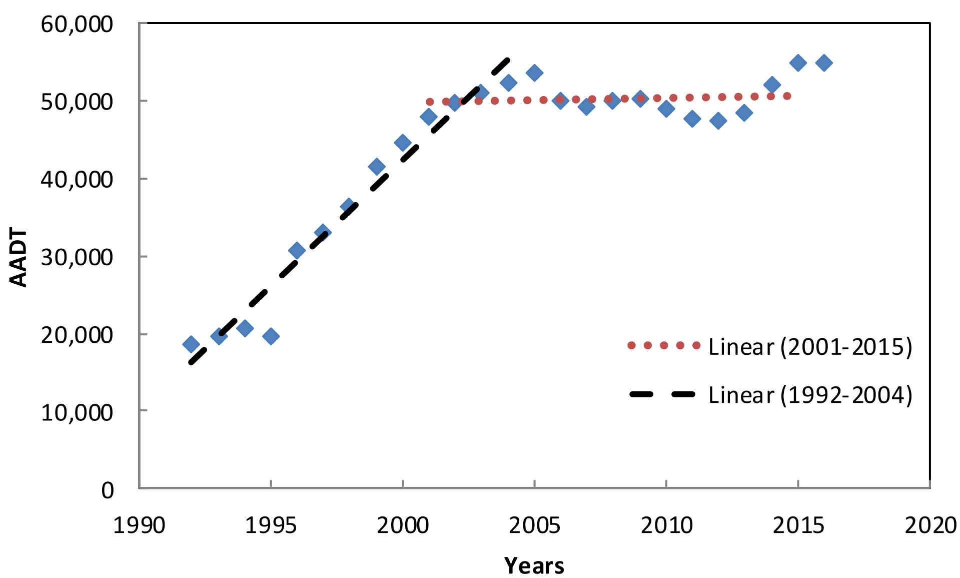

Figure A.2. AADT Trend from ADOT TDMS for WIM Location ID 100166 (I-10)

Axle Load Distribution

Axle load distribution inputs were also based on the I-19 and I-10 WIM site data available in TDMS. Analysis of the available axle load distribution data from WIM 100455 (I-19), from December 2013 to June 2016, revealed significant deviation in the data. WIM calibration information was not listed on the TDMS website, so it was not possible to judge the accuracy of the data. A particular month of data was selected that best represented the overall distribution of axle loads per vehicle class and axle type. Data from February 2015 had the least deviation from the average distribution of the whole dataset and therefore were chosen to represent the axle load distributions for I-19. Figure A.3 shows axle load distributions for Class 9 truck tandem axles in the dataset. The Class 9 truck tandem axle load distribution for the month of February 2015 showed an unloaded peak between 12,000 to 16,000 pound weights and a loaded peak at 32,000 pounds, which was consistent with the months of June 2014 to June 2015. Table A.9 presents the representative axles per truck for each vehicle class based on TDMS data from February 2015, WIM ID 100455 on I-19. These values were used as input to PaveME for analysis of pavement sections on I-19.

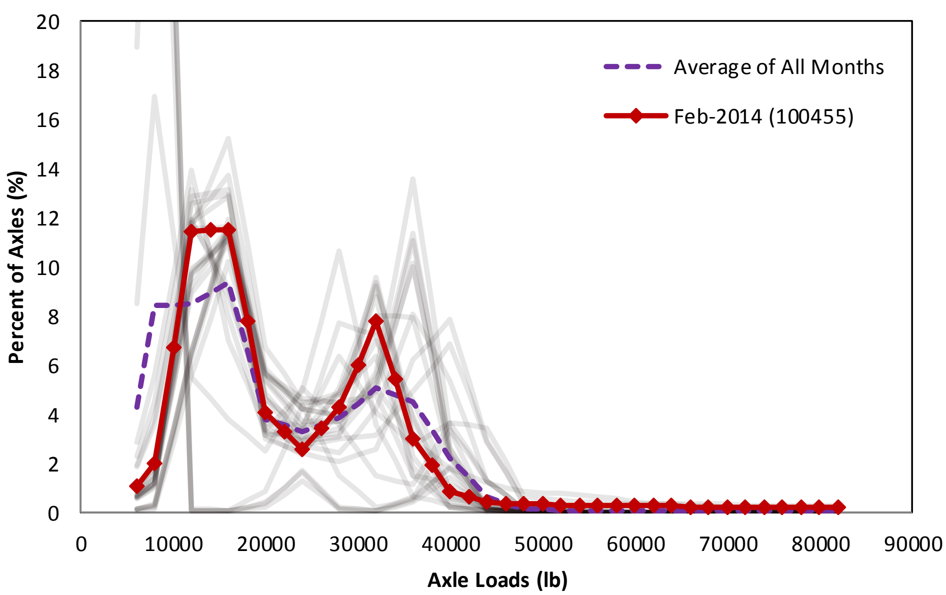

Figure A.3. Class 9 Truck Tandem Axle Load Distributions for I-19

Table A.9. Representative Axles per Truck for I-19

Vehicle Class	Single	Tandem	Tridem	Quad
4	1.96	0.13	0	0
5	2	0	0	0
6	1.06	0.97	0	0
7	1.61	0.39	0.5	0
8	2.35	0.73	0	0
9	1.02	1.98	0	0
10	2.34	1.45	0.15	0
11	4.64	0.17	0	0
12	2.77	1.34	0.01	0.12
13	2.55	1.15	0.39	0.24

For I-10, analysis of axle load distribution data from July 2014 from June 2016 showed consistent seasonal trends for single and tandem axles for all vehicle classes. Averaging the axle load distribution from the most recent 12 months (July 2015 to June 2016) best represented the axle load distribution dataset. While data were available for 24 months at this site, the axle load distributions in the most recent 12 months (July 2015 to June 2016) showed more distinct unloaded and loaded axle load peaks when compared to the earlier 12 month period (July 2014 to June 2015). Figure A.4 shows I-10 axle load distributions for Class 9 truck tandem axles in the dataset. The Class 9 truck tandem axle distribution showed an unloaded peak at 20,000 pounds and a loaded peak at 32,000 pounds, which was consistent with the months of May 2015 to June 2016. Table A.10 presents the I-10 axle per truck data for each vehicle class based on data from July 2014 to June 2016. These values were used as input to PaveME for analysis of pavement sections on I-10.

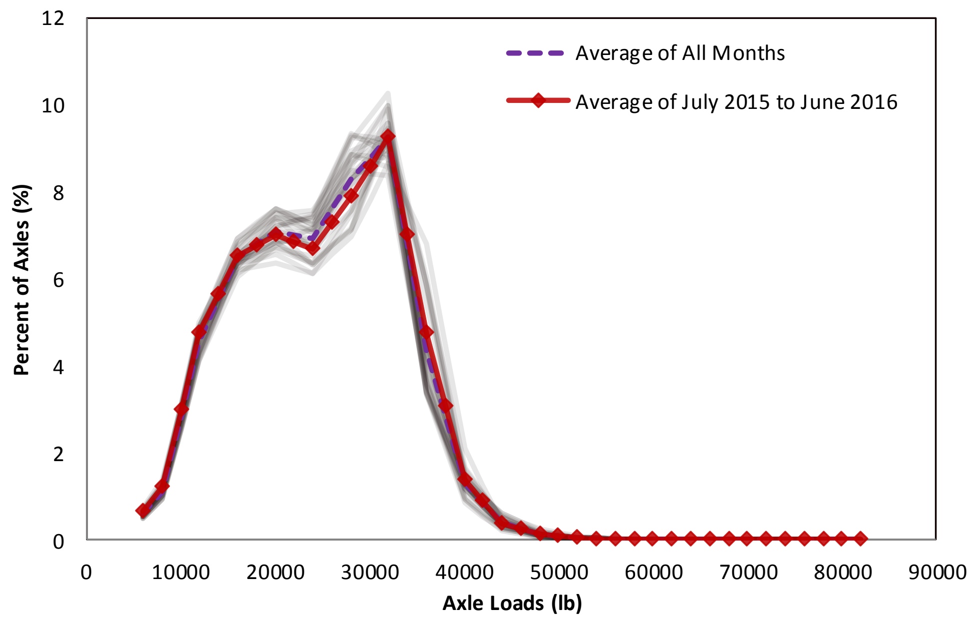

Figure A.4. Class 9 Truck Tandem Axle Load Distributions for I-10

Table A.10. Representative Axles per Truck for I-10

Vehicle Class	Single	Tandem	Tridem	Quad
4	1.61	0.39	0	0
5	2	0.15	0.02	0
6	1.02	0.99	0	0
7	2.91	0.02	0.35	0
8	2.82	0.5	0	0
9	1.22	1.89	0	0
10	1.61	0.71	0.56	0.29
11	5	0	0	0
12	4	1	0	0
13	2.59	1.09	0.68	0.05

Comparison of WIM Data

During the project's information collection phase, a new WIM facility (Loc ID 100463) opened on I-19 southbound at Canoa, south of Green Valley. The project team analyzed the Canoa WIM (new technology) data and compared results to data obtained by the existing WIM (Loc ID 100455) on I-19 (older technology). While the existing WIM (Loc ID 100455) was found to be representative of current truck traffic, the following insights about the differences with the Canoa WIM help frame the importance of accurate and timely vehicle data collection:

- The Canoa WIM data were more consistent on a monthly basis.
- The Canoa WIM recorded higher AADT (38,000 vs. 26,300) than the existing WIM did.
- Compared to the existing WIM, Canoa showed roughly 17 percent more fully loaded trucks, in part because there appeared to be a systemic shift in load axle distribution, with the steering peak 2,000 pounds higher and tandem axles peak 4,000 pounds higher (the latter is illustrated in Figure A.5).
- The shift in Canoa WIM axle load distribution data appeared in TDMS prior to any analysis with the Pavement ME software, and thus the research team was not confident in the accuracy of the Canoa WIM data available in TDMS.

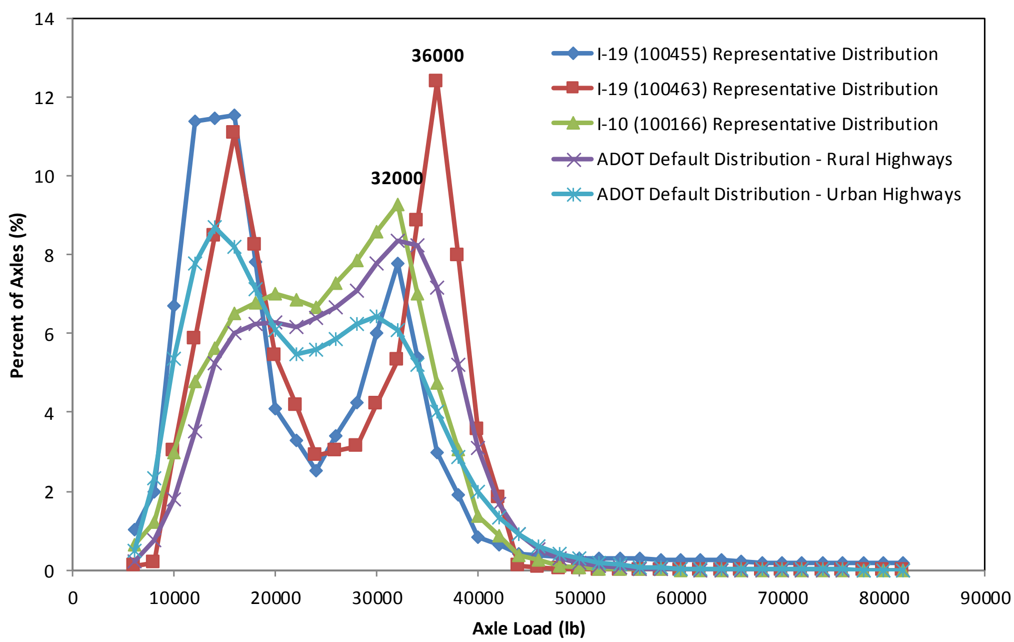

Figure A.5. Tandem Axle Load Distribution Comparison Among WIM Sites

Given the available traffic data, conclusions for the analysis process are as follows:

- When available, the baseline AADTT for the "no permit" scenario was taken from the measured TDMS data (WIMs 100455 [I-19] and 100166 [I-10]). However, for most sections, the TDMS website includes only AADT, and for these sections, AADTT was estimated using a regression between AADT and AADTT at adjacent locations. AADTT (measured and actual) values were available, as described above.

- Baseline axle load spectra, class distribution, axles per truck, and truck distribution were based on WIM data posted on the TDMS website. The WIM station on I-19 (Loc ID 100455) was chosen for the I-19 pavement sections, and the WIM station on I-10 within the project limits (Loc ID 100166) was chosen for the 1-10 pavement sections. FHWA classification distribution information for the WIM stations was available, with the default ADOT distributions provided for reference.

Monthly Adjustment Factor

Another required input to PaveME is the monthly adjustment factors for Vehicles Classes 4-13. There was a significant amount of monthly deviation in the TDMS data for both I-19 and I-10 WIM site data, which complicated determination of monthly adjustment factors. Numerous assumptions would have been required to develop monthly adjustment factors from multiple years of data. As a result, ADOT default monthly adjustment factors were used as PaveME input for I-19 and I-10.

Representation of Base and Overweight Traffic

Representing base case traffic and overweight traffic in PaveME requires modification to three key traffic data inputs: AADTT, vehicle class distribution, and axle load distribution. Modification of AADTT and vehicle class distribution are relatively straightforward, whereas modification of the axle load distribution is more complex. Therefore, the majority of this section discusses the procedure used to modify axle load distributions to represent anticipated overweight vehicles in Scenario 1 (90,800 pound permit on 5 axles).

AADTT values for the overweight scenario were reduced by the number of Class 9 trucks that were projected to be removed due to fewer overweight vehicles (permitted) carrying the same cargo. The methodology of equivalent overweight vehicles was presented in the main body of the report. The vehicle class distributions were adjusted by calculating a new percentage of each truck class, assuming a lower percentage of Class 9 trucks in the distribution.

Determination of axle load distributions for the overweight scenarios required additional calculations and input. The general steps in this procedure are as follows:

1. Generate a table of the axle load distribution based on WIM data.
2. Plot the base case axle distribution for Class 9 trucks as a function of axle load bins defined in PaveME.
3. For each AADTT, shift a specified portion of axles from the legal weight bin (and some adjacent bins) to overweight bins.
4. Re-compute the axle load distribution based on the adjusted axle weights and the expected percent of overweight axles in each bin.

The following detailed example of this procedure is based on the I-19 axle load distribution and the one-way AADTT level of 1,300 trucks selected to represent this corridor.

The current Class 9 legal maximum gross vehicle weight (GVW) in Arizona is 80,000 pounds, with a maximum tandem axle weight of 34,000 pounds and a maximum steering axle weight of 12,000 pounds. For pavement analysis purposes, overweight trucks operating under the proposed permit were modeled using a maximum tandem axle weight of 39,400 pounds and a maximum steering axle weight of 12,000 pounds (GVW of 90,800 pounds).

One assumption used, as determined in a previous phase of this project, is that the permit is not expected to generate new demand. Thus, existing trucks at the legal tandem axle limit or slightly overweight (unpermitted) tandem axles (32,000-, 34,000-, and 36,000-pound weight bins) were considered candidates for purchasing the permit, and a portion of the axle weights was shifted to the overweight tandem axle bin of 40,000 pounds (legal under the proposed permit). The percentage of axles redistributed was dependent on AADTT, since it was assumed that a fixed number of trucks (not a percentage of AADTT) shifted to the overweight case under the proposed permit. As AADTT increased, the number of axles to be shifted remained the same but represented a lower percentage of overall AADTT. Therefore, separate overweight axle load distributions were generated for each corridor and representative AADTT on the corridor.

An example of I-19 (one-way AADTT of 1,300) base case and overweight Scenario 1 axle load distributions is shown in Figure A.6. In this portion of I-19 where truck volume is lower, the permit volume is a disproportionately high percentage of the total truck traffic at those higher weights, and the corresponding distribution is uneven. In higher-volume portions of I-19, the same number of vehicles is transferred (it is not proportional to the total traffic), and the distribution appears smoother. To demonstrate this concept, Figure A.7 presents a plot of the axle distributions for the I-10 corridor (one-way AADTT of 4,650 and one-way AADTT of 5,650). Note that Scenario 1 AADTTs were reduced by 20 legal weight trucks, as discussed in the main body of the report.

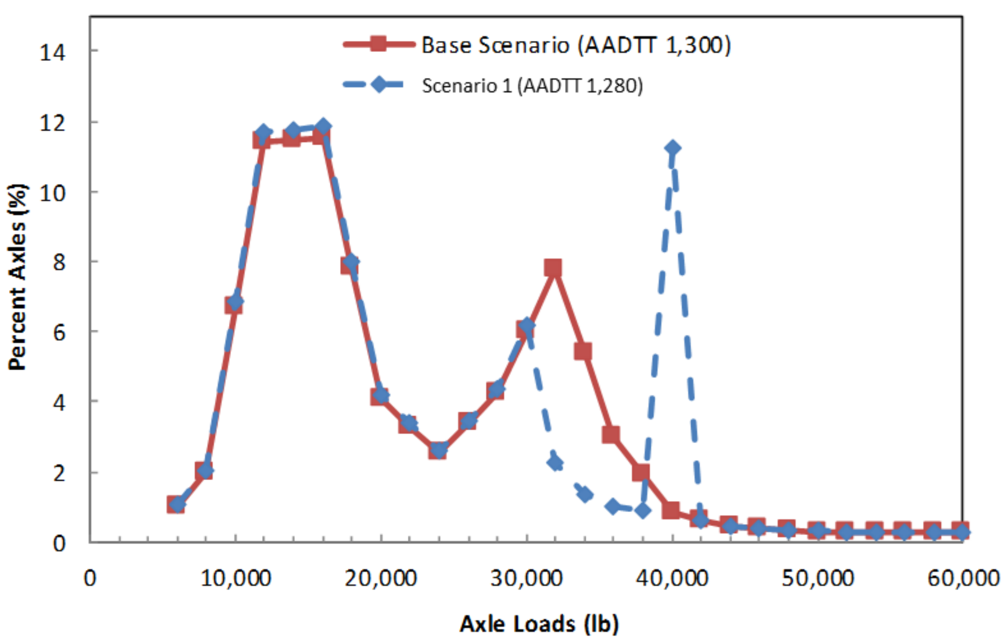

Figure A.6. Application of Permit Scenario to Existing I-19 Traffic Distribution

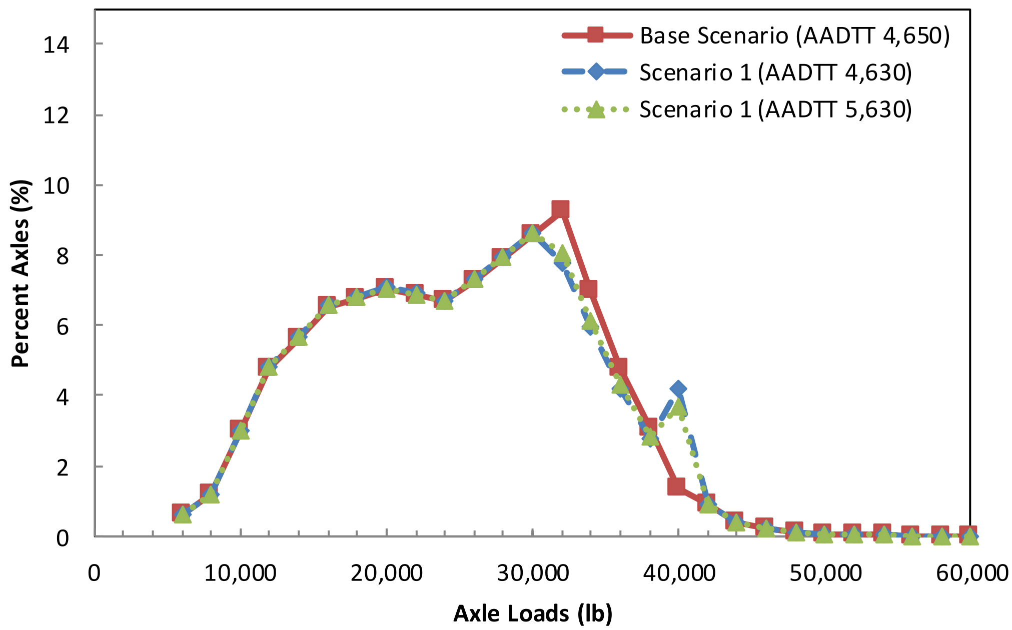

Figure A.7. Application of Permit Scenario to Existing I-10 Traffic Distribution

Final axle load distributions were used as inputs to PaveME for I-19 and I-10 pavement sections and can be found in Tables A.11 through A.21. Note that the axle load distributions for single, tridem, and quad axle groups used in Scenario 1 were the same as in the Base Scenario.

Table A.11. Single Axle Load Distribution, I-19 Base Scenario (1,300 AADTT)

CLASS	TOTAL	3000	4000	5000	6000	7000	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
4	100.0	1.18	1.53	3.74	5.95	8.90	11.84	10.80	9.75	8.90	8.04	6.20	4.36	3.54	2.71	2.01	1.31	0.92	0.53	0.45
5	100.0	15.90	27.26	18.26	9.27	6.47	3.67	3.21	2.74	2.17	1.60	1.26	0.91	0.82	0.74	0.60	0.47	0.43	0.39	0.38
6	100.0	0.68	1.16	2.41	3.66	3.28	2.89	6.00	9.11	13.52	17.94	13.26	8.58	5.52	2.46	1.66	0.87	0.70	0.53	0.39
7	100.0	5.57	4.88	6.97	9.06	5.57	2.09	6.27	10.45	8.36	6.27	5.92	5.57	4.53	3.48	2.09	0.70	0.70	0.70	0.70
8	100.0	5.06	6.88	6.08	5.28	5.11	4.95	8.06	11.17	8.33	5.49	4.64	3.78	3.44	3.09	2.42	1.75	1.38	1.02	0.93
9	100.0	0.12	0.19	0.99	1.78	2.22	2.66	5.16	7.66	17.32	26.97	16.19	5.41	3.50	1.58	1.07	0.56	0.41	0.27	0.24
10	100.0	5.58	4.49	6.08	7.68	6.08	4.49	5.82	7.15	9.95	12.75	8.59	4.42	3.56	2.70	2.36	2.02	1.39	0.76	0.62
11	100.0	2.23	3.39	5.06	6.74	6.08	5.43	6.46	7.50	5.96	4.42	4.75	5.08	5.77	6.46	5.48	4.49	3.32	2.14	1.49
12	100.0	5.03	3.52	4.56	5.61	5.53	5.44	6.53	7.62	7.79	7.96	7.50	7.04	5.70	4.36	3.27	2.18	1.88	1.59	1.21
13	100.0	8.72	3.57	3.45	3.32	3.86	4.40	4.90	5.40	8.26	11.12	9.26	7.39	6.10	4.82	3.74	2.66	1.91	1.16	0.91

CLASS	22000	23000	24000	25000	26000	27000	28000	29000	30000	31000	32000	33000	34000	35000	36000	37000	38000	39000	40000	41000
4	0.37	0.28	0.19	0.25	0.31	0.41	0.50	0.41	0.31	0.28	0.25	0.30	0.34	0.34	0.34	0.37	0.41	0.55	0.69	0.45
5	0.37	0.32	0.27	0.24	0.22	0.17	0.12	0.16	0.19	0.17	0.15	0.14	0.12	0.15	0.18	0.14	0.09	0.09	0.08	0.08
6	0.24	0.17	0.10	0.12	0.14	0.07	0.00	0.10	0.19	0.24	0.29	0.24	0.19	0.29	0.39	0.41	0.43	0.55	0.68	0.53
7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.35	0.00	0.00	0.00	0.00	0.00	0.70	1.39	1.05	0.70	0.35	0.00	0.70
8	0.84	0.76	0.69	0.62	0.55	0.49	0.44	0.58	0.73	0.69	0.65	0.58	0.51	0.56	0.62	0.42	0.22	0.31	0.40	0.49
9	0.21	0.16	0.10	0.07	0.04	0.04	0.04	0.05	0.07	0.15	0.22	0.37	0.51	0.60	0.68	0.60	0.52	0.46	0.41	0.39
10	0.48	0.25	0.03	0.05	0.08	0.12	0.15	0.09	0.03	0.11	0.18	0.15	0.11	0.12	0.14	0.22	0.29	0.30	0.31	0.31
11	0.83	0.66	0.48	0.43	0.38	0.33	0.28	0.40	0.52	0.47	0.41	0.35	0.28	0.24	0.21	0.22	0.24	0.31	0.38	0.35
12	0.84	0.67	0.50	0.34	0.17	0.17	0.17	0.13	0.08	0.21	0.34	0.25	0.17	0.17	0.17	0.29	0.42	0.29	0.17	0.17
13	0.66	0.46	0.25	0.25	0.25	0.17	0.08	0.12	0.17	0.17	0.17	0.17	0.17	0.12	0.08	0.25	0.42	0.42	0.42	0.29

Table A.12. Tandem Axle Load Distribution, I-19 Base Scenario (1,300 AADTT)

CLASS	TOTAL	6000	8000	10000	12000	14000	16000	18000	20000	22000	24000	26000	28000	30000	32000	34000	36000	38000	40000	42000
4	100.0	5.47	6.77	7.03	7.29	5.47	3.65	3.39	3.13	4.95	6.77	5.99	5.21	5.73	6.25	4.69	3.13	2.86	2.60	2.34
5	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	100.0	2.75	4.79	9.02	13.25	9.21	5.17	5.94	6.72	6.11	5.50	5.28	5.07	3.88	2.68	2.04	1.41	1.57	1.74	1.32
7	100.0	27.87	13.11	6.56	0.00	8.20	16.39	11.48	6.56	3.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	100.0	3.80	4.87	7.61	10.35	11.37	12.38	10.00	7.61	5.44	3.27	2.65	2.03	1.28	0.53	0.66	0.80	0.80	0.80	0.80
9	100.0	1.02	1.99	6.70	11.41	11.47	11.54	7.81	4.08	3.30	2.52	3.39	4.25	6.02	7.78	5.39	2.99	1.91	0.82	0.62
10	100.0	0.31	0.35	2.24	4.13	5.91	7.70	6.33	4.96	4.75	4.53	6.24	7.94	8.56	9.17	7.22	5.26	3.57	1.88	1.54
11	100.0	6.55	5.24	4.37	3.49	5.68	7.86	8.30	8.73	6.55	4.37	4.37	4.37	4.80	5.24	3.49	1.75	0.87	0.00	0.44
12	100.0	3.63	6.84	9.11	11.37	9.56	7.75	7.54	7.33	5.23	3.13	3.21	3.30	3.34	3.38	2.72	2.06	1.44	0.82	1.07
13	100.0	2.76	3.34	5.58	7.82	8.53	9.25	6.82	4.39	3.91	3.43	4.15	4.86	5.29	5.72	4.91	4.10	3.43	2.76	1.95

CLASS	44000	46000	48000	50000	52000	54000	56000	58000	60000	62000	64000	66000	68000	70000	72000	74000	76000	78000	80000	82000
4	2.08	1.56	1.04	0.78	0.52	0.26	0.00	0.00	0.00	0.00	0.00	0.26	0.52	0.26	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.89	0.68	0.47	0.38	0.28	0.21	0.14	0.16	0.19	0.16	0.14	0.21	0.28	0.23	0.19	0.33	0.47	0.40	0.33	0.42
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64	3.28	1.64	0.00	0.00	0.00	0.00
8	0.80	0.80	0.80	0.71	0.62	0.66	0.71	0.62	0.53	0.75	0.97	0.88	0.80	0.57	0.35	0.35	0.35	0.53	0.71	0.44
9	0.42	0.37	0.32	0.30	0.28	0.28	0.28	0.27	0.26	0.26	0.26	0.23	0.19	0.19	0.19	0.18	0.17	0.17	0.16	0.19
10	1.21	1.01	0.80	0.66	0.51	0.42	0.32	0.27	0.21	0.16	0.11	0.24	0.38	0.27	0.16	0.13	0.11	0.13	0.16	0.16
11	0.87	1.31	1.75	0.87	0.00	0.00	0.00	0.44	0.87	0.44	0.00	0.44	0.87	0.44	0.00	0.00	0.00	1.31	2.62	1.31
12	1.32	1.03	0.74	0.58	0.41	0.33	0.25	0.29	0.33	0.29	0.25	0.16	0.08	0.08	0.08	0.16	0.25	0.21	0.16	0.16
13	1.14	0.81	0.48	0.43	0.38	0.38	0.38	0.29	0.19	0.14	0.10	0.14	0.19	0.14	0.10	0.10	0.10	0.38	0.67	0.48

Table A.13. Tridem Axle Load Distribution, I-19 Base Scenario (1,300 AADTT)

CLASS	TOTAL	12000	15000	18000	21000	24000	27000	30000	33000	36000	39000	42000	45000	48000	51000	54000	57000	60000	63000	66000
4	100.0	37.21	13.02	12.09	13.02	10.23	7.44	4.65	2.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	100.0	3.23	4.47	6.70	10.43	11.17	10.92	10.67	8.38	6.08	4.47	0.87	1.24	1.37	1.49	1.12	0.74	0.87	0.00	1.12
8	100.0	33.33	17.95	15.38	17.95	10.26	5.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	100.0	10.11	11.95	12.32	14.15	13.05	11.03	9.01	5.61	2.21	1.65	0.00	0.55	1.10	1.65	1.93	2.21	1.47	0.00	0.00
10	100.0	3.08	4.53	6.92	7.01	11.69	13.94	16.20	13.30	10.40	7.24	1.51	0.92	0.54	0.16	0.19	0.23	0.24	0.34	0.26
11	100.0	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	100.0	3.44	6.18	8.93	14.43	14.43	13.06	11.68	8.25	4.81	4.12	4.81	2.75	1.37	0.00	0.00	0.00	0.00	0.00	0.00
13	100.0	5.32	7.36	7.72	10.20	8.43	7.68	6.93	7.58	8.23	6.42	3.03	2.80	2.52	2.24	1.95	1.65	1.46	1.65	1.06

CLASS	69000	72000	75000	78000	81000	84000	87000	90000	93000	96000	99000	102000
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	1.61	2.11	1.49	0.87	0.99	0.87	1.24	1.37	1.49	1.12	0.74	0.77
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.19	0.12	0.09	0.07	0.09	0.07	0.13	0.15	0.17	0.11	0.06	0.06
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.69	0.71
13	0.75	0.43	0.59	0.75	0.63	0.28	0.39	0.43	0.47	0.39	0.32	0.32

Table A.14. Quad Axle Load Distribution, I-19 Base Scenario (1,300 AADTT)

CLASS	TOTAL	12000	15000	18000	21000	24000	27000	30000	33000	36000	39000	42000	45000	48000	51000	54000	57000	60000	63000	66000
4	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	100.0	41.86	25.58	9.30	6.98	4.65	2.33	1.55	0.78	0.00	0.78	1.55	2.33	1.55	0.78	0.00	0.00	0.00	0.00	0.00
8	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	100.0	2.70	2.70	2.70	2.70	2.70	2.70	1.80	0.90	0.00	0.90	1.80	2.70	4.05	5.41	6.76	9.46	12.16	14.86	10.81
10	100.0	0.51	1.01	1.52	3.03	4.55	6.06	6.06	6.06	6.06	8.59	11.11	13.64	10.10	6.57	3.03	2.02	1.01	0.00	1.01
11	100.0	66.67	33.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	100.0	0.00	0.00	0.00	0.25	0.49	0.74	2.47	4.20	5.93	7.65	9.38	11.11	11.11	11.11	11.11	7.90	4.69	1.48	1.98
13	100.0	3.76	5.98	8.21	10.51	12.82	15.13	12.14	9.15	6.15	4.62	3.08	1.54	1.54	1.54	1.54	1.03	0.51	0.00	0.00

CLASS	69000	72000	75000	78000	81000	84000	87000	90000	93000	96000	99000	102000
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	6.76	2.70	1.80	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	2.02	3.03	2.02	1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	2.47	2.96	1.98	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.09	0.17	0.26	0.17	0.09	0.00	0.00	0.00	0.00	0.00

Table A.15. Tandem Axle Load Distribution, I-19 Scenario 1 (1,280 AADTT)

CLASS	TOTAL	6000	8000	10000	12000	14000	16000	18000	20000	22000	24000	26000	28000	30000	32000	34000	36000	38000	40000	42000
4	100.0	5.47	6.77	7.03	7.29	5.47	3.65	3.39	3.13	4.95	6.77	5.99	5.21	5.73	6.25	4.69	3.13	2.86	2.60	2.34
5	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	100.0	2.75	4.79	9.02	13.25	9.21	5.17	5.94	6.72	6.11	5.50	5.28	5.07	3.88	2.68	2.04	1.41	1.57	1.74	1.32
7	100.0	27.87	13.11	6.56	0.00	8.20	16.39	11.48	6.56	3.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	100.0	3.80	4.87	7.61	10.35	11.37	12.38	10.00	7.61	5.44	3.27	2.65	2.03	1.28	0.53	0.66	0.80	0.80	0.80	0.80
9	100.0	1.05	2.04	6.87	11.70	11.77	11.84	8.01	4.18	3.39	2.59	3.47	4.36	6.17	2.27	1.37	0.99	0.92	11.24	0.64
10	100.0	0.31	0.35	2.24	4.13	5.91	7.70	6.33	4.96	4.75	4.53	6.24	7.94	8.56	9.17	7.22	5.26	3.57	1.88	1.54
11	100.0	6.55	5.24	4.37	3.49	5.68	7.86	8.30	8.73	6.55	4.37	4.37	4.37	4.80	5.24	3.49	1.75	0.87	0.00	0.44
12	100.0	3.63	6.84	9.11	11.37	9.56	7.75	7.54	7.33	5.23	3.13	3.21	3.30	3.34	3.38	2.72	2.06	1.44	0.82	1.07
13	100.0	2.76	3.34	5.58	7.82	8.53	9.25	6.82	4.39	3.91	3.43	4.15	4.86	5.29	5.72	4.91	4.10	3.43	2.76	1.95

CLASS	44000	46000	48000	50000	52000	54000	56000	58000	60000	62000	64000	66000	68000	70000	72000	74000	76000	78000	80000	82000
4	2.08	1.56	1.04	0.78	0.52	0.26	0.00	0.00	0.00	0.00	0.00	0.26	0.52	0.26	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.89	0.68	0.47	0.38	0.28	0.21	0.14	0.16	0.19	0.16	0.14	0.21	0.28	0.23	0.19	0.33	0.47	0.40	0.33	0.42
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64	3.28	1.64	0.00	0.00	0.00	0.00
8	0.80	0.80	0.80	0.71	0.62	0.66	0.71	0.62	0.53	0.75	0.97	0.88	0.80	0.57	0.35	0.35	0.35	0.53	0.71	0.44
9	0.43	0.38	0.33	0.31	0.29	0.29	0.29	0.28	0.27	0.27	0.27	0.23	0.20	0.20	0.20	0.18	0.17	0.17	0.17	0.19
10	1.21	1.01	0.80	0.66	0.51	0.42	0.32	0.27	0.21	0.16	0.11	0.24	0.38	0.27	0.16	0.13	0.11	0.13	0.16	0.16
11	0.87	1.31	1.75	0.87	0.00	0.00	0.00	0.44	0.87	0.44	0.00	0.44	0.87	0.44	0.00	0.00	0.00	1.31	2.62	1.31
12	1.32	1.03	0.74	0.58	0.41	0.33	0.25	0.29	0.33	0.29	0.25	0.16	0.08	0.08	0.08	0.16	0.25	0.21	0.16	0.16
13	1.14	0.81	0.48	0.43	0.38	0.38	0.38	0.29	0.19	0.14	0.10	0.14	0.19	0.14	0.10	0.10	0.10	0.38	0.67	0.48

Table A.16. Single Axle Load Distribution, I-10 Base Scenario (4,650 AADTT and 5,650 AADTT)

CLASS	TOTAL	3000	4000	5000	6000	7000	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
4	99.9	0.79	0.88	1.81	2.75	6.50	10.25	10.75	11.25	10.66	10.07	8.22	6.38	5.02	3.65	2.90	2.15	1.70	1.25	0.96
5	100.0	9.40	18.08	19.16	20.24	13.05	5.86	4.29	2.72	2.02	1.32	0.97	0.63	0.49	0.36	0.30	0.25	0.21	0.16	0.13
6	99.3	0.47	0.75	2.74	4.74	5.09	5.45	9.14	12.84	13.04	13.23	9.77	6.31	4.71	3.11	2.36	1.62	1.20	0.77	0.54
7	100.0	37.91	24.84	12.70	0.56	0.52	0.48	0.72	0.97	1.35	1.74	2.13	2.52	2.58	2.64	2.24	1.85	1.46	1.07	0.73
8	98.3	9.60	12.51	9.88	7.25	6.74	6.24	7.10	7.97	6.35	4.73	3.72	2.72	2.30	1.89	1.62	1.35	1.15	0.94	0.78
9	99.7	0.46	0.82	1.38	1.93	2.28	2.63	6.77	10.90	16.53	22.17	14.47	6.78	4.50	2.21	1.77	1.32	0.96	0.59	0.40
10	96.4	0.93	1.04	1.45	1.87	2.89	3.92	6.71	9.50	11.53	13.56	10.67	7.79	6.02	4.25	3.36	2.47	1.85	1.23	0.89
11	100.0	0.36	0.68	1.88	3.07	3.80	4.52	8.31	12.10	11.36	10.63	9.13	7.63	6.67	5.71	4.60	3.49	2.48	1.47	0.97
12	100.0	0.27	0.52	1.58	2.64	3.71	4.78	7.74	10.71	13.93	17.15	13.21	9.27	6.30	3.32	2.23	1.13	0.73	0.34	0.22
13	93.8	1.14	1.38	1.90	2.43	3.50	4.57	7.03	9.48	9.35	9.22	7.56	5.91	4.91	3.91	3.18	2.46	2.02	1.58	1.30

CLASS	22000	23000	24000	25000	26000	27000	28000	29000	30000	31000	32000	33000	34000	35000	36000	37000	38000	39000	40000	41000
4	0.66	0.47	0.27	0.19	0.11	0.08	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5	0.09	0.06	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.31	0.22	0.13	0.10	0.08	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.04	0.04
7	0.39	0.25	0.10	0.07	0.05	0.03	0.01	0.02	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.62	0.48	0.34	0.28	0.21	0.18	0.15	0.13	0.11	0.10	0.10	0.09	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09
9	0.21	0.14	0.08	0.06	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
10	0.56	0.44	0.33	0.27	0.22	0.22	0.22	0.19	0.16	0.17	0.18	0.17	0.15	0.16	0.17	0.17	0.16	0.18	0.19	0.18
11	0.47	0.31	0.14	0.09	0.05	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.10	0.06	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	1.02	0.79	0.56	0.61	0.66	0.67	0.68	0.67	0.66	0.55	0.43	0.48	0.54	0.49	0.45	0.38	0.30	0.34	0.37	0.37

Table A.17. Tandem Axle Load Distribution, I-10 Base Scenario (4,650 AADTT and 5,650 AADTT)

CLASS	TOTAL	6000	8000	10000	12000	14000	16000	18000	20000	22000	24000	26000	28000	30000	32000	34000	36000	38000	40000	42000
4	100.0	0.80	0.73	1.19	1.65	2.79	3.93	7.37	10.82	10.59	10.37	9.80	9.23	8.56	7.89	5.58	3.27	2.24	1.21	0.82
5	100.0	26.62	30.51	20.77	11.03	6.67	2.31	1.29	0.26	0.15	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
6	100.0	5.50	10.29	10.54	10.79	8.85	6.90	6.31	5.72	5.13	4.53	4.04	3.55	3.37	3.19	2.78	2.38	1.91	1.44	1.04
7	100.0	72.53	9.46	5.03	0.60	0.58	0.56	0.28	0.00	0.59	1.17	0.95	0.72	0.66	0.60	0.30	0.00	0.00	0.00	0.00
8	99.9	7.72	9.60	11.39	13.19	12.71	12.24	9.46	6.68	4.89	3.10	2.28	1.45	1.16	0.86	0.67	0.48	0.39	0.30	0.24
9	100.0	0.64	1.20	2.98	4.77	5.64	6.52	6.77	7.02	6.85	6.68	7.28	7.88	8.57	9.27	7.00	4.74	3.06	1.38	0.87
10	99.8	0.88	0.81	1.32	1.84	3.23	4.63	5.81	6.98	7.15	7.31	7.29	7.27	6.83	6.38	5.76	5.14	4.51	3.89	3.20
11	33.3	4.17	8.33	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	4.17	2.08	0.00	0.00	0.00	0.00	0.00	0.00
12	100.0	0.23	0.39	2.18	3.96	7.55	11.13	17.42	23.71	16.36	9.02	5.28	1.54	0.87	0.20	0.11	0.03	0.01	0.00	0.00
13	99.3	1.00	1.05	4.01	6.97	8.84	10.72	9.53	8.33	6.07	3.82	3.32	2.82	3.09	3.36	3.42	3.48	3.09	2.69	2.28

CLASS	44000	46000	48000	50000	52000	54000	56000	58000	60000	62000	64000	66000	68000	70000	72000	74000	76000	78000	80000	82000
4	0.42	0.28	0.14	0.11	0.07	0.05	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
6	0.64	0.44	0.23	0.16	0.09	0.06	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.64	1.28	0.64	0.00	0.86	1.71	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.19	0.15	0.11	0.09	0.06	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.02
9	0.37	0.24	0.11	0.07	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	2.51	1.97	1.43	1.09	0.74	0.55	0.37	0.27	0.18	0.13	0.08	0.06	0.03	0.02	0.02	0.03	0.04	0.03	0.03	0.03
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	4.17	2.08	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	1.88	1.68	1.47	1.16	0.84	0.76	0.67	0.55	0.42	0.36	0.30	0.23	0.16	0.17	0.17	0.15	0.12	0.11	0.09	0.09

Table A.18. Tridem Axle Load Distribution, I-10 Base Scenario (4,650 AADTT and 5,650 AADTT)

CLASS	TOTAL	12000	15000	18000	21000	24000	27000	30000	33000	36000	39000	42000	45000	48000	51000	54000	57000	60000	63000	66000
4	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	100.0	29.04	31.18	20.65	10.13	6.09	2.06	0.52	0.23	0.03	0.02	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
6	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	100.0	1.27	1.87	2.46	3.05	3.35	3.65	5.14	7.22	9.13	10.71	12.28	10.48	8.68	6.86	5.04	3.42	2.25	1.07	0.81
8	98.7	11.68	6.05	6.26	6.46	6.38	6.29	7.27	8.79	9.09	6.94	4.79	3.29	1.78	1.35	1.45	1.40	1.03	0.66	1.07
9	99.6	25.46	24.00	15.70	7.40	5.16	2.92	2.22	2.31	2.37	2.41	2.44	1.82	1.19	0.86	0.67	0.52	0.46	0.39	0.39
10	100.0	3.08	4.53	6.92	7.01	11.69	13.94	16.20	13.30	10.40	7.24	1.51	0.92	0.54	0.16	0.19	0.23	0.24	0.34	0.26
11	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	100.0	1.02	1.37	1.39	1.41	2.25	3.09	4.14	5.29	6.19	6.59	6.99	7.93	8.87	9.36	9.63	8.94	6.33	3.72	2.50

CLASS	69000	72000	75000	78000	81000	84000	87000	90000	93000	96000	99000	102000
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.56	0.36	0.20	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	1.48	1.53	1.40	1.14	0.60	0.07	0.07	0.07	0.07	0.07	0.07	0.07
9	0.38	0.29	0.14	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.03
10	0.19	0.12	0.09	0.07	0.09	0.07	0.13	0.15	0.17	0.11	0.06	0.06
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	1.27	0.69	0.43	0.23	0.15	0.07	0.06	0.04	0.03	0.02	0.01	0.00

Table A.19. Quad Axle Load Distribution, I-10 Base Scenario (4,650 AADTT and 5,650 AADTT)

CLASS	TOTAL	12000	15000	18000	21000	24000	27000	30000	33000	36000	39000	42000	45000	48000	51000	54000	57000	60000	63000	66000
4	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	16.7	1.06	1.45	1.84	1.45	1.06	0.68	0.46	0.25	0.04	0.95	1.86	2.78	1.85	0.93	0.00	0.00	0.00	0.00	0.00
6	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	33.3	11.16	5.63	0.10	0.15	0.20	0.25	0.36	0.46	0.56	1.42	2.28	3.13	2.29	1.45	0.61	0.58	0.56	0.53	0.47
8	100.0	54.19	27.64	1.10	1.05	0.99	0.94	0.90	0.86	0.82	0.87	0.93	0.98	1.17	1.36	1.56	1.09	0.63	0.16	0.34
9	100.0	2.30	2.59	2.87	2.74	2.61	2.47	3.13	3.79	4.44	5.93	7.42	8.91	8.99	9.08	9.17	7.17	5.18	3.19	2.52
10	100.0	4.17	7.24	10.30	9.25	8.20	7.15	5.94	4.72	3.51	4.87	6.24	7.60	6.22	4.84	3.45	2.54	1.63	0.72	0.53
11	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	91.7	23.79	14.42	5.05	4.13	3.20	2.27	2.53	2.78	3.03	3.20	3.37	3.53	3.46	3.39	3.32	2.52	1.72	0.92	1.03

CLASS	69000	72000	75000	78000	81000	84000	87000	90000	93000	96000	99000	102000
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.40	0.33	0.22	0.11	0.00	0.01	0.02	0.03	0.02	0.01	0.00	0.00
8	0.52	0.71	0.52	0.34	0.16	0.11	0.05	0.00	0.00	0.00	0.00	0.00
9	1.84	1.17	0.85	0.54	0.22	0.22	0.22	0.21	0.14	0.08	0.01	0.01
10	0.35	0.17	0.12	0.08	0.04	0.03	0.02	0.02	0.01	0.01	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	1.14	1.25	0.87	0.48	0.10	0.07	0.05	0.03	0.02	0.01	0.00	0.00

Table A.20. Tandem Axle Load Distribution, I-10 Scenario 1 (4,630 AADTT)

CLASS	TOTAL	6000	8000	10000	12000	14000	16000	18000	20000	22000	24000	26000	28000	30000	32000	34000	36000	38000	40000	42000
4	100.0	0.80	0.73	1.19	1.65	2.79	3.93	7.37	10.82	10.59	10.37	9.80	9.23	8.56	7.89	5.58	3.27	2.24	1.21	0.82
5	100.0	26.62	30.51	20.77	11.03	6.67	2.31	1.29	0.26	0.15	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
6	100.0	5.50	10.29	10.54	10.79	8.85	6.90	6.31	5.72	5.13	4.53	4.04	3.55	3.37	3.19	2.78	2.38	1.91	1.44	1.04
7	100.0	72.53	9.46	5.03	0.60	0.58	0.56	0.28	0.00	0.59	1.17	0.95	0.72	0.66	0.60	0.30	0.00	0.00	0.00	0.00
8	99.9	7.72	9.60	11.39	13.19	12.71	12.24	9.46	6.68	4.89	3.10	2.28	1.45	1.16	0.86	0.67	0.48	0.39	0.30	0.24
9	100.0	0.64	1.20	3.00	4.81	5.68	6.56	6.82	7.07	6.90	6.72	7.33	7.93	8.63	7.80	5.94	4.21	2.80	4.17	0.88
10	99.8	0.88	0.81	1.32	1.84	3.23	4.63	5.81	6.98	7.15	7.31	7.29	7.27	6.83	6.38	5.76	5.14	4.51	3.89	3.20
11	33.3	4.17	8.33	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	4.17	2.08	0.00	0.00	0.00	0.00	0.00	0.00
12	100.0	0.23	0.39	2.18	3.96	7.55	11.13	17.42	23.71	16.36	9.02	5.28	1.54	0.87	0.20	0.11	0.03	0.01	0.00	0.00
13	99.3	1.00	1.05	4.01	6.97	8.84	10.72	9.53	8.33	6.07	3.82	3.32	2.82	3.09	3.36	3.42	3.48	3.09	2.69	2.28

CLASS	44000	46000	48000	50000	52000	54000	56000	58000	60000	62000	64000	66000	68000	70000	72000	74000	76000	78000	80000	82000
4	0.42	0.28	0.14	0.11	0.07	0.05	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
6	0.64	0.44	0.23	0.16	0.09	0.06	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.64	1.28	0.64	0.00	0.86	1.71	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.19	0.15	0.11	0.09	0.06	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.02
9	0.37	0.24	0.11	0.07	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	2.51	1.97	1.43	1.09	0.74	0.55	0.37	0.27	0.18	0.13	0.08	0.06	0.03	0.02	0.02	0.03	0.04	0.03	0.03	0.03
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	4.17	2.08	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	1.88	1.68	1.47	1.16	0.84	0.76	0.67	0.55	0.42	0.36	0.30	0.23	0.16	0.17	0.17	0.15	0.12	0.11	0.09	0.09

Table A.21. Tandem Axle Load Distribution, I-10 Scenario 1 (5,630 AADTT)

CLASS	TOTAL	6000	8000	10000	12000	14000	16000	18000	20000	22000	24000	26000	28000	30000	32000	34000	36000	38000	40000	42000
4	100.0	0.80	0.73	1.19	1.65	2.79	3.93	7.37	10.82	10.59	10.37	9.80	9.23	8.56	7.89	5.58	3.27	2.24	1.21	0.82
5	100.0	26.62	30.51	20.77	11.03	6.67	2.31	1.29	0.26	0.15	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
6	100.0	5.50	10.29	10.54	10.79	8.85	6.90	6.31	5.72	5.13	4.53	4.04	3.55	3.37	3.19	2.78	2.38	1.91	1.44	1.04
7	100.0	72.53	9.46	5.03	0.60	0.58	0.56	0.28	0.00	0.59	1.17	0.95	0.72	0.66	0.60	0.30	0.00	0.00	0.00	0.00
8	99.9	7.72	9.60	11.39	13.19	12.71	12.24	9.46	6.68	4.89	3.10	2.28	1.45	1.16	0.86	0.67	0.48	0.39	0.30	0.24
9	100.0	0.64	1.20	3.00	4.80	5.68	6.55	6.81	7.06	6.89	6.71	7.32	7.92	8.62	8.06	6.13	4.31	2.85	3.68	0.88
10	99.8	0.88	0.81	1.32	1.84	3.23	4.63	5.81	6.98	7.15	7.31	7.29	7.27	6.83	6.38	5.76	5.14	4.51	3.89	3.20
11	33.3	4.17	8.33	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	4.17	2.08	0.00	0.00	0.00	0.00	0.00	0.00
12	100.0	0.23	0.39	2.18	3.96	7.55	11.13	17.42	23.71	16.36	9.02	5.28	1.54	0.87	0.20	0.11	0.03	0.01	0.00	0.00
13	99.3	1.00	1.05	4.01	6.97	8.84	10.72	9.53	8.33	6.07	3.82	3.32	2.82	3.09	3.36	3.42	3.48	3.09	2.69	2.28

CLASS	44000	46000	48000	50000	52000	54000	56000	58000	60000	62000	64000	66000	68000	70000	72000	74000	76000	78000	80000	82000
4	0.42	0.28	0.14	0.11	0.07	0.05	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
6	0.64	0.44	0.23	0.16	0.09	0.06	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.64	1.28	0.64	0.00	0.86	1.71	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.19	0.15	0.11	0.09	0.06	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.02
9	0.37	0.24	0.11	0.07	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	2.51	1.97	1.43	1.09	0.74	0.55	0.37	0.27	0.18	0.13	0.08	0.06	0.03	0.02	0.02	0.03	0.04	0.03	0.03	0.03
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	4.17	2.08	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	1.88	1.68	1.47	1.16	0.84	0.76	0.67	0.55	0.42	0.36	0.30	0.23	0.16	0.17	0.17	0.15	0.12	0.11	0.09	0.09

Design and Material Property Inputs

PaveME also requires numerous material property inputs for the pavement structure itself. When specific site data were not available, typical ADOT material input values were used as inputs to PaveME. This section presents material property inputs for asphalt concrete, jointed plan concrete pavement (JPCP), granular base, subgrade, and unbound layer moduli used in PaveME analysis.

Asphalt Concrete Properties

PG 70-10 and PG 76-16 were chosen as representative asphalt binder grades for I-19 and for I-10 in the study region, respectively. Table A.22 summarizes input values for the asphalt concrete layer. For dynamic modulus prediction, Level 3 analysis was selected, as material-specific test data were not available. If not specified herein, default PaveME values were used for other properties. Table A.23 summarizes the asphalt concrete gradations for the LTPP sections on I-19. The average gradation values for these sections most resembled the ADOT Specification 416 ¾” mixture; this choice was logical, as this type of Marshall mixture was commonly used throughout the state during the LTPP timeframe. The average gradation values specific to the study corridor (Table A.23) were used as inputs to PaveME.

Table A.22. AC Mixture Property Input Values

Property for ADOT ¾” 416 Mixture	Input Value
Binder Grade	PG 70-10 (I-19), PG 76-16 (I-10)
Effective Binder (Volume)	10.8 %
Unit Weight	141.9 lb/ft^3
In-place Air Voids	7.6 %
Dynamic Modulus	Level 3 – Binder Grade Input

Table A.23. Representative AC Aggregate Gradation Properties from LTPP

LTPP Section	Average Percent Passing			
	3/4"	3/8"	No. 4	No. 200
6060	98.3	73	55.2	4.2
1017	94.6	66.5	52.4	4.3
6054	98.5	75	58.5	7
1018	94.1	67.4	53.6	4.8
1016	96.1	64.5	50.5	4.4
1015	97	68	55	6.7
Average	**96.4**	**69.1**	**54.2**	**5.2**
St. Dev.	**1.84**	**4.05**	**2.74**	**1.27**
ADOT 3/4" 416 Spec.	*97.6*	*73.1*	*55.8*	*5.4*

Jointed Plan Concrete Pavement (JPCP)

There were no representative LTPP concrete sections available near the study corridor, and therefore ADOT default material properties (Table A.24) were used for JPCP sections analyzed. All unlisted but required PaveME input properties used default global values. It is important to note that the JPCP section on I-19 was not doweled pavement, whereas the JPCP section on I-10 has dowel bars.

Also, a coefficient of thermal expansion (CTE) value of $2.5*10^{-6}/°$ F was used in the analysis because the ADOT-recommended value of $4.5*10^{-6}/°$ F produced an unrealistically low time to JPCP failure (only a few years). The research team selected a CTE value that produced a practical time to failure (from PaveME) for a JPCP (considering the traffic and route).

Table A.24. JPCP Property Input Values

Property	Input Value
Cement Type	Type I
Cementitious Content	584 lb/yd^3
w/c	0.44
Unit weight	149 lb/ft^3
f_c	5,000 psi
E_c	4,000,000 psi
μ	0.16
Joint Spacing	15 feet

One key factor in PaveME analysis of JPCP is the inclusion of dowel bars for load transfer. Slab dimensions are also a factor, but AASHTOWare Pavement ME is more sensitive to the use of dowels. ADOT record drawings and historical typical section drawings provided the following details regarding the JPCP pavement along the study corridor:

- The nine-inch JPCP on I-19 is un-doweled, with approximately 12-foot by 15-foot joint spacing. The longitudinal center joint has tie bars.
- The nine-inch JPCP on I-10 is un-doweled, with staggered longitudinal joint spacing of 13, 15, and 17 feet with a 2-foot transverse skew across the lane. The longitudinal center joint has tie bars.
- The 15-inch JPCP on I-19 at the interchange with I-10 is un-doweled, with approximately 15-foot longitudinal joint spacing.
- The 13-inch JPCP on I-10 is doweled. Longitudinal joint spacing is staggered at 13, 15, and 17 feet, with a 2-foot transverse skew across the lane.

While the research team recognizes that other factors such as slab dimensions are important in AASHTOWare Pavement ME analysis, the scope of the project limits the analysis to the most critical factors of thickness and the use of dowel bars.

Granular Base and Subgrade Properties for both AC and JPCP Sections

The locations of existing LTPP sections on I-19 were reviewed and are summarized in Table A.25. Significant historical information related to material properties, pavement distress, and pavement section information is available for LTPP sections. Additional information contained in the LTPP database provided a more reality-based representation of material properties (than default PaveME values) for pavement analysis.

Table A.25. Locations of LTPP Sections along I-19

Route	Direction	LTPP Section	MP	AASHTO Soil Classification
I-19	NB	046060	14.88	A-2-6
		041017	32.98	A-2-6, A-2-4
	SB	046054	52.25	A-2-4
		041018	36.2	A-2-4, A-6
		041016	24.17	A-2-4
		041015	18.33	A-2-7

Granular base and subgrade material properties were determined from the original laboratory test results from the representative LTPP sections. Granular base gradation was determined as an average of four of the five LTPP sections; the fifth was not included, as the gradation was considerably different from the other four gradations. Table A.26 presents the aggregate gradations from the LTPP sites along with the average values that are used as PaveME input for the base material for all sections being evaluated. Table A.27 shows the subgrade gradations, liquid limit (LL), and plasticity index (PI) values used as input to PaveME for all pavement sections. These values were determined by averaging subgrade soil properties from LTPP sections that best represented the subgrade soil type chosen for the representative pavement sections. If LTPP data were deemed non-representative, soil property data were extracted from a soil mapping utility (Zapata and Cary, 2012) for the matching subgrade soil unit along the study corridor.

Table A.26. Granular Base Gradation Input

LTPP ID	Average Percent Passing										
	2"	1.5"	1"	3/4"	1/2"	3/8"	No. 4	No. 10	No. 40	No. 80	No. 200
6060	100	98	95.5	92	80.5	73.5	56	38	20	11	7.5
1017	99	98.5	94	90.5	80.5	75	63	46	23.5	13.5	8.6
~~*6054*~~[a]	~~*100*~~	~~*100*~~	~~*100*~~	~~*99*~~	~~*96*~~	~~*94*~~	~~*86.5*~~	~~*73.5*~~	~~*38.5*~~	~~*17.5*~~	~~*11.15*~~
1018	100	97.5	96	92.5	80	74.5	62.5	51.5	32.5	20	13.65
1016	100	98	92.5	85	77	73	63	51	30.5	19.5	13.85
1015	100	99	93.5	88	82	78.5	70.5	57.5	35	20	13
Average	**99.8**	**98.2**	**94.3**	**89.6**	**80**	**74.9**	**63**	**48.8**	**28.3**	**16.8**	**11.3**
StDev	**0.45**	**0.57**	**1.44**	**3.11**	**1.84**	**2.16**	**5.14**	**7.29**	**6.31**	**4.25**	**3.03**

[a]Section 6054 was removed because of the apparent gradation differences from the other sections.

Table A.27. Subgrade Gradation Input

Section	Representative LTPP Sections	Average % Passing											Soil Properties	
		2"	1.5"	1"	3/4"	1/2"	3/8"	No. 4	No. 10	No. 40	No. 80	No. 200	LL	PI
1	1017, 1018	98.8	97.3	94	90.8	86.3	82.8	72.5	61	46.3	37.3	29.5	28	12
2	6060, 1015, 1016	96.7	92.2	86	81.7	75	71.3	61.2	47.8	32	23.8	17.5	33	17
3	N/A[a]	99.6	99.4	98.7	98	96.7	95.6	93	89.9	82.7	73.9	60.6	21	5
4	N/A[a]	99.6	99.4	98.7	98	96.7	95.6	93	89.9	82.7	73.9	60.6	21	5
5	N/A[a]	99.6	99.4	98.7	98	96.7	95.6	93	89.9	82.7	73.9	60.6	21	5

[a]Data from (Zapata and Cary, 2012)

Unbound Layer Moduli

Back-calculated unbound layer modulus data, extracted from the representative LTPP sections, were considered as inputs to PaveME. However, review of data revealed low modulus values for the granular base and uncharacteristically high values for the subgrade. It was very likely that the back-calculated modulus of the granular base and the subgrade modulus values are smeared together, resulting in the high subgrade modulus values observed. The ADOT standard design value for granular base modulus (34 kilopounds per square inch, or ksi) was considered; however, it was likely the case that older pavement sections were not constructed with high-quality crushed aggregate base (represented by a 34 ksi modulus value). Therefore, a representative back-calculated value of 25 ksi (derived from the LTPP data) was selected to represent the granular base material in all sections. In cases where the subgrade modulus values were higher, the base modulus was set equal to the subgrade modulus. Reasonable subgrade values were calculated using the outer sensor from LTPP Falling Weight Deflectometer (FWD) data (similar to the ADOT method); if data were not available, the ASU soil map website [14] was used, and subgrade modulus values were based on the soil unit along the representative section of the I-19 and I-10 corridors. Note that back-calculated (LTPP) subgrade modulus values were adjusted according to ADOT guidance.

Pavement Performance Criteria

The *Arizona DOT User Guide for AASHTO DARWIN-ME Pavement Design Guide* specifies design failure criteria for AC (Table A.28) and JPCP (Table A.29) pavements based on a reliability level of 97%. These values were used as distress thresholds to trigger a pavement treatment.

Table A.28. AC Failure Criteria

Distress	Maximum value
Initial IRI	45 inch/mile
Fatigue Cracking	10 % of lane area
Longitudinal cracking	N/A
Total Rutting	0.50 inch
Thermal cracking	N/A
IRI	150 inch/mile

Table A.29. JPCP Failure Criterion

Property	Failure Limit
Mean Joint Faulting	0.12 in. mean all joints
Percent Slab Transverse Cracking	10 %
Initial IRI	63 in/mile[1]
IRI	150 in/mile

[1] Bare JPCP, 50 in/mile with an asphalt concrete friction course over JPCP.

ADOT Local Calibration Coefficients

Table A.30 and Table A.31 present the ADOT-specific PaveME model coefficients used in the analysis. All other national calibration coefficients can be found in ADOT SPR-606 "Calibration and Implementation of the AASHTO Mechanistic-Empirical Pavement Design Guide in Arizona" (Darter et al., 2014).

Table A.30. Arizona Calibration Coefficients for AASHTOWare Pavement ME Software

Model	Parameter	Value
AC Fatigue	K1	0.007566
	K2	3.9492
	K3	1.281
	BF1	249.0087232
	BF2	1
	BF3	1.2334
AC Cracking Bottom	C1	1
	C2	4.5
	C4	6000
	Standard Dev.	1.1+22.9/(1+exp(-0.1214-2.0565*LOG10(BOTTOM+0.0001)))
Reflection Cracking	a	3.5+0.75*heff
	b	-0.688584-3.37302*Pow(heff,-0.915469)
	c	2.55
	d	1.23
AC rutting	K1	-3.3541
	K2	1.5606
	K3	0.4791
	BR1	0.69
	BR2	1
	BR3	1
	Standard Dev.	0.0999*Pow(RUT,0.174)+0.001
Base Rutting (granular subgrade rutting)	K1 (base)	2.03
	BS1 (base)	0.14
	Standard Dev.	0.05*Pow(BASERUT,0.115)+0.001
Subgrade Rutting (fine subgrade rutting)	K1 (subgrade)	1.35
	BS1 (subgrade)	0.37
	Standard Dev.	0.05*Pow(SUBRUT,0.085)+0.001

Table A.31. Arizona Calibration Coefficients for AASHTOWare Pavement ME Software (cont.)

AC Thermal Cracking	1K	1.5
	Level 1 St.Dev.	0.1468*THERMAL+65.027
	2K	0.5
	Level 2 St.Dev.	0.2841*THERMAL+55.462
	3K	1.5
	Level 3 Std.Dev.	0.3972*THERMAL+20.422
AC IRI	C1 (rutting)	1.2281
	C2 (fatigue)	0.1175
	C3 (transverse)	0.008
	C4 (SF)	0.0280
JPCP Fatigue	C1	2
	C2	1.22
JPCP Transverse Cracking	C4	0.19
	C5	-2.067
	Standard Dev.	Pow(9.87*CRACK,0.4012)+0.5
Faulting	C1	0.0355
	C2	0.1147
	C3	0.00436
	C4	1.1e-07
	C5	20000
	C6	2.0389
	C7	0.1890
	C8	400
	Standard Dev.	Pow(0.037*FAULT,0.6532)+0.001
JPCP IRI	J1 (cracking)	0.60
	J2 (spalling)	3.48
	J3 (faulting)	1.22
	J4 (SF)	45.20
	Standard Dev.	5.4

Summary of Structural Input Values

Table A.32 provides an overall summary of the pavement structural input parameters to PaveME.

Table A.32. Pavement Structure Input to PaveME

Representative Pavement Section	Route	Layer 1 Material	Layer 1 Thickness (in)	Base Thickness[a] (in)	Subgrade	Subgrade Modulus (ksi)	AADTT (1-way)
1	I-19	AC	8.5	8	A-2-4	24	1300
2	I-19	AC	11	10	A-2-4	24	1300
3	I-19	AC	9.5	19.5	A-4	22.8[b]	1300
4	I-10	JPCP	9[c]	9	A-4/A-6	15.8[b]	5650
5	I-10	AC	8	19.5	A-4/A-6	15.8[b]	4650

[a]Back-calculated value of 25 ksi was selected to represent the granular base material in all sections (based on LTPP test sections on I-19).
[b]Value taken from (Zapata and Cary 2012)
[c]Records show un-doweled JPCP. Doweled was assumed in PaveME to generate reasonable distress results.

PAVEMENT COST ANALYSIS

The cost analysis was carried out as described in the main body of the report. Additional details are provided and described in this section. In general, the pavement analysis procedure was as follows:

1. Assign a typical ADOT treatment activity based on the time of critical distress from PaveME for the Surface Transportation Assistance Act (STAA) case traffic (base case) and Match AZ 90800 (overweight case) traffic. Also assign a typical cost associated with each treatment.
2. Assign additional treatments based on the following
    a. A 12-year rehabilitation cycle for base case traffic
    b. An 11-year rehabilitation cycle for overweight traffic
3. Determine the present value (PV) of each treatment, and then calculate the equivalent uniform annual cost (EUAC) of the difference between net present values (base traffic and overweight traffic). A discount rate of 1.9% was applied. Note that the initial cost was not included in the analysis, as it was assumed that the new pavement (assumed for PaveME analysis) was designed for the Base/STAA case traffic (same initial cost for both scenarios).
4. Determine the cost per overweight trucks (80 overweight trucks per day over 365 days per year).

Key items to note in this analysis include:

- Analysis was performed on a “new pavement” scenario for all pavement sections, and the service life of the pavement determined the timing of the first rehabilitation treatment.

- It is not likely that 80 overweight trucks will purchase the permit every day of the year. However, PaveME calculates damage based on 365 days, and thus the cost calculations addressed damage from overweight trucks operating daily.
- A 12-year rehabilitation interval was chosen for the base case traffic scenario, consistent with the timeframe used in the recent 2015 MAP-21 Comprehensive Truck Size and Weight Limits Study and with typical ADOT rehabilitation intervals. However, an 11-year rehabilitation interval (1-year reduction in timing) was selected for the overweight traffic scenario. The difference in timing of the first rehabilitation treatments (base versus overweight traffic) for all five representative pavement sections ranged from 0.1 year to 2.0 years, and thus a 1-year reduction in service life of the subsequent treatments is reasonable.
- The overall analysis is limited by the fact that rehabilitation treatments were placed at assumed intervals: 12 years for the Base/STAA (base) and 11 years for the Match AZ 90800 (overweight) scenarios. A more accurate approach would require redesigning the pavement rehabilitation treatment/thickness at each rehabilitation time in the future (given the expected truck traffic at that time interval). However, the extensive assumptions required and the effort required to build the traffic inputs (traffic and truck axle load distributions) make this type of analysis impractical within the project scope. Given the limited pavement sections in the scope and subsequent extension to the entire corridor, the research team's approach is justified. Thus, the selection of the assumed rehabilitation interval was based on (1) *2015 MAP-21 Comprehensive Truck Size and Weight Limits Study* (FHWA 2015) and (2) a typical rehabilitation time for ADOT highways. Early in the project analysis, the research team analyzed two AC overlay scenarios, and the percentage of cracking distress (controlling factor) was nearly the same at the 12-year interval. However, the team believes that selection of the 11-year interval in Scenario 1 is a more conservative approach and more realistic in that the addition of overweight vehicles will likely shorten the lifespan of a rehabilitation treatment.

Costs and treatment types were provided by ADOT and are shown in Table A.33. Table A.34 through Table A.38 present the cost breakdowns based on applied treatments and timing of treatments. In these tables, "Base/STAA" and "Match AZ 90800" refer to the base truck scenario and the overweight truck scenario, respectively.

Table A.33. ADOT Treatments and Loaded Construction Costs

Treatment ID	Type of Rehabilitation	Construction Cost ($1000/Lane Mile)
100	RR(5"TL, 3"PL) + FR	359
101	RR4"AC + FR	359
102	RR(4"TL, 3"PL) + FR	330
103	RR(4.5"TL, 2.5"PL) + FR	326
104	RR(3.5"TL, 2.5"PL) + FR	301
105	RR3"AC + FR	300
1001	4.5" AC OL + FR	365

TL – travel lane
PL – passing lane
RR – remove (mill) and replace asphalt concrete
FR – asphalt concrete friction course (open graded)
AC – asphalt concrete
AC OL – asphalt concrete overlay

Table A.34. Cost Analysis for Structure 1 (8.5" AC, 8" AB)

Activity	Traffic Scenario		ADOT Treatment
	Base/STAA	Match AZ 90800	
Failure Mode	Rut	Rut	
Activity 1 (yrs)	22.9	22.8	102
Cost 1	$660,000	$660,000	
PV 1	$428,899	$429,707	
Activity 2 (yrs)	34.9	33.8	104
Cost 2	$602,000	$602,000	
PV 2	$312,117	$318,646	
Activity 3 (yrs)	46.9	44.8	104
Cost 3[a]	$155,517	$284,582	
PV 3	$64,329	$122,463	
Total PV	$805,345	$870,816	
Diff. PV	$65,471		
EUAC	$2,040		
$ / Truck	**$0.070**		

[a]Prorated cost based on time to the 50th year.

Table A.35. Cost Analysis for Structure 2 (11" AC, 10" AB)

Activity	Traffic Scenario		ADOT Treatment
	Base/STAA	Match AZ 90800	
Failure Mode	Rut	Rut	
Activity 1 (yrs)	32.9	32.8	102
Cost 1	$660,000	$660,000	
PV 1	$355,315	$355,984	
Activity 2 (yrs)	44.9	43.8	104
Cost 2 [a]	$255,850	$339,309	
PV 2	$109,892	$148,787	
Activity 3 (yrs)	56.9	54.8	104
Cost 3	-	-	
PV 3	-	-	
Total PV	$465,206	$504,772	
Diff. PV	$39,565		
EUAC	$1,233		
$ / Truck	**$0.042**		

[a]Prorated cost based on time to the 50th year.

Table A.36. Cost Analysis for Structure 3 (9.5" AC, 19.5" AB)

Activity	Traffic Scenario		ADOT Treatment
	Base/STAA	Match AZ 90800	
Failure Mode	Rut	Rut	
Activity 1 (yrs)	26.8	26.7	102
Cost 1	$660,000	$660,000	
PV 1	$398,544	$399,294	
Activity 2 (yrs)	38.8	37.7	104
Cost 2	$602,000	$602,000	
PV 2	$290,027	$296,094	
Activity 3 (yrs)	50	48.7	104
Cost 3[a]	$0	$71,145	
PV 3	$0	$27,761	
Total PV	$688,570	$723,150	
Diff. PV	$34,579		
EUAC	$1,077		
$ / Truck	**$0.037**		

[a]Prorated cost based on time to the 50th year.

Table A.37. Cost Analysis for Structure 4 (9" JPCP, 9" AB)

Activity	Traffic Scenario		ADOT Treatment
	Base/STAA	Match AZ 90800	
Failure Mode	Slab Cracking	Slab Cracking	
Activity 1 (yrs)	11.9	10.4	1001
Cost 1	$730,000	$730,000	
PV 1	$583,512	$600,221	
Activity 2 (yrs)	23.9	21.4	105
Cost 2	$600,000	$600,000	
PV 2	$382,638	$401,073	
Activity 3 (yrs)	35.9	32.4	105
Cost 3	$600,000	$600,000	
PV 3	$305,280	$326,068	
Activity 4 (yrs)	47.9	43.4	101
Cost 4[a]	125,650	430,800	
PV 4	$51,006	$190,334	
Total PV	$1,322,436	$1,517,696	
Diff. PV	$195,260		
EUAC	$6,084		
$ / Truck	**$0.208**		

[a]Prorated cost based on time to the 50th year.

Table A.38. Cost Analysis for Structure 5 (8" AC, 19.5" AB)

Activity	Traffic Scenario		ADOT Treatment
	Base/STAA	Match AZ 90800	
Failure Mode	Rut	Rut	
Activity 1 (yrs)	10.8	8.8	100
Cost 1	$718,000	$718,000	
PV 1	$585,927	$608,403	
Activity 2 (yrs)	22.8	20.8	102
Cost 2	$660,000	$660,000	
PV 2	$429,707	$446,191	
Activity 3 (yrs)	34.8	32.8	102
Cost 3	$660,000	$660,000	
PV 3	$342,833	$355,984	
Activity 4 (yrs)	46.8	44.8	100
Cost 4[a]	191,467	339,418	
PV 4	$79,349	$146,060	
Total PV	$1,437,816	$1,556,639	
Diff. PV	$118,823		
EUAC	$3,702		
$ / Truck	**$0.127**		

[a]Prorated cost based on time to the 50th year.

Each section of the corridor was then assigned a representative pavement section and associated infrastructure damage cost, presented in Table A.39 to Table A.42. The project scope did not permit analysis of every pavement structure along the I-19 and I-10 corridor, and thus the infrastructure damage costs for Pavement Sections 6 and 7 were derived from similar pavement structures already analyzed, as follows:

- Section 6 (I-19) cost was based on Section 4 (I-10), scaled by the ratio of AADTT between the sections. Section 4 had similar pavement type and thickness as Section 6.
- Section 7 (I-10) cost was determined as the damage cost on Section 4 (I-10), scaled by the ratio of thickness between the sections. Section 4 had similar pavement type and AADTT as Section 7.

A summary of the cost analysis can be found in the main body of the report.

Table A.39. Infrastructure Damage Cost Breakdown on Northbound I-19

Northbound I-19			Thickness (in)		Distance (mi)	% of Mileage	Base Thickness (in)	Rep. Section[a]	$/truck/mi	$/truck
ADOT Project	Beg. MP	End MP	AC	JPCP						
H636701C	0	0.3	5	-	0.3	0.5%	10	-	-	-
H839501C	0.3	6.08	9.4	-	5.78	9.3%	19.5	3	$0.037	$0.21
H480301C	6	8.56	10.1	-	2.56	4.1%	11	2	$0.042	$0.11
H480301C	8.56	9.41	10.1	-	0.85	1.4%	9	2	$0.042	$0.04
H480301C	9.41	16.17	10.1	-	6.76	10.8%	13	2	$0.042	$0.29
H815601C	16.2	21.1	12.7	-	4.9	7.9%	10.5	2	$0.042	$0.21
H379801C	21.1	25.3	8.3	-	4.2	6.7%	9	1	$0.070	$0.29
H355801C	25.3	31.88	9	-	6.58	10.5%	5	1	$0.070	$0.46
H871601C	31.88	42.5	8.4	-	10.62	17.0%	9	1	$0.070	$0.74
H310201C	42.5	47	7.8	-	4.5	7.2%	10	1	$0.070	$0.31
H310201C	47	50.24	10	-	3.24	5.2%	16	2	$0.042	$0.14
H480401C	50.1	54.76	11.1	-	4.66	7.5%	29	2	$0.042	$0.20
H480401C	54.76	58.5	1	9	3.74	6.0%	10	6	$0.048	$0.18
H022501C	58.5	59.7	1	9	1.2	1.9%	10	6	$0.048	$0.06
H659501C	59.7	60	1	9	0.3	0.5%	9	6	$0.048	$0.01
H846701C	60.86	62.25	1	9	1.39	2.2%	9	6	$0.048	$0.07
H319003C	62.25	63.09	-	15	0.84	1.3%	4" AC	-	-	-
									Total NB	**$3.31**

[a]A short distance at the beginning and end of the I-19 corridor was excluded, as similar pavement sections were not analyzed and thus a prorated cost could not be determined.

Table A.40. Infrastructure Damage Cost Breakdown on Southbound I-19

Southbound I-19			Thickness (in)		Distance (mi)	% of Mileage	Base Thickness (in)	Rep. Section[a]	$/truck/mi	$/truck
ADOT Project	Beg. MP	End MP	AC	JPCP						
H319003C	63.09	62.25	-	15	0.84	1.3%	4" AC	-	-	-
H846701C	62.25	60.86	1	9	1.39	2.2%	10	6	$0.048	$0.07
H659501C	60	59.7	1	9	0.3	0.5%	10	6	$0.048	$0.01
H022501C	59.7	58.5	1	9	1.2	1.9%	9	6	$0.048	$0.06
H480401C	58.5	54.76	4.5	9	3.74	6.0%	9	6	$0.048	$0.18
H480401C	54.76	50.1	11.4	-	4.66	7.5%	29	2	$0.048	$0.22
H310201C	50.2	47	9.3		3.2	5.1%	16	3	$0.048	$0.15
H310201C	47	42.5	10.5	-	4.5	7.2%	10	2	$0.042	$0.19
H871601C	42.5	31.88	8.6	-	10.62	17.0%	9	1	$0.070	$0.74
H355801C	31.88	25.3	9	-	6.58	10.5%	6	1	$0.070	$0.46
H379801C	25.3	21.1	10.9		4.2	6.7%	9	2	$0.042	$0.18
H815601C	21.1	16	12.1	-	5.1	8.2%	9.5	2	$0.042	$0.22
H480301C	16	6	10	-	10	16.0%	11	2	$0.042	$0.42
H839501C	6.08	0.3	9.9	-	5.78	9.3%	19.5	3	$0.037	$0.21
H636701C	0.3	0	5	-	0.3	0.5%	10	-	-	-
									Total SB	**$3.11**

[a]A short distance at the beginning and end of the I-19 corridor was excluded, as similar pavement sections were not analyzed and thus a prorated cost could not be determined.

Table A.41. Infrastructure Damage Cost Breakdown on Eastbound I-10

Eastbound I-10			Thickness (in)		Distance (mi)	% of Mileage	Base Thickness (in)	Rep. Section	$/truck/mi	$/truck
ADOT Project	Beg. MP	End MP	AC	JPCP						
H319001C	259.92	260.5	-	13.5	0.58	4.6%	4	7	$0.139	$0.08
H016404C	260.35	262.7	-	13	2.35	18.8%	4	7	$0.139	$0.33
H765801C	262.4	267.5	1	9	5.1	40.7%	9	4	$0.208	$1.06
H806501C	267.5	272	8	-	4.5	35.9%	22	5	$0.127	$0.57
									Total EB	**$2.04**

Table A.42. Infrastructure Damage Cost Breakdown on Westbound I-10

Westbound I-10			Thickness (in)		Distance (mi)	% of Mileage	Base Thickness (in)	Rep. Section	$/truck/mi	$/truck
ADOT Project	Beg. MP	End MP	AC	JPCP						
H806501C	272	267.5	8	-	4.5	35.1%	22	5	$0.127	$0.57
H765801C	267.5	262.4	1	9	5.1	39.8%	9	4	$0.208	$1.06
H016404C	262.73	260.05	-	13	2.68	20.9%	4	7	$0.139	$0.37
H319001C	260.44	259.91	-	13.5	0.53	4.1%	4	7	$0.139	$0.07
									Total WB	**$2.08**

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