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Minimizing Bridge and Pavement Deterioration from Large Trucks: A Policy Analysis for Damage Recovery

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MINIMIZING BRIDGE AND PAVEMENT DETERIORATION FROM LARGE TRUCKS: A POLICY ANALYSIS FOR DAMAGE RECOVERY

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ABSTRACT

Facing an exceptional challenge of maintaining state roadways with ever-shrinking financial resources, this research examined multiple facets of the impact of overweight trucks. The objectives of this research were to investigate the impact of overweight trucks on pavements and bridges, and develop policy recommendations based on technical analysis and the modern political and institutional environment in South Carolina. To achieve the objectives, this research modeled pavement and bridge deterioration, investigated the adequacy of standard practices in state agencies, examined how trucking industry perceives those practices, and developed policy analysis models. Pavement and bridge deterioration analysis revealed that pavement and bridge damages increase significantly with incremental weights. Combined bridge and pavement damage costs per mile for different overweight truck types were estimated in this research.

Permit fees to recover damage costs from overweight trucks are of five basic structures: flat, distance based, weight based, weight and distance based, and axle based. To recover additional costs of damage imparted by overweight trucks for load in excess of the legal weight limits in an axle based fee structure, damage fee will vary between \$24 and \$175 per trip for different overweight truck types, while a flat fee structure will charge all overweight trucks \$65 per trip (including \$10 adminstrative permit processing fee). Consideration of axle load, axle configuration and trip length in the fee structure will reflect damage imparted by each overweight truck more accurately. Under the current fee structure, overweight trucks in South Carolina pay \$30 for a single trip

permit, and $100 for an annual permit which is equivalent to 3.33 trips. An Ohio DOT study found that with an annual permit, on average, 24.8 trips were made by an overweight truck.

This research applied a multiobjective analysis approach to address conflicting objectives, and to generate detailed tradeoffs between different overweight truck damage cost recovery fee options. This research presents a case study with two objectives: 1) minimization of unpaid pavement and bridge damage by overweight freight trucks, and 2) minimization of overweight damage cost recovery fees. The tradeoff analysis reveals that increasing the flat overweight damage cost recovery fee by $1 from $43 will reduce unpaid damages by $4.2 million in year 2012 in South Carolina with a high elasticity of demand. In the axle-based damage cost recovery fee type, increasing the average axle-based overweight damage cost recovery fee by $1 from $43 will reduce unpaid damages of $3.8 million in year 2012 in South Carolina. These types of tradeoff analyses provide valuable information to decision makers in selecting an appropriate type and level of fee for overweight trucks.

Interviews with overweight trucking stakeholders in South Carolina did not reveal any common consensus on how overweight permit polices should be refined. Stakeholders expressed their concern that increasing permit fee will surge illegal overweight trips. It is critical to develop effective enforcement plan to deter illegal overweight trucks before implementation of new fee policies. As consensus does not exist among stakeholders, SCDOT must establish a working group with all interested parties to understand everyone's concerns before proposing any new policies.

DEDICATION

Dedicated to My Family

ACKNOWLEDGMENTS

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CHAPTER I: INTRODUCTION

Over the last decade, the American highway system has faced an ever growing funding shortage, and legacy state highways are falling into disrepair. In response, national forums have engaged in debate over how to generate funds for road maintenance and upgrade capacity to support the ever increasing traffic demand. Between 1990 and 2003, vehicle-miles travelled (VMT) increased at an average annual rate of 2.32% while truck ton-miles increased much faster at an average annual rate of 3.06%. Among all modes of freight transportation, share of highway freight transportation increased from 24% in 1990s to 28% in 2003 (USDOT, 2007). Moreover, trucks and other heavy vehicles inherently inflict the greatest deterioration due to their large Gross Vehicle Weight (GVW) and individual axle loads. Additionally, the proportion of trucks configured with multiple units increased from 24% in 1980 to 28% in 2002 (RITA, 2006). Long-term trends toward larger and heavier trucks have exacerbated the impact of trucks on the deterioration of roadway infrastructure.

1.1 Problem Statement

The Federal Highway Administration (FHWA) has estimated that from 2008 to 2035 there will be a 72% increase in highway freight demand in the US (FHWA, 2012). This trend has led to increased demand for the public highway system to support heavier loads. With decaying infrastructure and shrinking funding allocation to build new highway systems, transportation agencies must somehow maintain existing highways at acceptable levels to support this increased demand (ASCE, 2013).

With a steady increase in highway freight demand, the average size of freight trucks has also increased. Freight shippers have increased the use of multi-unit trucks to minimize their transportation costs (FHWA, 2000). Trade negotiations among neighboring countries and international trade treaties have allowed cross-border operation of relatively heavy truck traffic. The Texas-Mexico trade corridor experienced a rapid change in truck traffic and volume after the North American Free Trade Agreement (NAFTA) partially opened US highways to Mexican trucks with different axle configurations in 1993 (Hong et al., 2007). Besides regular freight truck traffic within federal and state legal weight limits, overweight truck traffic demand (i.e. trucks over legal limits) were also increasing at a faster pace (FHWA, 2012). As pavement and bridge damage increases exponentially with load, it is a significant challenge for transportation agencies to manage overweight truck traffic demand to minimize infrastructure damage.

Aging transportation infrastructure, a dwindling maintenance budget, and increasing traffic demand, particularly the increase in the frequency and weight of trucks, are posing a significant challenge to the US transportation grid in terms of operations and safety. Truckers have been paying for their additional burden on public infrastructure via a few revenue mechanisms. Because trucks use large amounts of fuel, they are subject to proportionately higher gas taxes, higher registration fee, and tire taxes. Toll roads have typically had variable rates according to the number of axles on vehicles (i.e. the more axles the greater the cost).

Public agencies have monitored truck weights to ensure they stay within acceptable limits. For the largest of loads, all states charge fees for oversized and/or overweight vehicles. The effectiveness of these fees structures in collecting enough revenue for mitigating the costs inflicted is unknown, however. The legacy fee structure's insufficiency has not been examined in context of changing freight demand, rising cost of maintenance, and changing heavy-vehicle policies across the nation. Due to this confluence of conditions, multiple factors must be addressed at once in order to update the fee policies for heavy vehicles.

1.2 Research Objectives and Tasks

This research addresses the effectiveness of overweight freight truck fee structures in collecting enough revenue for mitigating the costs inflicted by specific overweight loads. The research objectives entail (1) characterizing the extent to which state departments of transportation (DOTs) have recovered maintenance costs incurred from allowing passage of overweight loads and current practices among all U.S. states, (2) identifying scientific reasons of pavement and bridge deterioration due to trucks above legal weight limits, (3) identifying current and promising practices to overcome these adverse effects in order to ensure healthy transportation infrastructure, and (4) using a multi-objective analysis to evaluate conflicting freight mobility policies. Finally, this research will create policy recommendations related to overweight truck mobility. To accomplish the research objectives, following six tasks were conducted:

Task 1: Literature Review (Chapter 2)

Task 2: Research Method (Chapter 3)

Task 3: Pavement and Bridge Damage Estimation (Chapter 4)

Task 4: Evaluation of Fee Structures (Chapter 5)

Task 5: Policy Trade-off and Implementation Challenges (Chapter 6)

Task 6: Conclusions and Recommendations (Chapter 7)

This dissertation is organized into seven chapters. Chapter 1 describes an overview of the research problem and objectives of this research. Chapter 2 includes a comprehensive literature review on pavement and bridge damage estimation, current overweight freight policies among states in the US and application of policy analysis techniques. The method adopted in this research is summarized in Chapter 3. Chapter 4 presents pavement and bridge damage estimation and quantification details for overweight trucks in South Carolina. Chapters 5 and 6 discuss fee structure comparison and policy analysis, respectively. Conclusions and recommendation were developed based on the findings of this research, and is presented in Chapter 7. Appendices included data and background related to key analyses conducted in this research.

CHAPTER II: LITERATURE REVIEW

In this chapter, previous research on pavement and bridge deterioration due to freight traffic, especially overweight trucks, were summarized with a discussion on freight traffic demand trends and current overweight permit practices among states in the US.

2.1 Trends in Freight Traffic Demand

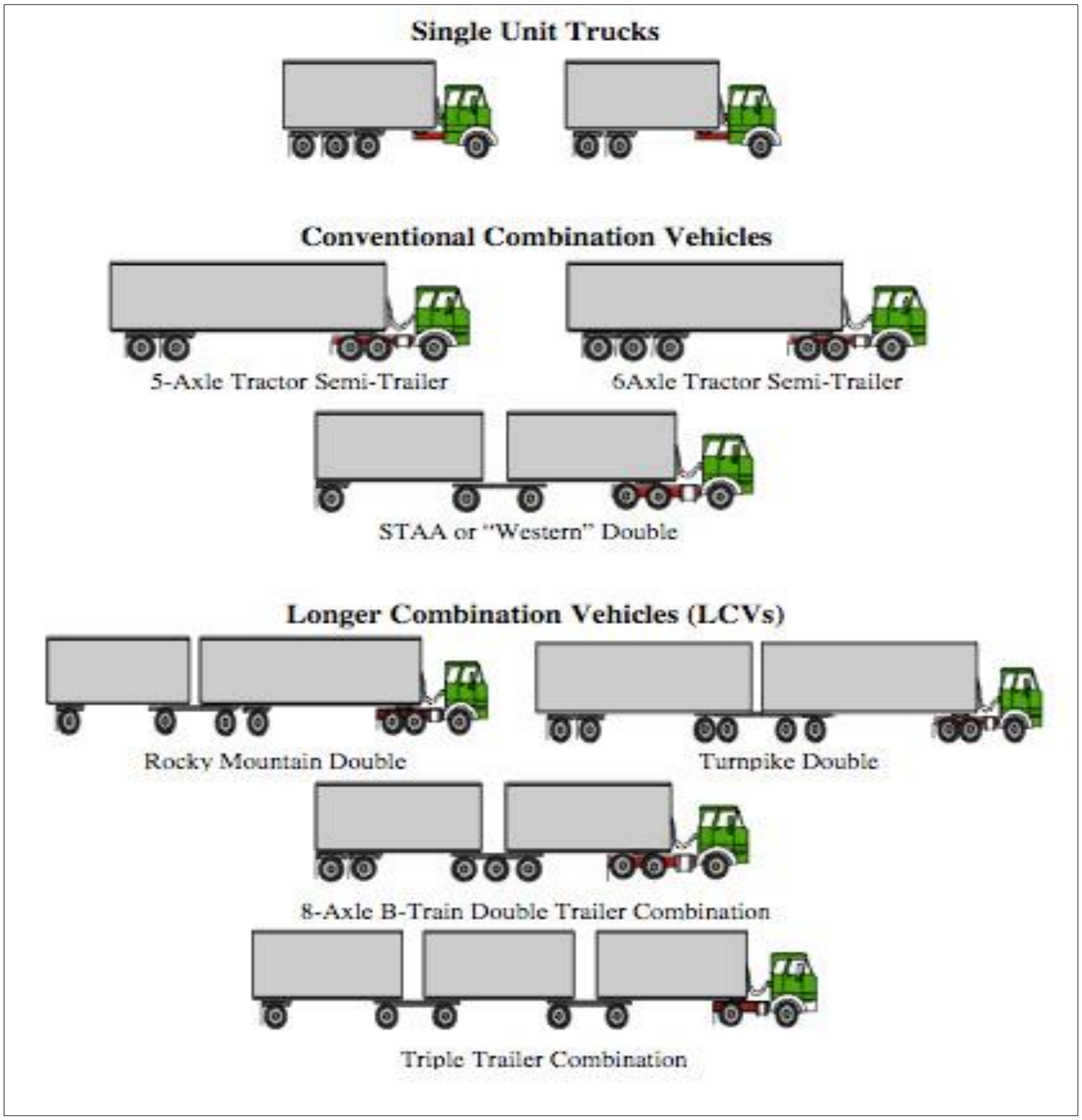
The Federal Highway Administration (FHWA) has predicted an overall 73-percent increase in shipment volume from 2008 to 2035 with a concurrent increase in truck freight of 72 percent (Table 1). With decaying infrastructure and lack of resources to build new highway systems, transportation agencies are challenged to maintain existing highways at acceptable levels while truck freight is increasing significantly (ASCE, 2013).

Table 1 Projected Weight of Shipments by Transportation Mode: 2008 and 2035 (millions of tons)

Shipment Type	2008	2035	Change	Annual Change
Truck	13,243	22,813	72.3%	2.7%
Rail	2,007	3,525	75.6%	2.8%
Water	632	1,041	64.8%	2.4%
Air, air & truck	13	61	355.2%	13.2%
Intermodal	1,661	2,598	56.4%	2.1%
Pipeline & unknown	3,940	7,172	82.0%	3.0%
Total	21,496	37,211	73.1%	2.7%

Source: Federal Highway Administration, 2010

While the number of trucking loads has increased, the size of individual loads has also increased. Freight shippers have turned to multi-unit trucks (Figure 1) to minimize their transportation costs (RITA, 2006). The United States Department of Transportation (USDOT) identified a trend of heavy vehicles increasing their vehicle miles between 1987 and 2002 (Table 2 and Figure 2), which increased axle loadings on pavements and gross vehicle weights on bridges.



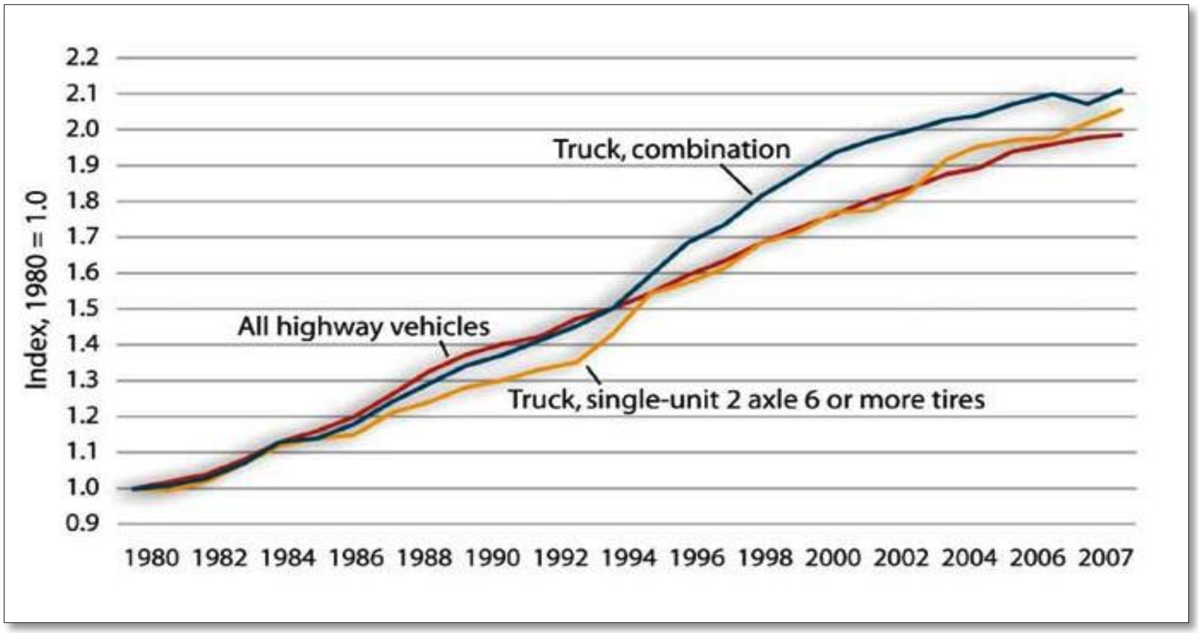
Source: Federal Highway Administration, 2000

Figure 1 Truck configurations have grown versatile to accommodate increased freight (Longer combination vehicles are not legal in South Carolina)

Table 2 Truck Vehicle Miles Traveled (VMT) by Average Weight: 1987-2002

Average Weight (pounds)	1987 VMT (millions)	2002 VMT (millions)	Percentage Change	Annual Change
Total	89,972	145,624	62%	4.1%
Light-heavy	10,768	26,256	144%	9.6%
10,001 to 14,000	5,440	15,186	179%	11.9%
14,001 to 16,000	2,738	5,908	116%	7.7%
16,001 to 19,500	2,590	5,161	99%	6.6%
Medium-heavy	7,581	11,766	55%	3.7%
19,501 to 26,000	7,581	11,766	55%	3.7%
Heavy-heavy	71,623	107,602	50%	3.3%
26,001 to 33,000	5,411	5,845	8%	0.5%
33,001 to 40,000	4,113	3,770	-8%	-0.5%
40,001 to 50,000	7,625	6,698	-12%	-0.8%
50,001 to 60,000	7,157	8,950	25%	1.7%
60,001 to 80,000	45,439	77,489	71%	4.7%
80,001 to 100,000	1,254	2,950	135%	9.0%
100,001 to 130,000	440	1,571	257%	17.1%
130,001 or more	185	329	78%	5.2%

Source: Federal Highway Administration, 2010



Source: Federal Highway Administration, 2010

Figure 2 Highway Vehicle Miles Traveled: 1980-2007

International trade treaties have increased this heavy-vehicle traffic by allowing cross border operation of trucks from other countries. The Texas-Mexico trade corridor showed a rapid change in truck traffic and volume after 1993 when the North American Free Trade Agreement (NAFTA) opened US highways partially to Mexican trucks with different axle configurations (Hong et al., 2007). A Texas study estimated a $7.7 billion investment was needed to increase the load-carrying capacity of Texas highway bridges alone, while a significant cost would be simultaneously incurred in rerouting existing traffic during construction (Luskin and Walton, 2001).

2.2 How Trucks Deteriorate Transportation Infrastructure

According to the 2013 ASCE Infrastructure Report Card, 30% of bridges are older than design life, and to replace deficient bridges by 2028, an annual investment of

$20.5 billion is needed; however, the current annual investment is only $ 12.8 billion (ASCE, 2013). The increasing demand and decreasing support for maintenance has only exacerbated this difficulty; highways continue to degrade in service capacity. An Arizona study found that overweight trucks alone caused approximately $12 million to $53 million in annual uncompensated pavement and bridge damage in the state (Straus et al., 2006).

Experimental analysis has shown that the greatest damage to pavement is associated with axle weight, axle spacing, and thickness of pavement layers; in contrast, bridge damage has been attributed mostly to heavy GVW (Luskin and Walton, 2001). Unless engineers across the nation anticipate about 72 percent increase in truck loads by 2035 as indicated in Table 1 and act accordingly, growing volumes of heavy loads will accelerate transportation infrastructure deterioration. The following subsections depict how trucks impact pavement and bridge deterioration.

2.2.1 Pavement Deterioration

Roadways have a range of standards from high-standard interstates to low-standard local streets. A truck that will cause little or insignificant damage to interstates might cause significant damage to local streets. An Ontario study examined the relative impact of regular trucks on different types of roadways and concluded that pavement damage costs for a typical truck over 1 km (0.62mi) of roadway might vary from $0.004 for a high-standard freeway to $0.46 for a local street (Hajek et al., 1998).

Although light passenger vehicles are the dominant users of highways, they are not considered in pavement design due to the relatively low amount of damage imparted by these vehicles compared to trucks. Therefore, freight traffic is the primary traffic input considered in pavement design. The heavier truck loads develop excessive stress and strain on different pavement structural layers, and results in different form of distress and ultimate pavement fatigue failure. Pavement damage increases exponentially with increase of vehicle axle load magnitude (Luskin and Walton, 2001; WSDOT, 2001). Pavement damage due to one heavy freight truck could be equivalent to that of thousands of light weight passenger vehicles. Due to limited axle numbers in buses, loaded articulated bus could cause much more damage compared to heavy trucks (Pavement Interactive, 2013).

Though only a small percentage of trucks operate beyond legal weight limits, they account for significant amount of total pavement damage (Luskin and Walton, 2001; Liu, 2007). To manage permitted and illegal overweight trucks, an Arizona study estimated a savings of $4.50 in pavement damage for every $1 invested in mobile enforcement (Luskin and Walton, 2001). A study in Egypt estimated that increasing axle weight limits from 10 tons to 13 tons will reduce pavement service life by half, and overweight loads beyond maximum pavement load bearing capacity should not be allowed in any circumstance due to sudden structural failure (Salem et al., 2008).

The emergence of modern truck configurations, as indicated in Figure 1, has necessitated evolution in pavement design to handle the effect of load and configuration (FHWA, 2010). A Michigan study found that single and tandem axles of trucks had a more significant impact on cracking than trucks with multiple axles (tridem and higher). Conversely, the trucks with multiple axles elicited more detrimental effect on pavement rutting than single and tandem-axle trucks. No correlations appeared between axle configurations and pavement roughness (Salama et al., 2006). Another study found that larger axle combinations reduced pavement fatigue damage while increasing rutting (Chatti et al., 2004; FHWA, 2000). A study of overloaded tridem and trunnion axles reported differing impacts depending on the flexible or rigid pavement. While tridem axles cause the most damage to flexible pavements, trunnion axles cause more damage to rigid pavements with identical axle loads (Hajek et al., 1998).

While transportation professionals have mostly focused on truck loadings, other factors have also contributed to pavement deterioration (e.g., vehicle design). Research has found that a passive-axle suspension system and optimized suspension stiffness and damping resulted in a 5.8% reduction in pavement damage by minimizing the dynamic impact of axle loads (Cole et al., 1996). Dynamic forces from axle loading cause most pavement fatigue failures. When heavy loads exceed typical vehicle speeds, damage may accelerate by a power of four and service life can decrease by 40% or more (Luskin and Walton, 2001).

Advances in pavement design are accommodating modern refinements in awareness of the impact of weight, as well as other factors. New pavement modeling techniques have the potential to use diverse geographic and traffic-demand scenarios (Hajek et al., 1998; Sadeghi et al., 2007; Salem, 2008). It is quite evident from the literature that trucks cause disproportionately higher damage to pavement than passenger cars because of their higher weights and axle configurations.

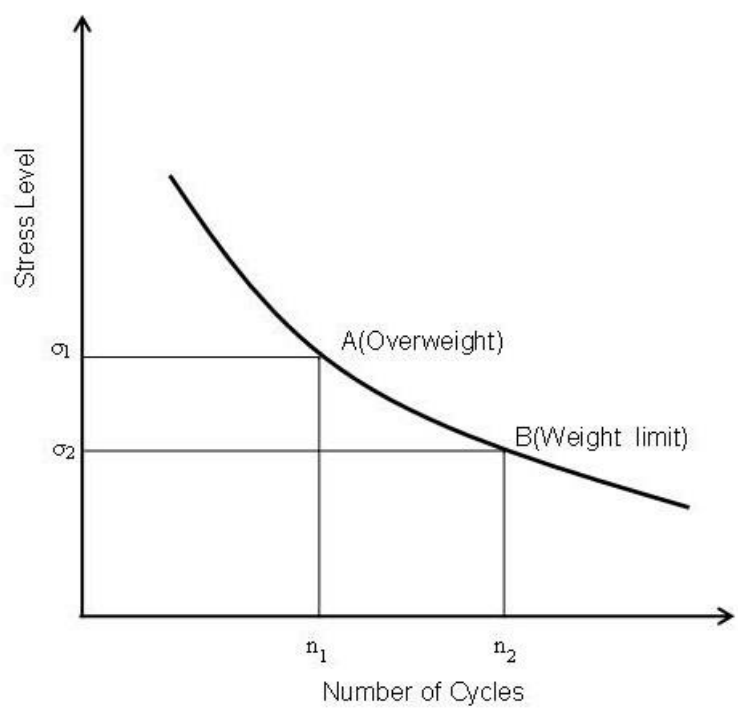
2.2.2 Bridge Deterioration

Though bridges comprise a small percentage of total highway mileage, their costs, construction time, and traffic disruption upon failure or temporary closing significantly impact highway system performance. Moreover, the catastrophic nature of bridge failures in terms of user fatality, property loss, and traffic disruption necessitates maintaining the structural integrity and serviceability of bridges and merits substantial consideration.

In 2009, 12 percent and 13 percent of U.S. highway bridges were classified structurally deficient and functionally obsolete respectively (Office of Bridge Technology, 2010). The American Association of State Highway and Transportation Officials (AASHTO) estimated $140 billion of repairs needed to raise existing bridges to acceptable standards in 2008. Merely maintaining current bridge conditions would require an investment of $13 billion per year while total investment was $10.5 billion in 2004 (ASCE, 2009).

Though many factors affect bridge structures, overweight truck loading is a fundamental cause of such deterioration. Although load factors are specified in the design codes and utilized in the design of bridges for increased safety and reliability (AASHTO, 2007), overweight trucks can compromise bridge safety and accelerate deterioration. Overloading old bridges can cause substantial problems in that modern overweight trucks are much heavier than the initial bridge design load and older bridges might have been compromised by deicing agents corroding reinforcement (Jaffer et al., 2009). Existing bridges might also exhibit other deteriorations (e.g. thermal or fatigue cracking). The compounding effect of corrosion, fatigue cracking, and overloading can significantly exacerbate the deterioration.

Overweight trucks also reduce the service lives of bridges or cause fatigue failures (Chotickai et al., 2006a, Chotickai et al., 2006b). Repetitive low-level stress reversal causes structure fatigue failure. A typical fatigue failure curve represents stress versus the number of loading cycles (Figure 3). Under overweight loading, stress increases from σ_2 (point B) to σ_1 (point A) and the corresponding number of loading cycles to fatigue failure reduces from n_2 to n_1.



Graph adapted from Chotickai et al., 2006

Figure 3 Fatigue failure curves indicate the relationship between cycles and stress

In addition to fatigue cracking, cracks initiated by other factors might have existed prior to overloading fatigue cracks. Cracks are expected to occur in reinforced concrete structures must be considered in their design. In contrast, prestressed concrete bridges must maintain service-level compressive stress throughout the lifetime of the bridges. An inappropriate construction sequence (e.g. wrong stressing sequences) can cause cracks in prestressed bridges (Moon et al., 2005), the initiation of which plus overloading from heavy trucks will accelerate deterioration of prestressed bridges. In addition, cracking can render rebar vulnerable to water erosion, which will result in corrosion, and possibly accelerate bridge deterioration. Corrosion will reduce the effective cross-section area of the reinforcing bars and bond between the rebar and concrete, strength (Stewart and Rosowsky, 1998). This combination of corrosion and cracking with overloading from heavy trucks can significantly reduce the service life of bridges under such stressors.

A Minnesota study of steel bridges built before 1980 found 33 percent and 73 percent more repairs were necessary if GVW increased by 10 percent and 20 percent respectively. Newly built steel-girder bridges, however, may not exhibit any significant damage due to increased GVW of up to 20 percent because of upgraded design standards. For concrete bridges, shear failure is more dominant than fatigue failure and existing old concrete girder bridges may lack any shear failure risk for a GVW increase up to 20 percent (Altay et al., 2003).

Creating standards for bridges has been particularly difficult. State and local agencies use the Federal Bridges Formula (FBF) or modified FBF to determine the maximum allowable load on bridges. This FBF formula gives advantages to multi-axle trucks by allowing them to carry more weight and restricts small trucks (FHWA, 1990). While many bridge studies and models exist, researchers cannot generalize many findings because the specific bridge conditions, traffic patterns, truck fleets, and environmental conditions were not replicated elsewhere. However, all bridges studies revealed that heavy weight trucks reduce bridge service life significantly due to excessive stress, and require more frequency maintenance.

2.3 Federal and State Weight Limits

States began establishing regulations to preserve transportation infrastructure as early as 1913 (FHWA, 2000) and the federal government established the first national standards with the Federal-Aid Highway Act of 1956. The Federal-Aid Highway Act Amendments of 1974 refined the national weight standards based on research from the American Association of State Highway Transportation Officials (AASHTO), and only minor modifications have appeared since (FHWA, 2000). Table 3 presents current federal weight limits for interstates.

Table 3 Federal Weight Standards for Interstate Highways

Weight	Axles
20,000 pounds per axle	Single axles
34,000 pounds per axle pair	Tandem axles
80,000 pounds or Federal Bridge Formula (FBF)	Gross vehicle weight

Source: Federal Highway Administration, 2000

While these federal regulations appear standard, several anomalies are still inherent in standard practice. Three states gross vehicle weight limits on interstates are higher than federal 80,000-pound limit (Table 4). On non-interstate highways, thirteen states have allowed gross vehicle weights higher than 80,000 pounds. A combination of seventeen states has exceeded federal single-axle weight limits on interstate and non-interstate highways. Twelve states have allowed interstate loads to surpass federal tandem-axle limits, and twenty states have allowed excessive weights on non-interstate highways.

Table 4 Interstate Gross Vehicle Weight Standards Exceeding Federal Limits

State	Standard
Oregon	105,500 pounds
Washington	105,500 pounds
Wyoming	117,000 pounds

2.4 Exceptions to Weight Limits

For situations where shippers cannot fit their loads to federal and state regulations, states have created permitting structures for oversized and/or overweight loads through a combination of parameters. These overweight loads could be classified in two different types: divisible and non-divisible. Non-divisible means loads that cannot be broken down into smaller pieces and weigh more than the legal weight limit, whereas divisible loads mean general overweight trucks that can be reduced in weight to maintain the legal weight limit. Most of the states do not issue overweight permits for divisible loads. Focusing on weight issues rather than size because weight deteriorates infrastructure, this section identifies common parameters used.

2.4.1 Distribution of Permits

States have established permitted exceptions for either single use or blanket coverage (multiple uses, monthly use, seasonal use, or annual use). In most states, truckers using single-use permits must perform the trip within a specified period of time, usually 3 to 5 days. Data collected from the web sites of state departments of transportation in 2011, and the Truck Sizes and Weights Manual (J.J. Killer & Associates, 2011) revealed 21 states had single-trip permits with fees ranging from $5 to $135 irrespective of either weight or total distance traveled. States issue annual permits in a goal to reduce related administrative permit processing costs as well as to ease permit applications for overweight trucking companies. Overall there is a growing trend of more annual permits of non-divisible overweight loads (a 28% increase between 2005 and 2009) than single permit increase of 21% (Table 5). A similar case is true for divisible overweight permits. Annual permits with a flat fee can benefit trucking companies by reducing time spent applying for permits for every trip and by reducing the overall fee paid. Flat annual permits allow unlimited trips during the year.

Table 5 Distribution of Permit Types

Permit Type	Year 2005	Year 2009
Non-divisible single trip permits (thousands)	2,712	3,286
Non-divisible annual permits (thousands)	233	299
Divisible single trip permits (thousands)	288	370
Divisible annual permits (thousands)	393	574
Total Permits (thousands)	**3,626**	**4,529**

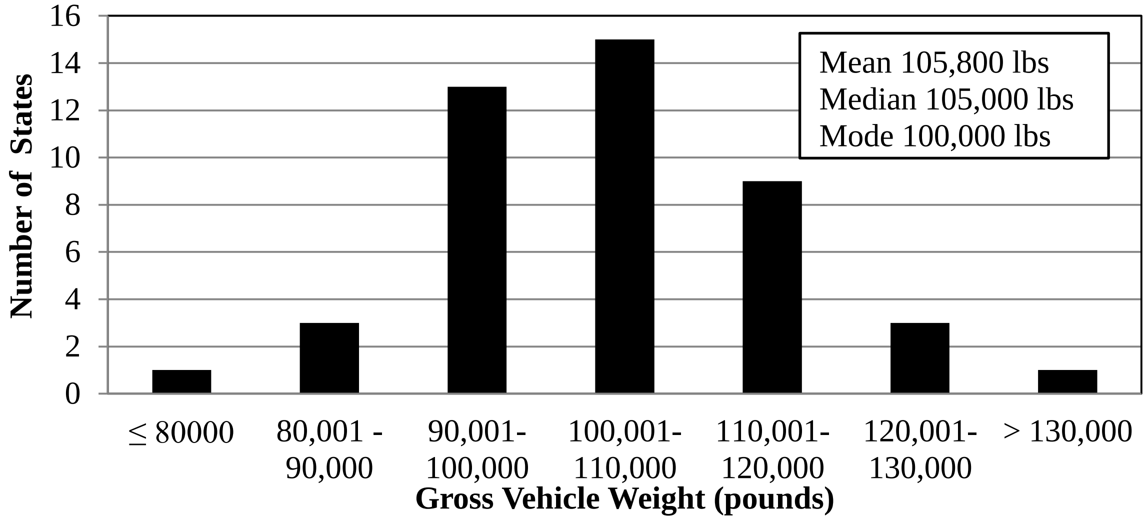
Source: Federal Highway Administration, 2010

To account for infrastructure deterioration with an annual permit, states must estimate how many trips per year a permit will generate, the average distance each trip will cover, and the amount of excess weight the truck will carry. Although some states consider distance and amount of overweight in setting fees for annual permits, most states charge fixed rates for annual permits irrespective of distance and excess weight. A 1995 study indicated annual permitting generated less revenue than single-use permitting (Moffett and Whitford, 1995) as an annual permit is not associated with the total number of trips.

2.4.2 Allowable Gross Vehicle Weight

Gross vehicle weight directly relates to the impact of truckloads on bridge deterioration. Whereas the federal government has limited GVW up to 80,000 pounds, states have been willing to allow much heavier loads with permits, as Figure 4 indicates. The most commonly permitted weights in the US for five-axle semi-trailer range from

100,001 pounds to 110,000 pounds, with a mean of 105,800 pounds and the maximum reach 132,000 pounds. Five states have not specified a maximum GVW.

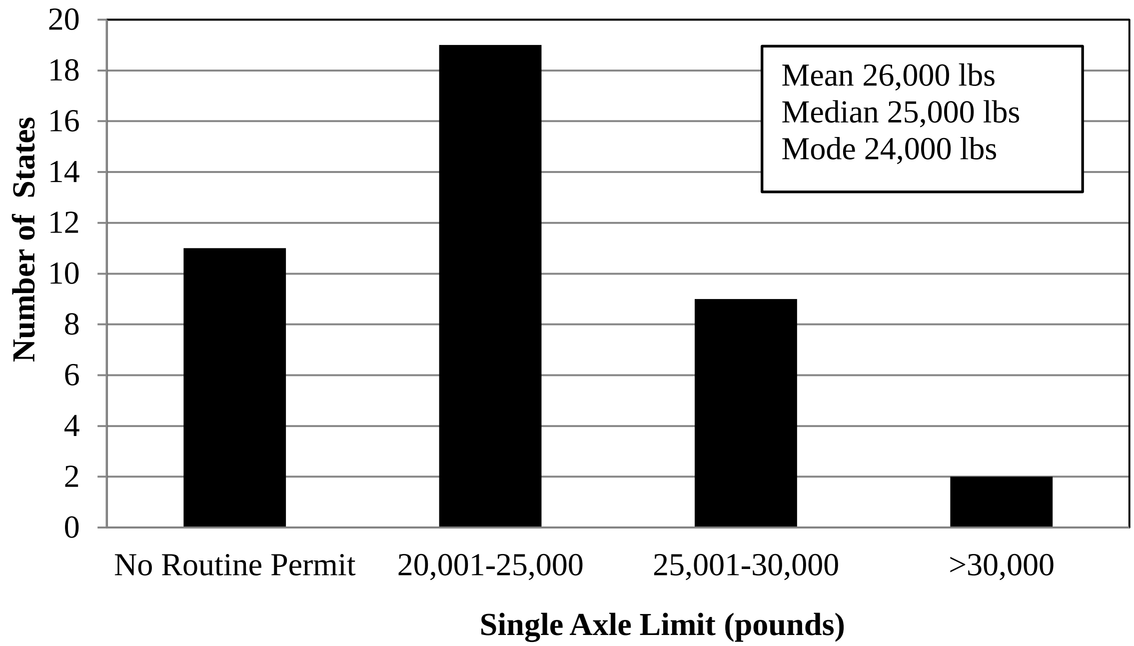


Data sources: J.J Keller & Associates, Inc, 2011 and state departments of transportation

Figure 4 Routinely Permitted Allowable Limits for 5-Axle Semi-Trailers

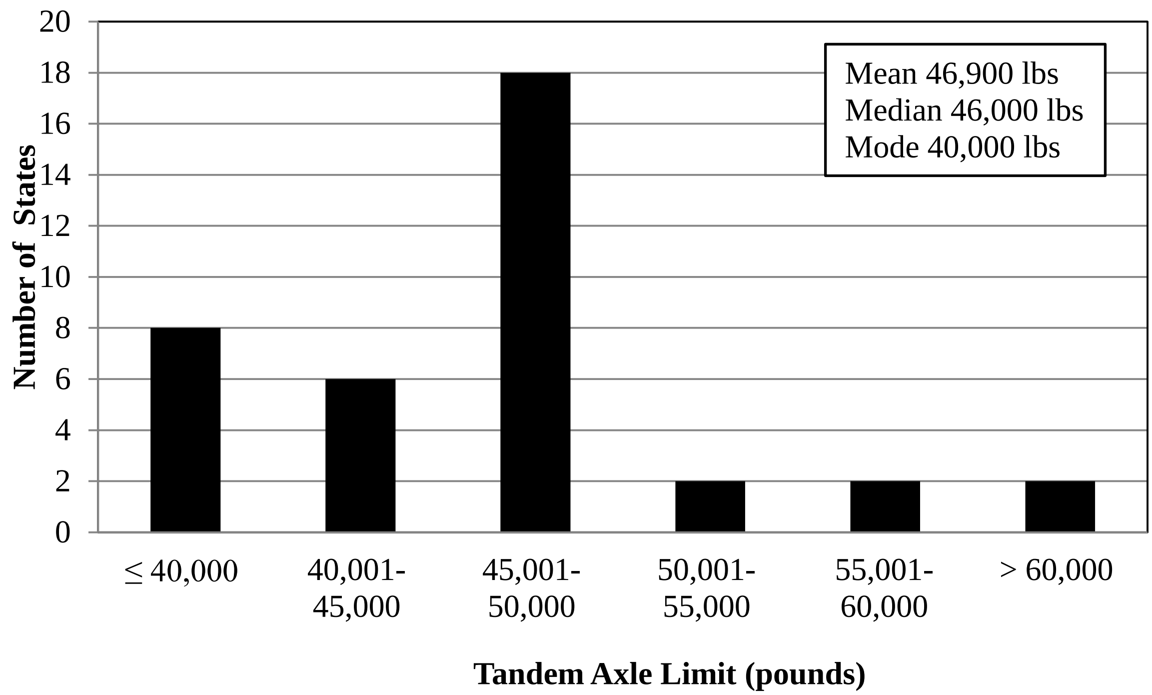
2.4.3 Allowable Axle Weights

In addition to maximum allowable GVW, any load can be classified as overweight if any axle load exceeds the axle weight limit. In certain states, the number of axles (or implicitly, the weight per axle) is considered in maximum loading thresholds. The maximum permitted load allowed for a single axle ranges from 20,000 pounds to 45,000 pounds (Figure 5). Nine states have not specified a maximum single-axle limit. Figure 6 shows that limits on tandem axles range from 34,000 pounds to 65,000 pounds with 7 states setting the most common limit at 40,000 pounds. Twelve states have no specified maximum for tandem axles.



Data sources: J.J Keller & Associates, Inc, 2011 and state departments of transportation

Figure 5 Routine Permit Allowable Limit (Single Axle)

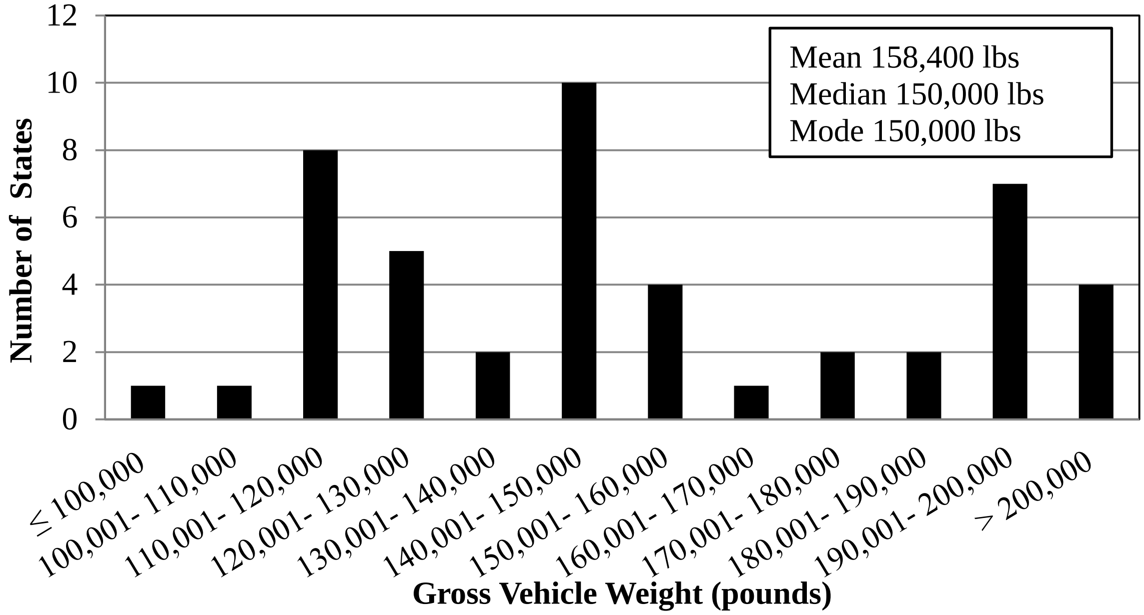


Data sources: J.J Keller & Associates, Inc, 2011, and state departments of transportation

Figure 6 Routinely Permitted Tandem Axle Weights

2.4.4 Superload Classification

For loads in excess of the upper thresholds of regular overweight permits known as “super-loads,” states have often required a route study to avoid excessive infrastructure damage or failure and to verify infrastructure capacity and safe operation. Permit structures have included super-loads only in terms of gross vehicle weight (no explicit consideration of axles) especially to protect the load carrying capacity of bridges along the specific super-load route. While some states have implicitly or explicitly prohibited highway operations for trucks that exceeded the maximum overweight limit allowed with typical overweight permits, others have simply allowed super-load provided a permit has been issued. For example, New Mexico has allowed loads as high as 200,000 pounds or more, but has imposed additional fees for such weight and relied on engineering studies to verify the load carrying capacity of the route where the truck with super-load will travel. Figure 7 indicates the distribution of super-loads states have permitted. Three states have not specified the load beyond which a special permit is required, and they deal with super-loads on a case by case basis.



Data sources: J.J Keller & Associates, Inc, 2011, and state departments of transportation

Figure 7 Routinely Permitted Weights for Super-Loads among States

2.5 User Fees for Overweight Trucks

All of the parameters identified in section 2.4 allow state DOTs to track the extent of overweight shipping on roadways to greater or lesser degrees of refinement. This tracking is useful for estimating acceleration of deterioration, which facilitates maintenance scheduling and inventory tracking. At a minimum, fees for overweight permits cover the cost of this administrative tracking that follows from shippers placing excessive loads on public infrastructure.

In addition to the administrative costs of the permitting process, some state DOTs would like permit fees to contribute to funding maintenance and rehabilitation of infrastructure proportionate to the damage an overweight load inflicts. Efficient and equitable user fees can lead to highway system provisions meeting a more demanding standard that reduces overall lifecycle costs (Small et al., 1989). The following subsections explore the theory and application of such user fees.

2.5.1 User-Fee Concepts

User fees have appeared since early civilizations for basic municipal services like water and sewage removal. Political, philosophical, and economic rationales have been used to justify user fees for public services (Bowlby et al., 2001).

Political rationales for user fees are characterized by user acceptance of the fees and the accountability of collected revenue. Conflicting objectives influence any financial decision made by elected bodies; they maintain special considerations to assure user fees represent actual use and ensure accountability by attributing the fee to a proposed use. Political action on transportation user fees has shifted in the United States, devolving from federal and state initiatives to local initiatives such as local taxes to build and maintain transportation infrastructure (Wachs, 2003).

Philosophical rationales of user fees justify that only people who benefit from a service should pay for that service; non-users should not have to subsidize what they do not use. In the context of transportation funding, localities increasing general sales taxes (e.g. a one-cent sales tax dedicated to funding public transit) do not qualify as user fees because non-transportation goods are also taxed. The general sales tax does not charge transportation users directly for benefitting from the system; hence the sales tax is less equitable and efficient than the fuel tax (Crabbe et al., 2005). Overweight permit fees do qualify as user fees because only users of the permits pay the tax; however, shippers might share the benefit indirectly. If that user fee improves infrastructure and passenger cars use the infrastructure in the future, those drivers should philosophically pay a fee.

Economic rationales seek economic efficiency. When truckers are willing to pay the same amount of money that the transportation department needs to receive to cover costs, the market achieves economic efficiency by reaching the equilibrium state. Economic evidence says the United States has not reached economic equilibrium in the market for freight infrastructure. The Engineering News-Record's cost index identified an 817-percent increase in major construction materials between 1957 and 2002 (McGraw Hill Construction, 2003) while the 50-state average fuel tax in inflation adjusted dollars was 11 cents per gallon less in 2003 than in 1957 (Wachs, 2003). This acute revenue shortage has contributed to the current crisis of infrastructure deterioration while demand for new capacity is increasing at a rapid pace.

2.5.2 Setting User Fees

Evidence has shown the axle-based fee structures common to toll roads and overweight permitting fails to collect money proportionate to damage inflicted by loads on roads. A 2008 study of fee collection among different truck classes used weigh-in-motion (WIM) data from two stations along Texas highway SH 130. Single-unit trucks caused more damage compared to semitrailers, but paid less in fees (Conway et al., 2008).

Assigning the correct cost to a truckload's trip requires modeling different traffic loads over infrastructure in the condition of a specific state. A Louisiana study investigated the extent of bridge damage along non-interstate corridors for four different combinations of gross vehicle weight and axle weight. With models of all 87 bridges on the corridors, the study concluded that trucks with GVW of 120,000 pounds caused $11.75 fatigue cost per trip per bridge where gross weights of 100,000 pounds caused only $0.90 fatigue cost per trip per bridge (Wang et al., 2005). Notably, this study provided cost estimations per trip per bridge. A single origin-destination trip in the state might involve a large number of bridges, incurring many times the cost per bridge.

How should fees increase as weight increases? A pavement deterioration model for a flexible pavement section in Iran considered pavement material properties, including asphalt layer thickness, pavement temperature, subgrade condition, and traffic speed. Upon determining relative damage due to several truck weights, the pavement damage increased exponentially, with significant amounts of damage experienced when weights exceeded the allowable weight limit (Sadeghi et al., 2007).

2.5.3 User Fees in Practice

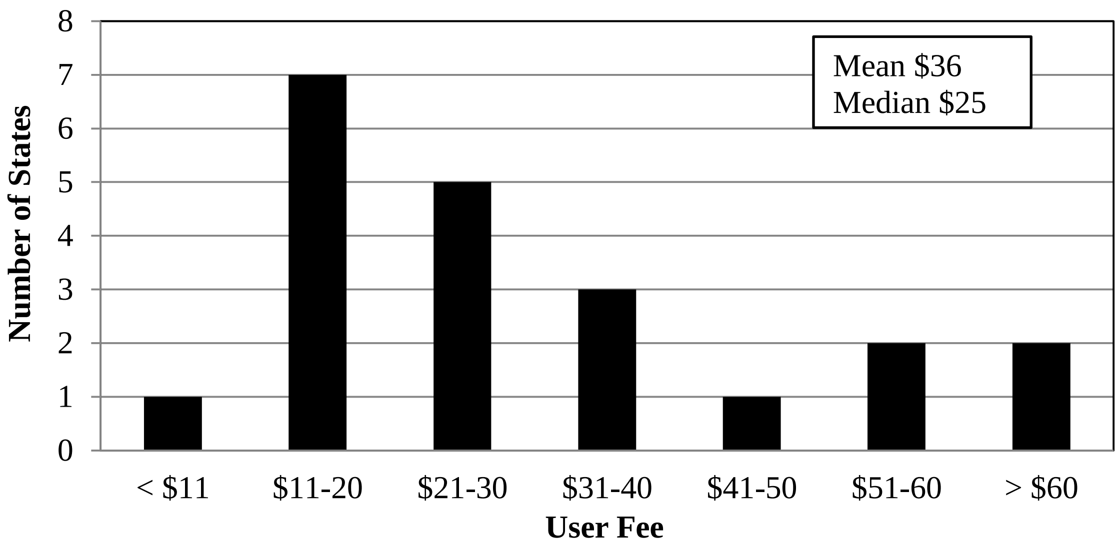
Overweight single-trip truck fees in fifty states have fallen into five categories, as indicated in Table 6. While single trip permit can be categorized into five different types, annual/blanket permits are mostly flat with limited consideration of distance or excess weight. Two states have not engaged in issuing single trip permits.

Table 6 Prevalence of Single-Trip Fee Categories

Type of Fee	States Administering in 2011
Flat	21
Axle based	5
Weight based	10
Distance based	2
Weight and distance based	11

2.5.3.1 Flat Fees

The flat user fee is simplest to administer for both state permit offices and trucking companies. In 2011, 21 states issued flat-fee single-use permits with charges ranging from $5 to $135 with a median of $25 per single trip (Figure 8). Flat fees commonly have addressed the administrative costs of issuing permits with contribution to highway maintenance. To date, South Carolina has issued flat-fee permits for overweight trips.

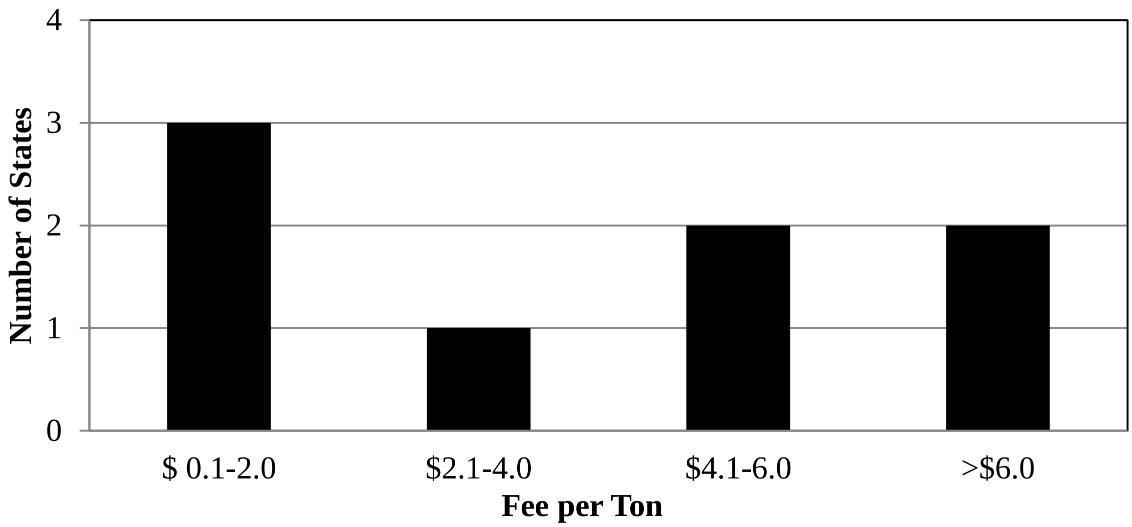


Data sources: J.J Keller & Associates, Inc, 2011, and state departments of transportation

Figure 8 States Issuing Single Trip Permits with a Flat User Fee

2.5.3.2 Weight Based Fees

Weight based fees charge for tons of load exceeding the legal limit, as indicated in Figure 9. States with low weight based fees inherently encourage heavy-weight industries while higher fees discourage them. States administering single-trip weight-based permits in 2011 charged from $0.1 to $20 for per ton of excess load.

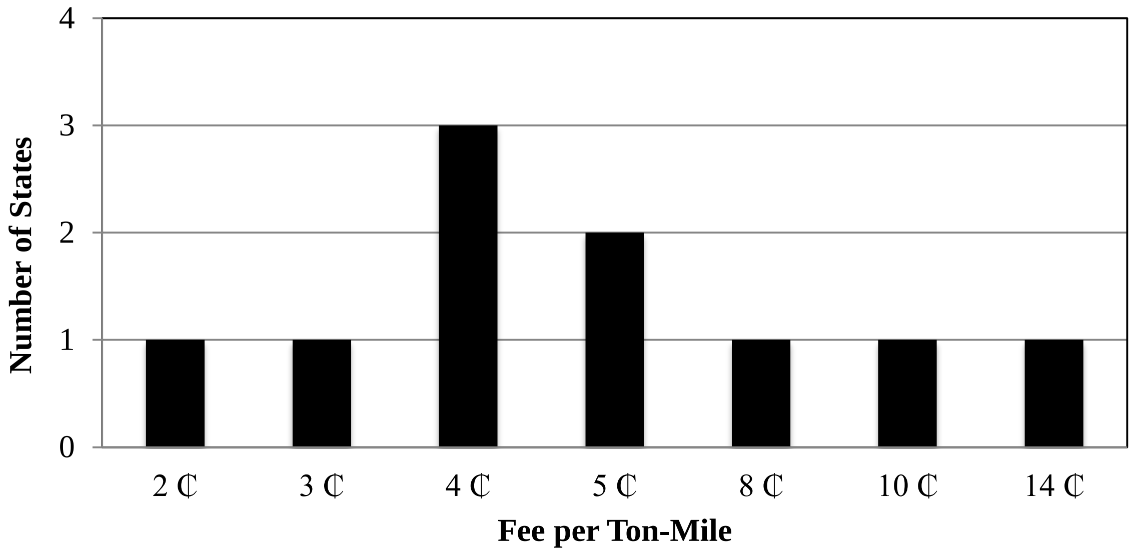


Data sources: J.J Keller & Associates, Inc, 2011 and state departments of transportation

Figure 9 States Issuing Single Trip Permits with a Weight Based User Fee

2.5.3.3 Weight and Distance Based Fees

Comprehensive fee structures used at the state level at the time of this research considered both the excess weight imposed on infrastructure and the length of infrastructure exposed to that weight. In 2011, 11 states offered single-use overweight permits based on weight and distance. Figure 10 shows their fee structures ranging from 2 cents to 14 cents per ton-mile.



Data sources: J.J Keller & Associates, Inc, 2011, and state departments of transportation

Figure 10 Single Permit Fees per Ton-Mile

2.5.3.4 Distance Based Fees

While weight permits account for the stress placed on a piece of infrastructure, they do not account for the extent of exposure. Two trucks might have equal weight and pay equal amounts for permits while one traverses a local trip and the other crosses the entire state. Charging for distance offers consideration of how much length of roadway an overweight vehicle impacts. Two states issue distance-based single-use permits without considering the amount of excess weight shipped. Virginia set its distance rate at 10¢ per mile while Indiana set rate at 34¢ per mile up to 120,000 lbs. Just as many states have done with weight-based permitting, Virginia has not attempted to create a distance-based annual permit.

2.5.3.4 Axle Based Fees

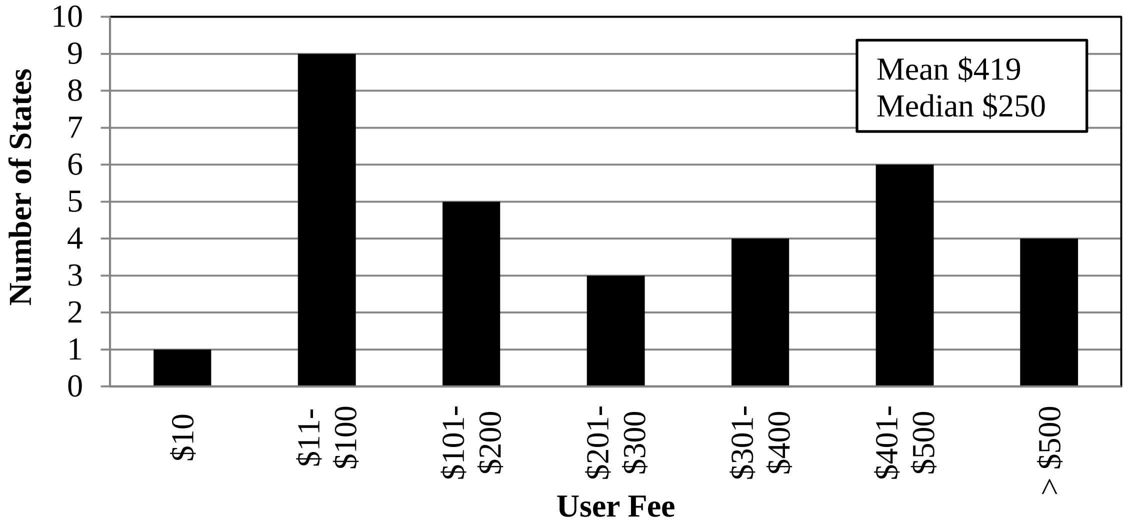
Axle-based fees have commonly emerged for individual facilities, such as turnpikes and toll bridges. Evidence has shown the axle-based fee structures common to toll roads and overweight permitting fails to collect money proportionate to damage inflicted by loads on roads. A 2008 study among different truck classes used weigh-in-motion (WIM) data from two stations along Texas highway SH 130. Single-unit trucks caused more damage compared to semitrailers while paying less in fees (Conway et al., 2008). A truck with many axles can spread its weight across them, thus impacting pavement with less weight per axle, yet a higher number of axles is penalized in traditional axle-based fees.

Consideration of axles appears to be gaining favor. Five states have been setting overweight fees with number of axles and vehicle configurations in fee calculation for single trips. South Carolina's stakeholders supported consideration of vehicle configuration in principle with recognition of demand for increasing weight per axle.

For a system based on axles and vehicle configuration, South Carolina stakeholders voiced regional consistency as their biggest concern. Some shipping companies have voiced resistance to reconfiguring their fleets to accommodate one state. One stakeholder suggested private companies will be more willing to invest in new equipment if South Carolina, North Carolina, and Georgia all recognize the same standards.

2.5.3.5 Annual Fees

Regardless of the type of single-use permit employed, most states have offered permits for unlimited overweight trips in a year. Most annual permits are in the form of flat-fee permit with limited consideration for weight and distance. Flat-fee annual permit rates of states varied from $10 to $2,500 with median at $250 (Figure 11). The logic of annual fees is unclear. Presumably, states would offer a rational relationship between single-use and annual permits; however, the data have failed to reveal a strong connection. In 2011, one state charged $5 for a single use and $10 for an annual permit even though truckers with annual permits likely took more than two trips per year. An Ohio DOT study found that with annual permits 24.8 trips were made on average (ODOT, 2009). A survey among trucking companies or a log book survey of overweight trucks with annual permits could reveal this imbalance between annual and single-trip permit rates.



Data sources: J.J Keller & Associates, Inc, 2011, and state departments of transportation

Figure 11 Flat User Fee- Annual Permit

2.6 Multiobjective Analysis in Transportation Infrastructure Policy Making

Multiobjective analysis has been applied in transportation decision making endeavors such as resource allocation, asset management, investment decision making, and network optimization to address the conflicting multiobjective nature of each decision problem (Atkinson and Shultz, 2009; Chowdhury et al., 2002; Chowdhury et al., 2000; Fwa et al., 2000; Bai et al., 2012). Fwa et al. demonstrated the superiority of multiobjective optimization over traditional single objective optimization in pavement maintenance programming (Fwa et al., 2000), the efficiency of which has been achieved by simultaneously considering minimization of cost, maximization of network condition and maximization of maintenance work. Similarly, Bai et al. applied multiobjective optimization in highway asset management, in which they conducted a tradeoff analysis to optimize multiple network level performance measures (Bai et al., 2012). To overcome the difficulty of including a number of criteria that cannot be translated into monetary unit in traffic safety improvement projects, multiobjective optimization was applied to select a level of investment in several conflicting highway safety improvement projects to maximize overall safety benefits as well as to minimize the total investment level (Chowdhury et al., 2002). In another study by Chowdhury and Tan, a multiobjective optimization technique was applied to a transportation investment policy tradeoff analysis. The selection of the best alternative from multiple options was guided by a multiple conflicting measure of effectiveness (MOEs) (Chowdhury and Tan; 2005). Additionally, multiobjective analysis has been utilized in tradeoff analysis in many transportation studies (Fwa et al., 2000; Bai et al., 2012; Chowdhury et al., 2002; Chowdhury et al., 2000).

In the context of freight transportation, most of the research entailing multiple objectives has been conducted in freight transportation supply chain management to develop optimal solutions to minimize freight truck fleet size, environmental impact, and inventory and transportation costs (Hwang, 2009; Sabria and Beamon, 2000). No effort has been made to investigate the impact of overweight truck policies that considers both the damage to aging transportation infrastructure service life while considering freight operators' objectives or interests in the context of multiple conflicting objectives. This research utilized a multiobjective analysis to develop tradeoffs associated to different overweight truck damage cost recovery fee types.

CHAPTER III: RESEARCH METHOD

As outlined in section 1.2, this research was divided in six distinct tasks to accomplish the research objectives. In the following sections, the research method adopted for each task is elaborated.

3.1 Literature Review

A comprehensive review was conducted to compile previous researches on pavement and bridge deterioration estimation due to heavy trucks, and current overweight freight truck fee structures and management policies among US states and presented in Chapter 2.

3.2 Pavement and Bridge Damage Estimation

Quantification of pavement and bridge damage due to different vehicle type is a critical issue for any highway transportation cost allocation studies. In the following subsections the details of damage quantification approach adopted for this research are discussed.

3.2.1 Pavement Damage Estimation Method

An analysis procedure based on a study by the Ohio DOT was adopted to estimate overweight truck pavement damage parameters (ODOT, 2009). As flexible pavements are the major paving material used in South Carolina, this research assumed the asphalt concrete built state highway system. The analysis was based on the different highway functional classes considered in the damage estimations to represent a variation in traffic demand by functional class. All pavements were assumed to possess the identical Hot

Mix Asphalt (HMA) Surface Course (1.9 inch), HMA Intermediate Course (2.0 inch), and Graded Aggregate Base Course thicknesses (6.0 inch) (Figure 12). The thickness of the HMA Base Course varied depending upon traffic demand in that this layer is the most likely to be altered to adjust the varying traffic demand (the average annual daily truck traffic).

The primary concern with any pavement design is the amount of truck traffic that the pavement must endure throughout its life. It was estimated that 8.3% of the trucks in each truck category were loaded to the respective maximum weight limit based on WIM data collected at the St. George WIM station (Chowdhury et al., 2013). The average annual daily traffic (AADTT) for each functional class included in this research was estimated based upon the South Carolina statewide freight model. AADTT estimates compiled for each functional classes and 85-percentile of all AADTT estimates in each functional class was used in pavement design and damage calculations.

The pavement design utilized the procedures set forth by the SCDOT Pavement Design Guidelines (2008), which uses an equivalent single axle load (ESAL) approach to determine the required structural number to accommodate a given number of design ESALs (AASHTO, 1993). As the ESAL factor does not change significantly between SN 5 and 7, a standard highway flexible pavement section with structural number (SN) 5 and terminal serviceability index (P_t) 2.5 were assumed to estimate the corresponding damage of each weight category of each truck type, which was used to estimate the pavement damage ESALs.

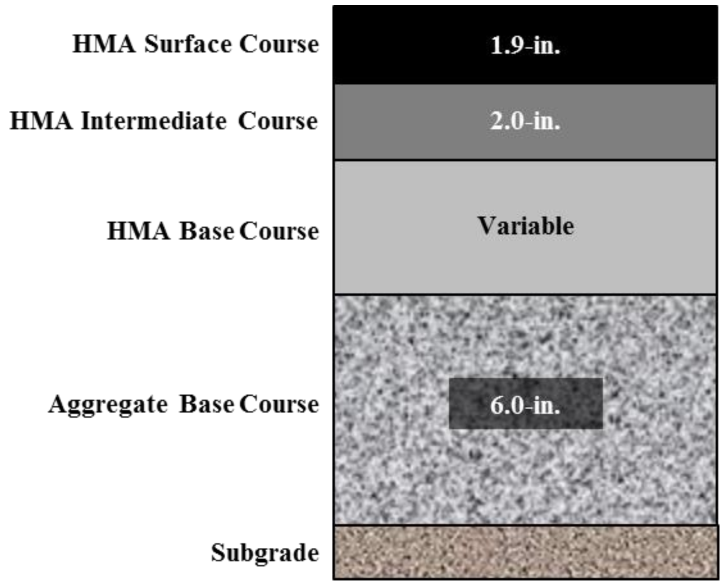


Figure 12 Schematic of Flexible Pavement Design Dimensions

To quantify the pavement damage costs due to overweight trucks, three design scenarios were considered. In design scenario 1, pavements were designed for minimum design standards when there was 0% truck in the traffic stream. These costs were distributed to all vehicles (e.g. passenger cars and trucks) irrespective of damage contribution of vehicle types. In design scenario 2, pavements were designed for truck traffic demand (AADTT) with no overweight trucks. The additional costs above minimum design scenario were distributed to all trucks as additional costs were accounted for pavement design improvement to support demand truck traffic. In design scenario 3, 8.3% trucks were considered overweight and the design cost excess of scenario 2 was distributed to overweight trucks only.

3.2.2 Bridge Damage Estimation Model

Figure 13 shows steps followed to estimate bridge damage by overweight trucks. Representative trucks models from SC Permit Database and Violation Database were developed to conduct bridge fatigue damage analysis. As it is not feasible to model all bridges, four archetypes bridges were selected based on statistical analysis of South Carolina bridge characteristics. National Bridge Inventory database was utilized to extract bridge characteristics information, such as total bridge length, traffic volume, and material type (NBI, 2012). Finite element (FE) models for archetype bridges were developed in LS-DYNA to perform fatigue analysis and analyzed at Argonne National Laboratory supercomputing facility.

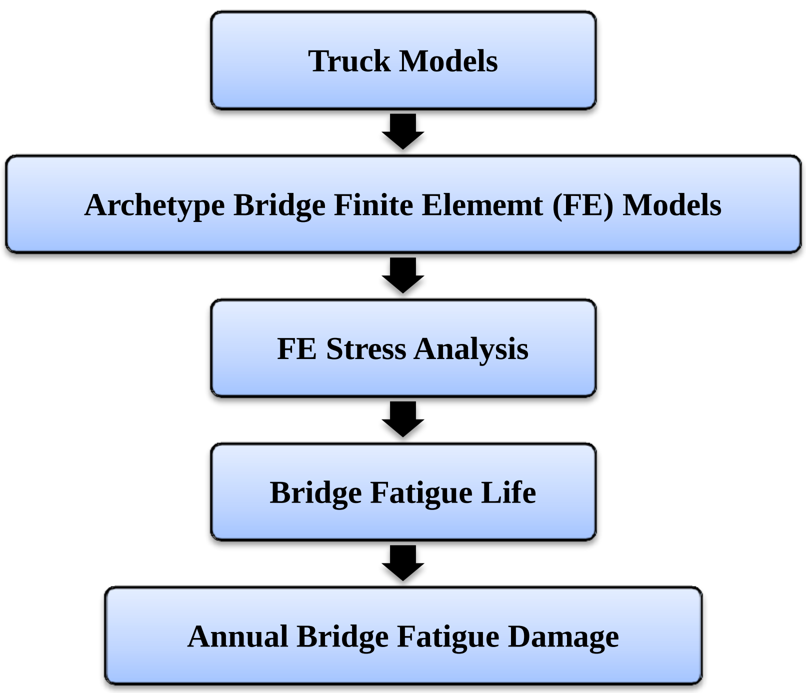


Figure 13 Bridge Damage Modeling Methodology

Next step was to determine monetary value of bridge damage due to overweight trucks. Bridge replacement cost models were first developed utilizing HAZUS-MH program database (HAZUS-MH, 2003). To estimate bridge damage cost due to overweight trucks, bridge fatigue damage models and bridge replacement cost models were combined and used as inputs for the bridge cost estimation methodology outlined in Figure 14.

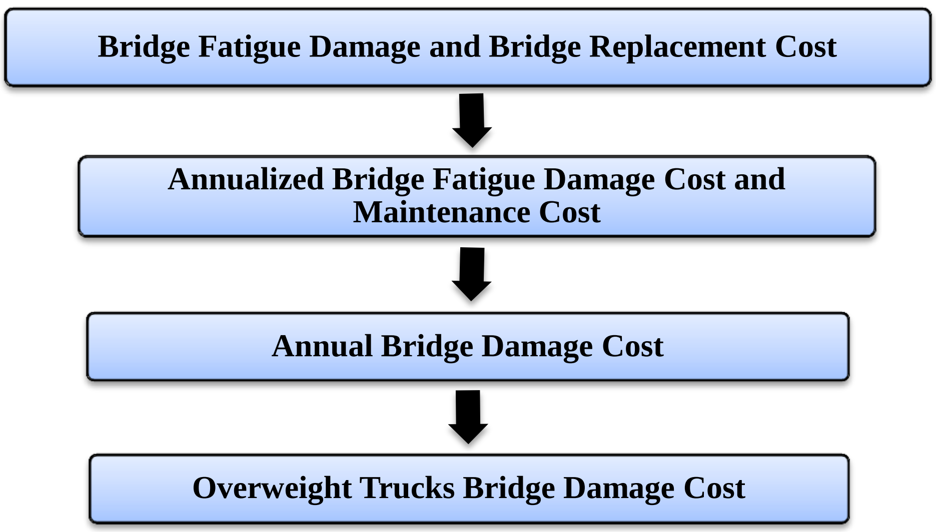


Figure 14 Bridge Cost Estimation Methodology

Finally, annual bridge fatigue damage cost and annual bridge maintenance cost were combined to estimate total annual bridge damage cost due to overweight trucks (Chen, 2013). Results of pavement and bridge damage estimation following the research method discussed in this section are presented in Chapter 4.

3.3 Evaluation of Fee Structures

Before implementation of new fee structure supported by pavement and bridge damage estimation, it is critical to investigate relative performance of different fee structures and select the best option which will maximize revenue without any negative or minimum impact on overweight business and economy. Based on the survey of existing fee structure implemented by DOTs, an analysis was conducted to examine the relative efficiency of different fee structures, which is presented in Chapter 5.

3.4 Policy Tradeoff and Implementation Challenges

Preserving and extending the longevity of the US public transportation infrastructure is one of the primary goals of state DOTs for supporting the increased volume of passengers and freight traffic in terms of volume and average payload. In this section, tradeoff analyses were performed to provide valuable information to decision makers (DMs) to select an appropriate type and level of fee structure for overweight trucks (section 3.4.1). Besides, an online survey with state DOTs in US and Canada, and an interview with trucking stakeholders in South Carolina were conducted to understand and investigate concern of public agencies involved in transportation decision making and trucking associations (section 3.4.2).

3.4.1 Policy Tradeoff Analysis

The primary goal of the overweight permit program maintained by DOTs is to record the extent of all overweight trips in the states. Overweight truck operators are required to secure a permit by paying a fee to DOTs stating the amount of excess weight above legal weight limits. This permit fee covers the administrative costs of the dedicated DOT permit program, and a damage fee to recover additional damage to pavements and bridges for weights above legal weight limits. There are several overweight permit fee types implemented by DOTs nationwide. Different fee types place a different cost burden on different truck types, favoring some types over others. Such as flat permit fee would favor heavy overweight trucks as they pay less for much higher damage than light overweight trucks.

The most challenging aspect of any optimization model is the development of functional relationships among constraints and multiple objectives. An overweight freight operation scenario with two objectives (bi-objective) is formulated and solved to examine the applicability of a multiobjective optimization approach in overweight permit fee and policy analysis. Details of the multiobjective optimization method are explained in Appendix A. Two objective functions are considered: (1) minimization of unpaid damage due to overweight freight trucks, and (2) minimization of overweight truck damage cost recovery fee to reduce the transportation cost in the context of overweight trucking operations on the South Carolina state highway system. Currently, South Carolina DOT issues permits to overweight trucks and charges a flat $30 for single trips. The damage quantification shows that the damage imparted by overweight trucks is much higher than the current fee (Chowdhury et al., 2013). A review of overweight permit fee types among the 50 states reveals four most frequently used fee types (Chowdhury et al., 2013). In the second objective of the bi-objective problem (minimization of overweight truck damage fee), the following four fee types were considered:

1) Flat damage cost recovery fee, where all overweight trucks pay the identical permit fee without any consideration to the amount of overweight load and the distance traveled in each trip,
2) Axle based damage cost recovery fee, where the overweight amount, the truck configuration, the axle loads and the trip distance are considered in determining the damage cost recovery fee,
3) Weight based damage cost recovery fee, where overweight trucks pay for the amount of excess weight above the legal weight limits, and
4) Weight and distance based damage cost recovery fee, where the amount of the overweight load as well as the trip distance are considered in the damage cost recovery fee calculation.

Generally, an increase of transportation cost (i.e., permit fee), tends to decrease the demand for overweight freight shipped. It is known that freight demand is comparatively less sensitive to increases in transportation cost (i.e., inelastic), and in the existing literature, though limited, there are wide variations in the elasticity estimates of freight demand, primarily due to differences in the estimation models (Graham and Glaister, 2004). It has been observed in various supply and demand studies on freight that the elasticity of the freight demand varies between -0.5 and -1.5 depending upon the type of freight goods (Graham and Glaister, 2004). In this research, it was assumed elasticity values of high (-1.5), medium (-1.0), and low (-0.5) to present the sensitivity of the overweight freight demand to transportation cost (i.e., permit fee). In response to demand sensitivity, the number of overweight permits demand decreases with an increase in permit fees.

In this research, the multiobjective model led to a bi-objective optimization problem (BOP) for four different damage cost recovery fee types to generate tradeoffs between different fee levels (Table 7 and Table 8). Table 7 explains the model parameters and decision variable, and Table 8 summarized the mathematical representation of two objective functions and constraints.

Table 7 Bi-objective model parameters and decision variable

Parameters	Explanation
f_o	Current single trip permit fee in SC ($30)
f_{ij}	New proposed permit fee for $i-th$ truck class and $j-th$ GVW category
F_{ij}	Estimated pavement and bridge damage cost due to one trip by $i-th$ truck class and $j-th$ GVW category
N_{ij}	Number of trips in $i-th$ truck class and $j-th$ GVW category without change in permit fee
N_{ij}'	Adjusted number of trips in $i-th$ truck class and $j-th$ GVW category due to change in permit fee
f_c	Fixed administrative cost of permitting program
r_{ij}	Perecentage of truck trips in $i-th$ truck class and $j-th$ GVW category
e	Overweight freight trip demand elasticity $(-0.5, -1.0, -1.5)$
E_{ij}	Change in permit demand for $i-th$ truck class and $j-th$ GVW category

Table 7 Bi-objective model parameters and decision variable (continued)

dc_{ij}	Per trip damage cost recovery fee for $i-th$ truck class and $j-th$ GVW category due to additional imparted damages by a truck loaded above the legal weight limit up to maximum weight limit with a typical overweight permit
dc	Flat per trip damage cost recovery fee for all overweight trucks
wdc_{ij}	Per ton per trip damage cost recovery fee for $i-th$ truck class and $j-th$ GVW category due to additional imparted damages by a truck loaded above the legal weight limit up to maximum weight limit with a typical overweight permit
$wddc_{ij}$	Per ton-mile damage cost recovery fee for $i-th$ truck class and $j-th$ GVW category due to additional imparted damages by a truck loaded above the legal weight limit up to maximum weight limit with a typical overweight permit
Decision Variable	**Explanation**
x	Damage recovery percentage (%)

Note: ij denotes truck class $i = 2, \ldots, n$ where n is the number of axles in each truck type and GVW category $j = 1, \ldots, 5$

Table 8 Objectives and Constraints

Conflicting Objectives	
Primary objective (Minimize unpaid damage)	$\sum_{i=1}^{i=n}\sum_{j=1}^{j=m}(F_{ij} - f_{ij})N_{ij}'$
Second objective (Minimize damage cost recovery fee)	$\sum_{i=1}^{i=n}\sum_{j=1}^{j=m} r_{ij}f_{ij}'$
Constraints (to be satisfied by Pareto optimal solutions)	**Explanation**
1) $N_{ij}' = N_{ij}E_{ij}$	Change in permit demand due to change in permit fee
2) $E_{ij} = \left(1 + e\frac{f_o - f_{ij}}{f_o}\right)$	Change in demand due to demand elasticity
3) Per trip damage cost recovery fee at 100% damage cost recovery scenario	
$F_{ij} = dc_{ij} + f_c$	In axle based fee type
$F_{ij} = dc + f_c$	In flat damage fee type
$F_{ij} = wdc_{ij} * w_{ij} + f_c$	In weight based fee type
$F_{ij} = wddc_{ij} * w_{ij} * t_{ij} + f_c$	In weight distance based fee type
4) Per trip damage cost recovery fee at x% damage cost recovery scenario	
$f_{ij} = f_{ij}'$	In axle based fee type
$f_{ij} = f_{ij}'$	In flat damage fee type
$f_{ij} = f_{ij}' * w_{ij} + f_c$	In weight based fee type
$f_{ij} = f_{ij}' * w_{ij} * t_{ij} + f_c$	In weight distance based fee type
5) Unit damage fee at x% damage cost recovery scenario	
$f_{ij}' = (dc_{ij} + f_c) * x$	In axle based fee type
$f_{ij}' = (dc + f_c) * x$	In flat damage fee type
$f_{ij}' = (wdc_{ij}) * x$	In weight based fee type
$f_{ij}' = (wddc_{ij}) * x$	In weight distance based fee type
6) $N_{ij}' \geq 0.1N_{ij}$	At least 10% of trips will exist irrespect of demand elasticity
7) $0 \leq x \leq 1$	Damage recovery percentage

3.4.2 Implementation Challenges

To explore the state-of-the-art practices across the nation and perspectives of all stakeholders related to overweight businesses in South Carolina two distinct tasks were conducted: 1) comparison of standard practices among states in US and Canadian provinces, and 2) interview with the freight stakeholders within South Carolina.

3.4.2.1 Review of Current Practices

This research captured the current state of the practice by bringing together public records and a survey of state and provincial departments of transportation in the United States and Canada. Public records provided general truck weight limits and information on overweight permit programs from the 50 states. Web data gathered in October and November 2011 validated and supplemented data and information on overweight truck management practices from the Vehicle Sizes and Weights Manual (J.J Keller & Associates Inc., 2011).

For the online invited survey, DOTs in the United States and Canada received invitations to participate to provide their perspectives about current overweight permit practices in the fall of 2011. The questioners and response summary tables can be found in Appendix B and Appendix C, respectively. Total 16 responses were received, amounting to 27 percent of the total population of 60. Attempts were made to raise the response rate by sending email reminders twice and extending the time allowed for responses. Still facing low response and a small sample size, this research only presents data from questions where respondent answers generally matched.

3.4.2.2 Stakeholders' Interview

The main objective of stakeholders' interview was to present findings of this research to stakeholders involved with overweight trucking, and to explore how permit policies should be formulated and revised to tackle infrastructure deterioration issues. The objectives of these interviews were to:

- Establish the discussion framework where all public and private sector stakeholders learn about the issues related to overweight truck operations and transportation infrastructure maintenance needs in South Carolina,
- provide opportunities to each stakeholder to explain individual's issues and needs,
- get familiar with diverse overweight business practices in South Carolina, and
- explore the acceptability of potential new policies to all stakeholders to improve current overweight permit policies in South Carolina.

Interview methodology followed in this research was built upon a similar study conducted by Virginia Transportation Research Center (VTRC, 2008). Interview questions were sent about one month before scheduled interview date with findings from this research, which allowed respondents to prepare their agency perspectives by discussing the questions and responses with agency members. Supporting information was provided to give an overview of current South Carolina overweight permit practices and funding needs to maintain status quo of SCDOT maintained highways.

3.4.2.2.1 Participating Organizations

A set of interview participants was selected considering organizations and agencies expected to have a stake in trucking and the transportation infrastructure in South Carolina. The list focused on state organizations, but some national organizations were contacted because they might have perspective of national viewpoints and stances. Following organizations were participated in the interview:

- Greenville Chamber of Commerce Transportation and Infrastructure Committee representing business and shippers
- South Carolina Trucking Association representing shipping companies
- South Carolina State Transport Police representing law enforcement
- South Carolina Department of Transportation representing interests of infrastructure maintenance
- South Carolina Farm Bureau representing the agricultural industry
- Carolinas Ready-Mixed Concrete Association representing heavy construction materials

Several other organizations were contacted to participate in this interview. The Federal Motor Carrier Safety Administration (FMCSA) South Carolina office referred to Federal Highway Administration (FHWA) as research objective mostly aligns with FHWA mission. However, FHWA did not participate, because FHWA was also a sponsor of this research. The American Trucking Association recommended contacting

South Carolina Trucking Association which has local experience with South Carolina overweight permit issues. The South Carolina Department of Commerce declined to participate. The office of South Carolina State Senate Transportation Committee Chairman Larry Grooms indicated willingness to participate but was unavailable to set an interview date within the research timeline.

3.4.2.2.2 Interview Process

All participating organizations were contacted first in mid-February 2013 describing primary objectives of the interview and this research. Then an email with details supporting document was sent. Supporting document explained the interview objectives, preliminary findings from this research including permit practices across the nation, interview questions and list of all participating organizations. Each participant discussed the questions with colleagues to summarize their agency perspectives about interview questions before the final phone interview. Phone interviews were conducted in early April 2013. As the primary objective of this interview was to compile stakeholders' perspective accurately, it was assured that no one will be cited explicitly without prior confirmation.

3.4.2.2.3 Interview Content

The interviews covered the following nine questions.

1) Regarding the information provided, what comments or questions do you have?

2) What are the primary issues to consider when balancing the needs of freight movement and infrastructure maintenance?

3) Equity can be viewed in many ways. What are the primary considerations for ensuring fairness in setting permitting policies and fees?

4) How should overweight permitting fees be set relative to the calculated amount of damage overweight vehicles inflict? If you recommend a difference from the exact amount of damage, how do you justify it? How should that difference be calculated?

5) What are the strengths, weaknesses, opportunities, and threats of implementing the following potential fee structures in South Carolina?

- Flat fees
- Weight-based fees
- Fees based on weight and distance
- Fees considering axle configurations

6) Annual permitting practices in the United States have ranged from charging less than the cost of 2 single permits to the equivalent cost of 52 single permits. South Carolina currently sets an annual permit fee equivalent to 3 ⅓ single trips. Should South Carolina offer flat fees for annual permits, and if so, what frequency of usage should be assumed in setting the value for the permit? Why that frequency?

7) Setting permitting structures must consider permit value. If South Carolina increases fees for overweight vehicles, what transportation-system improvements should emerge to serve operators of heavy and overweight vehicles and related stakeholders?

8) Beyond the numbers, what considerations need to be evaluated for weight and infrastructure policies? Examples might include but not be limited to administrative processes, logistics, legal frameworks, state or global competitiveness, and so forth.

9) What other issues would you like to raise? what remaining comments do you have?

Interview did not include any questions on research results rather focused on stakeholders' perspectives, and issues that are critical and need to be addressed in future public discussion for new fee policies. Findings of stakeholders' interviews were summarized in Chapter 6, Section 6.3.

3.5 Development of Conclusions and Recommendations

Based on the findings of this research, research findings were summarized in Conclusions (Section 7.1) and recommendations were proposed to improve South Carolina's current overweight permit practices (Section 7.2) and presented in Chapter 7.

CHAPTER IV: PAVEMENT AND BRIDGE DAMAGE ESTIMATION

In this chapter, pavement and bridge damage estimation results were presented and damage cost was quantified to facilitate damage fee calculation.

4.1 Estimation of Pavement Deterioration

To estimate pavement and bridge damage, representative truck models were developed utilizing SCDOT overweight permit database for year 2011 and South Carolina legal weight limits (SC Code of Laws, 2012; SCDOT, 2012a, b). The truck configurations included in Figure 15 were used in this research; however, the analysis was based on a distribution of trucks and not just a single truck. This change was made for this analysis to more accurately represent the damage (or design changes) that would result from having only a portion of the truck traffic be considered overweight, which was a more realistic scenario. In this study, it was assumed that 8.3% of the trucks in each truck category were loaded to the respective maximum limit. This assumption is based on WIM data collected at the St. George WIM station in South Carolina on I-95.

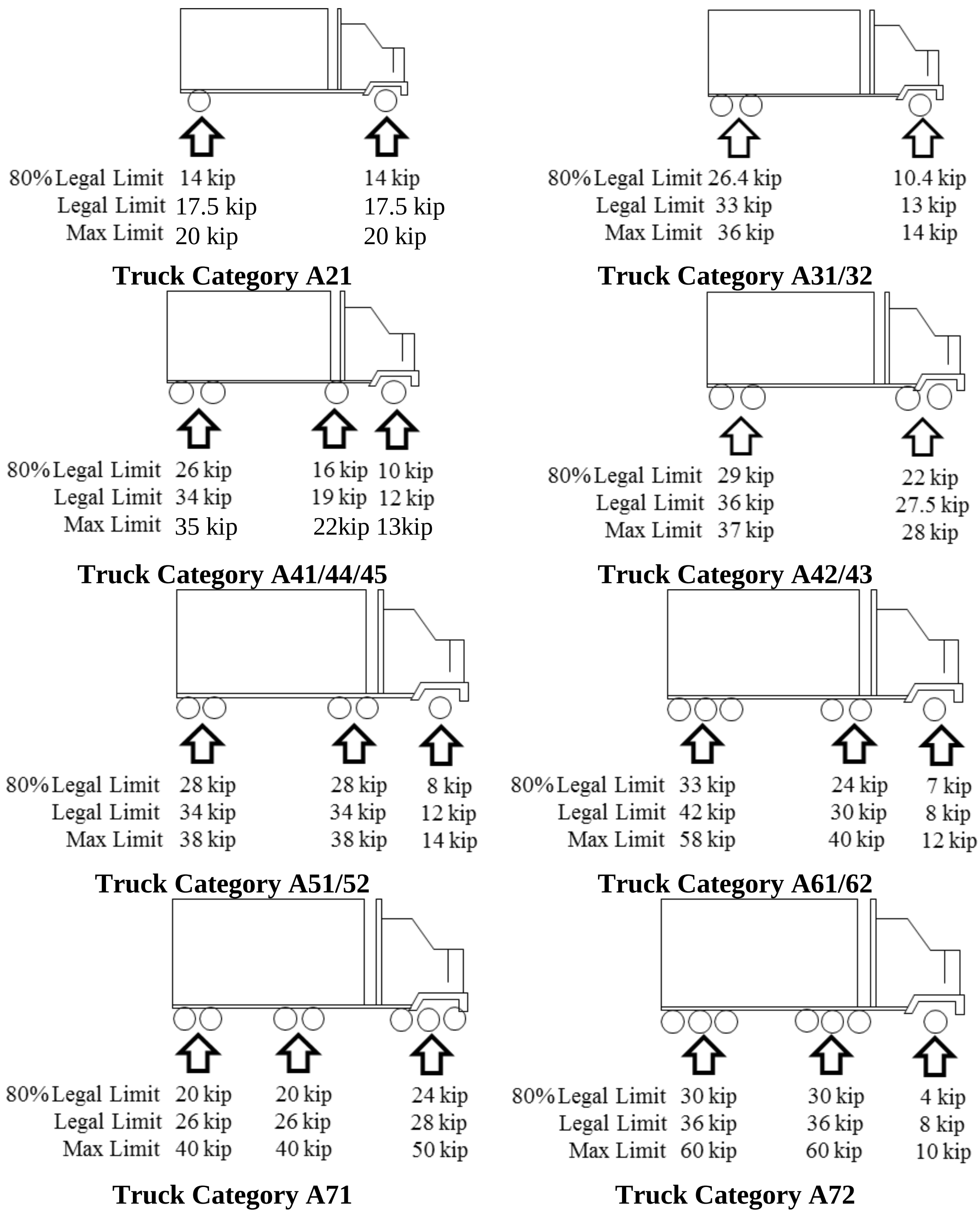


Figure 15 Truck Categories and Load Distribution for Each Load Scenario

4.1.1 Freight Demand on Different Functional Highway Classes

To estimate pavement and bridge damage caused by different truck types, the AADTT on different functional classes of SCDOT maintained highways were compiled using the TRANSEARCH database and a statistical analysis was performed to determine 85th -percentile AADTTs for 2011 as summarized in Table 9. This 85th -percentile AADTTs for year 2011 were utilized to design typical pavement sections (see Appendix D for summary statistics). The distribution of truck types was included in Table 10 and was based on the WIM data collected from St George station on Interstate 85.

Table 9 AADTT Estimate on Different Functional Classes in South Carolina

Functional Class	AADTT (2-way) 85th Percentile
Rural Interstate	13,150
Rural Arterial	1,210
Rural Collector	570
Rural Local	640
Urban Interstate	14,080
Urban Freeway/Expressways	10,870
Urban Arterial	1,700
Urban Collector	1,940
Urban Local	730

4.1.2 Truck Traffic Composition

Truck classification data was collected from the St. George weigh-in-motion (WIM) station on I-95 from November 2010 to May 2011 (SCDPS, 2012). Table 10 presents the summarized truck type distribution at the St. George WIM station. The data shown on Table 10 includes the only tuck type distributions available; thus they were applied to all truck routes considered in this research.

Table 10 Truck Type Distribution at the St. George WIM Station

FHWA Vehicle Class	FHWA Vehicle Class	Axle Grouping	Percentage
5	Single unit 2-axle truck	2-Axle	8.84%
6	Single unit 3-axle truck	3-Axle	1.15%
7	Single unit 4 or more-axle truck	4-Axle	0.05%
8	Single trailer 3 or 4-axle truck	3-Axle	9.10%
		4-Axle	
9	Single trailer 5-axle truck	5-Axle	75.97%
10	Single trailer 6 or more- axle truck	6-Axle	2.30%
		7-Axle	
11	Multi trailer 5 or less-axle truck	5-Axle	2.52%
12	Multi trailer 6-axle truck	6-Axle	0.02%
13	Multi trailer 7 or more-axle truck	7-Axle	0.06%
		8-Axle	

4.1.3 Estimated Vehicle Miles Traveled

Vehicle miles traveled (VMT) is the most commonly used performance measure in transportation system performance analysis. The total damage imparted to pavements and bridges by any truck depends on the total vehicle miles traveled. To estimate unit damage cost due to different truck types, the VMT in 2011 on SCDOT maintained highways were estimated. Primarily 2011 VMT was collected from the 2011 Highway Statistics for South Carolina (FHWA, 2012). VMT on SCDOT maintained highways were then adjusted using the statewide total lane miles and SCDOT maintained lane miles. Total lane miles on all South Carolina highways and SCDOT maintained highways are presented in Table 11 (CDM Smith, 2013). Utilizing the FHWA passenger vehicle and heavy vehicle VMT estimate, the average truck percentage on different functional classes were estimated (Table 12) (FHWA, 2012). Truck VMT on SCDOT maintained highways were estimated using truck percentages from Table 12 and are presented in Table 13. To estimate the percentage of trucks above legal axle or gross vehicle weight limits, WIM observations were utilized. An analysis of WIM data from the St. George weigh station on I-95 revealed that, on average, 8.3% of total truck observations were overweight, either by axle or gross vehicle weight. This estimate was used to compute statewide overweight truck VMT.

Table 11 Statewide and SCDOT Maintained Highway Lane Miles (Year- 2011)

Functional Class	Total SC Lane Miles	SCDOT Maintained Lane Miles
Rural Interstate	2,376	2,376
Rural principal Arterial	3,860	3,860
Rural Minor Arterial	7,266	7,247
Rural Major Collector	21,057	20,734
Rural Minor Collector	4,307	3,952
Rural Local	63,669	25,661
Urban Interstate	1,424	1,424
Urban Freeway/Expressways	322	322
Urban Principal Arterial	3,955	3,952
Urban Minor Arterial	4,076	3,968
Urban Major Collector	5,180	4,646
Urban Local	21,988	12,205
Total	**139,480**	**90,347**

Table 12 Percentages of Trucks on Different Functional Classes (Year- 2011)

Functional Class	Truck Percentage
Interstate Rural	23.45%
Other Arterial Rural	12.40%
Other Rural	9.18%
All Rural	13.98%
Interstate Urban	10.06%
Other Urban	5.56%
All Urban	6.64%
Total Rural and Urban	9.07%

Table 13 SCDOT Maintained Highways VMT (Year- 2011)

Functional Class	SCDOT Maintained Highway, Daily VMT 2011	SCDOT Maintained Highway, Daily Truck VMT 2011
Rural Interstate	20,442,020	4,792,818
Rural Principal Arterial	9,446,629	1,171,446
Rural Minor Arterial	13,518,756	1,676,418
Rural Major Collector	13,188,164	1,211,170
Rural Minor Collector	699,462	64,237
Rural Local	2,625,464	241,116
Urban Interstate	16,725,902	1,682,109
Urban Freeway/Expressways	2,226,133	223,880
Urban Principal Arterial	19,843,849	1,102,329
Urban Minor Arterial	14,845,836	824,688
Urban Major Collector	8,491,119	471,683
Urban Local	3,255,881	180,865
Total	**125,309,215**	**13,642,759**

To determine the operational effects of truck traffic, a micro simulation model of 106 miles of Interstate 85 in South Carolina was developed using the VISSIM micro-simulator. Several scenarios with varied levels of truck distributions within the traffic stream were modeled for year 2011. Truck percentages among other traffic on the I-85 corridor were increased by 5% and 10 % from the existing average percentage of trucks in the corridor in each simulation experiment. No significant change in travel time along the corridor was observed due to increases in truck traffic.

4.1.4 Overweight Truck Trip Length

Pavement and bridge damage cost due to overweight trucks depends on each overweight trip length. Currently SCDOT overweight truck permit applications require that truckers provide information on both the origin and destination of trips. As trip lengths were not reported explicitly in current permit applications, a typical trip length by different truck types was estimated using the 2002 South Carolina Economic Census data (Table 17) (US Census, 2004). It has been assumed that trucks operate a regular five day work week, with an average of one trip per day. The total number of trips for a year (2012) was estimated using the estimated trip length and the annual VMT for each truck class.

Table 14 Estimated Overweight Truck Trip Length and Number of Trips

Truck Type	Trip Length (miles) (t_{ij})*	Number of Trips (N_{ij})*	Distribution of Trips(r_{ij})*
2 axle	75	496,667	17.12%
3 axle, single unit	100	48,448	1.67%
3 axle, combination	125	153,473	5.29%
4 axle, single unit	270	735	0.03%
4 axle, combination	270	71,052	2.45%
5 axle semi-trailer	160	2,067,989	71.29%
6 axle semi-trailer	160	30,723	1.06%
7 axle semi-trailer	160	30,927	1.07%
8-axle semi-trailer	160	681	0.02%
*t_{ij}, N_{ij} and r_{ij} are mutiobjective tradeoff analysis model parameters			

4.1.5 Pavement Damage Estimation

The pavement design utilized the procedures set forth by the SCDOT Pavement Design Guidelines (2008), which uses an ESAL approach to determine the required structural number to accommodate a given number of design ESALs (AASHTO, 1993). The number of design ESALs for each functional class was calculated using ESAL factors presented in Table 15. The ESAL Factor was based on the truck configuration (Figure 15) and the respective ESAL factor for each individual truck type (Table 15). Based on the required number of ESALs, the required structural number for each pavement design was determined.

Table 15 ESAL Factors for Pavement Design Scenarios

Truck Category	**Distribution of Truck Type in Traffic Stream**	**ESAL Factor for 80% Legal Limit**	**ESAL Factor for Max Limit**
A21	8.84%	0.720	3.020
A31/32	5.70%	0.488	1.74
A41/44/45	4.55%	1.075	3.835
A42/43	0.05%	0.755	2.035
A51/52	78.49%	1.024	3.760
A61/62	1.17%	0.501	4.469
A71	0.60%	0.299	5.380
A72	0.60%	0.292	5.108
Combined ESAL Factor with No Overweight Trucks		0.954	
Combined ESAL Factor with 8.3% Overweight Trucks			1.174

The required HMA Base Course thickness was then calculated based on the required structural number for each functional class. All of the pavement design inputs are summarized in Table 16. Total traffic ESALs demand for each functional for a design life of 20 years were calculated.

Table 16 Input Parameters Used For The Pavement Designs

Variable	Value
Structural Layer Coefficients (a)	
HMA Surface Course (a_1)	0.44
HMA Intermediate Course (a_2)	0.44
HMA Based Course (a_3)	0.34
Graded Aggregate Base Course (a_4)	0.18
Soil Support Value (SSV)	1.5
Regional Factor (R)	1.0
Present Serviceability Index	
Initial serviceability (p_o)	4.2
Initial serviceability (p_t)	2.5

$$ESALs = AADTT \times G \times f_d \times f_l \times 365 \times ESAL\ factor \quad (1)$$

where,

AADTT = Average annual daily truck traffic

f_d = Directional distribution factor (0.5)

f_l = Lane distribution factor (0.95)

ESAL factor = From Table 15

G = Growth factor = $\frac{(1+r)^n-1}{r}$

r = Growth rate (2%)

n = Design life (20 years)

The total number of 18-kip ESALs for each pavement design was calculated using Equation (1) from the SCDOT Pavement Design Guidelines (2008). The total number of design ESALs for each pavement design is presented in Table 17. Table 17 summarizes the number of ESALs for each design scenario along with the structural number (SN) and HMA Base Thickness (H_3) required to support the number of ESALs using Equation (2).

$$\log(\mathrm{ESALs}) = 9.36\log(\mathrm{SN}+1) - 0.20 + \frac{\log\left[\frac{(4.2-\mathrm{p_t})}{(4.2-1.5)}\right]}{0.40+\left[\frac{1094}{(\mathrm{SN}+1)^{5.19}}\right]} + \log\left(\frac{1}{\mathrm{R}}\right) + 0.372(SSV-3.0) \quad \text{......(2)}$$

Table 17 Functional-Class Pavement Design Specifics Used in Damage Estimation

Functional Class	No Overweight Trucks			8.3% Overweight Trucks		
	ESALs	SN	H_3 (in)	ESALs	SN	H_3 (in)
Rural Interstate	52,840,256	8.07	15.50	65,043,806	8.28	16.12
Rural Principal Arterial	4,862,107	5.98	9.35	5,985,019	6.15	9.85
Rural Minor Arterial	2,290,414	5.40	7.65	2,819,389	5.55	8.09
Rural Major Collector	2,571,693	5.48	7.88	3,165,630	5.64	8.35
Rural Local	56,577,248	8.14	15.71	69,643,862	8.35	16.33
Urban Interstate	43,678,600	7.89	14.97	53,766,249	8.09	15.1
Urban Freeway	6,831,060	6.24	10.12	8,408,705	6.41	10.62
Urban Principal Arterial	7,795,445	6.35	10.44	9,595,816	6.52	10.94
Urban Minor Arterial	2,933,337	5.58	8.18	3,610,797	5.74	8.65

To determine the cost of the damage attributed to overweight trucks, it was first necessary to determine the replacement cost for each pavement design included in the analysis. The replacement cost of construction was based on typical unit prices for the materials used to construct each pavement layer. Table 18 provides unit construction cost data for the different pavement layers. These unit costs included installation and were based on actual cost data provided by SCDOT for 2011.

Table 18 Unit Construction Cost Data for Flexible Pavement Layers (2011 $)

Pavement Layer	Cost
HMA Surface Course (Type A)	\$4.62 per inch/yd^2
HMA Surface Course (Type B)	\$4.22 per inch/yd^2
HMA Intermediate Course (Type B)	\$4.14 per inch/yd^2
HMA Base Course (Type A)	\$3.76 per inch/yd^2
Graded Aggregate Base	\$5.62 per 6-inches thickness

Based on the pavement design for each traffic scenario for different highway functional classes (Table 17) and the unit costs provided in Table 18, construction cost per lane-mile was estimated for each design scenario as summarized in Table 19. The total SCDOT highway network pavement replacement costs were calculated using per lane-mile costs and the total lane-miles for each functional class in the SCDOT network as summarized in Table 20. Based on this analysis, having8.3% of overweight trucks to the normal truck traffic will result in an estimated increase in pavement replacement costs by more than $1.1 billion.

Table 19 Pavement Cost Estimates (2011 US $) Related to Overweight Trucks

Functional Class	Estimated Cost per Lane-Mile	
	No Overweight Trucks	8.3% Overweight Trucks
Rural Interstate	569,944	586,356
Rural Arterial	401,801	415,036
Rural Collector	356,801	368,448
Rural Local	362,889	375,331
Urban Interstate	575,503	591,915
Urban Freeway/Expressways	555,915	559,356
Urban Arterial	422,183	435,418
Urban Collector	430,654	443,889
Urban Local	370,831	383,272
The absolute minimum pavement design at an estimated cost of $96,012 per lane-mile.		

Table 20 SCDOT-Maintained Pavement Replacement Costs (2011 $)

Functional Class	Total Lane-Miles	Estimated Total Cost	
		No Overweight Trucks	8.3% Overweight Trucks
Rural Interstate	2,376	1,354,142,109	1,393,134,871
Rural Arterial	11,107	4,462,827,371	4,609,831,531
Rural Collector	24,687	8,808,210,479	9,095,734,717
Rural Local	25,661	9,311,997,874	9,631,244,901
Urban Interstate	1,424	819,291,974	842,655,760
Urban Freeway/Expressways	322	179,182,525	180,291,677
Urban Arterial	7,920	3,343,648,472	3,448,469,933
Urban Collector	4,646	2,000,989,333	2,062,485,366
Urban Local	12,205	4,525,913,209	4,677,754,200
Total	**90, 347**	**34,806,203,346**	**35,941,602,957**

The pavement replacement cost was divided into three categories to distribute among all vehicle types depending on their damage contribution. These costs were distributed by considering two damage factors: i) miles of travel (VMT), and ii) relative damage to pavement (in terms of ESALs). In Table 21, three cost items were separated where; a) additional pavement cost represents costs required to increase pavement thickness to accommodate overweight trucks which was distributed to overweight trucks only by ESAL factor, b) minimum pavement cost that was shared by all vehicles irrespective of relative damage, and distributed to all vehicle types including overweight trucks by miles of travel (VMT), c) remaining cost to accommodate the no overweight truck scenario (when there was no overweight truck traffic on the system, and required pavement thickness dictated by AADTT demand are within legal limit) was distributed to all trucks based on relative damage factor ESAL. A minimum design scenario of a pavement section with a 1.9 inch HMA surface course and 6 inch graded aggregate base course was assumed when there was no truck traffic on highways.

Table 21 Total Pavement Replacement Cost (2011 US $)

Functional Class	Additional Pavement Cost (For Overweight Trucks)	Minimum Pavement Cost (No Truck Traffic)	Pavement Cost For All Trucks
Rural Interstate	38,992,763	228,116,831	1,126,025,278
Rural Arterial	147,004,161	1,066,411,045	3,396,416,326
Rural Collector	287,524,238	2,370,209,839	6,438,000,640
Rural Local	319,247,027	2,463,735,128	6,848,262,746
Urban Interstate	23,363,786	136,683,643	682,608,331
Urban Freeway/Expressways	1,109,152	30,946,588	148,235,938
Urban Arterial	104,821,460	760,405,439	2,583,243,033
Urban Collector	61,496,033	446,110,157	1,554,879,176
Urban Local	151,840,991	1,171,807,258	3,354,105,952
Total	**1,135,399,611**	**8,674,425,928**	**26,131,777,419**

To distribute the pavement cost to respective vehicle types, design VMT and ESAL-miles were estimated for a pavement design life of 20 years with a traffic growth factor of 2% based data from 2011 (Table 22). Then unit damage costs were estimated and shown in Table 23.

Table 22 Design VMT and ESAL-Miles for 20 Years of Pavement Design Life

Estimate	Daily 2011	20 Years Total
All VMT	125,309,215	1,111,430,084,065
Light Vehicles VMT	111,666,456	990,425,631,610
All truck VMT	13,642,759	121,004,452,455
Overweight truck VMT	1,132,349	10,043,369,554
Regular weight truck VMT	12,510,410	110,961,082,901
Overweight truck ESAL-mile	4,085,515	36,236,477,350
Regular weight truck ESAL-mile	11,934,931	105,856,873,088

Table 23 Unit Pavement Damage Cost Estimate

Estimate	Design Life Total	Unit Cost
All VMT	1,111,430,084,065	$0.0078 Per Mile
Overweight truck ESAL-mile	36,236,477,350	$0.0313 Per ESAL-Mile
All Truck ESAL-mile	142,093,350,438	$0.1839 per ESAL-mile

Finally, to estimate the damage cost for each truck type loaded at the maximum limit, per mile damage costs were estimated for respective overweight truck ESAL magnitude and summarized in Table 24.

Table 24 Unit Pavement Damage Cost by Truck Type and GVW (2012 US $)

Truck Type	ESAL	Per mile Damage Cost*
2-axle, 35-40 kips	3.02	$0.41
3-axle, single unit, 46-50 kips	1.74	$0.24
3-axle, combination, 50-55 kips	3.32	$0.46
4-axle, single unit, 63.5-65 kips	2.035	$0.29
4-axle, combination, 65-70 kips	3.835	$0.53
5-axle, 80-90 kips	3.76	$0.52
6-axle, 80-90 kips	1.848	$0.26
6-axle, 90-100 kips	2.966	$0.41
6-axle, 100-110 kips	4.469	$0.62
7-axle, 80-90 kips	0.998	$0.15
7-axle, 90-100 kips	1.61	$0.23
7-axle, 100-110 kips	2.48	$0.35
7-axle, 110-120 kips	3.66	$0.51
7-axle, 120-130 kips	5.24	$0.74
8-axle, 80-90 kips	0.808	$0.12
8-axle, 90-100 kips	1.268	$0.18
8-axle, 100-110 kips	1.976	$0.28
8-axle, 110-120 kips	2.775	$0.39
8-axle, 120-130 kips	3.885	$0.56

4.2 Bridge Damage Estimation

Bridges represent a relatively small percentage of total lane miles compared to pavement. However, bridge construction and maintenance costs as well as the disruption to traffic associated with replacement or failure are significantly high in comparison. In

* The damage cost values from base year 2011 to year 2012 with CPI of 1.17%.

the following subsections, the quantification of bridge damage due to overweight trucks was presented.

4.2.1 Bridge Deterioration Model

First step in bridge damage estimation was to develop archetype bridges to represent groups of bridges that share common features and structural characteristics. Four types of archetype bridges were modeled to quantify bridge damage due to trucks for this study. The details of the archetype bridge selection can be found in (Chowdhury et al., 2013).

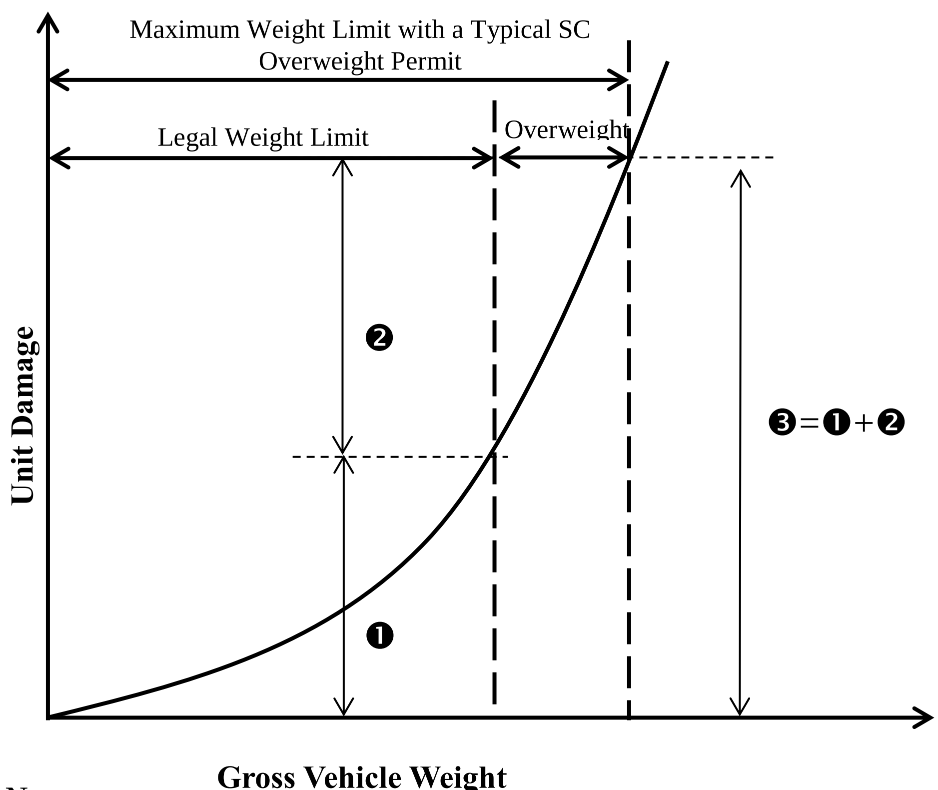
Finite element (FE) models for each archetype bridge was developed using the LS-DYNA finite element program. In this step, the FE models were developed and analyzed with combinations of archetype bridges and truck models. Bridge fatigue life for each archetype bridge using the stress ranges were calculated form the FE analysis performed at Aragon National Laboratory supercomputing facility. More details on the fatigue life analysis can be found in (Chen, 2013).

4.2.2 Bridge Damage Cost Estimation

To estimate bridge damage costs due to overweight trucks, bridge fatigue damage models and bridge replacement cost models were combined and used as inputs for the bridge cost estimation. The bridge replacement costs were estimated using HAZUS-MH program database (HAZUS-MH, 2003) which contains replacement costs of half of all South Carolina bridges. More details on the development of the bridge cost models can be found in (Chen, 2013).

4.3 Combined Axle-Based Pavement and Bridge Damage Cost

Total damage cost due to overweight trucks can be broken down into two parts (Figure 16). Part 1 is the total damage imparted by a truck loaded at legal weight limits, and Part 2 represents additional damage cost due to additional weight allowed with typical overweight permits beyond the legal weight limit. In this study, damage costs were estimated for trucks loaded at legal weight limits and at corresponding maximum weight limits with typical overweight permits. Pavement and bridge unit damage costs were combined to estimate per-mile and per-trip damage costs for different overweight truck configurations.



Note:

❶Unit damage cost for a truck loaded at the legal weight limit

❷Additional unit damage cost due to additional weights above the legal weight limit to the maximum weight limit with typical SC overweight permits

❸Unit damage cost for a truck loaded at the maximum weight limit with typical SC overweight permits

Figure 16 Damage Contribution of Trucks at Different Gross Vehicle Weights

In Table 25, combined pavement and bridge damage cost per mile and per trip are presented considering estimated trip length for different truck types (Table 14 provides trip length by different truck types). As truck axle load and configurations were considered in the cost calculation, this cost can be interpreted as axle based damage cost. Additional damage cost due to additional weight of overweight trucks is shown in Table 25 (Column 6). As shown in Table 25, pavement and bridge damage increase substantially above legal weight limits. As an example, a 2-axle truck is loaded at the legal weight limit of 35,000 pounds incurs a damage cost of $26.42 per trip. Permitting 5,000 pounds above the legal weight limit increases the damage by $24.19 to a total of $50.61 of damage imparted for the trip, which indicates that overweight trucks cause accelerated damage to pavements and bridges above the legal weight limit.

Table 25 Combined Pavement and Bridge Damage Cost for Different Truck Types (2012 $)

Truck Type (See Figure 15 for details)	Per Mile Damage for a Truck Loaded at the Legal Weight Limit	Per Mile Damage for an Overweight Truck Loaded up to the Maximum Overweight Limit	Per Trip Damage for a Truck Loaded at the Legal Weight Limit	Per Trip Damage for an Overweight Truck Loaded up to the Maximum Overweight Limit	Additional per Trip Damage above the Legal Limit for an Overweight Truck Loaded up to the Maximum Overweight Limit
2-axle, 35-40 kips	$0.3523	$0.6748	$26.42	$50.61	24.19
3-axle, single unit, 46-50 kips	$0.2474	$0.3933	$24.74	$39.33	14.58
3-axle, combination, 50-55 kips	$0.4442	$0.7444	$55.53	$93.05	37.53
4-axle, single unit, 63.5-65 kips	$0.3585	$0.4600	$96.78	$124.21	27.42
4-axle, combination, 65-70 kips	$0.4884	$0.8247	$131.87	$222.68	90.80
5-axle, 80-90 kips	$0.4583	$0.8420	$73.33	$134.73	61.40
6-axle, 80-90 kips	$0.2585	$0.4407	$41.36	$70.52	29.16
6-axle, 90-100 kips	$0.2585	$0.6834	$41.36	$109.35	67.99
6-axle, 100-110 kips	$0.2585	$1.0123	$41.36	$161.97	120.61
7-axle, 80-90 kips	$0.1428	$0.2556	$22.84	$40.89	18.05
7-axle, 90-100 kips	$0.1428	$0.3956	$22.84	$63.29	40.45
7-axle, 100-110 kips	$0.1428	$0.5880	$22.84	$94.08	71.23
7-axle, 110-120 kips	$0.1428	$0.8440	$22.84	$135.04	112.20
7-axle, 120-130 kips	$0.1428	$1.1730	$22.84	$187.67	164.83
8-axle, 80-90 kips	$0.1140	$0.2005	$18.23	$32.08	13.84
8-axle, 90-100 kips	$0.1140	$0.3059	$18.23	$48.94	30.70
8-axle, 100-110 kips	$0.1140	$0.4668	$18.23	$74.69	56.46
8-axle, 110-120 kips	$0.1140	$0.6497	$18.23	$103.96	85.72
8-axle, 120-130 kips	$0.1140	$0.9030	$18.23	$144.47	126.24

CHAPTER V: EVALUATION OF FEE STRUCTURES

Analyses comparing the performance of the most widely used overweight damage cost recovery fee types are presented in this chapter. All fee types developed in this research do not include a permit administration fee. Only damage costs due to additional weight above legal weight limit to be recovered through different damage cost recovery fee types were estimated. The analyses presented in this section compare damage costs for a single trip. State DOTs issue annual/blanket permits without limitation on number of trips. Due to lack of average number of trips with annual permit statistics, no attempt was made to compare annual permit fee types for overweight trucks.

5.1 Flat Damage Cost Recovery Fee and Axle Based Damage Cost Recovery Fee Comparison

South Carolina currently collects a flat fee of $30 for single trip overweight permits and $100 for annual overweight permits, both of which include a permit administrative fee. This research showed that trucks with identical loads but different axle configurations incur different damage costs. A flat fee is an average value and does not account for truck configurations and axle load distributions. Table 26 provides a comparison of axle-based damage cost recovery fee (Column 3) and flat damage cost recovery fee (Column 2). Based on the damage estimation, to recover additional pavement and bridge damage costs completely due to overweight trucks, a flat damage cost recovery fee of $55 (about two times of current flat fee in South Carolina) would need to be collected from each overweight trip. The flat damage cost recovery fee was calculated as a weighted average of axle based damage cost recovery fees. The relative weight of each truck type was estimated by dividing the number of trips in each truck type with the total number of trips by all truck types. In a flat damage cost recovery fee type, 2-axle overweight trucks would be paying 129% more compared to an axle based damage cost recovery fee, while 4-axle combination trucks would pay 40% less with a flat damage cost recovery fee compared to an axle based damage cost recovery fee. In effect, ignoring the axle distribution in flat damage cost recovery fee will cause some truck types to pay more than actual damage they imparted and some truck types will pay less than the actual damage they imparted.

Table 26 Axle Based Damage Fee and Flat Damage Fee (per Trip)

Truck Type	**Additional Damage up to Maximum Overweight Limit (dc_{ij})**	**Flat Additional Damage for Overweight Trucks (dc)**	**Difference between Axle Based Damage and Flat Additional Damage**
2-axle, 35-40 kips	$24.19	$54.93	$30.74
3-axle, single unit, 46-50 kips	$14.58	$54.93	$40.34
3-axle, combination, 50-55 kips	$37.53	$54.93	$17.40
4-axle, single unit, 63.5-65 kips	$27.42	$54.93	$27.50
4-axle, combination, 65-70 kips	$90.80	$54.93	-$35.88
5-axle, 80-90 kips	$61.40	$54.93	-$6.47
6-axle, 80-90 kips	$29.16	$54.93	$25.77
6-axle, 90-100 kips	$67.99	$54.93	-$13.06
6-axle, 100-110 kips	$120.61	$54.93	-$65.69
7-axle, 80-90 kips	$18.05	$54.93	$36.88
7-axle, 90-100 kips	$40.45	$54.93	$14.48
7-axle, 100-110 kips	$71.23	$54.93	-$16.30
7-axle, 110-120 kips	$112.20	$54.93	-$57.27
7-axle, 120-130 kips	$164.83	$54.93	-$109.90
8-axle, 80-90 kips	$13.84	$54.93	$41.09
8-axle, 90-100 kips	$30.70	$54.93	$24.22
8-axle, 100-110 kips	$56.46	$54.93	-$1.53
8-axle, 110-120 kips	$85.72	$54.93	-$30.79
8-axle, 120-130 kips	$126.24	$54.93	-$71.31

5.2 Weight Based Damage Cost Recovery Fee

Based on pavement and bridge damage estimates, to recover additional damage completely above the legal weight limit by overweight trucks in a weight based damage cost recovery fee type, a per ton per trip damage cost recovery fee between \$2.77 to \$36.57 (Column 4, Table 27) is attributed to different truck types. Truck type specific per ton per trip damage cost recovery fee (Column 4, Table 27) beyond the legal weight limit was estimated by dividing axle based damage cost recovery fee (Column 2, Table 26) by additional weight above the legal weight limit. A comparison between the average per ton per trip damage cost recovery fee (Column 5, Table 27) and the truck type specific per ton per trip damage cost recovery fee (Column 4, Table 27) is presented in Column 6 of Table 27. The average damage cost recovery fee per ton per trip was estimated as follows:

$$\frac{\sum_{\text{All truck types}} \begin{pmatrix} \text{Truck type specific per ton per trip damage cost recovery fee} \\ \times \text{ Number of trips} \times \text{ Additional tonnage} \end{pmatrix}}{\sum_{\text{All truck types}} (\text{Number of trips} \times \text{ Additional tonnage})}$$

Analysis showed truckers with 3-axle combination, 4, or 5 axles will pay less per trip under a simple average per ton per trip damage cost recovery fee type (Column 5) than under a damage cost recovery fee type that account for how axles are distributed in a specific truck type (Column 4). In essence, ignoring the axle distribution means that truckers with 3-axle combination, 4, or 5 axles will be subsidized by other truck types that cause less damage comparatively.

5.3 Weight and Distance Based Damage Cost Recovery Fee

To recover additional overweight damage costs above legal weight limit with a damage cost recovery fee type based on weight and distance, per ton-mile damage fee between \$0.0173 and \$0.1354 (Column 3, Table 28) would need to be assessed from different overweight truck types. Truck type specific damage cost recovery fees per ton-mile (Column 3, Table 28) were calculated by dividing the axle based damage cost recovery fee per trip (Column 2, Table 26) by the additional weight above the legal weight limit and trip length. The average damage cost recovery fee per ton-mile (Column 4, Table 28) was estimated as follows:

$$\frac{\sum_{\text{All truck types}}\begin{pmatrix}\text{Truck specific per ton} - \text{mile damage cost recovery fee}\\ \times \text{ Number of trips} \times \text{ Trip length } \times \text{ Additional tonnage}\end{pmatrix}}{\sum_{\text{All truck types}}(\text{Number of trips} \times \text{ Trip length } \times \text{ Additional tonnage})}$$

A comparison between the average per ton-mile damage cost recovery fee and truck type specific per ton-mile damage cost recovery fee is presented in Column 5 of Table 28. Table 28 indicates that a truck with 2-axle, 3-axle combination and 4 axles will benefit from permitting fees that consider average per ton-mile damage cost recovery fee.

Table 27 Weight Based Damage Fee for Different Truck Types (per Ton per Trip)

Truck Type	Overweight Tonnage (w_{ij})	Damage at the Legal Weight Limit	Additional Damage above the Legal Limit up to the Maximum Overweight Limit (wdc_{ij})	Average of Additional Damage above the Legal Limit up to the Maximum Overweight Limit	Difference between Truck Specific Damage and Average Additional Damage
2-axle, 35-40 kips	2.5	$1.51	$9.68	$11.95	$2.27
3-axle, single unit, 46-50 kips	2	$1.08	$7.29	$11.95	$4.65
3-axle, combination, 50-55 kips	2.5	$2.22	$15.01	$11.95	-$3.06
4-axle, single unit, 63.5-65 kips	0.75	$3.05	$36.57	$11.95	-$24.62
4-axle, combination, 65-70 kips	2.5	$4.06	$36.32	$11.95	-$24.38
5-axle, 80-90 kips	5	$1.83	$12.28	$11.95	-$0.33
6-axle, 80-90 kips	5	$1.03	$5.83	$11.95	$6.11
6-axle, 90-100 kips	10	$1.03	$6.80	$11.95	$5.15
6-axle, 100-110 kips	15	$1.03	$8.04	$11.95	$3.90
7-axle, 80-90 kips	5	$0.57	$3.61	$11.95	$8.34
7-axle, 90-100 kips	10	$0.57	$4.04	$11.95	$7.90
7-axle, 100-110 kips	15	$0.57	$4.75	$11.95	$7.20
7-axle, 110-120 kips	20	$0.57	$5.61	$11.95	$6.34
7-axle, 120-130 kips	25	$0.57	$6.59	$11.95	$5.35
8-axle, 80-90 kips	5	$0.46	$2.77	$11.95	$9.18
8-axle, 90-100 kips	10	$0.46	$3.07	$11.95	$8.88
8-axle, 100-110 kips	15	$0.46	$3.76	$11.95	$8.18
8-axle, 110-120 kips	20	$0.46	$4.29	$11.95	$7.66
8-axle, 120-130 kips	25	$0.46	$5.05	$11.95	$6.90

Table 28 Weight Distance Based Damage Fee for Different Truck Types (per Ton-Mile)

Truck Type	Damage at the Legal Weight Limit	Additional Damage above the Legal Limit up to the Maximum Overweight Limit ($wddc_{ij}$)	Average of Additional Damage above the Legal Limit up to the Maximum Overweight Limit	Difference between Truck Specific Damage and Average Additional Damage
2-axle, 35-40 kips	$0.0201	$0.1290	$0.0785	-$0.0505
3-axle, single unit, 46-50 kips	$0.0108	$0.0729	$0.0785	$0.0056
3-axle, combination, 50-55 kips	$0.0178	$0.1201	$0.0785	-$0.0416
4-axle, single unit, 63.5-65 kips	$0.0113	$0.1354	$0.0785	-$0.0569
4-axle, combination, 65-70 kips	$0.0150	$0.1345	$0.0785	-$0.0560
5-axle, 80-90 kips	$0.0115	$0.0767	$0.0785	$0.0018
6-axle, 80-90 kips	$0.0065	$0.0365	$0.0785	$0.0421
6-axle, 90-100 kips	$0.0065	$0.0425	$0.0785	$0.0360
6-axle, 100-110 kips	$0.0065	$0.0503	$0.0785	$0.0283
7-axle, 80-90 kips	$0.0036	$0.0226	$0.0785	$0.0560
7-axle, 90-100 kips	$0.0036	$0.0253	$0.0785	$0.0533
7-axle, 100-110 kips	$0.0036	$0.0297	$0.0785	$0.0489
7-axle, 110-120 kips	$0.0036	$0.0351	$0.0785	$0.0435
7-axle, 120-130 kips	$0.0036	$0.0412	$0.0785	$0.0373
8-axle, 80-90 kips	$0.0028	$0.0173	$0.0785	$0.0612
8-axle, 90-100 kips	$0.0028	$0.0192	$0.0785	$0.0593
8-axle, 100-110 kips	$0.0028	$0.0235	$0.0785	$0.0550
8-axle, 110-120 kips	$0.0028	$0.0268	$0.0785	$0.0517
8-axle, 120-130 kips	$0.0028	$0.0316	$0.0785	$0.0470

CHAPTER VI: POLICY TRADEOFF AND IMPLEMENTATION CHALLENGES

To develop effective policies, decision makers (DMs) must develop policy options considering multiple conflicting objectives and associated tradeoff simultaneously. At the same time, it is necessary for DMs to explore the anticipated impacts of candidate policy options to all stakeholders involved in overweight freight business. This chapter discussed tradeoff analysis of different fee structures and policy implications for realizing different fee structures.

6.1 Tradeoff of Fee Structures

Multiobjective analysis is useful in solving complex problems with conflicting objectives encountered in business, engineering, and planning. In a scenario with multiple conflicting objectives, there are infinitely many solutions which are equally good. The decision stage naturally involves a DM with subjective preferences, priorities, expectations and personal aspirations about conflicting objectives. The differences between different efficient or Pareto optimal solutions or options, generated from solving optimization problems with multiple objectives, is that each solution is better in one objective but worse in another objective. The relative improvement of one objective over another objective is known as tradeoff. In general, a tradeoff between two objective functions at a Pareto point is the ratio between increase of one function and decrease of the other assuming that all other objective functions remain constant. Tradeoffs quantification is useful to DMs in selecting an alternative after reviewing the trade-offs between alternatives and used in many multiobjective analysis procedures.

This section demonstrates how fee structures for overweight permitting affect fee incidence. A multi-objective model was developed (as described in Chapter 3 section 3.5.2) with the following two objective functions to demonstrate the trade-offs between different fee structures:

- minimizing unpaid bridge and pavement damage cost due to overweight truck trips (primary objective), and
- minimizing overweight permit fees to reduce freight transportation cost (secondary objective).

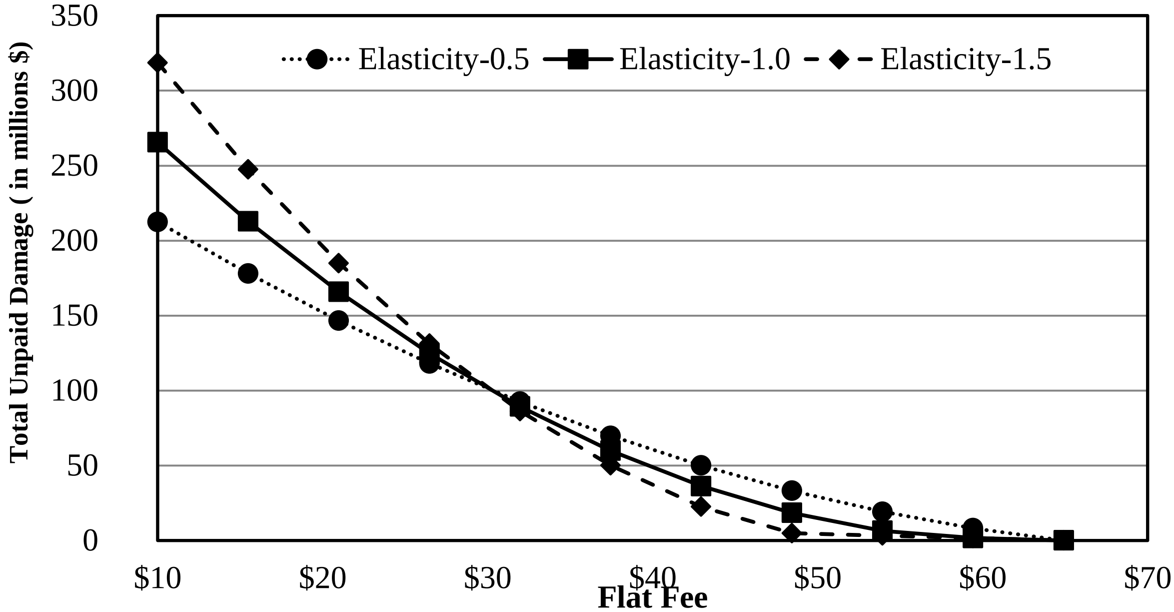
The estimated model parameters were incorporated into the bi-objective models developed in Section 4. Bi-objective models were reformulated into the single-objective ε-constraint models (Chowdhury et al., 2000; Chankong and Haimes, 1983). These reformulated single-objective models were solved with an optimization software to generate the optimal solutions that were also Pareto-optimal solutions for the original bi-objective models. The ε-constraint problem was solved for ten values corresponding to 0% to 100% damage recovery which generate Pareto-optimal solutions of the bi-objective models based on type of fee considered in the second objective function. Performances of both objective functions and tradeoffs are presented in Figure 18 to 21 for the flat, axle based, weight-based, and weigh-distance-based damage cost recovery fee types, respectively. Each model was solved for an elasticity value of -0.5, -1.0 and -1.5 to represent the sensitivity of the overweight freight demand to the damage cost recovery fee. Each figure shows the unpaid pavement and bridge damage corresponding to several fee levels and the associated tradeoffs. Each model was solved through optimization software and can be found in Appendix E.

The tradeoffs of the Pareto-optimal solutions of the two objective functions were calculated as the dual variables associated with the ε-constraint related to the second objective of original bi-objective models. These tradeoff values indicate how much unpaid damage could be recovered by a unit increase in damage cost recovery fee. For example, when the flat damage cost recovery fee is $43, the unpaid damage is $22.4 million in year 2012 (for elasticity value of 1.5) (Figure 17). The tradeoff corresponding to a $43 flat damage cost recovery fee is $4.2 million. The tradeoff of $4.2 million indicates that increasing the flat overweight damage cost recovery fee by $1 to $44 (from $43) would reduce the unpaid damage of $4.2 million in a year in South Carolina (in 2012 $). Reduction in unpaid damage is achieved by, (1) more revenue collection from all overweight trips in South Carolina at a higher fee rate, and (2) an overall reduction in overweight freight demand in South Carolina. Though the permit fee would increase by a small amount ($43 to $44), significant reduction in unpaid damage would be achieved due to the fact that, the additional $1 fee will be collected from all overweight trips made in a year. The tradeoff analysis conducted in this research did not consider percentage of overweight trucks without permits as no statistics were available on number of illegal overweight trips in South Carolina. The tradeoff at different damage cost recovery levels shows how to select overweight permit policies to achieve the preferred performance tradeoff. Quantitative tradeoff estimate of each Pareto-optimal solutions provide information to decision makers to make an informed choice among available policy options (fee rates) to select either the best alternative or to modify the generated solutions towards the direction of an expected tradeoff. Selection of an appropriate level of damage cost recovery fee depends on tradeoff analysis as well as expected positive and negative impacts on overweight freight businesses. If none of the generated solutions satisfies decision makers' expectations, the interactive multiobjective analysis can be used to compute new solutions with the input from the decision makers concerning their respective preferences (Chowdhury et al., 2000; Ehrgott and Wiecek, 2005).

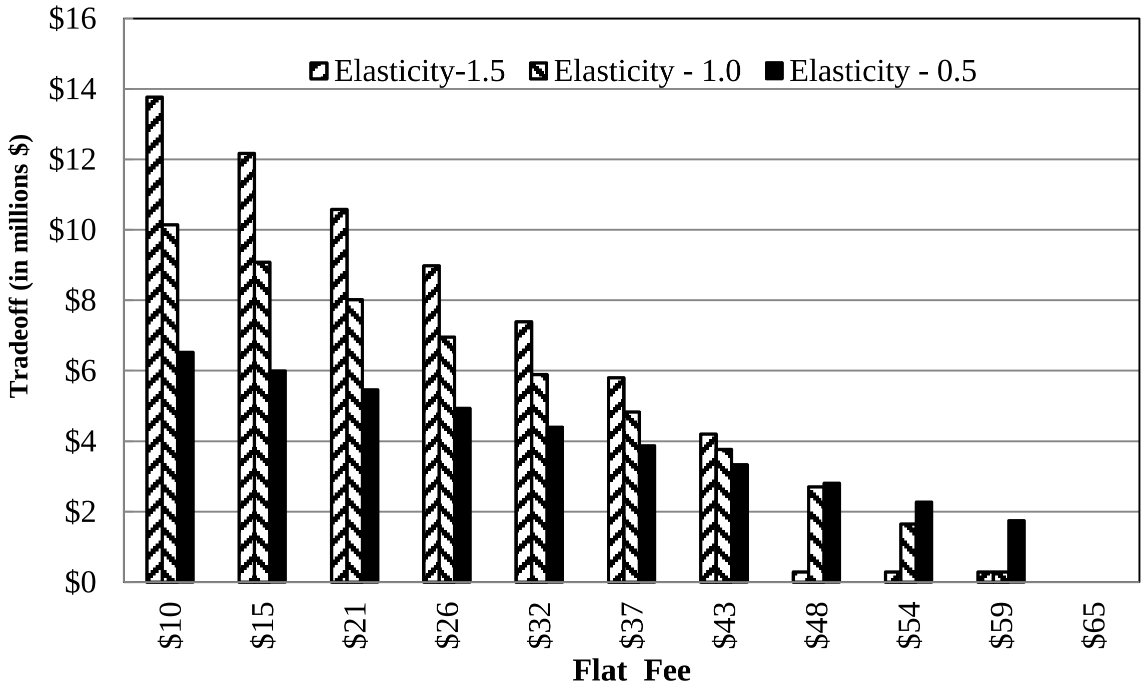
In the axle based damage cost fee type, the average axle based permit fee of $43 resulted in unpaid damages of $17.2 million in year 2012 in South Carolina (for elasticity value of 1.5). The corresponding tradeoff value of $3.8 million indicates that increasing the axle-based overweight permit fee by $1 on averageto $44 would reduce the unpaid damage of $3.8 million in a year (Figure 18).

In the weight based damage cost recovery fee type, the average damage cost recovery fees may be varied between $12.37 per ton (100% damage recovery, upper limit) to no charge (0% damage recovery, lower limit) (Figure 19). The bi-objective analysis reveals that when a per ton damage cost recovery fee of $6.2 is levied, the unpaid damage is $42.3 million (for elasticity value of 1.5), with a corresponding tradeoff of $23.8 million in year 2012. The tradeoff value indicates that an increase in the per ton damage cost recovery fee by $1 on average from the $6.2 per ton damage fee would reduce the unpaid damage of $23.8 million in year 2012 in South Carolina.

In the weight-distance based damage cost recovery fee type, the average per ton-mile damage cost recovery fee may be varied between 9 cents per ton-mile (100% damage recovery) to no charge (0% damage recovery) (Figure 20). The bi-objective analysis reveals that when per ton-mile damage cost recovery fee is 6.2 cents the unpaid damage is $9.9 million (for elasticity value of 1.5), with a corresponding tradeoff value of $4.6 million in year 2012. A tradeoff value of $4.6 million indicates that increasing per ton-mile fee by 1 cent per ton-mile on average to 5.6 cents per ton-mile, in turn could reduce the unpaid damage of $4.6 million in year 2012.

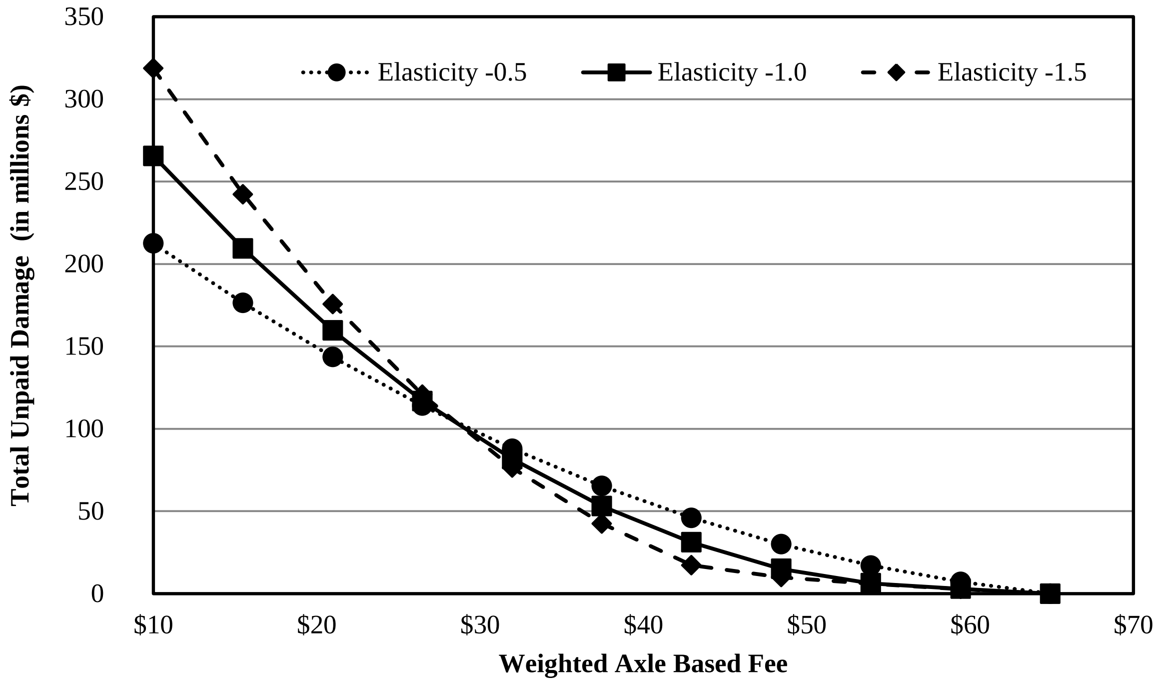


(a) Pareto optimal solutions

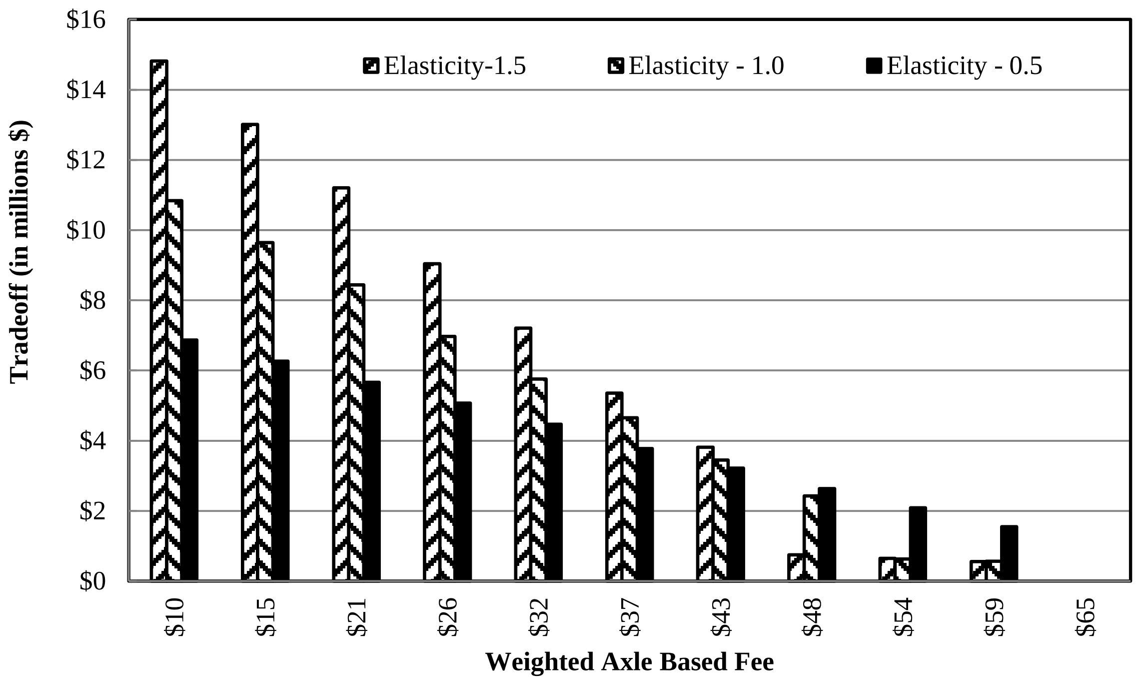


(b)Tradeoffs of Pareto optimal solutions

Figure 17 Unpaid damage and tradeoffs corresponding to flat damage cost recovery fees ($10 administrative cost included in flat damage fee)

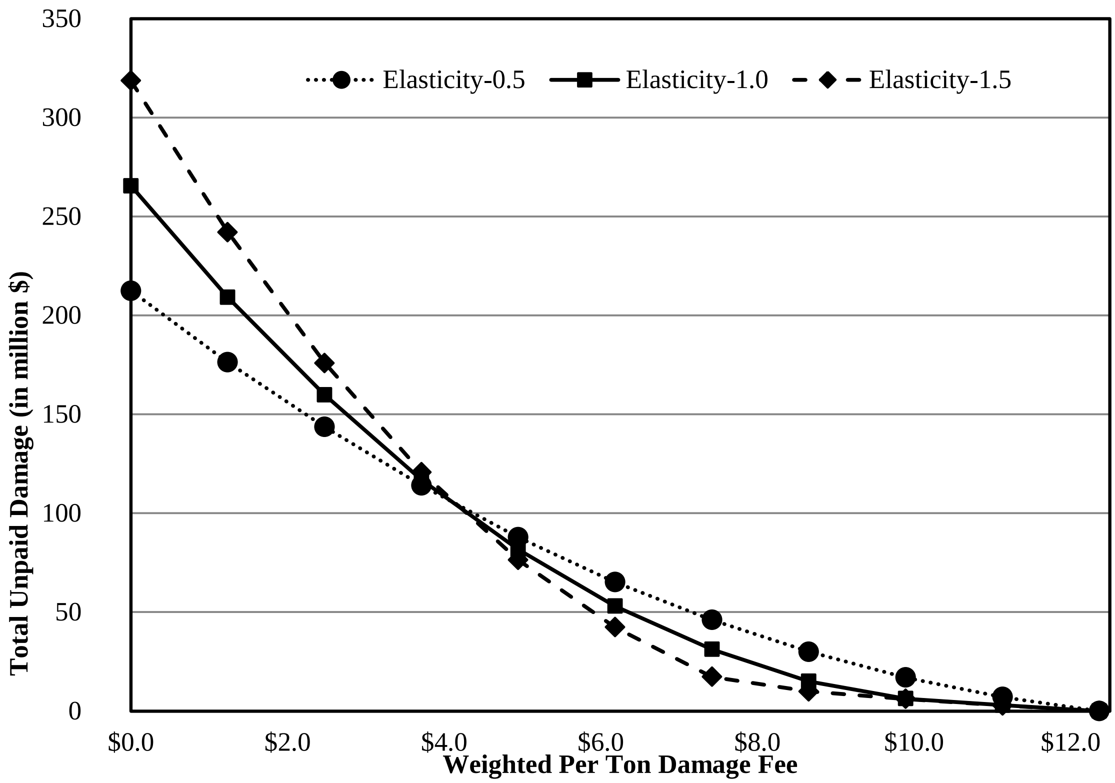


(a) Pareto optimal solutions

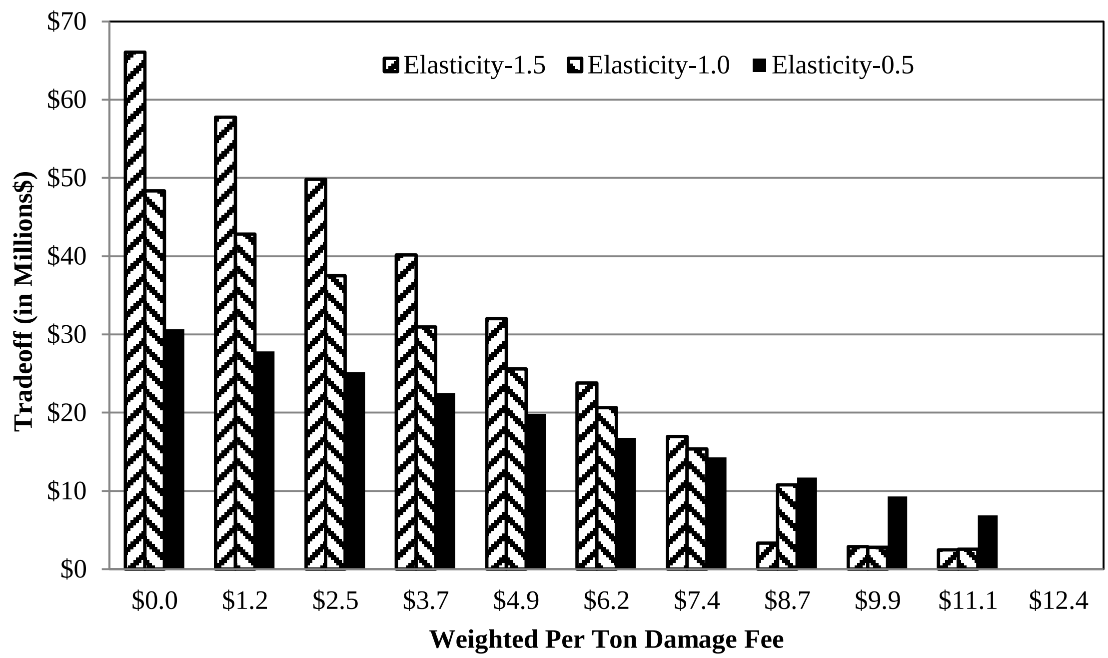


(b) Tradeoffs of Pareto optimal solutions

Figure 18 Unpaid damage and tradeoffs corresponding to average axle based damage cost recovery fee ($10 Administrative cost included in axle based damage fee)

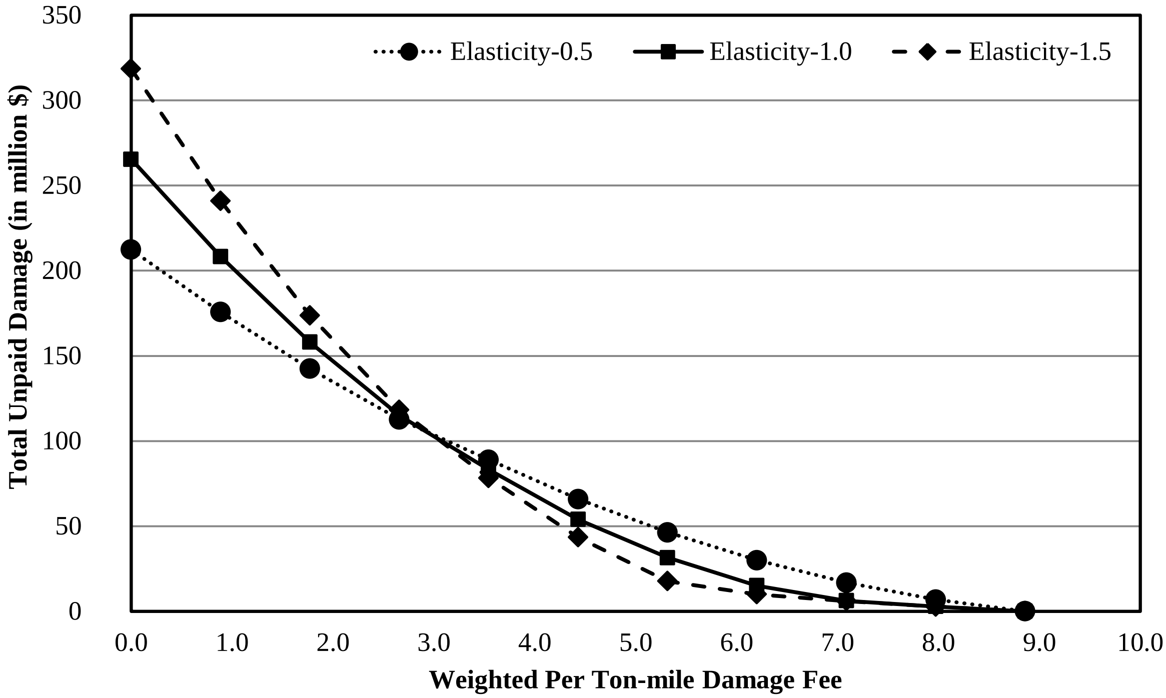


(a) Pareto optimal solutions

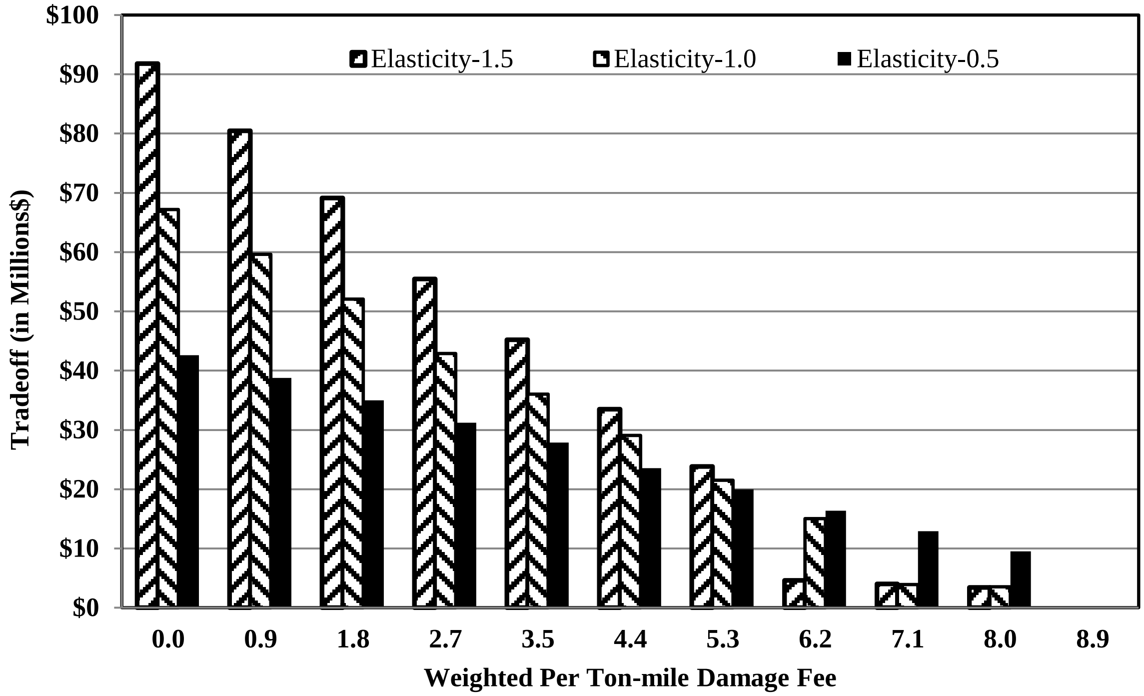


(b) Tradeoffs of Pareto-optimal solutions

Figure 19 Unpaid damage and tradeoffs corresponding to average per ton damage cost recovery fee (administrative fee of $10 was not included in damage fee)



(a) Pareto optimal solutions



(b) Tradeoffs of Pareto optimal solutions

Figure 20 Unpaid damage and tradeoffs corresponding to per ton-mile damage cost recovery fee (administrative fee of $10 was not included damage fee)

This bi-objective model showed the usefulness of a multiobjective approach to the overweight freight truck operations policy analysis. Revising trucking fee structures takes place in a public context, which inherently brings a number of stakeholder interests and considerations. Implementing policies based on tradeoffs would face many challenges as discussed in the following section.

6.2 Stakeholders Perspective on Different Fee Types

In stakeholders' interview, participants expressed their views about different type of permit fee structures and summarized in the following subsections.

6.2.1 Flat Fee

Most participants in stakeholders' interview stated that flat fee carries little advantage beyond its simplicity to maintain. One interviewee mentioned that flat fee is most unfair for state when it sets at too low and most unfair to trucking companies when it sets at high compared to damage imparted to pavements and bridges.

6.2.2 Weight Based Fee

Most stakeholders strongly agree weight should be a factor in calculating appropriate permit fee. However, there are several issues in using weight as a factor:

- It is always challenging to weight loads accurately for small rural industries such as small agricultural company cannot afford installation of scale. If new rules require scale at loading areas, it will advantage bigger industries which can accommodate installation cost in their balance sheet easily.

- Another issue stated by stakeholders is the exemption of certain industries to carry loads above legal weight limits without permits. If significant numbers of trips are allowed to operate without permits it question the validity of whole permit system.

6.2.3 Distance Based Fee

Most stakeholders strongly agree distance/trip length is a fair indicator to be considered in calculating appropriate permit fee. Most of the trucks are equipped with GPS units and tracking trip length is not a big concern to trucking companies. However, it will be challenging to enforce a distance based fee as enforcement officers will have hard time to verify total distance travelled by each overweight truck.

6.2.4 Axle Based Fee

Based on engineering analysis of this research, it was evident that axle based fee structure which consider number of axle, axle configuration, axle load and trip length is most accurate to represent total damage cost. But implementing axle based fee in South Carolina will be inconsistent with neighboring states and will create problems for trucking companies. Most stakeholders recommend to work with neighboring states to develop consist fee structure which will allow companies to standardize their fleet configuration that can operate in multiple states.

6.2.5 Annual Permit Fee

Most of the stakeholders felt one flat rate for annual permits is not fair and does not consider total number of trips made by each permit holder in a year. To incorporate number of trips, one stakeholder recommended eliminating annual permits and issuing single trip permits only to ensure each trip paying fair share of the damage cost. Stakeholders recognized that eliminating annual permits will increase permit administration significantly for SCDOT and trucking companies. To establish a more efficient system, SCDOT will require expending current permit program workforce to process large permit application volume in a timely manner. One stakeholder suggested a base fee for annual permit holders and add incremental fee for each trip made in a year similar to a club membership. Another participant mentioned that flat annual fee keeps South Carolina trucking companies competitive to neighboring states.

6.3 Policy Implementation Challenges

Decision that's might increase operating cost of overweight freight transportation business demand a comprehensive analysis of stakeholders perception about any policy changes. Based on the stakeholders' interview with public and private trucking organizations in South Carolina, this section summarizes stakeholders' perspectives about overweight trucking business and SCDOT fee polices.

6.3.1 Impacts on Different Types of Business

Revisions to permit fee structure should consider positive and negative impacts on different business types. In stakeholders' interview, one participant defined trucking business as a diverse industry which requires different types of truck configuration to transport varieties of goods. Increasing permit fee will disproportionately affect different businesses depending on business structure of each company. Such as higher fees will have relatively adverse impact on small business while bigger companies can easily accommodate the increased fee. To minimize overall negative impact to different types of business, decision makers must consider how to provide special considerations to small business.

All stakeholders in SC recognized the need of more revenue to maintain transportation infrastructure. Several stakeholders mentioned that as demand for overweight permits increased; SCDOT has restricted more bridges with limited load carrying capacity. Load restrictions instead of replacing sub-standard bridges force trucking companies to take longer routes. Especially rural agri-businesses disproportionately affected because of more sub-standard bridges on rural highways.

Stakeholders have diverse opinions about current South Carolina overweight permit fee structure. While one stakeholder believe current $30 fee for single trip is fairest among neighboring states, another stakeholder mentioned that current fee is low and expressed willing to contribute more to SCDOT maintenance program. One participant stated the importance of considering trip length in determining appropriate fee. Though there are conflicting opinions on how current fee structure should be revised, all stakeholders stressed the need of effective enforcement to deter illegal overweight trucks. In today's competing business environment, higher fees will encourage more illegal overweight trips if there is less surveillance. It is necessary to develop an effective and efficient enforcement program to deter illegal overweight trips which create additional financial burden to DOT. Adaptation of technology based truck weight monitoring systems such as Weigh-In-Motion (WIM) provided most effective enforcement solution to inspect more trucks efficiently (Cambridge Systematics, 2009).

The survey of state departments of transportation showed that states have been using combinations of enforcement techniques to achieve specific regional freight monitoring goals. Mobile enforcement teams or units and weigh-in-motion (WIM) are the most commonly used techniques (14 states out of 16 respondents). Traditional weigh stations (random and fixed schedule) with weight scales were also common; nine states (out of 16) were maintaining weigh stations 24 hours a day. Four states have implemented pre-pass check points and other strategies to reduce processing and traffic operations at checkpoints. One Canadian province reported using remote-controlled weigh stations. All types of monitoring for enforcement can also contribute data for system monitoring and traffic modeling.

The most challenging task to deter illegal overweigh trucks is to put sufficient enforcement efforts with limited resources. Without sufficient enforcement officials and WIM stations, no state can have a good estimate of the extent of overweight trucks operating with and without a permit. The few caught through enforcement cannot be extrapolated to indicate the extent of the problem. As illegal overweight trucks follow WIM operation schedule closely and avoid permanent weigh stations, mobile enforcement is critical. Moreover, it is also challenging to pick illegal overweight trucks based on visual observation as there are no distinct clue to suspect overweight trucks. Besides, on non-interstate highways, enforcement officers often face challenges to find a roadside space to scale suspected trucks.

6.3.2 Appropriate Time for Implementation of Higher Fee

Trucking stakeholders in a recent study in Virginia mentioned that "No time is good time" to business for implementation of higher permit fee (VTRC, 2008). As economy advances around good and bad periods, there is no appropriate time for implementation of higher fees considering global competitive market place. Such as when economy is growing, new fee might slow down the growth due to higher business operation cost. On the other hand, when economy is slowing down, new fee might extend the recession and have bitter impact on overall economy. That means, there will be always a reason to keep the fee at low level.

Despite this dilemma of appropriate time in economic cycles, several stakeholders expressed their concerns for deteriorating transportation infrastructure and initiatives must be taken to improve the situation. One stakeholder indicated that without healthy transportation system, SC business competitiveness will erode above time. At the same time, few stakeholders stated that pro-business regulation in South Carolina might not support any new user fee.

6.3.3 Prioritization of Infrastructure Investment

Revenue generated by increasing fees must be utilized to improve the infrastructure. South Carolina's trucking stakeholders had stated their preference on how additional revenue to be utilized if higher fees were collected from overweight trucks. None of stakeholders believe permit revenue should go to build new infrastructure rather to maintain existing infrastructure such as resurfacing, repair and so forth. When it was asked to identify key highways that should get priority for improve, stakeholders mentioned the improvement need of all types of highways from interstate to rural highways. Though there is no high priority, but rural highways was mentioned most which are lacking maintenance most. Stakeholders believe because of bad condition of rural pavement and bridges, businesses need to detour frequently.

One stakeholder stated that SCDOT has been constructing highways will less expensive materials due to funding shortage which will increase overall life-cycle cost for highways. Same stakeholder wants to see consideration of life-cycle cost in new infrastructure maintenance activities funded by permit fee revenue.

6.3.4 Revising Fee Structure- Current Practices

Though recommendations based on engineering studies would offer rational basis for setting a comprehensive overweight user-fee structure, eleven of the sixteen states responding to the survey of state DOTs reported that legislature and lobbyists were the main contributors to decisions on adjusting permit fees. In this research, comprehensive analysis was conducted to estimate tradeoff analysis to assist policy development.

Implementation of any new fee will face opposition from business and effective implementation strategies need to be developed to build consensus among stakeholders to ensure effectiveness of new policies. Though South Carolina stakeholders voiced their general consensus that SCDOT needs more resources to maintain infrastructure at a good condition, they do not have common view about overweight permit fee program.

According to the survey of state departments of transportation, the most common objectives of overweight fees were:

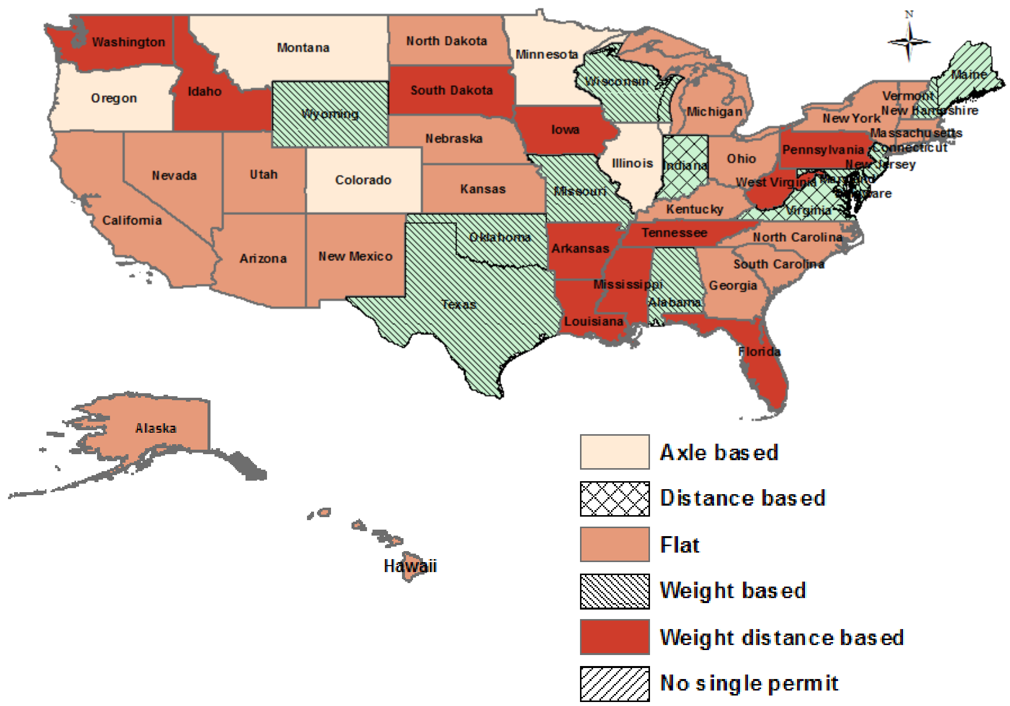
- to recover costs for infrastructure damage incurred accurately and
- to increase revenue for infrastructure maintenance programs.

Though all states want to generate revenue to compensate additional damage by overweight trucks, review of existing fee structures revealed wide inconsistencies among states. In this scenario, building consensus among stakeholders require to involve in an ongoing discuss to develop and execution of effective fee policies. Having higher permit fee may affect demand for overweight permits. Some business may decide to avoid states with higher permit fees (Bowlby et al., 2001) which will have negative impact on state economy. Early consideration and exploration of negative impacts of higher permit fee will guide policy makers to revise implementation strategies accordingly.

6.3.5 Regional Competition and Permit Structure Consistency

Regional competition is one of the biggest factor need to be addressed while formulating new fee policies. As all neighboring state are competing to attract more manufacturing plants, existing and new businesses might find other states more profitable if permit fee were increased. Though increasing fee is challenging in competitive regional business, without strong infrastructure, only low fee will not ensure competitive advantage of a state.

In most of cases, a single trip requires trucks to travel multiple states with different permit fee structures. Figure 21 shows the geographic proximities of states with the five types of single trip fee structures. Flat rates have appeared throughout the United States with particular prevalence in the southwest. Weight-based policies have emerged in central states.



Data sources: J.J Keller & Associates, Inc, 2011 and state departments of transportation

Figure 21 Single Trip Overweight Fee Structures in the US

Among South Carolina's neighbors, two other states have charged flat fees for regular overweight single trips. North Carolina charges $12 for a single overweight trip, compared to $30 in South Carolina and Georgia. Florida considers trip length and GVW to determine per trip fee ($0.27-$0.47 per mile). Tennessee also considers both distance and weight in its calculations. However, all neighboring states offer annual permits for flat fees ranging from $100 to $1000 (Table 29).

Table 29 Overweight Permit Fees from South Carolina's Neighbors

State	Single Permit Fee	Annual Permit Fee
South Carolina	$30	$100
Florida	$3.33 + $0.27-$0.47 per mile	*$240-$500
Georgia	$30	$150
North Carolina	$12	**$100, $200
Tennessee	$15 + $0.05 per ton-mile	***$500, $1000

*$240 for up to 95,000 pounds and $500 for up to 199,000 pounds,
** $100 for general overweight vehicles and $200 for mobile homes,
***$500 for up to 120,000 pounds and $1000 for 120,000 to 150,000lbs

Multiple stakeholders in South Carolina recommended developing collaborative efforts among neighboring states to harmonize the permit fee structures. As multi-state operations are very common for trucking companies, single fee structure will promote overweight business. If multiple states decide to implement more rationale fee structure with considerations of number of axle, axle configuration and axle load, trucking companies will have willingness to invest on fleets to comply with new policies. In this context, one stakeholder mentioned South Carolina should not establish itself as barrier state without considering consultation with neighboring states.

CHAPTER VII: CONCLUSIONS AND RECOMMENDATIONS

To generate revenue to maintain excessive pavement and bridge damage inflicted by overweight trucks, transportation policy makers need to match permitting structures and rates to the needs of transportation infrastructure. Engineering and economic analyses need to set rates for permit fees and fines to reduce the political influence and tying rates to infrastructure costs rather than administrative processes that represent a minor fraction of the total overweight truck damage. In the following sections, conclusions and recommendations are presented based on engineering and economic analyses performed in this research.

7.1 Conclusions

The largest loads on public road systems disproportionately inflict the largest damage on pavements and bridges. Pavement damage models showed overweight trucks reduce pavement service life exponentially, and current SCDOT pavement design standards do not include these heavy trucks. Besides charging overweight trucks for associated damage, it will be economical to include heavy loads in pavement design to minimize premature pavement maintenance or rehabilitation.

Analysis of bridge damage models indicated that bridge damage increase exponentially with increase in GVW. Preservation of bridges will require charging vehicle for associated damage or designing bridges to withstand higher weight trucks. Even though, SCDOT issues permits for overweight trucks, current fees do not recover the amount of imparted pavement and bridge damage.

Permitting rules and fee structures allowing overweight trucks are inconsistent from state to state. For shippers, this heterogeneous nature can confuse interstate overweight trucking operations along major corridors crossing several states, which suggests a need for coordination among neighboring states. Trucking industry representatives have indicated they would like to see coordination of fee structures among states in a region.

Five types of overweight permit fee have been implemented by state DOTs to recover pavement and bridge damage cost: flat, distance-based, weight-based, weight-distance-based and axle-based fee structures. Flat fees, which South Carolina has been administering, are most common but least fair in terms of collecting revenue. Comparative analysis of fee structures conducted in this research has shown relative performance of fee structures. Considering axle load, axle configuration and trip length in fee structure will be more appropriate to reflect imparted damages.

Selection of appropriate and responsible fee structure require involving diverse stakeholders related to overweight trucking business. Web survey responses have indicated that legislators and lobbyists, rather than engineering analysis of infrastructure damage costs, have played significant roles in setting overweight fees and fines in most states.

To generate sufficient revenue to recover the damage inflicted by overweight trucks, the primary challenge lies in selecting an appropriate permit fee that will enhance the financial viability of DOTs highway maintenance programs without unnecessary negative impacts on businesses and economy. A multiobjective model that considers both the objectives of public transportation agencies and overweight freight trucking companies is an important step in developing an effective fee policy. Applying the multiobjective optimization method, tradeoffs with two objective functions (minimize unpaid damage, and minimize permit fee) were generated for the purpose of aiding DMs in South Carolina to select a fee alternative based upon expected impacts from these two objectives. Bi-objective problem was solved for four most frequent fee structures to compare the relative tradeoffs of each fee structure. Tradeoff analysis of the weight based damage cost recovery fee showed that increasing the fee by $1 per ton on average for all overweight truck types from $7.4 per ton damage fee (at a 70% damage recovery scenario) would reduce unpaid damage cost of $16.9 million annually with a high elasticity of demand in South Carolina. Reduction in unpaid damage with an increase in the permit fee is attributed to additional revenue collected from all overweight trips and an overall reduction in overweight freight demand. Similarly, in the weight-distance based damage cost recovery fee type when per ton-mile damage cost recovery fee of 5.3 cents on average (at a 70% damage recovery scenario) is charged, the tradeoff value is $23.8 million. A tradeoff of $23.8 million means that increasing the fee by 1 cent per ton-mile on average from 5.3 cents per ton-mile would reduce unpaid damage by $23.8 million annually with a high elasticity of demand. Additional objectives reflecting interests of stakeholders who may be affected from any changes in the state policies can be included in the model to develop more comprehensive policy options.

7.2 Recommendations

This research has conducted comprehensive analysis to estimate pavement and bridge damage cost due to overweight trucks, and investigated stakeholder perspectives in South Carolina and current overweight practices among states. Based on the findings of this research, the following recommendations were made to improve SCDOT maintained overweight truck permit program:

1) Enforcement of illegal overweight trucks was identified as of the main concerns to South Carolina stakeholders. As illegal overweight truck operations is likely to increase if permit fee were increased, to ensure stakeholders' support for higher fee, SCDOT must develop accurate estimate of illegal overweight trips to design effective enforcement plan.

2) This research estimated per trip damage cost for additional load above legal weight limits by overweight trucks. Before implementation of any new fee structures, it is critical to determine the economic impacts of new policies to trucking companies that ship overweight goods. Therefore, an economic study should be conducted to identify economic vulnerability of different business type before implementation of new policies.

3) As stakeholders want to know how additional revenue from higher permit fees will be spent to improve transportation infrastructure, before implementation of new fee policies, it is also important for SCDOT to have a comprehensive financial plan for new permit program.

4) Few stakeholders expressed their concern about the current pavements and bridges design and construction standards. As pavement and bridge damage increase

exponentially with loads, increasing design standards will improve infrastructure service life as well as overall life cycle cost. SCDOT should review current design practices to optimize infrastructure life cycle cost.

5) As most accurate permit fee system will consider number of axle, axle spacing, axle load and trip length in permit fee calculation, it'll increase the administrative burden for SCDOT permit program. To ensure effective transition to new fee system, an audit should be conducted before and after implementation to identify issues in terms of additional manpower needs, ways to streamline services such as permit automation.

6) Online survey with DOTs revealed that in most of the states, legislators play the biggest role in setting permit fee for overweight trucks. As without engineering analysis, it's impossible for legislators to determine appropriate fees, SCDOT must establish a focus group consists for legislators, trucking company representatives and SCDOT engineers, and should meet periodically to discuss conflicting issues. Through this process, a consensus will emerge based on mutual understanding, which will serve well than a new policy through legislative process.

7) Accurate estimation of damage cost by overweight trucks depends on the accuracy of different overweight truck characteristic in South Carolina. In this research percentage of overweight trucks on SCDOT maintained highways was estimated based on one WIM station data. This estimate can be improved by compiling data from more WIM stations around the state. In addition, currently trucking companies do not report trip length for overweight trips. In this research, trip length was estimated based on 2004

SC economic census. As per trip damage cost is directly related to total miles of travel, SCDOT should keep track of overweight truck trip lengths which can be utilized to revise per trip permit fee.

8) As concern was voiced by trucking companies, SCDOT should work with neighboring states before revising current fee system and should consider neighboring states future plan. This way, SCDOT can ensure that new permit policies will not establish SC as a barrier state.

9) In the survey of state departments of transportation, 75% of respondents (12 out of 16) reported they have no set schedule for reviewing overweight fee policies. To ensure the timely revision of permit fees to adjust for inflation and any other policy issues, a sunset clause should be incorporated in a new policy. This clause will force policy makers to work at regular interval to adjust policies to adopt permit rules to evolving businesses scenarios and will gain support from more stakeholders.

APPENDICES

APPENDIX A

Multiobjective analysis methodology

In the context of freight transportation, conflicting objective criteria may include freight traffic flow, transportation cost, damage of infrastructure (e.g., pavement, bridge), and freight truck pollution. Multiobjective analysis consists of two paired stages: mathematics-based optimization stage and decision maker-driven decision stage (Ehrgott, 2005; Miettinen, 1999).

The goal of the optimization stage is to formulate multiobjective optimization problems (MOPs), i.e., mathematical programs with multiple objective functions, and find their solution sets (Ehrgott, 2005; Ehrgott and Wiecek, 2005). In multiple conflicting objectives scenario, there are infinitely many solutions which are equally good. While the solution set in the optimization sense can be clearly defined based on rigorous mathematical concepts (such as the Pareto optimality), the decision stage naturally involves a DM with subjective preferences, priorities, expectations and personal aspirations which are often not easily described. The differences between different efficient or Pareto optimal solutions or options, generated from solving optimization problems with multiple objectives, is that each solution is better in one objective but worse in another objective. The relative improvement of one objective over another objective is known as tradeoff. In general, a tradeoff between two objective functions at a Pareto point is the ratio between increase of one function and decrease of the other assuming that all other objective functions remain constant

From the perspective of a DM, the optimization stage of multiobjective analysis is only a preliminary step to select a final preferred decision which then constitutes the overall solution to the multiobjective model and, after translation into the real-life problem context, to the original decision-making problem (Miettinen, 1999). While the solution set in the optimization sense can be clearly defined based on rigorous mathematical concepts (such as the Pareto optimality), the decision stage naturally involves a DM with subjective preferences, priorities, expectations and personal aspirations which are often not easily described or readily articulated in terms of the chosen mathematical model. Hence, finding a final solution can still be quite difficult if DM's preferences are not completely modeled or known and if the numbers of potential candidates and objectives are too large to make use of existing enumeration or visualization techniques.

Of special interest to DMs performing the decision stage are tradeoffs associated with each Pareto-optimal outcome and a corresponding efficient decision. In general, a tradeoff between two objective functions at a Pareto point is the ratio between increase of one function and decrease of the other when moving from this Pareto point to a point in a small neighborhood assuming that all other objective functions remain constant. Additionally, if the size of the neighborhood approaches zero, the definition of the tradeoff is supplemented with a limit of the ratio. In any case, tradeoffs quantification is of great value to DMs and used in many multiobjective analysis procedures supporting decision making with multiple criteria. The typical steps involved in executing a multiobjective analysis are presented in Figure A.1 in the context of research problem presented in this paper. Illustrations of the steps are in the example below (Chankong and Haimes, 1983).

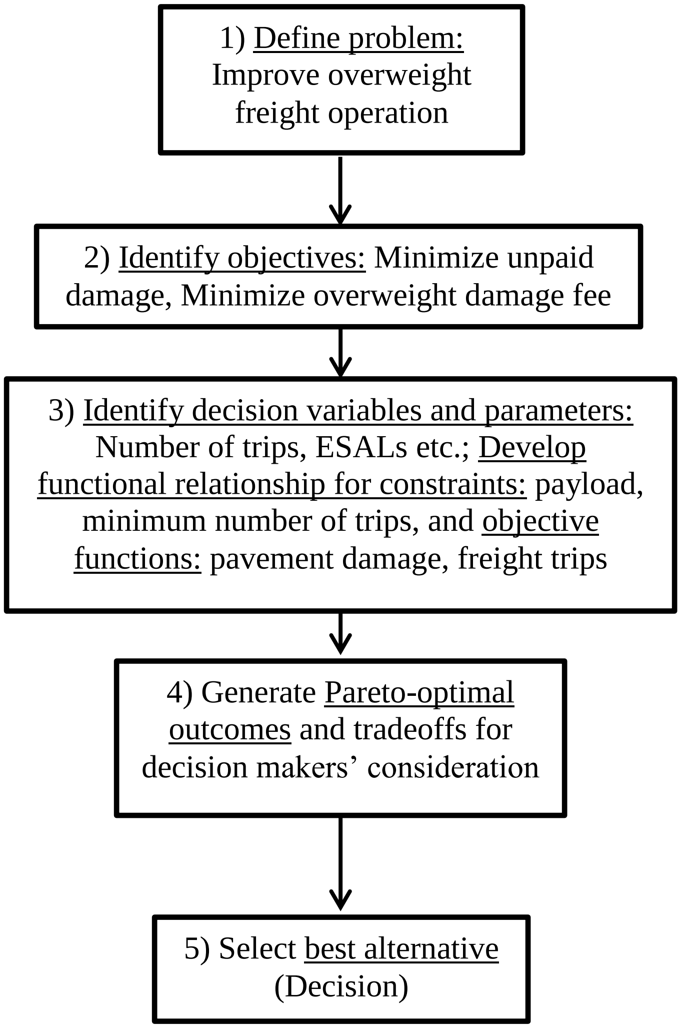


Figure A.1 Typical multiobjective analysis process

In the context of the freight traffic operation, a general MOP can be formulated as:

Minimize $\mathbf{f}(x_1, x_2, \ldots, x_n) = [f_1(x_1, x_2, \ldots, x_n), f_2(x_1, x_2, \ldots, x_n), \ldots, f_p(x_1, x_2, \ldots, x_n)]$

Subject to $\quad \mathbf{g}(x_1, x_2, \ldots, x_n) \leq \mathbf{0}$

$\mathbf{h}(x_1, x_2, \ldots, x_n) = \mathbf{0}$

$x_i \geq 0, \; i = 1,2, \ldots, n$

The problem involves n decision variables, x_i, $i = 1,2, \ldots, n$, and p scalar-valued conflicting objective functions , f_i , $i = 1,2, \ldots, p$, that make up the vector-valued function **f**. The variables represent unknown quantities such as the number of trips in each gross vehicle weight category, the unit load transportation cost, and others, while the functions model the longevity of pavements and bridges, maintenance requirements on pavements and bridges, freight trips, and transportation cost. The vectors **g** and **h** define the inequality constraints (such as the number of freight truck in each vehicle class) and equality constraints (such as the total overweight pay load), respectively.

There are two general classes of approaches to generating efficient solutions of MOPs: (a) scalarization, and (b) nonscalarizing methods (Ehrgott and Wiecek, 2005). Scalarization methods are used to transform the MOP to a single objective optimization problem (SOP). Among the nonscalarizing methods other optimality concepts than Pareto are used, a class of set-oriented methods including a variety of metaheuristics, in particular, genetic algorithms (Deb, 2001).

In this paper, the ε-constraint method, one of the most often applied scalarization techniques, is selected to carry out the optimization stage of the multiobjective analysis, because of its relative simplicity in controlling the objective functions while converting the MOP into an SOP. Epsilon (ε)-constraint method can be used in both linear and non-linear multiobjective optimization scenarios.

The advantage of the ε-constraint method is that if the analyst can determine upper and lower bounds for the objective functions values, then the original MOP can be converted into an SOP by moving all objective functions but one to the constraints. The right-hand-side values of these new constraints are given by the parameter ε that is selected by the analyst from the intervals constructed by the upper and lower bounds so that the resulting SOP is feasible (i.e., the original constraints together with the newly added constraints yield a nonempty set of feasible solutions). The objective function that is not moved to the constraints and remains as the objective function of the SOP is referred to as the primary objective.

In the ε-constraint method, the SOP assumes the following form:

Minimize $f_l(x_1, x_2, \ldots, x_n)$

Subject to $f_k(x_1, x_2, \ldots, x_n) \leq \varepsilon_k$ where k= 1, 2,…,l-1, l+1,….,p

$\mathbf{g}(x_1, x_2, \ldots, x_n) \leq \mathbf{0}$

$\mathbf{h}(x_1, x_2, \ldots, x_n) = \mathbf{0}$

$x_i \geq 0$, i = 1,2, . . . , n

Here, the l-th objective function is chosen as the primary objective to be minimized and the other objective functions generate the ε-constraints with predefined values of the parameter ε_k , k = 1,2, . . ., l-1, l+1, . . . , p, in the right-hand-side. The selection of ε_k depends on the analyst who may choose any value from the interval within which this SOP remains feasible. It is a well-known result that a unique optimal solution x* to this SOP is an efficient solution for the MOP and the image **f**(**x***) is Pareto-optimal for the MOP (Ehrgott, 2005; Ehrgott and Wiecek, 2005; Deb, 2001).

Let (f_k^{min}, f_k^{max}), k =1, 2,…,*l*-1, *l*+1,….,p, be the interval determined by the individual minimum and maximum value of the objective function f_k subject to the constraints of the original MOP. One way of choosing the parameter ε_k is as follows:

$$\varepsilon_k^t = f_{min} + t\,(f_{max} - f_{min}) / (r - 1)$$

where r is the desired number of different Pareto-optimal outcomes to be found and t = 1, 2,….., r-1.

As pareto-optimal points along a Pareto-optimal frontier are inexact indicators of optimal outcomes, tradeoff analysis is then used to yield ordered Pareto-optimal points based on a tradeoff measure. A tradeoff λ_{lk} between two objective functions *k* and *l* at an efficient solution x* can be calculated following the mathematical relationship (Chankong and Haimes, 1983):

$\lambda_{lk}(x^*) = \partial f_l \,/\, \partial f_k$, k=1, 2,…,*l*-1, *l*+1,….,p where λ_{lk} represents the amount of improvement of the primary objective function, ∂f_l, due to a unit deterioration in objective function ∂f_k, $k \neq l$, while all other objective functions remain constant. When the ε-constraint method is applied to MOPs, tradeoffs can be calculated as the dual variables (prices) associated with the ε constraints.

APPENDIX B

1) What state do you represent? *We will use this information to complement your responses to data we are gathering from state web sites.*

____

Freight Monitoring

2) What types of enforcement strategies does your state use to enforce truck weight limits on the road system?

a. 24-hour weigh stations □

b. Part-time weigh stations (regular operating schedule) □

c. Part-time weigh stations (random operating schedule) □

d. Mobile weigh equipment units or teams □

e. Weigh-in-motion (WIM) □

f. Pre-pass checkpoints □

g. Other: ____________________________________

3) How many teams or stations of the following does your state use to enforce truck weight limits on the road system? *Enter a number for each line.*

a. 24-hour weigh stations _____

b. Part-time weigh stations _____

c. Mobile weigh equipment units or teams _____

d. Weigh-in-motion (WIM) _____

(Standalone-not located near weigh stations)

e. Pre-pass checkpoints _____

(Standalone-not located near weigh stations)

f. Other: ________________________ _______________

4) What type of truck information does your state check at weigh stations?

Checked

a. Vehicle classification □

b. Number of axles □

c. Axle loads □

d. Axle spacing □

e. Gross vehicle weight □

f. Trip origin □

g. Trip destination □

5) Are data on the number of trucks checked for weight categorized by axle limits and gross vehicle weight limits? (ie. Is the number of trucks whose axle weights were checked recorded as well as the number of trucks whose gross vehicle weights were checked recorded?)

□ Yes □ No

6) Are data on the number or percentage of trucks exceeding weight limits categorized by axle limits and gross vehicle weight limits?

□ Yes □ No

If the answer to question 5) or 6) is no, skip to question 8).

7) How many trucks in calendar year 2010 fit in the following categories? Please enter either the absolute number of trucks or the percentage of all trucks. If the data are not readily available, who may we contact to obtain these data?

	Percentage or Number	Contact name	Contact email or phone
a. Trucks checked for axle loads	____________	______________	____
b. Trucks at or under legal axle weight	______	_____	______________
c. Permitted trucks with axle(s) overweight	______	______	________
d. Trucks with axle(s) overweight (no permit)	______	______	________
e. Gross vehicle weights checked	______	____________	______________
f. Trucks at or under legal gross vehicle weight	______	_____	_____
g. Permitted trucks over the gross vehicle weight limit	______	______	________
h. Trucks over gross vehicle weight limit (no permit)	______	______	_____

8) What is the percentage or number of trucks in calendar year 2010 for each of the following? If the data are not readily available, who may we contact to obtain these data?

Percentage or Number Contact name Contact email or phone

a. Trucks checked for gross vehicle or axle weight ___________ ______ ______

b. Trucks at or under weight limits ______ _____ _____

c. Trucks over gross vehicle or axle weight limit (no permit) _____ ______ ______

d. Permitted trucks over gross vehicle or axle weight limit _____ ______ ______

9) What, if any other vehicle information does your state check and/or keep records of at weigh stations? ____

10) Does your state keep records on fines issued for overweight violations?

□ Yes □ No

If the answer to question 10) is no, skip to question 12).

11) Is the severity of the overweight violations included in records on fines issued for overweight violations?

□ Yes □ No □ Do not know

12) Who may we contact about records on fines issued for overweight violations?

a. Name

b. Email or phone

Overweight Vehicles

13) How does your state handle trucks with overweight permits? *Check all that apply.*

- Checked for declared weight at weigh stations
- Checked for declared weight by weigh-in-motion units

- Checked for declared weight by mobile units
- Not checked by enforcement efforts
- Other _______________

14) Does your state keep records on permits issued for overweight vehicles?

□ Yes □ No

If the answer to question 14) is no, skip to question 16).

15) How many overweight permits were issued in calendar year 2010? _____

16) Does your state estimate how many overweight trucks (exceeding axle or gross vehicle weight) without permits are **not** caught by enforcement efforts?

□ Yes □ No □ Do not know

If the answer to question 16) is “do not know,” skip to question 0.

If the answer to question 16) is no, skip to question 20).

17) How many overweight trucks (exceeding axle or gross vehicle weight) without permits does your state estimate are **not** caught by enforcement efforts?

____

____

18) How does your state derive these estimates?

____

____

19) Who can we contact to learn about these estimates of overweight trucks not caught by enforcement efforts?

a. Name

b. Email or phone

Trucking Fee Structures

20) Who participates in determining the structure for overweight fees?

□ Advisory committee

□ Focus group

□ Legislature and lobbyists

□ Dedicated DOT department

□ Maintenance or engineering department of DOT

□ Business stakeholders

□ Other:____

21) Have the fee structures been reviewed on a set schedule?

□ Yes □ No

If the answer to question 21) is no, skip to question 23).

22) How frequently has the fee structure been reviewed?

□ ≤ 1 year

□ 2-3 years

□ 4-5 years

□ 6-7 years

□ 8-9 years

□ ≥ 10 years

23) When was the last revision of overweight fee structures performed?

Year:__________________________

24) Based on the last change in the overweight fee structure, what were the main factors in the decision? *Check all that apply.*

□ Reduce freight costs to encourage freight activity

□ Increase freight costs to discourage freight activity

□ Accurately recover costs for infrastructure damage incurred

□ Increase revenue for infrastructure maintenance program

□ Other:____

□ I do not know.

If the answer to question 24) is "I don't know," skip to question 27).

25) Has your state conducted an economic or engineering study for developing or reviewing the fee structure?

□ Yes □ No

If the answer to question 25) is no, skip to question 27).

26) How can we find this study or who can we contact about it?

____

____

____

27) Who can we contact to inquire about changes in the overweight fee structure?

a. Name ______________________________

b. Email or phone ______________________________

Trucking Fine Structures

28) Who participates in determining the structure for illegal and overweight fines?

□ Advisory committee

□ Focus group

□ Legislature and lobbyists

□ Dedicated DOT department

□ Maintenance or engineering department of DOT

□ Business stakeholders

□ Other:____

29) Have the fine structures been reviewed on a set schedule?

☐ Yes   ☐ No

If the answer to question 29) is no, skip to question 31).

30) How frequently has the fine structure been reviewed?

☐ ≤ 1 year

☐ 2-3 years

☐ 4-5 years

☐ 6-7 years

☐ 8-9 years

☐ ≥ 10 years

31) When was the last revision of illegal and overweight fine structures performed?

Year:______________________________

32) Based on the last change in the illegal and overweight fine structure, what were the main factors in the decision? *Check all that apply*.

☐ Discourage illegal and overweight freight activity

☐ Accurately recover costs for infrastructure damage incurred

☐ Increase revenue for infrastructure maintenance program

☐ Other:____

☐ I do not know.

If the answer to question 32) is “I don’t know,” skip to question 35).

33) Has your state conducted an economic or engineering study for developing or reviewing the fine structure?

□ Yes □ No

If the answer to question 33) is no, skip to question 35).

34) How can we find this study or who can we contact about it?

____

____

____

35) Who can we contact to inquire about changes in the illegal and overweight fine structure?

a. Name ________________________________

b. Email or phone ________________________________

Surface freight in the next 10 years

36) How does your state expect its magnitude and distribution of freight volume by mode to change in the next 10 years?

____

____

37) How does your state expect demand for designated trucking routes in your state to change in the next 10 years? Include changes due to generators such as ports, airports, distribution centers or specific industries, as well as any other changes your state foresees.

____

____

38) How is changing demand affecting freight and infrastructure planning in your state? For example, will your state make changes to designated trucking routes, implement highway technologies, facilitate mode shift, or take other measures?

____

____

39) What is your state doing to increase freight capacity? (check box options will be: not considered, considered but no implemented, implemented, implemented but since ceased)

a. Creating/extending highway corridors or routes	□	□	□	□
b. Adding capacity to existing highway corridors	□	□	□	□
c. Adding truck-only lanes	□	□	□	□
d. Adding truck-only toll lanes (TOT)	□	□	□	□
e. Improving highway access or capacity to ports	□	□	□	□
f. Improving highway access or capacity to airports	□	□	□	□
g. Improving highway access to rail	□	□	□	□

h. Improving rail access or capacity to ports	□	□	□	□
i. Improving rail access or capacity to airports	□	□	□	□
j. Upgrading functionally obsolete infrastructure (e.g., weight-restricted bridges)	□	□	□	□
k. Easing freight-related restrictions (e.g. increasing weight limits)	□	□	□	□
l. Improving regulation efficiency (e.g. implementing weigh-in-motion technology)	□	□	□	□
m. Introducing mandatory freight-traffic bypasses	□	□	□	□

n. Other: ____

40) If you have any further comments about freight planning in your state, this survey, or this study, please include them here.

____

____

Thank you for your time completing this survey. If there is anyone else who might contribute further to this study please forward the survey to them.

APPENDIX C

Survey Response Summary Tables

Table C.1 Types of Enforcement strategies

Enforcement Strategies	States/Provinces
Mobile weigh equipment units or teams	14
Weigh-in-motion (WIM)	14
Part-time weigh stations (random operating schedule)	11
Part-time weigh stations (regular operating schedule)	7
24-hour weigh stations	9
Pre-pass checkpoints	4

Table C.2 Number of Enforcement stations/ Teams

Enforcement type	Number of stations/teams				
	Minimum	Mean	Median	Maximum	Standard Deviation
24-hour weigh stations	0	2	1	8	3
Part-time weigh stations	1	16	9	80	19
Mobile weigh equipment units or teams	0	36	27	140	40
Weigh-in-motion (WIM) (Standalone-not located near weigh stations)	0	12	4	100	25
Pre-pass checkpoints (Standalone-not located near weigh stations)	0	1	0	8	2

Table C.3 Type of information collected by Enforcement

Type of information collected	States/ Provinces
Axle loads	16
Axle spacing	16
Gross vehicle weight	16
Number of axles	15
Vehicle classification	13
Trip origin	11
Trip destination	11
Other information: Tax, Registration, Safety compliance, Driver hours of service, dangerous goods, permit conditions, load securement, safety equipment, mechanical condition, insurance, Equipment, log books, equipment, DOT number etc.	

Table C.4 Participants involved in determining overweight permit fee and violation fine

Participants	Overweight fee	Illegal Overweight fine
Legislature and lobbyists	11	12
Dedicated DOT department	5	4
Maintenance or engineering department of DOT	4	2
Business stakeholders	4	1
Advisory committee	2	4
Focus group	1	0
Other		*4

* State Police, Judicial branch, Special Committee

Table C.5 Last revision of Overweight Permit fee and Violation fine structure

Last revision	Overweight fee	Illegal Overweight fine
Last Year	1	0
1-5 Years ago	5	2
6-10 Years ago	3	2
11-15 Years ago	2	2
More than 15 Years ago	5	4

Table C.6 Factors considered in Overweight fee and violation fine setting

Factors	Overweight fee	Illegal Overweight fine
Discourage illegal and overweight freight activity	-	6
Do not know	7	4
Accurately recover costs for infrastructure damage incurred	4	1
Increase revenue for infrastructure maintenance program	2	1
Other	*5	**2
*To cover increased administrative costs, Ensure that the overweight permit program is not subsidized by taxpayers, To bring fees closer to surrounding states ,Deter the operation of overweight vehicles		
** Public safety, Allowing 80,000 lbs on part of other highways		

Strategies to improve freight capacity:

1 Creating/extending highway corridors or routes
2 Adding capacity to existing highway corridors
3 Adding truck-only lanes
4 Adding truck-only toll lanes (TOT)
5 Improving highway access or capacity to ports
6 Improving highway access or capacity to airports
7 Improving highway access to rail
8 Improving rail access or capacity to ports
9 Improving rail access or capacity to airports
10 Upgrading functionally obsolete infrastructure (e.g., weight-restricted bridges)
11 Easing freight-related restrictions (e.g. increasing weight limits)
12 Improving regulation efficiency (e.g. implementing weigh-in-motion technology)
13 Introducing mandatory freight-traffic bypasses

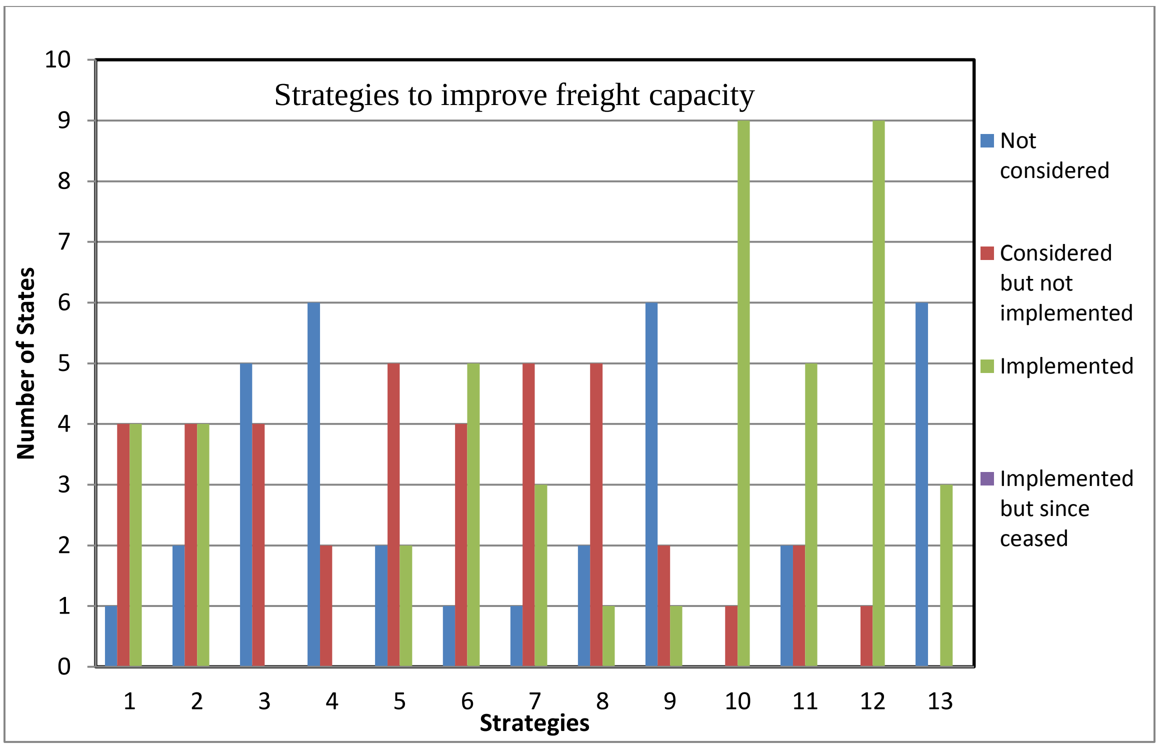
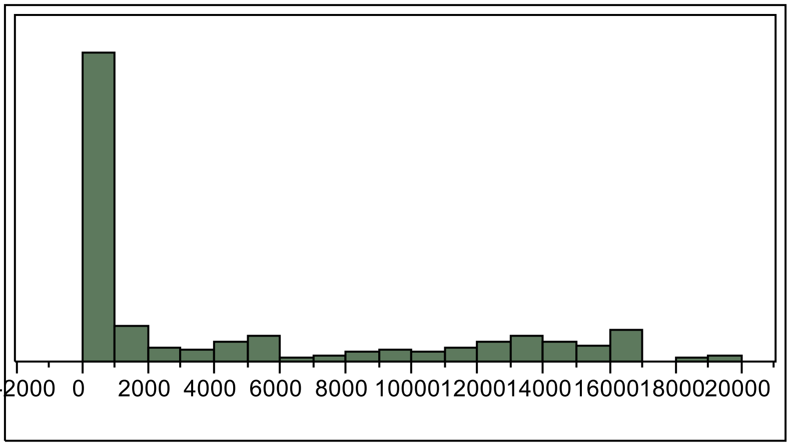


Figure C.1 Strategies to improve freight capacity

APPENDIX D

Distributions
AvgDlyTrkLds2011_ Rural (1/2)



Quantiles

100.0%	maximum	19728.9
99.5%		19336.6
97.5%		16576
90.0%		14813.2
85%		13145.5
75.0%	quartile	9464.84
50.0%	median	839.508
25.0%	quartile	358.36
10.0%		84.7363
2.5%		5.94517
0.5%		1.73059
0.0%	minimum	1.73059

Summary Statistics

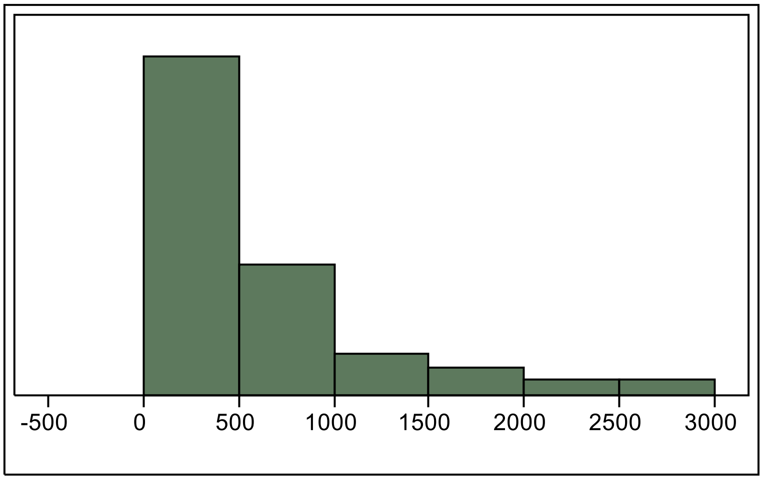
Mean	4529.3599
Std Dev	5869.9871
Std Err Mean	274.28648
Upper 95% Mean	5068.379
Lower 95% Mean	3990.3407
N	458

Custom Quantiles

Quantiles

Quantile	Estimate	Lower 95%	Upper 95%	Actual Coverage
85%	13145.5	12154	14054.1	95.06

Distributions
AvgDlyTrkLds2011_Rural_3Distributions
AvgDlyTrkLds2011



Quantiles

100.0%	maximum	2926.26
99.5%		2926.26
97.5%		2870.05
90.0%		1737.37
75.0%	quartile	679.122
50.0%	median	276.037
25.0%	quartile	176.386
10.0%		34.6934
2.5%		3.42195
0.5%		2.48619
0.0%	minimum	2.48619

Summary Statistics

Mean	574.00089
Std Dev	664.38307
Std Err Mean	101.31747
Upper 95% Mean	778.46781
Lower 95% Mean	369.53396
N	43

Custom Quantiles

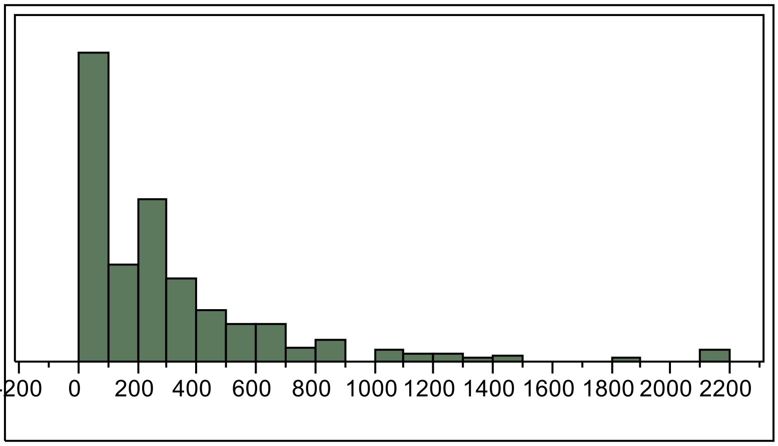
Quantiles

Quantile	Estimate	Lower 95%	Upper 95%	Actual Coverage
85%	1210.71	679.122	2926.26	95.03

Smoothed Empirical Likelihood Quantiles

Quantile	Estimate	Lower 95%	Upper 95%
85%	1137.03	672.102	1970.77

Distributions
AvgDlyTrkLds2011_Rural_5_6



Quantiles

100.0%	maximum	2150.58
99.5%		2150.58
97.5%		1230.41
90.0%		668.614
75.0%	quartile	371.483
50.0%	median	211.167
25.0%	quartile	55.3733
10.0%		10.2247
2.5%		1.1453
0.5%		0.28013
0.0%	minimum	0.28013

Summary Statistics

Mean	285.12592
Std Dev	348.95414
Std Err Mean	14.825641
Upper 95% Mean	314.24737
Lower 95% Mean	256.00446
N	554

Custom Quantiles

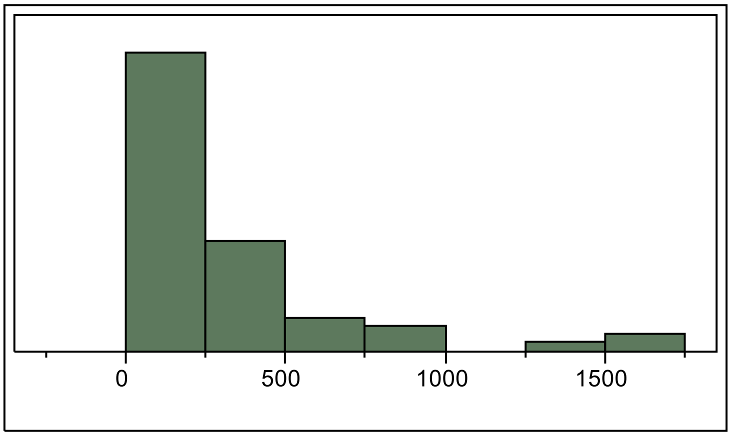
Quantiles

Quantile	Estimate	Lower 95%	Upper 95%	Actual Coverage
85%	569.293	480.191	607.31	95.06

Smoothed Empirical Likelihood Quantiles

Quantile	Estimate	Lower 95%	Upper 95%
85%	568.184	483.693	608.228

Distributions
AvgDlyTrkLds2011_Rural_7



Quantiles

100.0%	maximum	1598.24
99.5%		1598.24
97.5%		1598.24
90.0%		749.709
75.0%	quartile	339.607
50.0%	median	154.095
25.0%	quartile	30.3163
10.0%		4.44003
2.5%		0.47387
0.5%		0.47387
0.0%	minimum	0.47387

Summary Statistics

Mean	275.88802
Std Dev	373.40144
Std Err Mean	47.42203
Upper 95% Mean	370.71423
Lower 95% Mean	181.06181
N	62

Custom Quantiles

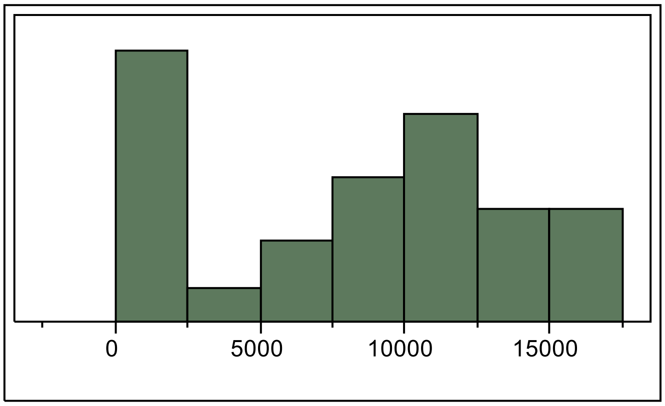
Quantiles

Quantile	Estimate	Lower 95%	Upper 95%	Actual Coverage
85%	641.497	396.194	985.493	95.01

Smoothed Empirical Likelihood Quantiles

Quantile	Estimate	Lower 95%	Upper 95%
85%	580.455	359.876	806.878

Distributions
AvgDlyTrkLds2011_Urban_11



Quantiles

100.0%	maximum	17075.2
99.5%		17075.2
97.5%		17075.2
90.0%		15758.8
75.0%	quartile	12032.4
50.0%	median	9297.73
25.0%	quartile	646.97
10.0%		39.3294
2.5%		27.762
0.5%		14.9771
0.0%	minimum	14.9771

Summary Statistics

Mean	8101.2569
Std Dev	5826.4013
Std Err Mean	752.18517
Upper 95% Mean	9606.3759
Lower 95% Mean	6596.1378
N	60

Custom Quantiles

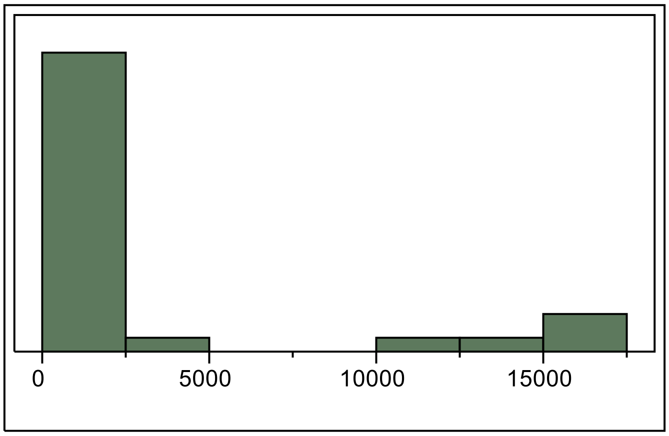
Quantiles

Quantile	Estimate	Lower 95%	Upper 95%	Actual Coverage
85%	14083.5	12103.6	16839.2	95.60

Smoothed Empirical Likelihood Quantiles

Quantile	Estimate	Lower 95%	Upper 95%
85%	14381.9	13164.9	15913.5

Distributions
AvgDlyTrkLds2011_Urban_12



Quantiles

100.0%	maximum	15957.8
99.5%		15957.8
97.5%		15957.8
90.0%		15514.7
75.0%	quartile	1789.12
50.0%	median	586.501
25.0%	quartile	483.744
10.0%		254.649
2.5%		254.649
0.5%		254.649
0.0%	minimum	254.649

Summary Statistics

Mean	2978.114
Std Dev	5189.352
Std Err Mean	932.03514
Upper 95% Mean	4881.5837
Lower 95% Mean	1074.6443
N	31

Custom Quantiles

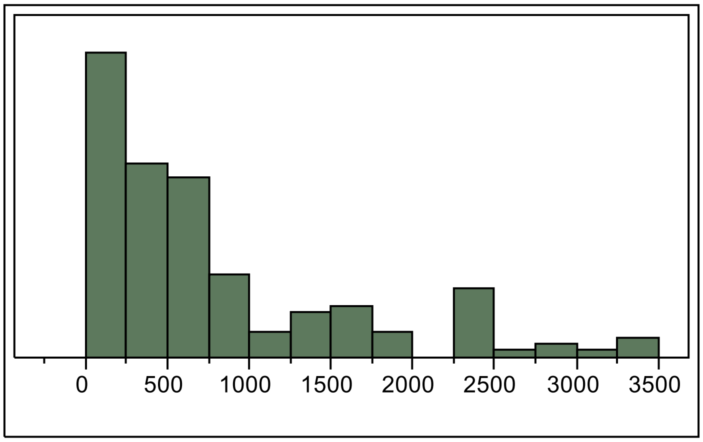
Quantiles

Quantile	Estimate	Lower 95%	Upper 95%	Actual Coverage
85%	10869	1654.92	15957.8	95.94

Smoothed Empirical Likelihood Quantiles

Quantile	Estimate	Lower 95%	Upper 95%
85%	4474.94	1491.51	15861

Distributions
AvgDlyTrkLds2011_Urban_14



Quantiles

100.0%	maximum	3421.33
99.5%		3421.33
97.5%		3117.68
90.0%		2280.78
75.0%	quartile	1007.34
50.0%	median	527.061
25.0%	quartile	191.513
10.0%		72.9499
2.5%		1.35991
0.5%		0.91406
0.0%	minimum	0.91406

Summary Statistics

Mean	771.53214
Std Dev	815.39851
Std Err Mean	63.86694
Upper 95% Mean	897.65119
Lower 95% Mean	645.41308
N	163

Custom Quantiles

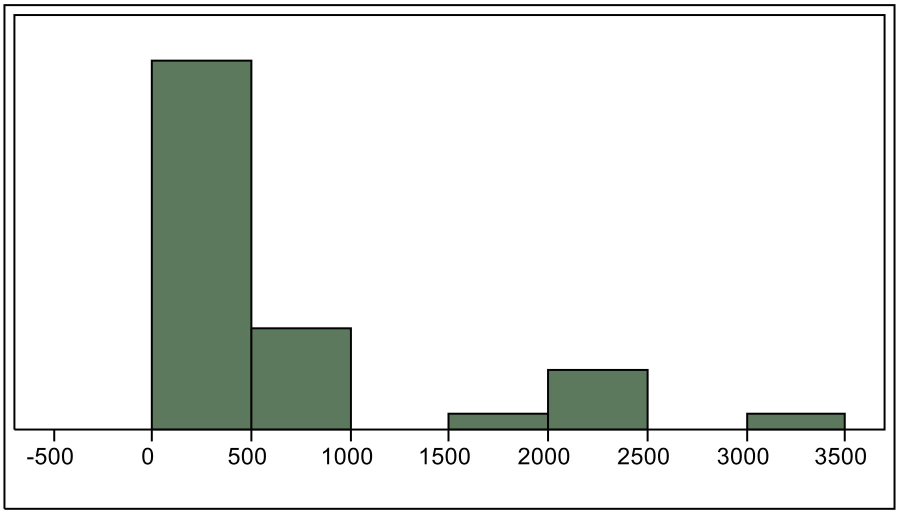
Quantiles

Quantile	Estimate	Lower 95%	Upper 95%	Actual Coverage
85%	1701.8	1380.43	2290.3	95.27

Smoothed Empirical Likelihood Quantiles

Quantile	Estimate	Lower 95%	Upper 95%
85%	1718.92	1386.38	2225.16

Distributions
AvgDlyTrkLds2011_Urban_16



Quantiles

100.0%	maximum	3136.28
99.5%		3136.28
97.5%		3136.28
90.0%		2364.09
75.0%	quartile	717.856
50.0%	median	291.992
25.0%	quartile	50.1013
10.0%		7.78063
2.5%		0.77979
0.5%		0.77979
0.0%	minimum	0.77979

Summary Statistics

Mean	580.4511
Std Dev	826.73558
Std Err Mean	132.38364
Upper 95% Mean	848.44777
Lower 95% Mean	312.45442
N	39

Custom Quantiles

Quantiles

Quantile	Estimate	Lower 95%	Upper 95%	Actual Coverage
85%	1942.91	531.755	2364.09	96.11

Smoothed Empirical Likelihood Quantiles

Quantile	Estimate	Lower 95%	Upper 95%
85%	1247.82	616.892	2374.61

APPENDIX E

AXLE BASED FEE MODELS

Elasticity -1.5

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;

!Fee Constraint (minimize fee, 2nd objective);
f2*0.1712+f3s*0.0167+f3c*0.0529+f4s*0.0003+f4c*0.0245+f5*0.7129
+0.0106*(f61*0.14+f62*0.32+f63*0.54)+0.0107*(f71*0.01+f72*0.03+f7
3*0.07+f74*0.13+f75*0.76)+0.0002*(f81*0.01+f82*0.05+f83*0.03+f84*
0.1+f85*0.81)<=f; !f, epsilon value;

!Current Trip Frequency;
n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;

n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;

!Revised Trip Frequency;
n21= @if (n2*(1+1.5*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+1.5*(30-f2)/30));
n3s1= @if (n3s*(1+1.5*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+1.5*(30-f3s)/30));
n3c1= @if (n3c*(1+1.5*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+1.5*(30-f3c)/30));

n4s1= @if (n4s*(1+1.5*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+1.5*(30-f4s)/30));
n4c1= @if (n4c*(1+1.5*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+1.5*(30-f4c)/30));
n51= @if (n5*(1+1.5*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+1.5*(30-f5)/30));

n611= @if (0.14*n6*(1+1.5*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+1.5*(30-f61)/30));
n621= @if (0.32*n6*(1+1.5*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+1.5*(30-f62)/30));
n631= @if (0.54*n6*(1+1.5*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+1.5*(30-f63)/30));
```

```
n711= @if (0.01*n7*(1+1.5*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+1.5*(30-f71)/30));
n721= @if (0.03*n7*(1+1.5*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+1.5*(30-f72)/30));
n731= @if (0.07*n7*(1+1.5*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+1.5*(30-f73)/30));
n741= @if (0.13*n7*(1+1.5*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+1.5*(30-f74)/30));
n751= @if (0.76*n7*(1+1.5*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+1.5*(30-f75)/30));

n811= @if (0.01*n8*(1+1.5*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+1.5*(30-f81)/30));
n821= @if (0.05*n8*(1+1.5*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+1.5*(30-f82)/30));
n831= @if (0.03*n8*(1+1.5*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+1.5*(30-f83)/30));
n841= @if (0.1*n8*(1+1.5*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+1.5*(30-f84)/30));
n851= @if (0.81*n8*(1+1.5*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+1.5*(30-f85)/30));

!Minimum Trip Frequency;
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0;
n711>=0; n721>=0; n731>=0; n741>=0; n751>=0;
n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;

x<=1; !recovery Upper Limit;
x>=0; !recovery Lower Limit;

!Permit Fee at x% recovery;
f2= 24.19 *x+10;
f3s= 14.58*x+10;
f3c= 37.53*x+10;

f4s= 27.42*x+10;
f4c= 90.80*x+10;
f5= 61.40*x+10;

f61= 29.16*x+10;
f62= 67.99*x+10;
f63= 120.61*x+10;

f71= 18.05*x+10;
f72= 40.45*x+10;
f73= 71.23*x+10;
f74= 112.20*x+10;
```

```
f75= 164.83*x+10;

f81= 13.84*x+10;
f82= 30.70*x+10;
f83= 56.46*x+10;
f84= 85.72*x+10;
f85= 126.24*x+10;

!Maximum Permit Fee;
f12= 24.19 +10;
f13s= 14.58+10;
f13c= 37.53+10;

f14s= 27.42+10;
f14c= 90.80+10;
f15= 61.40+10;

f161= 29.16+10;
f162= 67.99+10;
f163= 120.61+10;

f171= 18.05+10;
f172= 40.45+10;
f173= 71.23+10;
f174= 112.20+10;
f175= 164.83+10;

f181= 13.84+10;
f182= 30.70+10;
f183= 56.46+10;
f184= 85.72+10;
f185= 126.24+10;

END
:
```

Elasticity -1.0

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;

!Fee constraint (minimize fee, 2nd objective);
f2*0.1712+f3s*0.0167+f3c*0.0529+f4s*0.0003+f4c*0.0245+f5*0.7129
```

```
+0.0106*(f61*0.14+f62*0.32+f63*0.54)+0.0107*(f71*0.01+f72*0.03+f7
3*0.07+f74*0.13+f75*0.76)+0.0002*(f81*0.01+f82*0.05+f83*0.03+f84*
0.1+f85*0.81)<=f; !f, epsilon value;

!Current Trip Frequency;

n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;

n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;

!Revised Trip Frequency;
n21= @if (n2*(1+1.0*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+1.0*(30-f2)/30));
n3s1= @if (n3s*(1+1.0*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+1.0*(30-f3s)/30));
n3c1= @if (n3c*(1+1.0*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+1.0*(30-f3c)/30));

n4s1= @if (n4s*(1+1.0*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+1.0*(30-f4s)/30));
n4c1= @if (n4c*(1+1.0*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+1.0*(30-f4c)/30));
n51= @if (n5*(1+1.0*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+1.0*(30-f5)/30));

n611= @if (0.14*n6*(1+1.0*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+1.0*(30-f61)/30));
n621= @if (0.32*n6*(1+1.0*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+1.0*(30-f62)/30));
n631= @if (0.54*n6*(1+1.0*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+1.0*(30-f63)/30));

n711= @if (0.01*n7*(1+1.0*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+1.0*(30-f71)/30));
n721= @if (0.03*n7*(1+1.0*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+1.0*(30-f72)/30));
n731= @if (0.07*n7*(1+1.0*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+1.0*(30-f73)/30));
n741= @if (0.13*n7*(1+1.0*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+1.0*(30-f74)/30));
n751= @if (0.76*n7*(1+1.0*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+1.0*(30-f75)/30));

n811= @if (0.01*n8*(1+1.0*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+1.0*(30-f81)/30));
```

```
n821= @if (0.05*n8*(1+1.0*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+1.0*(30-f82)/30));
n831= @if (0.03*n8*(1+1.0*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+1.0*(30-f83)/30));
n841= @if (0.1*n8*(1+1.0*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+1.0*(30-f84)/30));
n851= @if (0.81*n8*(1+1.0*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+1.0*(30-f85)/30));

!Minimum Trip Frequency;
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0;
n711>=0; n721>=0; n731>=0; n741>=0; n751>=0;
n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;

x<=1; !recovery upper limit;

x>=0; !recovery lower limit;

!Permit Fee at x% recovery;
f2= 24.19 *x+10;
f3s= 14.58*x+10;
f3c= 37.53*x+10;

f4s= 27.42*x+10;
f4c= 90.80*x+10;
f5= 61.40*x+10;

f61= 29.16*x+10;
f62= 67.99*x+10;
f63= 120.61*x+10;

f71= 18.05*x+10;
f72= 40.45*x+10;
f73= 71.23*x+10;
f74= 112.20*x+10;
f75= 164.83*x+10;

f81= 13.84*x+10;
f82= 30.70*x+10;
f83= 56.46*x+10;
f84= 85.72*x+10;
f85= 126.24*x+10;

!Maximum Permit Fee;
f12= 24.19 +10;
f13s= 14.58+10;
f13c= 37.53+10;
f14s= 27.42+10;
```

```
f14c= 90.80+10;
f15= 61.40+10;

f161= 29.16+10;
f162= 67.99+10;
f163= 120.61+10;

f171= 18.05+10;
f172= 40.45+10;
f173= 71.23+10;
f174= 112.20+10;
f175= 164.83+10;

f181= 13.84+10;
f182= 30.70+10;
f183= 56.46+10;
f184= 85.72+10;
f185= 126.24+10;

END
:
```

Elasticity -0.5

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;

!Fee constraint (minimize fee, 2nd objective);
!x<=1;
f2*0.1712+f3s*0.0167+f3c*0.0529+f4s*0.0003+f4c*0.0245+f5*0.7129
+0.0106*(f61*0.14+f62*0.32+f63*0.54)+0.0107*(f71*0.01+f72*0.03+f7
3*0.07+f74*0.13+f75*0.76)+0.0002*(f81*0.01+f82*0.05+f83*0.03+f84*
0.1+f85*0.81)<=f; !f, epsilon value;

!Current Trip Frequency;
n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;

n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;

!Revised Trip Frequency;
n21= @if (n2*(1+0.5*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+0.5*(30-f2)/30));
```

```
n3s1= @if (n3s*(1+0.5*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+0.5*(30-f3s)/30));
n3c1= @if (n3c*(1+0.5*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+0.5*(30-f3c)/30));

n4s1= @if (n4s*(1+0.5*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+0.5*(30-f4s)/30));
n4c1= @if (n4c*(1+0.5*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+0.5*(30-f4c)/30));
n51= @if (n5*(1+0.5*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+0.5*(30-f5)/30));

n611= @if (0.14*n6*(1+0.5*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+0.5*(30-f61)/30));
n621= @if (0.32*n6*(1+0.5*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+0.5*(30-f62)/30));
n631= @if (0.54*n6*(1+0.5*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+0.5*(30-f63)/30));

n711= @if (0.01*n7*(1+0.5*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+0.5*(30-f71)/30));
n721= @if (0.03*n7*(1+0.5*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+0.5*(30-f72)/30));
n731= @if (0.07*n7*(1+0.5*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+0.5*(30-f73)/30));
n741= @if (0.13*n7*(1+0.5*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+0.5*(30-f74)/30));
n751= @if (0.76*n7*(1+0.5*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+0.5*(30-f75)/30));

n811= @if (0.01*n8*(1+0.5*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+0.5*(30-f81)/30));
n821= @if (0.05*n8*(1+0.5*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+0.5*(30-f82)/30));
n831= @if (0.03*n8*(1+0.5*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+0.5*(30-f83)/30));
n841= @if (0.1*n8*(1+0.5*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+0.5*(30-f84)/30));
n851= @if (0.81*n8*(1+0.5*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+0.5*(30-f85)/30));

!Minimum Trip Frequency;
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0;
n711>=0; n721>=0; n731>=0; n741>=0; n751>=0;
n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;

x<=1; !recovery upper limit;
```

```
x>=0; !recovery lower limit;

!Permit Fee at x% recovery;
f2= 24.19 *x+10;
f3s= 14.58*x+10;
f3c= 37.53*x+10;

f4s= 27.42*x+10;
f4c= 90.80*x+10;
f5= 61.40*x+10;

f61= 29.16*x+10;
f62= 67.99*x+10;
f63= 120.61*x+10;

f71= 18.05*x+10;
f72= 40.45*x+10;
f73= 71.23*x+10;
f74= 112.20*x+10;
f75= 164.83*x+10;

f81= 13.84*x+10;
f82= 30.70*x+10;
f83= 56.46*x+10;
f84= 85.72*x+10;
f85= 126.24*x+10;

!Maximum Permit Fee;
f12= 24.19 +10;
f13s= 14.58+10;
f13c= 37.53+10;

f14s= 27.42+10;
f14c= 90.80+10;
f15= 61.40+10;

f161= 29.16+10;
f162= 67.99+10;
f163= 120.61+10;

f171= 18.05+10;
f172= 40.45+10;
f173= 71.23+10;
f174= 112.20+10;
f175= 164.83+10;

f181= 13.84+10;
f182= 30.70+10;
f183= 56.46+10;
```

```
f184= 85.72+10;
f185= 126.24+10;
END
:
```

FLAT FEE BASED MODELS
Elasticity -1.5

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;

!Fee Constraint (minimize fee, 2nd objective);
f2<=f; !f, epsilon value;


!Current Trip Frequency;
n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;

n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;

!Revised Trip Frequency;
n21= @if (n2*(1+1.5*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+1.5*(30-f2)/30));
n3s1= @if (n3s*(1+1.5*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+1.5*(30-f3s)/30));
n3c1= @if (n3c*(1+1.5*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+1.5*(30-f3c)/30));

n4s1= @if (n4s*(1+1.5*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+1.5*(30-f4s)/30));
n4c1= @if (n4c*(1+1.5*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+1.5*(30-f4c)/30));
n51= @if (n5*(1+1.5*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+1.5*(30-f5)/30));

n611= @if (0.14*n6*(1+1.5*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+1.5*(30-f61)/30));
n621= @if (0.32*n6*(1+1.5*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+1.5*(30-f62)/30));
n631= @if (0.54*n6*(1+1.5*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+1.5*(30-f63)/30));
```

```
n711= @if (0.01*n7*(1+1.5*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+1.5*(30-f71)/30));
n721= @if (0.03*n7*(1+1.5*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+1.5*(30-f72)/30));
n731= @if (0.07*n7*(1+1.5*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+1.5*(30-f73)/30));
n741= @if (0.13*n7*(1+1.5*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+1.5*(30-f74)/30));
n751= @if (0.76*n7*(1+1.5*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+1.5*(30-f75)/30));

n811= @if (0.01*n8*(1+1.5*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+1.5*(30-f81)/30));
n821= @if (0.05*n8*(1+1.5*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+1.5*(30-f82)/30));
n831= @if (0.03*n8*(1+1.5*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+1.5*(30-f83)/30));
n841= @if (0.1*n8*(1+1.5*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+1.5*(30-f84)/30));
n851= @if (0.81*n8*(1+1.5*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+1.5*(30-f85)/30));

!Minimum Trip Frequency;
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0;
n711>=0; n721>=0; n731>=0; n741>=0; n751>=0;
n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;

x<=1; !recovery upper limit;

x>=0; !recovery lower limit;

!Permit Fee at x% recovery;
f2= 54.93 *x+10;
f3s= 54.93*x+10;
f3c= 54.93*x+10;

f4s= 54.93*x+10;
f4c= 54.93*x+10;
f5= 54.93*x+10;

f61= 54.93*x+10;
f62= 54.93*x+10;
f63= 54.93*x+10;

f71= 54.93*x+10;
f72= 54.93*x+10;
f73= 54.93*x+10;
f74= 54.93*x+10;
```

```
f75= 54.93*x+10;

f81= 54.93*x+10;
f82= 54.93*x+10;
f83= 54.93*x+10;
f84= 54.93*x+10;
f85= 54.93*x+10;

!Maximum Permit Fee;
f12= 54.93+10;
f13s= 54.93+10;
f13c= 54.93+10;

f14s= 54.93+10;
f14c= 54.93+10;
f15= 54.93+10;

f161= 54.93+10;
f162= 54.93+10;
f163= 54.93+10;

f171= 54.93+10;
f172= 54.93+10;
f173= 54.93+10;
f174= 54.93+10;
f175= 54.93+10;

f181= 54.93+10;
f182= 54.93+10;
f183= 54.93+10;
f184= 54.93+10;
f185= 54.93+10;
END
:
```

Elasticity -1.0

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;

!Fee Constraint (minimize fee, 2nd objective);
f2<=f; !f, epsilon value;

!Current Trip Frequency;
n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;
```

```
n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;
!Revised Trip Frequency;
n21= @if (n2*(1+1.0*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+1.0*(30-f2)/30));
n3s1= @if (n3s*(1+1.0*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+1.0*(30-f3s)/30));
n3c1= @if (n3c*(1+1.0*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+1.0*(30-f3c)/30));

n4s1= @if (n4s*(1+1.0*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+1.0*(30-f4s)/30));
n4c1= @if (n4c*(1+1.0*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+1.0*(30-f4c)/30));
n51= @if (n5*(1+1.0*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+1.0*(30-f5)/30));

n611= @if (0.14*n6*(1+1.0*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+1.0*(30-f61)/30));
n621= @if (0.32*n6*(1+1.0*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+1.0*(30-f62)/30));
n631= @if (0.54*n6*(1+1.0*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+1.0*(30-f63)/30));

n711= @if (0.01*n7*(1+1.0*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+1.0*(30-f71)/30));
n721= @if (0.03*n7*(1+1.0*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+1.0*(30-f72)/30));
n731= @if (0.07*n7*(1+1.0*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+1.0*(30-f73)/30));
n741= @if (0.13*n7*(1+1.0*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+1.0*(30-f74)/30));
n751= @if (0.76*n7*(1+1.0*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+1.0*(30-f75)/30));

n811= @if (0.01*n8*(1+1.0*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+1.0*(30-f81)/30));
n821= @if (0.05*n8*(1+1.0*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+1.0*(30-f82)/30));
n831= @if (0.03*n8*(1+1.0*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+1.0*(30-f83)/30));
n841= @if (0.1*n8*(1+1.0*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+1.0*(30-f84)/30));
n851= @if (0.81*n8*(1+1.0*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+1.0*(30-f85)/30));

!Minimum Trip Frequency;
```

```
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0;
n711>=0; n721>=0; n731>=0; n741>=0; n751>=0;
n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;

x<=1; !recovery upper limit;

x>=0; !recovery lower limit;

!Permit Fee at x% recovery;
f2= 54.93 *x+10;
f3s= 54.93*x+10;
f3c= 54.93*x+10;

f4s= 54.93*x+10;
f4c= 54.93*x+10;
f5= 54.93*x+10;

f61= 54.93*x+10;
f62= 54.93*x+10;
f63= 54.93*x+10;

f71= 54.93*x+10;
f72= 54.93*x+10;
f73= 54.93*x+10;
f74= 54.93*x+10;
f75= 54.93*x+10;

f81= 54.93*x+10;
f82= 54.93*x+10;
f83= 54.93*x+10;
f84= 54.93*x+10;
f85= 54.93*x+10;

!Maximum Permit Fee;
f12= 54.93+10;
f13s= 54.93+10;
f13c= 54.93+10;

f14s= 54.93+10;
f14c= 54.93+10;
f15= 54.93+10;

f161= 54.93+10;
f162= 54.93+10;
f163= 54.93+10;

f171= 54.93+10;
f172= 54.93+10;
```

```
f173= 54.93+10;
f174= 54.93+10;
f175= 54.93+10;

f181= 54.93+10;
f182= 54.93+10;
f183= 54.93+10;
f184= 54.93+10;
f185= 54.93+10;

END
:
```

Elasticity -0.5

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;

!Fee constraint (minimize fee, 2nd objective);
f2<=f; !f, epsilon value;

!Current Trip Frequency;
n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;

n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;

!Revised Trip Frequency;
n21= @if (n2*(1+0.5*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+0.5*(30-f2)/30));
n3s1= @if (n3s*(1+0.5*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+0.5*(30-f3s)/30));
n3c1= @if (n3c*(1+0.5*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+0.5*(30-f3c)/30));

n4s1= @if (n4s*(1+0.5*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+0.5*(30-f4s)/30));
n4c1= @if (n4c*(1+0.5*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+0.5*(30-f4c)/30));
n51= @if (n5*(1+0.5*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+0.5*(30-f5)/30));

n611= @if (0.14*n6*(1+0.5*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+0.5*(30-f61)/30));
```

```
n621= @if (0.32*n6*(1+0.5*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+0.5*(30-f62)/30));
n631= @if (0.54*n6*(1+0.5*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+0.5*(30-f63)/30));

n711= @if (0.01*n7*(1+0.5*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+0.5*(30-f71)/30));
n721= @if (0.03*n7*(1+0.5*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+0.5*(30-f72)/30));
n731= @if (0.07*n7*(1+0.5*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+0.5*(30-f73)/30));
n741= @if (0.13*n7*(1+0.5*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+0.5*(30-f74)/30));
n751= @if (0.76*n7*(1+0.5*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+0.5*(30-f75)/30));

n811= @if (0.01*n8*(1+0.5*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+0.5*(30-f81)/30));
n821= @if (0.05*n8*(1+0.5*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+0.5*(30-f82)/30));
n831= @if (0.03*n8*(1+0.5*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+0.5*(30-f83)/30));
n841= @if (0.1*n8*(1+0.5*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+0.5*(30-f84)/30));
n851= @if (0.81*n8*(1+0.5*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+0.5*(30-f85)/30));

!Minimum Trip Frequency;
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0; n711>=0; n721>=0; n731>=0; n741>=0;
n751>=0; n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;

x<=1; !recovery upper limit;

x>=0; !recovery lower limit;

!Permit Fee at x% recovery;
f2= 54.93 *x+10;
f3s= 54.93*x+10;
f3c= 54.93*x+10;

f4s= 54.93*x+10;
f4c= 54.93*x+10;
f5= 54.93*x+10;

f61= 54.93*x+10;
f62= 54.93*x+10;
f63= 54.93*x+10;
```

```
f71= 54.93*x+10;
f72= 54.93*x+10;
f73= 54.93*x+10;
f74= 54.93*x+10;
f75= 54.93*x+10;

f81= 54.93*x+10;
f82= 54.93*x+10;
f83= 54.93*x+10;
f84= 54.93*x+10;
f85= 54.93*x+10;

!Maximum Permit Fee;
f12= 54.93+10;
f13s= 54.93+10;
f13c= 54.93+10;

f14s= 54.93+10;
f14c= 54.93+10;
f15= 54.93+10;

f161= 54.93+10;
f162= 54.93+10;
f163= 54.93+10;

f171= 54.93+10;
f172= 54.93+10;
f173= 54.93+10;
f174= 54.93+10;
f175= 54.93+10;

f181= 54.93+10;
f182= 54.93+10;
f183= 54.93+10;
f184= 54.93+10;
f185= 54.93+10;
END
:
```

WEIGHT BASED FEE MODELS Elasticity -1.5

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;
```

```
!Fee Constraint (minimize fee, 2nd objective);
f21*0.17122+f3s1*0.01670+f3c1*0.05291+f4s1*0.00025+f4c1*0.02449+f
51*0.71293+f611*0.00151+f621*0.00335+f631*0.00573+f711*0.00011+f7
21*0.00028+f731*0.00072+f741*0.00140+f751*0.00815+f811*0.000003+f
821*0.00001+f831*0.00001+f841*0.00002+f851*0.00019<=f; !f,
epsilon value;

x<=1; !recovery upper limit;

x>=0; !recovery lower limit;

!Current Trip Frequency;
n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;

n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;

!Revised Trip Frequency;
n21= @if (n2*(1+1.5*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+1.5*(30-f2)/30));
n3s1= @if (n3s*(1+1.5*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+1.5*(30-f3s)/30));
n3c1= @if (n3c*(1+1.5*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+1.5*(30-f3c)/30));

n4s1= @if (n4s*(1+1.5*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+1.5*(30-f4s)/30));
n4c1= @if (n4c*(1+1.5*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+1.5*(30-f4c)/30));
n51= @if (n5*(1+1.5*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+1.5*(30-f5)/30));

n611= @if (0.14*n6*(1+1.5*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+1.5*(30-f61)/30));
n621= @if (0.32*n6*(1+1.5*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+1.5*(30-f62)/30));
n631= @if (0.54*n6*(1+1.5*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+1.5*(30-f63)/30));

n711= @if (0.01*n7*(1+1.5*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+1.5*(30-f71)/30));
n721= @if (0.03*n7*(1+1.5*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+1.5*(30-f72)/30));
n731= @if (0.07*n7*(1+1.5*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+1.5*(30-f73)/30));
n741= @if (0.13*n7*(1+1.5*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+1.5*(30-f74)/30));
```

```
n751= @if (0.76*n7*(1+1.5*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+1.5*(30-f75)/30));

n811= @if (0.01*n8*(1+1.5*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+1.5*(30-f81)/30));
n821= @if (0.05*n8*(1+1.5*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+1.5*(30-f82)/30));
n831= @if (0.03*n8*(1+1.5*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+1.5*(30-f83)/30));
n841= @if (0.1*n8*(1+1.5*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+1.5*(30-f84)/30));
n851= @if (0.81*n8*(1+1.5*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+1.5*(30-f85)/30));

!Minimum Trip Frequency;
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0; n711>=0; n721>=0; n731>=0; n741>=0;
n751>=0; n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;

!Permit Fee at x% recovery;
f2= 2.5*9.68*x+10;
f3s= 2*7.29*x+10;
f3c= 2.5*15.01*x+10;

f4s= 0.75*36.57*x+10;
f4c= 2.5*36.32*x+10;

f5= 5*12.28*x+10;

f61= 5*5.83*x+10;
f62= 10*6.80*x+10;
f63= 15*8.04*x+10;

f71= 5*3.61*x+10;
f72= 10*4.04*x+10;
f73= 15*4.75*x+10;
f74= 20*5.61*x+10;
f75= 25*6.59*x+10;

f81= 5*2.77*x+10;
f82= 10*3.07*x+10;
f83= 15*3.76*x+10;
f84= 20*4.29*x+10;
f85= 25*5.05*x+10;

!Maximum Permit Fee;
f12= 2.5*9.68+10;
f13s= 2*7.29+10;
f13c= 2.5*15.01+10;
```

```
f14s= 0.75*36.57+10;
f14c= 2.5*36.32+10;

f15= 5*12.28+10;

f161= 5*5.83+10;
f162= 10*6.80+10;
f163= 15*8.04+10;

f171= 5*3.61+10;
f172= 10*4.04+10;
f173= 15*4.75+10;
f174= 20*5.61+10;
f175= 25*6.59+10;

f181= 5*2.77+10;
f182= 10*3.07+10;
f183= 15*3.76+10;
f184= 20*4.29+10;
f185= 25*5.05+10;

!Fee charged without administrative fee;
f21=9.68*x;
f3s1=7.29*x;
f3c1=15.01*x;

f4s1=36.57*x;
f4c1=36.32*x;

f51=12.28*x;

f611=5.83*x;
f621=6.80*x;
f631=8.04*x;

f711=3.61*x;
f721=4.04*x;
f731=4.75*x;
f741=5.61*x;
f751=6.59*x;

f811=2.77*x;
f821=3.07*x;
f831=3.76*x;
f841=4.29*x;
f851=5.05*x;

END
:
```

Elasticity -1.0

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;

!Fee Constraint (minimize fee, 2nd objective);
f21*0.17122+f3s1*0.01670+f3c1*0.05291+f4s1*0.00025+f4c1*0.02449+f
51*0.71293+f611*0.00151+f621*0.00335+f631*0.00573+f711*0.00011+f7
21*0.00028+f731*0.00072+f741*0.00140+f751*0.00815+f811*0.000003+f
821*0.00001+f831*0.00001+f841*0.00002+f851*0.00019<=f; !f,
epsilon value;

!Current Trip Frequency;
n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;

n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;

!Revised Trip Frequency;
n21= @if (n2*(1+1.0*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+1.0*(30-f2)/30));
n3s1= @if (n3s*(1+1.0*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+1.0*(30-f3s)/30));
n3c1= @if (n3c*(1+1.0*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+1.0*(30-f3c)/30));

n4s1= @if (n4s*(1+1.0*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+1.0*(30-f4s)/30));
n4c1= @if (n4c*(1+1.0*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+1.0*(30-f4c)/30));
n51= @if (n5*(1+1.0*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+1.0*(30-f5)/30));

n611= @if (0.14*n6*(1+1.0*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+1.0*(30-f61)/30));
n621= @if (0.32*n6*(1+1.0*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+1.0*(30-f62)/30));
n631= @if (0.54*n6*(1+1.0*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+1.0*(30-f63)/30));

n711= @if (0.01*n7*(1+1.0*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+1.0*(30-f71)/30));
```

```
n721= @if (0.03*n7*(1+1.0*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+1.0*(30-f72)/30));
n731= @if (0.07*n7*(1+1.0*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+1.0*(30-f73)/30));
n741= @if (0.13*n7*(1+1.0*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+1.0*(30-f74)/30));
n751= @if (0.76*n7*(1+1.0*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+1.0*(30-f75)/30));

n811= @if (0.01*n8*(1+1.0*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+1.0*(30-f81)/30));
n821= @if (0.05*n8*(1+1.0*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+1.0*(30-f82)/30));
n831= @if (0.03*n8*(1+1.0*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+1.0*(30-f83)/30));
n841= @if (0.1*n8*(1+1.0*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+1.0*(30-f84)/30));
n851= @if (0.81*n8*(1+1.0*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+1.0*(30-f85)/30));

!Minimum Trip Frequency;
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0;
n711>=0; n721>=0; n731>=0; n741>=0; n751>=0;
n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;

x<=1; !recovery upper limit;
x>=0; !recovery lower limit;

!Permit Fee at x% recovery;
f2= 2.5*9.68*x+10;
f3s= 2*7.29*x+10;
f3c= 2.5*15.01*x+10;

f4s= 0.75*36.57*x+10;
f4c= 2.5*36.32*x+10;

f5= 5*12.28*x+10;

f61= 5*5.83*x+10;
f62= 10*6.80*x+10;
f63= 15*8.04*x+10;

f71= 5*3.61*x+10;
f72= 10*4.04*x+10;
f73= 15*4.75*x+10;
f74= 20*5.61*x+10;
f75= 25*6.59*x+10;
```

```
f81= 5*2.77*x+10;
f82= 10*3.07*x+10;
f83= 15*3.76*x+10;
f84= 20*4.29*x+10;
f85= 25*5.05*x+10;

!Maximum Permit Fee;
f12= 2.5*9.68+10;
f13s= 2*7.29+10;
f13c= 2.5*15.01+10;

f14s= 0.75*36.57+10;
f14c= 2.5*36.32+10;

f15= 5*12.28+10;

f161= 5*5.83+10;
f162= 10*6.80+10;
f163= 15*8.04+10;

f171= 5*3.61+10;
f172= 10*4.04+10;
f173= 15*4.75+10;
f174= 20*5.61+10;
f175= 25*6.59+10;

f181= 5*2.77+10;
f182= 10*3.07+10;
f183= 15*3.76+10;
f184= 20*4.29+10;
f185= 25*5.05+10;

!Fee charged without administrative fee;
f21=9.68*x;
f3s1=7.29*x;
f3c1=15.01*x;

f4s1=36.57*x;
f4c1=36.32*x;

f51=12.28*x;

f611=5.83*x;
f621=6.80*x;
f631=8.04*x;

f711=3.61*x;
f721=4.04*x;
f731=4.75*x;
```

```
f741=5.61*x;
f751=6.59*x;

f811=2.77*x;
f821=3.07*x;
f831=3.76*x;
f841=4.29*x;
f851=5.05*x;
END
:
```

Elasticity -0.5

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;

!Fee Constraint (minimize fee, 2nd objective);
f21*0.17122+f3s1*0.01670+f3c1*0.05291+f4s1*0.00025+f4c1*0.02449+f
51*0.71293+f611*0.00151+f621*0.00335+f631*0.00573+f711*0.00011+f7
21*0.00028+f731*0.00072+f741*0.00140+f751*0.00815+f811*0.000003+f
821*0.00001+f831*0.00001+f841*0.00002+f851*0.00019<=f; !f,
epsilon value;

!Current Trip Frequency;
n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;

n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;

!Revised Trip Frequency;
n21= @if (n2*(1+0.5*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+0.5*(30-f2)/30));
n3s1= @if (n3s*(1+0.5*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+0.5*(30-f3s)/30));
n3c1= @if (n3c*(1+0.5*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+0.5*(30-f3c)/30));

n4s1= @if (n4s*(1+0.5*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+0.5*(30-f4s)/30));
n4c1= @if (n4c*(1+0.5*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+0.5*(30-f4c)/30));
n51= @if (n5*(1+0.5*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+0.5*(30-f5)/30));
```

```
n611= @if (0.14*n6*(1+0.5*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+0.5*(30-f61)/30));
n621= @if (0.32*n6*(1+0.5*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+0.5*(30-f62)/30));
n631= @if (0.54*n6*(1+0.5*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+0.5*(30-f63)/30));

n711= @if (0.01*n7*(1+0.5*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+0.5*(30-f71)/30));
n721= @if (0.03*n7*(1+0.5*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+0.5*(30-f72)/30));
n731= @if (0.07*n7*(1+0.5*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+0.5*(30-f73)/30));
n741= @if (0.13*n7*(1+0.5*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+0.5*(30-f74)/30));
n751= @if (0.76*n7*(1+0.5*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+0.5*(30-f75)/30));

n811= @if (0.01*n8*(1+0.5*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+0.5*(30-f81)/30));
n821= @if (0.05*n8*(1+0.5*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+0.5*(30-f82)/30));
n831= @if (0.03*n8*(1+0.5*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+0.5*(30-f83)/30));
n841= @if (0.1*n8*(1+0.5*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+0.5*(30-f84)/30));
n851= @if (0.81*n8*(1+0.5*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+0.5*(30-f85)/30));

!Minimum Trip Frequency;
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0;
n711>=0; n721>=0; n731>=0; n741>=0; n751>=0;
n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;

x<=1; !recovery upper limit;

x>=0; !recovery lower limit;

!Permit Fee at x% recovery;
f2= 2.5*9.68*x+10;
f3s= 2*7.29*x+10;
f3c= 2.5*15.01*x+10;

f4s= 0.75*36.57*x+10;
f4c= 2.5*36.32*x+10;

f5= 5*12.28*x+10;
```

```
f61= 5*5.83*x+10;
f62= 10*6.80*x+10;
f63= 15*8.04*x+10;

f71= 5*3.61*x+10;
f72= 10*4.04*x+10;
f73= 15*4.75*x+10;
f74= 20*5.61*x+10;
f75= 25*6.59*x+10;

f81= 5*2.77*x+10;
f82= 10*3.07*x+10;
f83= 15*3.76*x+10;
f84= 20*4.29*x+10;
f85= 25*5.05*x+10;

!Maximum Permit Fee;
f12= 2.5*9.68+10;
f13s= 2*7.29+10;
f13c= 2.5*15.01+10;

f14s= 0.75*36.57+10;
f14c= 2.5*36.32+10;

f15= 5*12.28+10;

f161= 5*5.83+10;
f162= 10*6.80+10;
f163= 15*8.04+10;

f171= 5*3.61+10;
f172= 10*4.04+10;
f173= 15*4.75+10;
f174= 20*5.61+10;
f175= 25*6.59+10;

f181= 5*2.77+10;
f182= 10*3.07+10;
f183= 15*3.76+10;
f184= 20*4.29+10;
f185= 25*5.05+10;

!Fee charged without administrative fee;
f21=9.68*x;
f3s1=7.29*x;
f3c1=15.01*x;

f4s1=36.57*x;
f4c1=36.32*x;
```

```
f51=12.28*x;

f611=5.83*x;
f621=6.80*x;
f631=8.04*x;

f711=3.61*x;
f721=4.04*x;
f731=4.75*x;
f741=5.61*x;
f751=6.59*x;

f811=2.77*x;
f821=3.07*x;
f831=3.76*x;
f841=4.29*x;
f851=5.05*x;
END
:
```

WEIGHT DISTANCE BASED FEE MODELS
Elasticity -1.5

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;

!Fee Constraint (minimize fee, 2nd objective);
(f21*0.17122+f3s1*0.01670+f3c1*0.05291+f4s1*0.00025+f4c1*0.02449+
f51*0.71293+f611*0.00151+f621*0.00335+f631*0.00573+f711*0.00011+f
721*0.00028+f731*0.00072+f741*0.00140+f751*0.00815+f811*0.000003+
f821*0.00001+f831*0.00001+f841*0.00002+f851*0.00019)*100<=f; !f,
epsilon value;

!Current Trip Frequency;
n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;

n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;

!Trip length;
t2=75; t3s=100; t3c=125; t4s=270; t4c=270; t5=160; t6=160;
t7=160; t8=160;
```

```
!Revised Trip Frequency;
n21= @if (n2*(1+1.5*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+1.5*(30-f2)/30));
n3s1= @if (n3s*(1+1.5*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+1.5*(30-f3s)/30));
n3c1= @if (n3c*(1+1.5*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+1.5*(30-f3c)/30));

n4s1= @if (n4s*(1+1.5*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+1.5*(30-f4s)/30));
n4c1= @if (n4c*(1+1.5*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+1.5*(30-f4c)/30));
n51= @if (n5*(1+1.5*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+1.5*(30-f5)/30));

n611= @if (0.14*n6*(1+1.5*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+1.5*(30-f61)/30));
n621= @if (0.32*n6*(1+1.5*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+1.5*(30-f62)/30));
n631= @if (0.54*n6*(1+1.5*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+1.5*(30-f63)/30));

n711= @if (0.01*n7*(1+1.5*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+1.5*(30-f71)/30));
n721= @if (0.03*n7*(1+1.5*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+1.5*(30-f72)/30));
n731= @if (0.07*n7*(1+1.5*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+1.5*(30-f73)/30));
n741= @if (0.13*n7*(1+1.5*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+1.5*(30-f74)/30));
n751= @if (0.76*n7*(1+1.5*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+1.5*(30-f75)/30));

n811= @if (0.01*n8*(1+1.5*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+1.5*(30-f81)/30));
n821= @if (0.05*n8*(1+1.5*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+1.5*(30-f82)/30));
n831= @if (0.03*n8*(1+1.5*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+1.5*(30-f83)/30));
n841= @if (0.1*n8*(1+1.5*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+1.5*(30-f84)/30));
n851= @if (0.81*n8*(1+1.5*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+1.5*(30-f85)/30));

!Minimum Trip Frequency;
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0;
n711>=0; n721>=0; n731>=0; n741>=0; n751>=0;
n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;
```

```
x<=1; !recovery upper limit;
x>=0; !recovery lower limit;

!Permit Fee at x% recovery;
f2= 2.5*0.129*t2*x+10;
f3s= 2*0.0729*t3s*x+10;
f3c= 2.5*0.1201*t3c*x+10;

f4s= 0.75*0.1354*t4s*x+10;
f4c= 2.5*0.1345*t4c*x+10;

f5= 5*0.0767*t5*x+10;

f61= 5*0.0365*t6*x+10;
f62= 10*0.0425*t6*x+10;
f63= 15*0.0503*t6*x+10;

f71= 5*0.0226*t7*x+10;
f72= 10*0.0253*t7*x+10;
f73= 15*0.0297*t7*x+10;
f74= 20*0.0351*t7*x+10;
f75= 25*0.0412*t7*x+10;

f81= 5*0.0173*t8*x+10;
f82= 10*0.0192*t8*x+10;
f83= 15*0.0235*t8*x+10;
f84= 20*0.0268*t8*x+10;
f85= 25*0.0316*t8*x+10;

!Maximum Permit Fee;
f12= 2.5*0.129*t2+10;
f13s= 2*0.0729*t3s+10;
f13c= 2.5*0.1201*t3c+10;

f14s= 0.75*0.1354*t4s+10;
f14c= 2.5*0.1345*t4c+10;

f15= 5*0.0767*t5+10;

f161= 5*0.0365*t6+10;
f162= 10*0.0425*t6+10;
f163= 15*0.0503*t6+10;

f171= 5*0.0226*t7+10;
f172= 10*0.0253*t7+10;
f173= 15*0.0297*t7+10;
f174= 20*0.0351*t7+10;
```

```
f175= 25*0.0412*t7+10;

f181= 5*0.0173*t8+10;
f182= 10*0.0192*t8+10;
f183= 15*0.0235*t8+10;
f184= 20*0.0268*t8+10;
f185= 25*0.0316*t8+10;

!Fee charged without administrative fee;
f21= 0.129*x;
f3s1= 0.0729*x;
f3c1= 0.1201*x;

f4s1= 0.1354*x;
f4c1= 0.1345*x;

f51= 0.0767*x;

f611= 0.0365*x;
f621= 0.0425*x;
f631= 0.0503*x;

f711= 0.0226*x;
f721= 0.0253*x;
f731= 0.0297*x;
f741= 0.0351*x;
f751= 0.0412*x;

f811= 0.0173*x;
f821= 0.0192*x;
f831= 0.0235*x;
f841= 0.0268*x;
f851= 0.0316*x;
END
:
```

Elasticity -1.0

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;

!Fee Constraint (minimize fee, 2nd objective);
(f21*0.17122+f3s1*0.01670+f3c1*0.05291+f4s1*0.00025+f4c1*0.02449+
f51*0.71293+f611*0.00151+f621*0.00335+f631*0.00573+f711*0.00011+f
721*0.00028+f731*0.00072+f741*0.00140+f751*0.00815+f811*0.000003+
```

```
f821*0.00001+f831*0.00001+f841*0.00002+f851*0.00019)*100<=f; !f,
epsilon value;

!Current Trip Frequency;
n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;

n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;

!Trip length;
t2=75; t3s=100; t3c=125; t4s=270; t4c=270; t5=160; t6=160;
t7=160; t8=160;

!Revised Trip Frequency;
n21= @if (n2*(1+1.0*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+1.0*(30-f2)/30));
n3s1= @if (n3s*(1+1.0*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+1.0*(30-f3s)/30));
n3c1= @if (n3c*(1+1.0*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+1.0*(30-f3c)/30));

n4s1= @if (n4s*(1+1.0*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+1.0*(30-f4s)/30));
n4c1= @if (n4c*(1+1.0*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+1.0*(30-f4c)/30));
n51= @if (n5*(1+1.0*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+1.0*(30-f5)/30));

n611= @if (0.14*n6*(1+1.0*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+1.0*(30-f61)/30));
n621= @if (0.32*n6*(1+1.0*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+1.0*(30-f62)/30));
n631= @if (0.54*n6*(1+1.0*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+1.0*(30-f63)/30));

n711= @if (0.01*n7*(1+1.0*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+1.0*(30-f71)/30));
n721= @if (0.03*n7*(1+1.0*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+1.0*(30-f72)/30));
n731= @if (0.07*n7*(1+1.0*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+1.0*(30-f73)/30));
n741= @if (0.13*n7*(1+1.0*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+1.0*(30-f74)/30));
n751= @if (0.76*n7*(1+1.0*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+1.0*(30-f75)/30));
```

```
n811= @if (0.01*n8*(1+1.0*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+1.0*(30-f81)/30));
n821= @if (0.05*n8*(1+1.0*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+1.0*(30-f82)/30));
n831= @if (0.03*n8*(1+1.0*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+1.0*(30-f83)/30));
n841= @if (0.1*n8*(1+1.0*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+1.0*(30-f84)/30));
n851= @if (0.81*n8*(1+1.0*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+1.0*(30-f85)/30));

!Minimum Trip Frequency;
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0;
n711>=0; n721>=0; n731>=0; n741>=0; n751>=0;
n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;

x<=1; !recovery upper limit;
x>=0; !recovery lower limit;

!Permit Fee at x% recovery;
f2= 2.5*0.129*t2*x+10;
f3s= 2*0.0729*t3s*x+10;
f3c= 2.5*0.1201*t3c*x+10;

f4s= 0.75*0.1354*t4s*x+10;
f4c= 2.5*0.1345*t4c*x+10;

f5= 5*0.0767*t5*x+10;

f61= 5*0.0365*t6*x+10;
f62= 10*0.0425*t6*x+10;
f63= 15*0.0503*t6*x+10;

f71= 5*0.0226*t7*x+10;
f72= 10*0.0253*t7*x+10;
f73= 15*0.0297*t7*x+10;
f74= 20*0.0351*t7*x+10;
f75= 25*0.0412*t7*x+10;

f81= 5*0.0173*t8*x+10;
f82= 10*0.0192*t8*x+10;
f83= 15*0.0235*t8*x+10;
f84= 20*0.0268*t8*x+10;
f85= 25*0.0316*t8*x+10;

!Maximum Permit Fee;
f12= 2.5*0.129*t2+10;
f13s= 2*0.0729*t3s+10;
```

```
f13c= 2.5*0.1201*t3c+10;

f14s= 0.75*0.1354*t4s+10;
f14c= 2.5*0.1345*t4c+10;

f15= 5*0.0767*t5+10;

f161= 5*0.0365*t6+10;
f162= 10*0.0425*t6+10;
f163= 15*0.0503*t6+10;

f171= 5*0.0226*t7+10;
f172= 10*0.0253*t7+10;
f173= 15*0.0297*t7+10;
f174= 20*0.0351*t7+10;
f175= 25*0.0412*t7+10;

f181= 5*0.0173*t8+10;
f182= 10*0.0192*t8+10;
f183= 15*0.0235*t8+10;
f184= 20*0.0268*t8+10;
f185= 25*0.0316*t8+10;

!Fee charged without administrative fee;
f21= 0.129*x;
f3s1= 0.0729*x;
f3c1= 0.1201*x;

f4s1= 0.1354*x;
f4c1= 0.1345*x;

f51= 0.0767*x;

f611= 0.0365*x;
f621= 0.0425*x;
f631= 0.0503*x;

f711= 0.0226*x;
f721= 0.0253*x;
f731= 0.0297*x;
f741= 0.0351*x;
f751= 0.0412*x;

f811= 0.0173*x;
f821= 0.0192*x;
f831= 0.0235*x;
f841= 0.0268*x;
f851= 0.0316*x;
END
```

:

Elasticity -0.5

```
!Minimize Unpaid Damage Cost($);
min= (f12-f2)*n21+(f13s-f3s)*n3s1+(f13c-f3c)*n3c1+(f14s-
f4s)*n4s1+(f14c-f4c)*n4c1+(f15-f5)*n51+(f161-f61)*n611+(f162-
f62)*n621+(f163-f63)*n631+(f171-f71)*n711+(f172-f72)*n721+(f173-
f73)*n731+(f174-f74)*n741+(f175-f75)*n751+(f181-f81)*n811+(f182-
f82)*n821+(f183-f83)*n831+(f184-f84)*n841+(f185-f85)*n851;

!Fee Constraint (minimize fee, 2nd objective);
(f21*0.17122+f3s1*0.01670+f3c1*0.05291+f4s1*0.00025+f4c1*0.02449+
f51*0.71293+f611*0.00151+f621*0.00335+f631*0.00573+f711*0.00011+f
721*0.00028+f731*0.00072+f741*0.00140+f751*0.00815+f811*0.000003+
f821*0.00001+f831*0.00001+f841*0.00002+f851*0.00019)*100<=f; !f,
epsilon value;

!Current Trip Frequency;
n2=496667; n3s=48448; n3c=153473; n4s=735; n4c=71052; n5=2067989;
n6=30723; n7=30927; n8=681;

n61=0.14*n6; n62=0.32*n6; n63=0.54*n6;
n71=0.01*n7; n72=0.03*n7; n73=0.07*n7; n74=0.13*n7; n75=0.76*n7;
n81=0.01*n8; n82=0.05*n8; n83=0.03*n8; n84=0.1*n8; n85=0.81*n8;

!Trip length;
t2=75; t3s=100; t3c=125; t4s=270; t4c=270; t5=160; t6=160;
t7=160; t8=160;

!Revised Trip Frequency;
n21= @if (n2*(1+0.5*(30-f2)/30) #LT# (0.1*n2),(0.1*n2),
n2*(1+0.5*(30-f2)/30));
n3s1= @if (n3s*(1+0.5*(30-f3s)/30) #LT# (0.1*n3s),(0.1*n3s),
n3s*(1+0.5*(30-f3s)/30));
n3c1= @if (n3c*(1+0.5*(30-f3c)/30) #LT# (0.1*n3c),(0.1*n3c),
n3c*(1+0.5*(30-f3c)/30));

n4s1= @if (n4s*(1+0.5*(30-f4s)/30) #LT# (0.1*n4s),(0.1*n4s),
n4s*(1+0.5*(30-f4s)/30));
n4c1= @if (n4c*(1+0.5*(30-f4c)/30) #LT# (0.1*n4c),(0.1*n4c),
n4c*(1+0.5*(30-f4c)/30));
n51= @if (n5*(1+0.5*(30-f5)/30) #LT# (0.1*n5),(0.1*n5),
n5*(1+0.5*(30-f5)/30));

n611= @if (0.14*n6*(1+0.5*(30-f61)/30) #LT# (0.1*n61),(0.1*n61),
0.14*n6*(1+0.5*(30-f61)/30));
n621= @if (0.32*n6*(1+0.5*(30-f62)/30) #LT# (0.1*n62),(0.1*n62),
0.32*n6*(1+0.5*(30-f62)/30));
```

```
n631= @if (0.54*n6*(1+0.5*(30-f63)/30) #LT# (0.1*n63),(0.1*n63),
0.54*n6*(1+0.5*(30-f63)/30));

n711= @if (0.01*n7*(1+0.5*(30-f71)/30) #LT# (0.1*n71),(0.1*n71),
0.01*n7*(1+0.5*(30-f71)/30));
n721= @if (0.03*n7*(1+0.5*(30-f72)/30) #LT# (0.1*n72),(0.1*n72),
0.03*n7*(1+0.5*(30-f72)/30));
n731= @if (0.07*n7*(1+0.5*(30-f73)/30) #LT# (0.1*n73),(0.1*n73),
0.07*n7*(1+0.5*(30-f73)/30));
n741= @if (0.13*n7*(1+0.5*(30-f74)/30) #LT# (0.1*n74),(0.1*n74),
0.13*n7*(1+0.5*(30-f74)/30));
n751= @if (0.76*n7*(1+0.5*(30-f75)/30) #LT# (0.1*n75),(0.1*n75),
0.76*n7*(1+0.5*(30-f75)/30));

n811= @if (0.01*n8*(1+0.5*(30-f81)/30) #LT# (0.1*n81),(0.1*n81),
0.01*n8*(1+0.5*(30-f81)/30));
n821= @if (0.05*n8*(1+0.5*(30-f82)/30) #LT# (0.1*n82),(0.1*n82),
0.05*n8*(1+0.5*(30-f82)/30));
n831= @if (0.03*n8*(1+0.5*(30-f83)/30) #LT# (0.1*n83),(0.1*n83),
0.03*n8*(1+0.5*(30-f83)/30));
n841= @if (0.1*n8*(1+0.5*(30-f84)/30) #LT# (0.1*n84),(0.1*n84),
0.1*n8*(1+0.5*(30-f84)/30));
n851= @if (0.81*n8*(1+0.5*(30-f85)/30) #LT# (0.1*n85),(0.1*n85),
0.81*n8*(1+0.5*(30-f85)/30));

!Minimum Trip Frequency;
n21>=0; n3s1>=0; n3c1>=0; n4s1>=0; n4c1>=0; n51>=0;
n611>=0; n621>=0; n631>=0;
n711>=0; n721>=0; n731>=0; n741>=0; n751>=0;
n811>=0; n821>=0; n831>=0; n841>=0; n851>=0;

x<=1; !recovery upper limit;
x>=0; !recovery lower limit;

!Permit Fee at x% recovery;
f2= 2.5*0.129*t2*x+10;
f3s= 2*0.0729*t3s*x+10;
f3c= 2.5*0.1201*t3c*x+10;

f4s= 0.75*0.1354*t4s*x+10;
f4c= 2.5*0.1345*t4c*x+10;

f5= 5*0.0767*t5*x+10;

f61= 5*0.0365*t6*x+10;
f62= 10*0.0425*t6*x+10;
f63= 15*0.0503*t6*x+10;

f71= 5*0.0226*t7*x+10;
```

```
f72= 10*0.0253*t7*x+10;
f73= 15*0.0297*t7*x+10;
f74= 20*0.0351*t7*x+10;
f75= 25*0.0412*t7*x+10;

f81= 5*0.0173*t8*x+10;
f82= 10*0.0192*t8*x+10;
f83= 15*0.0235*t8*x+10;
f84= 20*0.0268*t8*x+10;
f85= 25*0.0316*t8*x+10;

!Maximum Permit Fee;
f12= 2.5*0.129*t2+10;
f13s= 2*0.0729*t3s+10;
f13c= 2.5*0.1201*t3c+10;

f14s= 0.75*0.1354*t4s+10;
f14c= 2.5*0.1345*t4c+10;

f15= 5*0.0767*t5+10;

f161= 5*0.0365*t6+10;
f162= 10*0.0425*t6+10;
f163= 15*0.0503*t6+10;

f171= 5*0.0226*t7+10;
f172= 10*0.0253*t7+10;
f173= 15*0.0297*t7+10;
f174= 20*0.0351*t7+10;
f175= 25*0.0412*t7+10;

f181= 5*0.0173*t8+10;
f182= 10*0.0192*t8+10;
f183= 15*0.0235*t8+10;
f184= 20*0.0268*t8+10;
f185= 25*0.0316*t8+10;

!Fee charged without administrative fee;
f21= 0.129*x;
f3s1= 0.0729*x;
f3c1= 0.1201*x;

f4s1= 0.1354*x;
f4c1= 0.1345*x;

f51= 0.0767*x;

f611= 0.0365*x;
f621= 0.0425*x;
```

```
f631= 0.0503*x;

f711= 0.0226*x;
f721= 0.0253*x;
f731= 0.0297*x;
f741= 0.0351*x;
f751= 0.0412*x;

f811= 0.0173*x;
f821= 0.0192*x;
f831= 0.0235*x;
f841= 0.0268*x;
f851= 0.0316*x;
END
:
```

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