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Overweight Vehicle Permitting Alternatives

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To my Grandfather and my Mom for showing me every day how to be a successful civil engineer, and to my family and friends who have supported me all the way.

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TABLE OF CONTENTS

Page

Page

Page

Page

LIST OF TABLES

Table Page

Appendix Table Page

LIST OF FIGURES

Figure Page

LIST OF ABBREVIATIONS

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
BTS	Bureau of Transportation Statistics
COE	Certificate of Entitlement
CV	Contingent Valuation
DOR	Department of Revenue
DOT	Department of Transportation
ESAL	Equivalent Single Axle Load
EU	European Union
FAF	Freight Analysis Framework
FHWA	Federal Highway Administration
FRA	Federal Railroad Association
GAMS	General Algebraic Modeling System
GIS	Geographic Information Systems
GVW	Gross Vehicle Weight
HCA	Highway Cost Allocation
HEA-1481	House Enrolled Act 1481
HOT	High Occupancy Toll
HSR	High Speed Rail
IFTA	International Fuel Tax Agreement
INDOR	Indiana Department of Revenue
INDOT	Indiana Department of Transportation
IRP	International Registration Plan

ISP	Indiana State Police
ISTEA	Intermodal Surface Transportation Efficiency Act
ITIC	Intermodal Transportation and Inventory Cost
LCV	Longer Combination Vehicle
MAP-21	Moving Ahead for Progress in the 21st Century
MDOT	Michigan Department of Transportation
MIT	Massachusetts Institute of Technology
MOU	Federal-Provincial-Territorial Memorandum of Understanding on Interprovincial Weights and Dimensions
NAFTA	North American Free Trade Agreement
NHS	National Highway System
NYSDOT	New York State Department of Transportation
PCLP	Private Car License Plate
RP	Revealed Preference
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SC	Stated Choice
SP	Stated Preference
SPIF	Safe, Productive, Infrastructure-friendly
STAA	Surface Transportation Assistance Act
STB	Surface Transportation Board
TEA-21	Transportation Equity Act for the 21st Century
TLC	Total Logistics Costs
TRB	Transportation Research Board
TS&W	Truck Size and Weight
UCC	Uncompensated Consumption Cost
USDOT	United States Department of Transportation
VDOT	Virginia Department of Transportation
VMT	Vehicle Miles Traveled
VQS	Vehicle Quota System

VTRC	Virginia Transportation Research Council
WASHTO	Western Association of State Highway and Transportation Officials
WGA	Western Governors’ Association
WTP	Willingness to Pay
XHDH	Extra Heavy Duty Highway

ABSTRACT

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Overweight vehicles exceed the federal and/or state statutory limits for either the gross vehicle weight (GVW) or the weight of individual axles or axle groups. National and state limits on vehicle weights were established to preserve the highway infrastructure. Past research has shown that overweight operations, while causing significant damage to roads and bridges, can enhance the trucking industry productivity, and thus yield economic benefits both regionally and nationally.

In the United States, individual states administer oversize and overweight vehicle permit programs to regulate and collect revenues from overweight operations. Differences in the truck size and weight limits and overweight permit programs across the states inhibit seamless and efficient truck travel across the country. Agencies responsible for maintaining the highway infrastructure realize that the cost of consumption of the infrastructure far exceeds the collected revenues.

The current study examines four options to improve overweight vehicle permitting systems: multiobjective optimization of traditional mechanisms, incentives for infrastructure-friendly vehicles, application of an auction-based quota for overweight

vehicle operations, and opportunities for harmonizing the regulations covering overweight vehicle operations that differ across the states.

The first three options are qualitatively and quantitatively applied to a case study involving Indiana's newly-established overweight commodity permits for vehicles carrying metal (up to 120,000 lbs), and agricultural (up to 97,000 lbs) goods. An incremental approach to harmonization of truck size and weight regulations and overweight vehicle permitting systems is qualitatively described, including available tools and data needs to promote harmonization.

The four options are not mutually exclusive; collectively, they provide opportunities for transportation decision makers to improve overweight vehicle permitting. Each option contributes to the ongoing discussion about how to address the issue of uncompensated consumption of highway infrastructure assets attributable to overweight vehicles. The multiobjective optimization formulated herein better reflects actual decisions made by both the agency and carriers than limited previous quantitative research. The quantification of willingness to pay for investment informs state agencies about the extent to which incentives for infrastructure-friendly vehicles can be adopted. The quota framework contained herein is an extension of strategies used previously to mitigate demand into a tool for controlling the amount of allowable infrastructure damage while collecting necessary revenues to protect infrastructure from undue damage. Finally, the harmonization of overweight vehicle permitting programs can streamline interstate overweight operations for both state agencies and carriers. The combination of several options can result in greater improvements to both the trucking industry's productivity and the preservation of highway infrastructure than any option alone.

CHAPTER 1. INTRODUCTION

1.1 Background

Overweight trucks are those that exceed the federal and/or state statutory limits for either the gross vehicle weight (GVW) or the weight of individual vehicle axles or axle groups. Both national and state limits were established to preserve the nation and state's highway infrastructure assets against undue deterioration. Extensive previous research has established that overweight vehicles cause damage to roads and bridges beyond the damage occasioned by vehicles within the statutory limits. At the same time, the trucking industry provides enormous socioeconomic benefits to the state. Permitted weights in excess of the statutory limits allow trucking companies to operate more productively; this, in turn, spurs economic development.

The balance between economic gains and increased asset preservation costs due to overweight vehicles is perhaps best viewed through the lens of the "Tragedy of the Commons" (Hardin, 1968). In Hardin's original framework, the commons is a shared pasture where herdsmen collectively raise their cattle. One rational herdsman realizes that increasing his herd by one more animal will increase his personal utility when he can sell that additional animal. The negative impact, whether realized or not by the herdsman, is that this additional cow will require some of the resources from the common; however, the cost of one additional animal is small compared to the economic gain experienced by the herdsman. Additionally, the small cost is shared among all herdsmen while the large financial benefit is realized by the one herdsman who sells the additional cow. Unfortunately, each herdsman makes decisions independently. In Hardin's postulation, when all of the herdsmen, acting rationally, increase their fold, the effects of overgrazing increase to the point that the commons can no longer support any of the cattle. Unless addressed by some intervening entity, the commons is not sustainable.

The tragedy of the commons can be applied to overweight vehicle operations using highway infrastructure. Adding one overweight vehicle leads to a small amount of damage to the "common" highway network; however, too many overweight vehicles cause an excessive amount of damage that cannot be recovered. Additionally, the benefit of operating overweight is exclusive to the carrier, while the costs are shared by all road users. As with the original tragedy, the common network of highway infrastructure assets is not sustainable unless undue consumption is moderated and/or the commons is maintained, repaired or replaced through external intervention.

In this modern-day example of the tragedy of the commons, additional traffic loading from overweight vehicles has a direct impact on the costs of pavement and bridge reconstruction, rehabilitation, and routine maintenance. Although there are economies of scale at play, the total cost of reconstruction increases for higher anticipated loads which require thicker pavements and bridges designed to accommodate higher loads. Also, when greater loads use highway assets, the rehabilitation and routine maintenance costs are also higher because they are more frequent. The present value of rehabilitation and maintenance expenditures increases when funds must be obligated sooner rather than later, due to the time value of money. The magnitude of the increase in routine maintenance and rehabilitation costs depends on the schedule: if maintenance is not carried out to accommodate additional loadings, the rehabilitation costs can increase substantially due to increased deterioration in the time between rehabilitation activities. The costs of inaction or deferred rehabilitation are borne not only by the agency but also by *all* users (not only those traveling overweight) through higher vehicle operating costs, additional delays that result from lower speeds, and higher crash risks associated with infrastructure in poor condition.

The economic benefits of using overweight vehicles have resulted in widespread use of permitting to allow vehicles to exceed federal and state truck size and weight (TS&W) limits. Permit revenues are important to transportation agencies to offset a fraction of such use; however, in most cases, the revenues collected from overweight vehicle permits fall far short of the cost of the *additional* consumption due to overweight operations. Additional consumption is defined as the usage beyond that which would have occurred from a non-overweight vehicle. Efficient permit fees need only recover additional usage to maintain common highway infrastructure assets because other funding and revenue collection mechanisms, i.e., registration fees, licensing fees, and fuel taxes, are all collected for all vehicles both non-overweight and overweight. For purposes of this research, efficient revenue collection refers to the full recovery of the cost of consumption while equitable revenue collection refers to the cost recovery that is equally imposed on different users as a fraction of the true consumption costs by vehicle class.

At an aggregate level, limited surface transportation funds are already insufficient to maintain the existing infrastructure. When the revenues collected from permit fees do not recover the full cost of additional consumption from overweight vehicles, the difference must be somehow supplemented to prevent premature physical degradation of infrastructure. Traditionally, states have offset such inefficiencies through transfers from general funds, special sales taxes, and increased state fuel taxes (infrequently in recent years). In addition to the consideration of limited funds, states must consider the economic impacts of permit policies. If the overweight vehicle permit fees are too high, industries that rely on heavy trucking may suffer. As a result, individual states have independently grappled with the issue of establishing and enforcing regulations and policies designed to enhance highway safety, mobility, and asset preservation without placing an undue burden on the trucking industry's operations.

1.2 History of Truck Size and Weight Regulation

Originally, the sizes and weights of vehicles were regulated by state and local laws in accordance with the state and local governments that provided transportation infrastructure. Federal TS&W laws were established and continue to exist for two basic reasons. First, large-scale federal investment allowed for the construction of the nation's vast Interstate System. Second, there is an ongoing need for national uniformity and funding for network preservation and expansion. The result is a complex system of both federal and state TS&W limits and legally-permitted exceptions or exemptions from those limits.

1.2.1 Evolution of Policy on National Truck Size and Weight Limits

Prior to the Federal-Aid Highway Act of 1956, truck weights and sizes were regulated by individual states. Federal TS&W limits were established in the Act to protect investments in the new Interstate and Defense Highway System (Interstate System) as follows: maximum width limit of 96 inches; single-axle weight limit of 18,000 pounds; tandem-axle weight limit of 32,000 pounds; and gross vehicle weight (GVW) limit of 73,280 pounds.

The 1956 regulations applied to travel on the Interstate System only. Furthermore, trucks in excess of federal limits could continue operation on the new system if legally allowed according to state regulations prior to July 1, 1956. This exception was the first "grandfather clause."

Subsequent to research studies in the 1950s and 1960s, the federal TS&W limits were increased in the Federal-aid Highway Amendments of 1974 as follows: single-axle weight limit increased to 20,000 pounds; tandem-axle weight limit increased to 34,000 pounds; and GVW limit increased to 80,000 pounds.

The 1974 Amendments also legally established the use of Bridge Formula B, a look-up table of allowable weights based on the number of axles and length of the vehicle, which was proposed in 1964 by the American Association of State Highway Officials (AASHO, renamed the American Association of State Highway and Transportation Officials, AASHTO, in 1973). The 1974 Amendments also included a grandfather clause. The limits established in 1974 are essentially the same as those presently in use, with the exception of an increase in the maximum vehicle width to 102 inches which occurred in 1982.

The 1974 Amendments and subsequent 1976 Federal-Aid Highway Act did not prohibit states from establishing lower limits on Interstate highways within their borders. As a result, six states (all in the Mississippi Valley) refused to allow trucks to operate at 80,000 lbs, inadvertently creating an institutional barrier to efficient cross-country trucking operations. The Surface Transportation Assistance Act of 1982 (STAA) rectified the situation by establishing the National Network for which the federal limits serve as *minimums*. The National Network includes the Interstate System and other federal-aid highways critical to the trucking industry. As previously noted, the 1982 STAA increased the maximum width limit to 102 inches. As with previous legislation, the 1982 STAA contained language that effectively extended the grandfather clause.

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 restricted the size, weight, and routes used by longer combination vehicles (LCVs) but did not make other changes to national TS&W limits for non-LCVs. LCVs are tractor-trailer combinations with two or more trailers. The "LCV freeze," as it is commonly referred to, also contained grandfather provisions for state regulations applicable to LCVs prior to June 1, 1991.

Recent surface transportation authorization legislation—Transportation Equity Act for the 21st Century (TEA-21) of 1998; Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) of 2005; and Moving Ahead for Progress in the 21st Century (MAP-21) of 2012—did not change the federal TS&W regulations. Due to widespread interest in TS&W limits, the Transportation Research Board (TRB) and the United States Department of Transportation (USDOT) conducted comprehensive national TS&W studies in 1990 and 2000 (USDOT, 2000;

TRB, 1990a). MAP-21 mandated that another Comprehensive TS&W Limits Study should examine safety risks, infrastructure impacts, and enforcement issues related to trucks operating in excess of federal limits. The MAP-21 mandated study was due to be submitted to Congress in November 2014 but is yet to be released because of the complexity of TS&W issues.

1.2.2 Current Practices in Oversize/Overweight Truck Permitting

The provisions grandfathered in 1956, 1974, and 1982 surface transportation authorization legislation allow individual states to permit trucking operations in excess of federal limits *if lawfully permitted prior to July 1, 1956*. Initially, there was no formal approval process in place for the application of grandfather rights; however, an amendment in the 1982 STAA (often referred to as the "Symms Amendment" for Idaho's Senator Steven Symms) allows states to determine which vehicles could lawfully operate prior to July 1, 1956. This permissive amendment has been used by many states to claim grandfather rights to permit the operation of larger and heavier trucks, even if the weights allowed today are higher than any used in practice in the 1940s and 1950s. Similarly the grandfather rights included in ISTEA apply to state LCV regulations in effect prior to June 1, 1991 as determined by the individual states.

Non-divisible loads or vehicles are defined as any load or vehicle exceeding TS&W limits which, if separated into smaller loads or vehicles would: compromise the intended use of the vehicle; destroy the value of the load or vehicle; or, require more than 8 hours work to dismantle using appropriate equipment. Divisible loads or vehicles are any load or vehicle which can be separated into units of legal size and weight without compromising the integrity of the load.

All fifty states have provisions for non-divisible load permits in excess of federal TS&W limits. The more permissive interpretation of grandfather provisions outlined in the Symms Amendment of the 1982 STAA is necessary for divisible load permits above the weights in effect in 1956. By 1995, thirty-seven states had exercised grandfather rights to issue permits for divisible loads (USDOT, 2000).

Most grandfather clause claims are made to allow exceptions to the federal weight limits. Extra-legal or overweight trucking operations translate into increased productivity and profits for trucking companies and ultimately benefit the consumers and end users of the commodities through lower prices. This is because even modest increases allowed in GVW represent larger increases in the amount of goods moved. For example, the typical weight of an unloaded 5-axle combination truck is 29,000 lbs (Luskin et al., 2002); therefore the payload for a legally loaded GVW of 80,000 lbs is 51,000 lbs. A 5% increase of the GVW (4,000 lbs) translates into a 7.8% increase of the payload becacuse there is no increase in the tare weight of the vehicle, only an increase in the payload. Similarly, increasing the GVW by 8,000 lbs (10%) increased the payload by approximately 15%. The increased profits carriers gain from additional delivered goods per trip is typically far in excess of the additional operating costs including fuel taxes and the costs of permits. By and large, state grandfather clause claims to permit GVWs over the 80,000 lbs federal limit for divisible loads require permitted vehicles to abide by all other state and federal truck size limits.

1.3 Motivation for the Present Study

TS&W and Highway Cost Allocation (HCA) studies dating back to the 1980s have consistently demonstrated that permit revenues for overweight vehicles do not fully recover the cost of additional asset consumption. Middleton et al. (1988) found that the permit fees paid by overweight trucks amounted to only $1/20^{th}$ of the overweight-attributable damage costs for pavements. This gap does not include the additional consumption cost for bridges, which far exceeds that for pavements (Everett et al., 2014; VTRC, 2008). In the most recent USDOT TS&W study it was determined that for combination trucks between 80,000 lbs and 100,000 lbs, only half of the usage cost was recovered (USDOT, 2000). Straus and Semmens (2006) estimated that $12-$53 million in uncompensated pavement consumption is attributable to overweight vehicles on Arizona's roadways. Again, this does not include the uncompensated bridge consumption.

The comprehensive overweight fee structure study conducted in Virginia by the Virginia Transportation Research Council (VTRC) recommended a two-part fee calculation method to determine appropriate permit fees to account for both pavement and bridge consumption (VTRC, 2008). The analysis results for pavements led to the establishment of equitable fees in terms of the unit cost of damage; however, the authors determined that it was not feasible to establish a similar fee to cover bridge consumption due to the excessive amount of bridge consumption associated with a small number of vehicles, and instead recommended a scheme to achieve "relative equity." The researchers stated that any fee based on the actual consumption of both pavements and bridges would be so high that trucking industry operations and productivity could be seriously impaired. In the end, VDOT adopted a fee structure which recovers only a portion of the attributable pavement consumption cost and excludes any recovery of bridge consumption costs.

Prozzi et al. (2012) conducted a similar comprehensive overweight fee structure study in Texas. Based on an analysis of the fees collected from more than 570,000 permits in fiscal year 2011, the authors concluded that the actual oversize/overweight pavement and bridge consumption and other monetized impacts (infrastructure operations and safety) exceeded six times the permit revenues. The actual consumption and monetized safety and mobility impacts amounted to approximately $410 million in excess of the $111.4 million collected in permit fees.

Other states have also recently carried out similar TS&W or oversize/overweight vehicle studies. These include Minnesota in 2006, Wisconsin and Ohio in 2009, South Carolina in 2013, and an ongoing study in Indiana (Cambridge Systematics, Inc. and SRF Consulting Group, Inc., 2006; Cambridge Systematics, Inc., 2009; ODOT, 2009; Chowdhury et al., 2013; Everett et al., 2014). Continued national and state interest in TS&W, HCA, and oversize/overweight vehicle studies indicates an unresolved issue, namely, how to address the excessive uncompensated consumption of highway infrastructure by overweight vehicles.

1.4 Options for Protecting Common Assets

There are a number of ways by which state agencies can preserve their highway infrastructure while allowing overweight truck operations. Nearly all 50 states use traditional revenue sources to attempt to recuperate some or all of the costs incurred from trucking companies. These include registration and licensing fees, fuel tax revenues, and existing permit fees. TS&W limits and fee structures, some proposed and others in place, have provided (or will potentially provide) incentives for investment in equipment that is less damaging to the existing infrastructure. These programs, if successfully implemented, can present a win-win situation where the infrastructure does not experience undue deterioration while the trucking industry benefits from more efficient operations. Although it has not been explicitly applied to overweight vehicles, transportation demand management through a quota system has been used in other countries as a viable method to control traffic growth. Quotas can be similarly applied to overweight vehicles to control the extent of highway infrastructure consumption.

1.4.1 Traditional Revenue Sources

The primary revenue sources currently employed by state departments of transportation (DOTs) and departments of revenue (DORs) include registration and licensing fees, fuel tax revenues, and permit revenues. Registration fees are paid by all vehicles. Typically, vehicles which operate at or above the federal limit of 80,000 lbs pay the same registration fee. Fuel tax revenues are meant to be a “pay as you go” system. Unfortunately, the federal fuel tax has not increased since 1993, although the cost of reconstruction, rehabilitation, and maintenance of the infrastructure has increased. Currently, the federal diesel fuel tax is 24.4 cents per gallon (Weingroff, 2013). Similar to registration fees, fuel taxes are paid by all vehicles regardless of weight. Typically, heavier vehicles are less fuel efficient; therefore, the fuel taxes paid by overweight vehicles are higher than for vehicles at or below the federal GVW limit. In addition to registration fees and fuel taxes which are paid by all users, permits are the traditional means to collect revenue specifically from overweight vehicles.

Previous research has indicated that the revenues generated from permit fees are insufficient to offset the pavement and bridge consumption from overweight vehicles, as discussed in Section 1.3. Additionally, reliance on overweight vehicle permitting fees alone may not lead to a balance between costs and benefits. If the fees are too low, the costs of consumption are not recovered and assets deteriorate more quickly compared to the situation where there are no additional loadings from overweight vehicles. Fees that are too high place an undue burden on the trucking industry, hinder economic development, and may even drive industry away to other locations that have more favorable overweight permitting policies. Mathematical programming tools can address the competing needs of protecting infrastructure and supporting economic activity to optimize traditional overweight vehicle permits.

1.4.2 Incentives for Infrastructure-Friendly Vehicle Usage

Since the 1980s, a number of states have explored the use of TS&W limits and permit fee structures which encourage the use of infrastructure-friendly vehicles. Perhaps the earliest known example is the "Turner Proposal" first proposed by Francis C. Turner in a 1984 address to AASHTO (TRB, 1990b). The Turner Proposal advocated for lower axle weight limits, longer vehicle length limits, and higher GVW limits. Although Turner's proposed TS&W limits were never adopted nationally, individual states have explored methods to move in this direction.

In Michigan, state TS&W limits allow vehicles up to 164,000 lbs, but limit most individual axle weights to only 13,000 lbs (MDOT, 2013). By requiring additional axles for higher GVW, Michigan Department of Transportation (MDOT) ensures that trucking companies use equipment that causes less damage to the infrastructure. That way, the trucking industry can increase, or in some cases more than double, their payload, increase efficiency, and reap the financial benefits.

Similarly, Indiana Department of Transportation (INDOT) introduced a new, inexpensive annual, multi-trip permit for vehicles configured to limit consumption of infrastructure beginning February 1, 2014 (INDOT, 2013). The INDOT annual, multi-trip permits cost $20 and require vehicles configured to less than 2.40 equivalent single axle loads (ESALs). ESALs are the traffic input parameter in the 1993 AASHTO Guide for the Design of Pavement Structures, the most widely-used pavement design method, and the method used to design most existing pavements. The ESAL for a given truck is the number of standard 18,000 lbs single axles that will cause the same amount of pavement consumption as the given axle load and axle configuration for that vehicle. INDOT's annual, multi-trip permits are based on a pavement consumption measure (ESAL-miles of travel); however, ESALS are not directly reflective of actual bridge consumption.

States may either mandate infrastructure-friendly vehicles, similar to the Michigan state TS&W limits, or may encourage vehicle loading behavior to limit consumption of highway assets through financial incentives, similar to the efforts in Indiana. Although INDOT uses an inexpensive permit option to encourage infrastructure-friendly vehicle use, other mechanisms available for implementation include rebates, bonuses, and other reduced fees.

1.4.3 Overweight Vehicle Permit Quotas

Quotas are a transportation demand management strategy that has been used to mitigate congestion. Transportation demand management can refer to any number of strategies that lead to an efficient use of transportation resources. Quotas have not been previously applied to overweight vehicle operations. Instead of targeting congestion, an overweight vehicle quota would lessen undue asset deterioration by enforcing an upper limit on the amount of infrastructure consumption allowable by overweight vehicles.

Quotas have been successfully applied in Singapore, Shanghai, and Beijing to control vehicle ownership and usage. The primary constraint in Singapore is the limited land available to add capacity. In all three locations, population growth, disposable income growth, and the increased car ownership associated with both have led to excessive congestion. In Singapore, the vehicle quota system (VQS) was adopted in combination with the existing cordon and tolls after high vehicle taxes and gasoline taxes were found to be ineffective at limiting demand for additional vehicles (Phang, 1993). In Singapore, Certificates of Entitlement (COEs) that entitle an individual to own and operate a vehicle for 10 years are auctioned off twice each month by the Singapre Land Transport Authority. Private car license plates (PCLPs) are also auctioned off in Shanghai; however, Beijing uses an egalitarian lottery system to allocate the limited quota of license plates. Chu (2012) observed that in the egalitarian system in Beijing, individuals wanted *the option* to purchase a license plate even if they did not have any *intention* to do so, or entered to help the chances of friends or family.

Vehicle quotas present a novel opportunity for overweight vehicle demand management. Existing overweight vehicle permit fees, both fixed and variable, clearly do not adequately address an increasing demand for use of such vehicles. Murphy et al. (2012) found that profits from a 4,000 lbs increase in GVW are sufficient to justify the purchase of permits that cost between $225 and $1080 annually in Texas; operating overweight vehicles leads to profits higher than the cost of those permits. Given the inefficiencies of the lottery system used in Beijing (which would also likely occur in a first-come first-served system), an auction is likely the most useful format to implement a quota system for overweight vehicles.

1.5 Research Objectives

The primary objective of the current study is to present options to address the growing use of overweight vehicles and their impacts on common highway infrastructure assets. Four overweight vehicle permitting alternatives are explored as follows:

- Optimization of traditional permitting mechanisms
- Incentives for infrastructure-friendly vehicle use
- Use of quotas with auction allocation to manage road consumption
- Harmonization of overweight vehicle permitting among multiple states

The options are not mutually exclusive. For example, both incentives for infrastructure-friendly vehicles and the quota can be employed simultaneously. Additionally, harmonization requires the implementation of some form of overweight vehicle permitting, whether through traditional permits (preferably optimized), incentives, and/or quotas.

For each of the first three alternatives, the framework is first described. Then, for illustrative purposes, the newly-introduced overweight vehicle permit fee structure in Indiana is used as a case study to demonstrate application of the framework.

In addition to the application of the three options for new permits in Indiana, a qualitative discussion of regional and national cooperation explores the additional efficiencies that can be achieved through TS&W and overweight vehicle permitting harmonization among several or all 50 United States.

1.5.1 Indiana Case Study

On June 1, 2013, Indiana's House Enrolled Act 1481 (HEA-1481) established a provisional permit structure based on equivalent single axle load miles (ESAL-miles) for overweight divisible loads of agricultural goods (up to 97,000 lbs) and metal goods (up to 120,000 lbs) (Permits for Loads, House Enrolled Act No. 1481, 2013). ESAL-mile fees are a special type of weight-distance fee that relates weight into a measure of pavement consumption, ESALs.

Pavement deterioration depends on several factors, including traffic loading, pavement materials and layer thickness, underlying soil characteristics, and environmental factors. Two approaches are currently used to design pavements to withstand the stresses and strains from each of these factors: empirical and mechanistic-empirical. Although mechanistic-empirical design is a newer, major change from traditional pavement design and the Federal Highway Administration (FHWA) considers implementation of this type of design to be a high priority, the vast existing network was designed based on empirical methods (FHWA, 2011). The 1993 AASHTO Guide for the Design of Pavement Structures remains one of the most widely-used pavement design methods. These procedures are based on an empirical AASHO Road Test conducted in the late 1950s and early 1960s on a test track in Ottawa, Illinois. The design equations have been modified four times since the original guide was published in 1961 to meet the needs of current users. The traffic input parameter for the traditional empirical approach is the Equivalent Single Axle Load (ESAL). As previously described, the ESAL for a given truck is the number of standard 18,000 lbs single axles that will cause the same amount of pavement damage as the given axle load and axle configuration. A standard single axle weight of 18,000 lbs was selected on the basis of the legal limit in many states at the time of the Road Test in Ottawa (Schwartz & Carvalho, 2007). As weight increases, the damage to pavement infrastructure is exponential; for example, doubling the weight on an axle causes approximately 16-times the amount of damage. ESAL calculations account for the non-linearity so that having twice as many ESALs does relate to twice the damage to pavement infrastructure. Although mechanistic-empirical design has many benefits over traditional empirical design (see for example the work of Zhang et al., 2000 and Prozzi et al., 2007), empirical methods use a single traffic input parameter, ESALs, which can also be estimated quickly for any given vehicle using the network. Straightforward ESAL calculations are the basis for INDOT’s overweight commodity permit fees.

The new overweight commodity permits introduced in HEA-1481 supplement several existing overweight vehicle permits available in Indiana including oversize/overweight (OS/OW) vehicle permits for non-divisible loads and Special Weight permits (also called Michigan Train permits) for overweight vehicles up to 134,000 lbs operating on a specified network known as the Extra Heavy Duty Highway Network (XHDH). Prior to June 1, 2013, overweight divisible loads could be moved only on the XHDH under Special Weight permits. Since enactment, overweight divisible loads can continue to be moved under the Special Weight permit on the XHDH or on other State and U.S. Routes and the Interstate system using the new overweight commodity permits as long as the vehicles are in compliance with the various regulations associated with each permit type.

As mandated in the original legislation, the fee structure defined in HEA-1481 was followed by Emergency Rules which took effect January 1, 2014. The Emergency Rules maintained the overweight commodity permits with changes to the fee schedule including an administrative fee, the charge per ESAL-mile of travel, the ESAL-credit or number of ESALs for which a carrier did not have to pay a fee in the ESAL-mile determination, and standard weights used to calculate ESAL-miles for larger axle groups with four or more axles. Additionally, the Emergency Rules established the annual, multi-trip permits available for vehicles configured and loaded at or below 2.40 ESALs.

To date, the introduction of overweight commodity permits in Indiana has followed the status quo of traditional permitting mechanisms. The state is able to permit overweight divisible loads because of the grandfather rights granted in surface transportation authorization legislation and the broad interpretation of those rights granted by the Symms Amendment included in the 1982 STAA. The new permit class was established by the state legislature but administration of those permits, including the selection of appropriate fees, was delegated to the state DOT and DOR.

By law, INDOT was required to consider the results of a study of the impacts of overweight divisible loads by December 31, 2014 to set final permitting rules. On behalf of INDOT, a research team at Purdue evaluated the impacts of overweight commodity permits on revenue generation, asset degradation, modal distribution, economic development, and economic competitiveness (Everett et al., 2014).

In addition to the impacts analysis, the decision makers at INDOT could be better informed through an analytical exploration of the tradeoffs associated with different fee levels (in terms of dollars per ESAL-mile of travel). The annual, multi-trip permits introduced in the Emergency Rules are a living example of incentives for infrastructure-friendly vehicles. Finally, the quota and auction allocation mechanism and the harmonization of overweight practices are additional alternatives that could supplement the existing incentives for infrastructure-friendly vehicles.

CHAPTER 2. OPTIMIZATION OF TRADITIONAL PERMITTING MECHANISMS

2.1 Introduction

Overweight vehicle permit fees are the traditional mechanism in place to collect revenue from overweight vehicles to offset the consumption from their excess loads. In an equitable and efficient system, overweight vehicle permit fees should be designed to collect the *additional* consumption specifically attributable to the overweight load. Here, additional consumption is defined as consumption beyond what would have occurred from a non-overweight vehicle. Appropriate permit fees need only recover the *additional* consumption because other revenue collection mechanisms (registration and licensing fees and fuel taxes) cover the portion of infrastructure consumption due to the first 80,000 lbs.

2.2 Framework

In the United States, the status quo of overweight vehicle operations is that each individual state separately exercises grandfather rights to determine, implement, and enforce their individual TS&W regulations including any overweight vehicle permitting procedures. Individual state and national TS&W, HCA, and oversize/overweight vehicle studies have been used to inform decision makers within state DOTs or DORs for establishing overweight vehicle permitting fee structures. The TS&W limits and overweight vehicle permit fee structures, including price points, vary across states and over time. Overweight vehicle permits can be categorized by the type of fee structure and the time period and/or number of trips for which permits are valid.

Overweight vehicle permitting fee structures can be classified as fixed fees, weight-based fees, distance-based fees, or a combination of weight-distance based fees. The fee types cover a spectrum in terms of both the administration complexity and the relationship to actual consumption, as shown in Figure 2.1. At one extreme, fixed fees are the easiest to administer, require the least administrative resources, but are the least reflective of actual asset consumption. On the opposite end of the spectrum, weight-distance based fees are the most closely linked to consumption but are the most complex to administer. More states are adopting (or at a minimum researching) fee structure based on weight, distance, or both; although several still use fixed fees which are the least related to actual consumption. Additionally, a state may offer multiple types of permits for different categories of overweight movements, all with different fee structures.

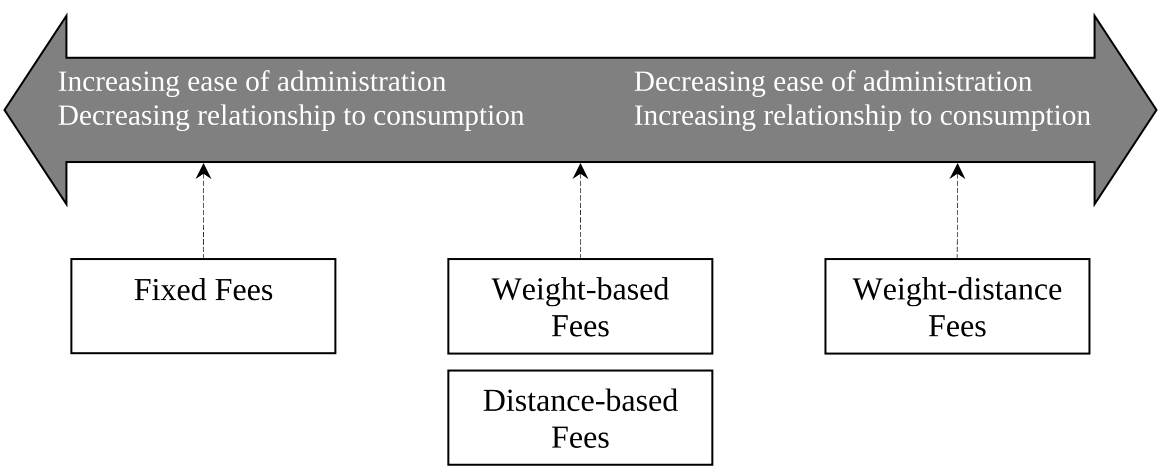

Figure 2.1 Classification of Permit Fee Structures

In addition to the different types of fee structures, transportation agencies may offer single-trip permits, blanket permits, or a combination of both. Single-trip permits are typically issued for one trip by a single vehicle within an established time period, often 7-, 10-, or 14-days. Blanket permits are issued individual vehicles for a specified time period (often quarterly or annually) and allow the vehicle to make an unlimited number of trips during the time period. Blanket permits are typically issued using a fixed fee structure, although this is not a requirement. Whitford and Moffett (1995) observed a general trend among highway agencies to move from single-trip permits to annual blanket permits with fixed fee structures which resulted in net loss in agencies revenues. They also estimated the cost savings from reduced monitoring efforts for Indiana specifically (an advantage of blanket fees) to be less than the loss in revenue. Another consequence of the widespread introduction of blanket permits, noted by Whitford and Moffett, was that many trucking companies consolidated their overweight operations by shifting from many vehicles, each operating on single-trip permits, to a few vehicles dedicated to overweight operations.

The primary benefit of blanket fees is administrative convenience. For trucking companies that frequently transport overweight loads, the process to request multiple single-trip permits is time consuming, laborious, and may make it impossible for truckers to make just-in-time deliveries. In the extreme, this can be disruptive to efficiency of operations, economic productivity, and lead to business losses. For agencies issuing overweight vehicle permits, the duplicate efforts to review each single-trip permit request are eliminated when carriers can obtain blanket permits.

In addition to overweight vehicle permits, several states make exemptions or exceptions to statutory limits for select industries. In these cases, carriers may operate specific vehicles that are beyond legal limits and/or normally would require a permit without paying the full amount, or in some cases any amount, of permit fees according to the existing fee structure. Exemptions significantly reduce the amount of revenue collected by the state agency while allowing additional consumption of highway assets. Prozzi et al. (2012) reported that a Texas permit fee structure that imposes fees on previously exempt vehicles could recover an additional $150 million in revenue annually. States typically make exceptions or exemptions for industries that are considered significant to the state economy and for equipment used in emergency operations. Examples include reduced fee permits for coal, sand gravel and crushed stone in Virginia; weight exceptions for seed cotton haulers in Texas; a ten percent extra weight allowance for agricultural products in certain states, such as Indiana; and, exemptions for equipment for fire rescue, the military, and train derailment recovery in a number of states. Although exemptions and exceptions may be appropriate for public safety or to promote economic activity, they contribute to additional consumption of public assets without additional revenue to pay for that usage.

Under traditional permitting mechanisms, individual states operate independently to determine TS&W limits, overweight vehicle fee structures including price, and any exemptions or exceptions. These policies, as well as the inefficient fuel taxes and licensing and registration fees, tend to result in insufficient funds for maintaining highway assets and providing safer, more efficient transportation networks.

2.2.1 Advantages and Disadvantages

The primary advantage of the current system, in which each state establishes overweight vehicle policies independently, is that states are given significant latitude to set priorities and make decisions appropriate for their infrastructure needs and economic climate. Beginning with the Federal Aid Road Act of 1916, highway maintenance has been recognized as a state rather than federal responsibility, even though both parties provide funding. The idea that states are best able to make decisions regarding TS&W limits has been perpetuated through the grandfather rights included in every major federal surface transportation authorization legislation. Although consumption typically exceeds revenues, the traditional permitting mechanisms have been the tried-and-true method used by nearly every state since the 1940s, even before construction of the Interstate System. States can and do easily and routinely exercise grandfather rights to establish new or revised permitting structures because these mechanisms were in place prior to January 1, 1956. State sponsored changes outside of the realm of grandfather rights likely would require modification to existing federal enabling legislation.

As previously discussed, the primary disadvantage of traditional overweight vehicle permitting mechanisms is that, at present rates, the consumption of infrastructure assets far exceeds permit revenues. Straus and Semmens (2006) estimated that $12-$53 million in uncompensated pavement consumption is attributable to overweight vehicles on Arizona’s roadways. The VTRC (2008) determined that equitable consumption fees could not be imposed in Virginia because a very small percentage of overweight vehicles caused a disproportionately large percentage of bridge consumption related damage to the state bridges; the consequences of imposing equitable fees likely would have decimated some industries. Prozzi et al. (2012) determined that the pavement consumption, bridge consumption, and monetized operations and safety impacts from overweight vehicles were more than six times greater than the permit revenues collected in Texas. TS&W, HCA, and oversize/overweight studies consistently document the highway equivalent of the tragedy of the commons when overweight vehicles disproportionately consume highway assets at reduced prices.

A second disadvantage of traditional individual state permitting mechanisms is the fostering of competitive regulations and/or pricing schemes that neither protect the existing infrastructure nor benefit haulers moving goods between multiple states. For example, steel production is a vital industry in the Midwest with several mills located in Illinois, Indiana, Michigan, Ohio, and Kentucky; yet, all five of these states have different permitting practices for moving steel coils. Illinois does not issue divisible load permits for metal goods over the federal limits of 80,000 lbs.

Michigan does allow GVWs in excess of 80,000 lbs through the unique application of axle weight TS&W limits. Carriers may load up to 164,000 lbs on vehicles with 13-axles without obtaining any explicit overweight vehicle permit. Instead of regulating the GVW, Michigan limits axle loadings for overweight vehicles to 13,000 lbs with the exception of a single tandem axle group which can be 32,000 lbs (16,000 lbs each) and a steering axle up to 18,000 lbs.

Kentucky and Ohio have similar regulations—each issue overweight divisible load permits for steel loads up to 120,000 lbs; however, both states impose travel limitations. Kentucky restricts travel to 150 miles. Ohio issues both steel and aluminum coil permits but also restricts travel to 150 miles. Furthermore, Ohio requires an approved steel coil facility as the origin for 90-day and 365-day permits. Ohio's approved steel coil facilities are all within the state of Ohio with the exception of the AK Steel Corporation facility located in Ashland, Kentucky on the Ohio River. Although not explicitly stated, the distance restrictions and requirements for origin facilities in Ohio appear to encourage overweight movements only within the state and prevent carriers from moving steel coils across Ohio. This effectively retains steel manufacturing and use facilities within the state issuing permits.

Recently, Indiana enacted legislation to introduce permits for metal commodities up to 120,000 lbs. In addition to creating new permits, the legislation explicitly required INDOT to conduct a study on the impacts of the new permits including Indiana's economic competitiveness compared to other Midwestern states.

Although there are no restrictions preventing Midwestern states from working together to enable carriers to move steel throughout the region, each state has independently adopted overweight divisible load permitting practices to protect their own interest in attracting and retaining steel mills within their own state boundaries.

The competition that is introduced through individual states establishing different permitting mechanisms presents two issues. First, carriers that desire to move goods across multiple states (or even from one state to another) are at a disadvantage when neighboring states have different GVW limits, different axle limits, or require different vehicle configurations. In some cases, carriers are able to move a vehicle across one state but then have to stop and unload to a different vehicle or multiple vehicles to meet the requirements of the next state on their route. Alternatively, lift axles, which are lowered when a vehicle is weighed by enforcement, and dummy axles, which carry very little weight, have been used in some sectors to meet the requirements of the law without meeting the spirit of the law to protect infrastructure. Fortunately, the use of lift axles and dummy axles has been prohibited in most overweight provisions for vehicles over 80,000 lbs. They are used more often for short haul vehicles such as waste disposal trucks, concrete mixers, etc which have lower GVW limits due to the length of the vehicles. The second potential downside is that infrastructure may not be adequately protected when states reduce permit fees and/or allow higher GVWs to induce companies to relocate from states with practices perceived to be less favorable to the trucking industry.

2.2.2 Permitting Efficiency and Economic Productivity Improvements through Optimization

Within the context of traditional permitting mechanisms, state agencies can improve overweight vehicle permitting fee structures through the use of mathematical programming. Assessing any type of usage fee is a critical decision that involves both transportation agencies and legislators who must be responsive to the needs of multiple stakeholders. Decisions have significant consequences for both the infrastructure owner and the infrastructure users (both overweight and non-overweight); therefore, choices should be made based on input from all parties, technical analysis of the anticipated consequences of each choice or policy, and information about tradeoffs between different alternatives. Similar to other transportation related decisions, mathematical programming tools can be used to better inform transportation agencies about the potential consequences and tradeoffs across various overweight vehicle permitting fee structures.

In setting appropriate TS&W limits and establishing overweight vehicle permitting mechanisms, decision makers must consider multiple conflicting objectives. On one hand, the state has a responsibility to protect highway infrastructure from excessive deterioration to provide a safe and efficient system for all users. Nominal permit fees do not adequately recover the cost of consumption. The current fees employed throughout the United States have led to underfunded highway infrastructure which deteriorates faster than expected. On the other hand, the state also has a responsibility to foster economic development. Excessively high permit fees may serve as a burden for the trucking industry, and may even induce companies—both trucking companies and those that rely on trucks to move their goods—to relocate to other states with more favorable policies. Permitting agencies should not adopt policies that will hinder economic productivity.

2.2.3 Optimization in South Carolina

Dey at al. (2014) identified two conflicting objectives in a multiobjective optimization of overweight vehicle permit fees in South Carolina; objectives in their multiobjective optimization formulation were to minimize the unrecovered consumption cost and to minimize the permit fee. Dey et al. (2014) used the percentage of cost recovery as the decision variable. The study additionally included tradeoffs between different permit fees to provide information to the South Carolina DOT prior to adopting a new fee structure.

2.2.4 Methodological Improvements for Indiana

In formulating a mathematical programming model for overweight vehicle permitting in Indiana, improvements were made to the work carried out by Dey et al. (2014) to correspond to choices available to both the agency and the trucking industry.

First, the decision variable for the Indiana study, the price of permits in dollars per ESAL-mile, is a better representation of the policy decision INDOT can make. Different vehicles consume highway infrastructure at different rates based on vehicle configuration and loading. It is impractical for INDOT to charge a specific percent of consumption unless INDOT can quantify the consumption for each permitted trip. Additionally, a fee structure based on the percentage of consumption cost recovery would be complicated for trucking companies to assess before requesting permits.

Additionally, the objective in Dey et al.'s (2014) formulation to minimize permit price is a rudimentary approach at capturing the agency's goal to support economic activity. Although all carriers would like to obtain permits at the lowest possible cost, vehicle permit acquisition costs are only a small fraction of total operating costs. Different overweight vehicle permits can be better or worse, independent of price, depending on how carriers can leverage those permits to move goods more efficiently. Carriers make decisions about which vehicles to load based on their available fleet and on the total logistics cost of moving goods from origin to destination. Total logistics costs include transportation costs, warehouse costs, and inventory costs. Minimizing the total logistics cost, or maximizing the total logistics cost savings, facilitates trade and commerce; minimizing permit prices does not necessarily achieve this goal. The multiobjective optimization formulation contained herein includes a more accurate representation of decision maker's goals following a brief overview of multiobjective optimization principles.

2.2.5 Multiobjective Optimization Introduction

Multiobjective optimization is a mathematical tool "in which the designer's goal is to minimize and/or maximize several objective functions simultaneously" (Gero, 1985). In general, a multiobjective optimization problem is formulated as follows:

$$\text{minimize } \{f_1(\boldsymbol{X}), f_2(\boldsymbol{X}), \cdots, f_k(\boldsymbol{X})\}$$

$$\text{subject to } \boldsymbol{X} \in \boldsymbol{S}$$

where k is the number of objective functions, $f_i(\boldsymbol{X})$ is the ith objective function, and $\boldsymbol{X}$ is the vector of decision variables that belong to the nonempty feasible region $\boldsymbol{S}$. In practice, the decision maker may wish to maximize some objective functions. Maximization objective functions can easily be transformed into minimization objective functions and some solving techniques can accommodate both minimization and maximization objectives at the same time. If there is only one objective ($k = 1$), the problem simplifies to a single objective optimization problem which can have zero, one, or many optimal solutions. Due to the conflicting nature of the objective functions, it is typically not possible to minimize/maximize all objective functions at the same time; therefore, objective vectors $\boldsymbol{z} = \boldsymbol{f}(\boldsymbol{X}) = \{f_1(\boldsymbol{X}), f_2(\boldsymbol{X}), \cdots, f_k(\boldsymbol{X})\}^T$, are considered optimal "if none of their components can be improved without deterioration to at least one of the other components" (Branke et al., 2008).

Often there is not a single optimal solution but a set of solutions called Pareto optimal or non-dominated solutions. (A dominant solution can only exist if the objective functions do not conflict.) Pareto optimal solutions are defined mathematically as follows: a decision vector $\boldsymbol{X}^* \in \boldsymbol{S}$ is pareto optimal if there does not exist another decision vector $\boldsymbol{X} \in \boldsymbol{S}$ such that $f_i(\boldsymbol{X}) \leq f_i(\boldsymbol{X}^*)$ for all $i = 1, 2, \cdots, k$ and $f_j(\boldsymbol{X}) < f_j(\boldsymbol{X}^*)$ for at least one objective function j (using minimzation notation for all objective functions) (Branke et al., 2008). In other words, if there does not exist a solution that dominates the feasible solution for at least one objective function while all others are at least as good, then that solution is a pareto optimal solution. The set of all pareto optimal solutions is called the Pareto frontier. When there are exactly two objective functions, the Pareto frontier takes the shape of a two-dimensional curve; when there are more objective functions, the Pareto frontier is a hyperplane or surface.

Given the multitude, often even infinite number, of Pareto optimal solutions, typically multiobjective solution methods are aimed at helping the decision maker choose the most preferred of Pareto optimal solutions. Solution methods are most often classified by decision maker's involvement in the analytical process (Mavrotas, 2009; Branke et al., 2008). In *a priori* methods, the decision maker first indicates his or her preferences then the analyst attempts to find an optimal solution that meets those preferences. If the decision maker provides preference information by way of goals or weights, a multiobjective optimization may be transformed into a single objective optimization problem. The drawbacks to *a priori* methods are that decision makers may not have realistic expecations, may not be confident in their preferences, and are not provided additional information about other Pareto optimal solutions.

In *interactive* methods, the decision maker and the analyst iteratively provide preference information and search for solutions until the process converges on a most preferred solution. Interactive approaches are an improvement from *a priori* methods when the decision maker alters their preferences based on knowledge about the interdependencies of the problem variables.

Finally, *a posteriori* methods seek to generate all or a sufficient representation of Pareto optimal solutions to provide the the decision maker. Then the decision maker can choose among the full set of Pareto optimal solutions. The drawbacks to *a posteriori* methods are that generating a representative set of Pareto optimal solutions can be time consuming and/or computationally expensive; and, if there are more than two or three objective functions, visualizing the Pareto frontier can be difficult.

In addition to these methods, the fourth class of solution methods are *no-preference methods* in which a decision maker is not present but assumptions are made about a "reasonable" decision maker's preferences (Branke et al., 2008). No-preference methods may or may not result in an "ideal" solution depnding on the assumptions made regarding the "reasonable" decision maker (Bai, 2012).

A posteriori methods are adopted for the present study. These methods provide the decision maker complete information, including visualizations of the Pareto optimal frontier and associated tradeoffs, to support the chosen permit fee structure. In the Indiana case study to follow, the resulting visualizations are a resource for INDOT, provided at the end of the optimization routine, so that decision makers can make an informed choice of permit fees. In contrast, *a priori* and interactive methods both require input from INDOT either prior to or during the optimization process. The optimal solution using either of those methods is influenced by INDOT's stated preferences, whereas INDOT may not realize that they would prefer a different optimal solution included in the Pareto optimal frontier defined using *a posteriori* methods. No-preference methods were not used because assumptions about a "reasonable" decision maker might not reflect the preferences of decision makers at INDOT and they do not provide as much information as *a posteriori* methods.

The two most widely used solution methods for multiobjective optimization are the weighting method and the ε-constraint method. In general, for the weighting method, the multiobjective optimization problem is re-stated using weights, w_i, as follows:

$$\text{minimize } z = \sum_{i=1}^{k} w_i f_i(\boldsymbol{X})$$

$$\text{subject to } \boldsymbol{X} \in \boldsymbol{S}$$

where $w_i \geq 0$ and $\sum_{i=1}^{k} w_i = 1$. In *a priori* settings, the decision maker states his or her preferences as weights initially. In *a posteriori* settings, the weights are varied to obtain multiple solutions which are then presented to the decision maker.

In the ε-constraint method, one objective function is optimized while all others are incorporated as additional constraints. The multiobjective optimization problem is re-stated as follows:

$$\text{minimize } z = f_1(\boldsymbol{X})$$

$$\text{subject to } f_j(\boldsymbol{X}) \leq \varepsilon_j \text{ for all } j = 2, 3, \cdots, k$$

$$\text{and } \boldsymbol{X} \in \boldsymbol{S}$$

where ϵ_j are either the upper bounds for each respective objective function (if known and specified by the decision maker) or are varied to develop the Pareto frontier. The ε-constraint method is thus an *a posteriori* method. As before, minimization notation has been used here, but in practice the decision maker may seek to minimize some objective functions and maximize others.

Mavrotas (2009) developed an augmented ε-constraint method which incorporates surplus variables (or slack variables) to overcome difficulties in determining the range of objective functions. Mavrotas formulated the augmented ε-constraint multiobjective optimization problem as follows:

$$\text{minimize } z = f_1(\boldsymbol{X}) - \delta\left(\sum_{j=2}^{k} s_j\right)$$

$$\text{subject to } f_j(\boldsymbol{X}) + s_j = \varepsilon_j \text{ for all } j = 2, 3, \cdots, k$$

$$\text{and } \boldsymbol{X} \in \boldsymbol{S}$$

where s_j are the surplus variables and δ is a very small number between 10^{-3} and 10^{-6}. In addition to the new solution method, Mavrotas created a General Algebraic Modeling System (GAMS) model publically available through the GAMS Model Library (http://www.gams.com/modlib/modlib.htm, Mavrotas' model is number 319, named "epscm").

2.3 Optimization of Overweight Commodity Permit Fees in Indiana

The first step in any multiobjective optimization is to formulate a mathematical model of the problem including the decision variables, objective functions, constraints, and variable bounds (Branke et al., 2008). The tradeoffs associated with the newly-introduced ESAL-mile based fee structure in Indiana can be explored using a bi-objective optimization model, a multiobjective model with exactly two objective functions.

2.3.1 Decision Variable

For the Indiana model, the decision variable is the ESAL-mile based fee to charge overweight commodity permit holders, consistent with the overweight commodity permits. Although other decision variables describing the fee structure could be used, the ESAL-mile based fee was used because it is a weight-distance usage measure. This is preferable to other fee structures in terms of its relationship to actual consumption; secondly, it is the consumption measure currently used to administer permits.

The drawback to using the ESAL-mile based fee as the decision variable is that ESAL-miles are a measure of marginal pavement consumption, not marginal bridge consumption. To remedy this situation, INDOT is able to charge a fee per ESAL-mile of travel that includes the cost of pavement consumption and the "relative" cost of bridge consumption (similar to that proposed by VTRC (2008) for bridge consumption in Virginia). The "effective" fee is therefore higher than the cost in $/ESAL-mile of pavement consumption alone to account for additional bridge consumption that would not be captured otherwise. ESAL-miles of travel are easy for both the agency and the carriers to compute for any given vehicle and trip.

2.3.2 Minimization of Uncompensated Consumption Cost

The first objective function is to minimize the uncompensated consumption cost (UCC). This objective captures INDOT's fiduciary responsibility to protect the state highway infrastructure from undue damage. This is similar to one of the objectives included in Dey et al.'s (2014) multiobjective optimization for South Carolina; however, Dey at al.'s results indicate the percentage of consumption that is uncompensated whereas the present analysis quantifies the amount of uncompensated consumption in dollars.

2.3.3 Maximization of Total Logistics Cost Savings

The second objective function is to maximize total logistics cost (TLC) savings with respect to the total logistics cost without overweight commodity permits. The total logistics costs include all of the costs associated with the flow of goods including both transportation costs and any other costs associated with storage or transportation of goods. TLC savings quantify the reduction in TLC for all carriers due to the introduction of overweight commodity permits. This objective captures the interests of freight operators and shippers who rely on trucks to move their goods. This objective also captures INDOT’s responsibility to adopt policies that will not be a burden to the trucking industry and will facilitate trade and commerce. Dey et al. (2014) minimized the permit fees themselves, which is only one aspect of the cost of moving goods from origin to destination. The maximization of TLC savings (and in turn the minimization of TLC) better reflects the actual decision making process of both shippers and carriers who would like to move goods as efficiently and cost-effectively as possible.

2.3.4 Constraints

The demand for overweight vehicle permits is influenced by changes in the total logistics cost. Often, transportation analysts consider the relationship between demand and transportation cost, only one component of total logistics cost. In this framework, TLC is more appropriate because a newly imposed permit fee (a small increase in one component of the transportation cost of a single trip) which allows previously prohibited movements often results in a reduction of both the overall transportation costs and other logistics costs. Demand is also related to the uncompensated consumption because demand pertains to the system users who pay a portion of the cost of consumption. Demand is incorporated into the bi-objective optimization model in both the objective functions and the constraints.

Dey et al. (2014) also incorporated demand as a constraint using elasticities; however, Dey et al. assumed that demand would decrease because permit fees would increase. Although this is true if regulations are the same but prices merely change, the South Carolina framework does not account for the cost savings carriers can experience by operating at weights previously not allowed. In contrast, the present analysis accounts for an increase in demand due to TLC savings.

2.3.5 Variable Bounds

The final constraint on the system is the variable bounds for the decision variable. Although it is technically possible to collect more money in permit fees than the cost of consumption, this would represent a reverse subsidy from the industry to maintain the public assets, opposite to the conventional use of subsidies, an undesirable outcome. Therefore, an additional constraint requires that the ESAL-mile based permit fees be less than or equal to the ESAL-mile based cost of consumption. Finally, it is not possible to have a negative ESAL-mile based permit fee; therefore, the decision variable must be a positive variable.

2.3.6 Mathematical Programming Formulation

The bi-objective model can be generally formulated as follows:

$$\text{minimize } z_1 = UCC = f(C, x, D_1) \tag{2-1}$$

$$\text{and maximize } z_2 = S = g(x) \tag{2-2}$$

$$\text{subject to } D_1 = h(D_0, S, TLC_0, e) \tag{2-3}$$

$$\text{and } x \leq C \tag{2-4}$$

$$\text{and } x \geq 0 \tag{2-5}$$

where UCC is the uncompensated consumption cost, C is the ESAL-mile based cost of consumption, x is the ESAL-mile based permit fee, D_1 is the resulting demand for overweight vehicle permits in ESAL-miles, S is the total logistics cost savings, D_0 is the initial demand for overweight vehicle permits in ESAL-miles, TLC_0 is the initial total logistics cost, and e is the elasticity of demand in ESAL-miles with respect to total logistics cost (note, the elasticity is not with respect to the initial total logistics cost, but with respect to the total logistics cost associated with any given permit price).

2.3.7 Parameter Estimation

2.3.7.1 Objective Function to Minimize Uncompensated Consumption

Intuitively, the functional relationship of the first objective is as follows:

$$z_1 = (C - x)D_1$$

(2-6)

where the uncompensated consumption cost is equal to the total cost of consumption, $C \times D_1$, minus the amount that was paid for via permit fees, $x \times D_1$. When the ESAL-mile based fee is equal to the cost of consumption there is no uncompensated consumption. The cost of consumption is a single estimated value in dollars per ESAL-mile. The ESAL-mile based fee is the decision variable being optimized. The demand for using the system (in ESAL-miles of travel) is also variable and changes due to the cost of doing business and any cost savings resulting from using overweight vehicles relative to non-overweight vehicles. The demand estimation is not a constant parameter in the multiobjective optimization and requires extended consideration; therefore, it is presented in a later subsection.

2.3.7.2 Cost of Infrastructure Consumption

The cost of consumption typically consists of a number of cost items. In their multiobjective optimization, Dey et al. (2014) included unit pavement damage costs per mile and per ESAL-mile and unit bridge damage costs per mile for each axle group ranging from 2-axles to 8-axles. In the comprehensive study of the Texas overweight vehicle fee structure, permit revenues were compared to the total cost of pavement damage, bridge damage, and monetized infrastructure operations and safety impacts (Prozzi et al., 2012). For the multiobjective optimization contained herein, the Indiana-specific consumption estimate includes the cost of pavement and bridge damage attributable to the additional weight of overweight vehicles (Everett et al., 2014).

The marginal cost of pavement consumption has previously been measured in ESAL-miles of travel. Ahmed et al. (2013) estimated the unit cost per ESAL-mile of travel in Indiana on different highway networks: the Interstate system, the non-Interstate National Highway System (NHS) (a network of high national importance that includes the Interstates plus other important routes), and the non-NHS.

Ahmed et al. (2013) also estimated unit bridge consumption. Bridge consumption estimation is much more complex than pavement consumption estimation because consumption depends on the moment created when an overweight (or any other vehicle) traverses the bridge. The moment depends on the axle weights and spacing, the bridge type (steel, pre-stressed concrete, reinforced concrete), the bridge span length, and the age of the bridge. Ahmed et al. established several lookup tables that provide the unit cost per foot-pass for each AASHTO equivalent vehicle, highway network (Interstate, non-Interstate NHS, non-NHS), bridge material, and bridge age. For a single overweight vehicle, the AASHTO equivalent vehicle is determined as a function of the GVW, the average axle spacing, and the average axle loading, as described in Ahmed et al. (2013).

The comprehensive study for Indiana used individual permit records to estimate the total cost of pavement and bridge consumption resulting from HEA-1481 (Everett et al., 2014). A total of 10,517 individual permit records were queried from the Indiana Department of Revenue (INDOR) database which contains vehicle configuration and permit information. Geographic information systems (GIS) software was used to determine the cost of pavement and bridge consumption based on the vehicle configuration, GVW, and permitted route for each individual record. In addition to the consumption cost for each record, a breakeven analysis was conducted to determine the ESAL-mile based fee that would result in full collection (via permit fees) of the total cost of pavement and bridge consumption.

Although bridge consumption is not measured in $/ESAL-mile, the breakeven fee was determined by taking the full cost of consumption (pavement plus bridge) and dividing that by the ESAL-miles of travel, to yield a *quasi* ESAL-mile based cost of consumption. The quasi ESAL-mile based cost of consumption was estimated to be $0.84 per ESAL-mile of travel (Everett et al., 2014).

Additionally, although the fee structure established in the Emergency Rules includes a $20 administrative fee per permit, it is assumed in this multiobjective optimization that the ESAL-mile component of the fee accounts for the consumption of highway infrastructure while the $20 administrative fee is for administrative purposes only.

2.3.7.3 Objective Function to Maximize Total Logistics Cost Savings

The functional relationship for the second objective function (to maximize total logistics costs savings) is not quite as straightforward as the first objective function. The overweight commodity permits introduced in HEA-1481 provide new opportunities for overweight divisible loads in Indiana. Overweight operations typically are more efficient for carriers compared to multiple trips at or below legal limits, typically resulting in cost savings. Murphy et al. (2012) considered permits for a 5% extra weight allowance, (i.e., a total GVW of 84,000 lbs) on non-load-zoned roadways in Texas. The authors found that companies were willing to pay between $225 and $1,080 annually for the 4,000 lb increase in GVW due to the increased profitability of doing so. The overweight commodity permits introduced in Indiana represent far larger payload increases than those studied by Murphy et al. (2012). In the northern portion of Indiana, specifically near the XHDH, it is epected that not all carriers will take advantage of the new overweight commodity permits because the existing Special Weight permits may be more profitable to use. Similarly, for some origin/destination and shipment combinations, movements at or below legal limits (and thus not requiring a permit) may be more profitable depending on the permit price. The following subsections detail the statistical tools used to estimate the functional relationship between total logistics costs savings and ESAL-mile based overweight vehicle permit fees, $S = g(x)$, where S is the TLC savings and $g(x)$ is a function of the permit price in dollars per ESAL-mile.

2.3.7.4 Total Logistics Cost Savings

The Intermodal Transportation and Inventory Cost (ITIC) model is a tool developed by FHWA to investigate the modal shifts that can occur between truck and rail and between multiple overweight truck configurations due to truck or rail productivity improvements. For each shipment record, ITIC evaluates the transportation and inventory costs using each available mode—rail if possible and each of the available truck configurations—and assigns the shipment to the mode with the minimum total logistics cost. ITIC uses an all-or-nothing assignment for each record, a shipment cannot be split among multiple modes or multiple truck configurations (TRB, 2014). Additionally, not every mode is available for each record. For example, rail is not an option for some origin-destination pairs which are not connected by existing rail lines. The outputs of the ITIC include the vehicle-miles traveled for each truck configuration and the transportation and inventory costs. The ITIC model was used to estimate the total logistics costs with various ESAL-mile based fees imposed on overweight operations.

The major drawback of using disaggregate models such as ITIC is the large amount of input data required for analysis. Fortunately, the ITIC software comes pre-loaded with freight data. Commodity flow data from the Freight Analysis Framework (FAF) and rail cost data from the Surface Transportation Board (STB) Waybill sample are included. The FAF incorporates data from a variety of sources including the periodic Commodity Flow Survey conducted jointly by the Census Bureau and the Bureau of Transportation Statistics (BTS) as part of the Economic Census. The most recent Commodity Flow Survey was conducted in 2012 but the most recent FAF release (version 3) included in the ITIC software uses data from the 2007 Commodity Flow Survey. FAF data include origin-destination pairs, commodity type and miles shipped. The FAF data are complemented by commodity attribute data such as density, value, etc. from the Federal Railroad Administration (FRA); transportation cost data from Trans-Research International, Inc.; and rail cost data from the STB Waybill sample (FHWA, 2006). The preloaded data also includes assumptions for drayage miles (distance required to transport a good from one mode to another when applicable) and circuity miles (additional distance required for truck transport in urban areas) which were not changed in analysis.

The user inputs for the ITIC include the vehicle configurations that can be used and the additional user fees associated with using each configuration. Additional assumptions preloaded in the ITIC software can be modified to reflect local conditions, but were not changed for this analysis. The present study considers the total logistics cost savings that result from the introduction of new overweight commodity permits at different price points; therefore, other input assumptions do not need to be changed.

The ITIC is limited in the types of vehicle configurations which can be included because it is not fully customizable. Typical vehicles included in ITIC were used in place of corresponding vehicles permitted in Indiana as shown in Table 2.1. For the larger vehicle configurations (8- and 9-axle vehicles), the ITIC allows higher GVWs than allowed in Indiana. These vehicles were penalized in individual model runs to represent the decreased payload allowed in Indiana.

Table 2.1 Representative Vehicles in Intermodal Transportation and Inventory Cost (ITIC) Software

Configuration	Maximum GVW in ITIC (lbs)	Permitted GVW in Indiana (lbs)
5-axle	80,000	80,000
6-axle light	90,000	90,000
6-axle heavy	97,000	97,000
7-axle	110,000	110,000
8-axle	124,000	120,000
9-axle	140,000	134,000

The ITIC is also limited in terms of origin-destination pair data. Exact origins and destinations are not included, only the corresponding states. To account for the Special Weight permit stipulations that users only travel on the XHDH, the database was split into two components for individual model runs. Records with origin-destination pairs between Illinois and Michigan and between Illinois and Ohio (and vice versa for each), were assumed to be able to use the Special Weight permits and the XHDH. All other origin-destination pairs—including Indiana-Indiana, Indiana-Illinois, Indiana-Kentucky, Indiana-Michigan, Indiana-Ohio, Illinois-Kentucky, Kentucky-Michigan, and vice versa for each—were assumed to use routes off of the XHDH. Some shipments in the XHDH pool, for example, Illinois to Michigan, might use routes that are not on the XHDH. Similarly, some shipments in the non-XHDH pool, for example within the state of Indiana, could potentially use the XHDH network. It is assumed that sufficient shipments in each pool that could have been placed in the other pool cancel each other out in determining the total logistics costs when the results from each pool are summed as a synthesis of freight movements throughout the entire state. Records for agricultural and metal commodities only were included in this analysis.

2.3.7.5 Initial Total Logistics Cost

For purposes of this research, the Base Case represents the available truck configurations used in practice prior to HEA-1481. The first model run established the initial total logistics cost. The initial total logistics cost is the reference point to determine the total logistics cost savings for successive model runs. The ITIC automatically creates its own default case for comparison in every model run where the 5-axle single trailer loaded up to 80,000 lbs is the only truck configuration available; however, there were Special Weight permits available for overweight divisible loads prior to HEA-1481. Therefore, the first model run included the option for 6-axle light, 6-axle heavy, 7-, 8-, and 9-axle vehicles in the XHDH pool but not in the non-XHDH pool.

The user fees, applicable to the carriers, were the primary inputs that were altered for model runs. ITIC uses per mile user fees; therefore, all Indiana permit fees were converted into per-mile fees. For the Base Case development, the Special Weight permit fee of $42.50 per 24-hour period was assumed equal to $0.089 per mile. Assuming that an overweight vehicle operates at approximately 60 miles per hour for 8 hours within the 24-hour period equates to approximately 480 miles per Special Weight permit. Not all carriers will use the Special Weight permits in the same manner. Some may make multiple short trips while others might make one trip across the entire state. For those who travel more than 480 miles on a single permit, the per-mile cost is lower; for those who travel fewer miles, the per-mile cost is higher. It was assumed that 480 miles was the typical distance on Special Weight permits and therefore for all successive model runs, the per-mile cost of a Special Weight permit was $0.089.

The results for the Base Case model run are presented in Table 2.2. The number of records and tons shipped do not change between successive model runs because each record is assigned to the minimum TLC. If overweight vehicles are used, each vehicle has a higher payload capacity, thus vehicle miles traveled (VMT) is reduced when fewer vehicles trips are made to move the same amount of goods. Finally, Table 2.2 includes the total logistics cost for each vehicle configuration and the sum is the initial total logistic cost of $844,491,655.19. In addition to being used to estimate the total logistics cost savings, this value is also a variable in the demand constraint to be discussed in Section 2.3.7.8.

2.3.7.6 Incremental Savings for Range of ESAL-mile Fees

Following the development of the Base Case, multiple model runs of the ITIC model software were used to estimate diversion among the various truck configurations and the resulting total logistics costs associated with various levels of the ESAL-mile based fee. Successive model runs were carried out for the following fees: $0.01, $0.02, $0.05, $0.07, $0.10, $$0.25, $0.40, $0.50, $0.75, and $1.00 per ESAL-mile of travel.

As previously discussed, the ITIC model software uses mile-based fees. Therefore, for each successive model run, the per-ESAL-mile fee was converted into an equivalent per-mile fee for each typical vehicle. The ESAL-mile fees were multiplied by the ESALs attributable to being overweight (i.e., the number of ESALs above the 2.40 ESAL credit) for each typical vehicle. Table 2.3 outlines the calculated total ESAL values assigned for each typical vehicle. The ESALs are calculated on the basis of the weights of each axle or axle group.

Vehicles with the same number of axles can be configured in a number of ways using different combinations of axle groups. For purposes of this research, the configuration and axle weights were assumed for each typical vehicle, as outlined in Table 2.3, to complete the ESAL computation. The penalties for 8- and 9-axle ITIC typical vehicles with GVWs higher than those permitted in Indiana are incorporated in the ESAL calculation step. The lower vehicle weights permitted in Indiana would result in lower ESALs which would then result in lower ESAL-mile fees and corresponding per-mile fees. As previously discussed, only the *additional* consumption attributable to overweight vehicles should be included in the cost of consumption because licensing and registration fees and fuel taxes account for the consumption of vehicles at or below legal limits. The Emergency Rules address this by providing an ESAL-credit of 2.40 ESALs which can be achieved using a 5-axle truck at or below 80,000 lbs. The per-mile fees entered into ITIC include only the ESALs above the 2.40 ESAL-credit which corresponds to a typical non-overweight vehicle. In addition to the ESAL based component of the fee (above 2.40 ESALs), the $20 administrative fee was incorporated into the per-mile fee. Unlike Special Weight permits which can be used for a period of time, the overweight commodity permits may only be used for a single trip (with exceptions for vehicles under 2.40 ESALs which would not incur a charge). An average trip distance of 250 miles was used to convert the $20 administrative fee into a per-mile fee of $0.08. Again, for trips longer than 250 miles, the per-mile fee is lower than the average, and for those shorter than 250 miles the per-mile fee is higher than the average.

Table 2.4 outlines the mileage-based fees entered into ITIC for each typical vehicle configuration for each successive model run using a different $/ESAL-mile fee. The fee per mile for 6-axle light vehicles does not change throughout the analysis because the 6-axle light vehicle is less than 2.40 ESALs and thus pays only the $20 administrative fee. The per-mile fee increases as the number of ESALs increases (down the columns) and as the per-ESAL-mile fee increases (across the rows).

For each successive run, the user fees were adjusted separately for the XHDH and non-XHDH pools and the results were summed to estimate the total logistics costs across the state. For the non-XHDH pool, the user fees are equal to the adjusted mileage-based overweight commodity permit fees detailed in Table 2.4. For the XHDH pool, the user fees are equal to the minimum of the adjusted Special Weight permit cost of $0.089 per mile or the adjusted overweight commodity permit fees outlined in Table 2.4.

Table 2.5 presents the ITIC model run results for permit fees of $0.01/ESAL-mile. As previously discussed, the number of records and tons shipped do not change by default because each shipment is moved by one configuration or another. Thus, the truck VMT decreases because fewer vehicles are necessary to move the same amount of goods between each origin-destination pair. As a result, even though carriers are paying more in permit fees which are a very small part of transportation costs, the total logistics costs are reduced.

The summary details for each successive ITIC model run are presented in Appendix A. Figure 2.2 depicts the total logistics cost savings for each level of the ESAL-mile based fee.

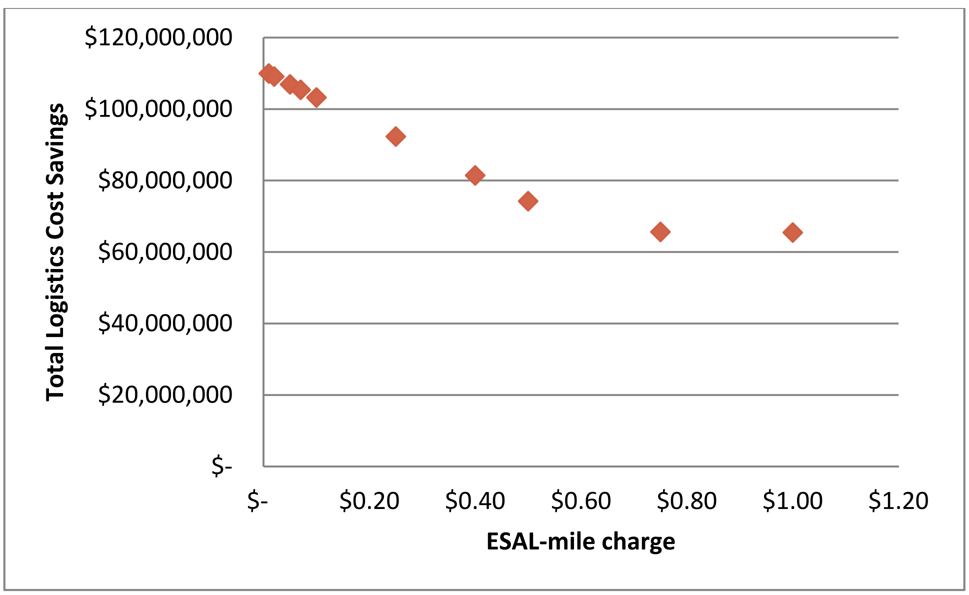

Figure 2.2 Total Logistics Cost Savings vs. Permit Fee

Table 2.2 Summary of ITIC Results for Base Case Scenario (Special Weight permits only)

Base Case	Special Weight Permits for XHDH Only						
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total
Number of Records	314	0	64	0	65	0	443
Tons Shipped	13,549,081.98	0	2,265,460.466	0	2,536,450.521	0	18,350,992.97
Number of Shipments	705,884	0	83483	0	61,870	0	851,237
Truck VMT	216,793,784	0	29,444,840.88	0	29,150,640.67	0	275,389,265.5
Logistics Cost ($)	650,666,262.52	-	93,696,379.39	-	100,129,013.28	-	844,491,655.19

Table 2.3 Vehicle Configurations, Axle Weights, and Calculated ESAL Values for Typical Vehicles

Vehicle	**Description**	**Axle Weights (lbs)**									**ESAL**
		Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	Axle 8	Axle 9	
5-axle	Single, tandem, tandem	12000	17000	17000	17000	17000	n/a	n/a	n/a	n/a	2.40
6-axle light	Single, tandem, tridem	12000	17000	17000	14000	15000	15000	n/a	n/a	n/a	2.13
6-axle heavy	Single, tandem, tridem	12000	17000	17000	17000	17000	17000	n/a	n/a	n/a	2.81
7-axle	Single, tridem, tridem	12000	17000	17000	15000	15000	17000	17000	n/a	n/a	2.77
8-axle	Single, tandem, tridem, tandem	12000	17000	17000	14000	15000	15000	17000	17000	n/a	3.23
9-axle	Single, tandem, tandem, tandem, tandem	12000	16000	16000	16000	16000	16000	16000	16000	16000	3.65

Table 2.4 Conversion of ESAL-Mile Fees to Per-Mile Fees for Each Vehicle Configuration

Vehicle	**$/ESAL-mile**									
	$ 0.01	**$ 0.02**	**$ 0.05**	**$ 0.07**	**$ 0.10**	**$ 0.25**	**$ 0.40**	**$ 0.50**	**$ 0.75**	**$ 1.00**
5-axle	No Fee (Not OW)									
6-axle light	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
6-axle heavy	0.084	0.088	0.100	0.109	0.121	0.182	0.243	0.284	0.386	0.488
7-axle	0.084	0.087	0.099	0.106	0.117	0.173	0.229	0.266	0.359	0.453
8-axle	0.088	0.097	0.122	0.138	0.163	0.289	0.414	0.497	0.706	0.914
9-axle	0.092	0.105	0.142	0.167	0.205	0.392	0.580	0.705	1.017	1.330

Table 2.5 Summary of ITIC Results for Introduction of Overweight Commodity Permits at $0.01/ESAL-mile

0.01	ESAL-mile Based Divisible Load Permits							Delta
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total	
Number of Records	50	1	205	122	65	0	443	0
Tons Shipped	8252.9315	121.6495	12975086.04	2831081.83	2536450.521	0	18350992.97	0
Number of Shipments	6827.5875	121.6495	10793108.57	2831081.83	61870	0	13693009.64	12841772.64
Truck VMT	198673.809	2878.774488	144396334.5	30805700.02	29150640.67	0	204554227.8	-70835037.69
Logistics Cost ($)	620,912.09	11,281.04	520,144,618.51	113,655,609.76	100,129,013.28	-	734,561,434.68	-109,930,220.51

2.3.7.7 Relationship Between Total Logistics Cost Savings and Permit Fee

As observed in Figure 2.2, the relationship between total logistics cost savings and permit fee is nonlinear. Nonlinear relationships can be modeled using simple linear regression by transforming either the predictor variable or the response variable. Several variable transformations were explored to linearize the relationship. Exponential regression was selected to model the relationship depicted in Figure 2.1.

The general form of the exponential regression models is as follows:

$$S = \alpha e^{(\beta x)}$$

(2-7)

where α and β are estimated parameters and S and x are as previously defined. The transformation of the response variable, in this case the total logistics cost savings, by taking the natural logarithm linearizes the relationship as follows:

$$\ln S = \ln \alpha + \beta x = \beta_0 + \beta_1 x$$

(2-8)

where β_0 and β_1 are estimated using linear regression. From the transformation above, it is clear that $\alpha = e^{\beta_0}$ and $\beta = \beta_1$. Using the data presented in Figure 2.1, $\alpha = 108137615$ and $\beta = -0.597$. The model fit is extremely reasonable with an R^2 value of 0.946.

Therefore, by replacing the parameters with estimated values into Equation (2-7), the second objective function is defined as follows:

$$S = 108137615e^{-0.597x}$$

(2-9)

where S is the total logistics cost savings, and x is the ESAL-mile based permit fee.

2.3.7.8 Demand for Overweight Vehicle Permits

The final step in parameter estimation is to model the demand for overweight vehicle permits in ESAL-miles of travel which serves as a constraint in the multiobjective optimization. Elasticity is a concept typically applied to travel demand forecasting. Elasticity is defined as the "percentage change in demand for a 1% change in a decision attribute" (Sinha & Labi, 2007). Mathematically, elasticity is defined as follows:

$$e_x(y) = \frac{x}{D}\frac{\partial y}{\partial x}$$

(2-10)

where x is the attribute which changes and y is the resulting demand. Elasticities can be used to estimate change in demand via elasticity-based demand models which are functions of the change in an attribute and the initial demand.

For this analysis, it is assumed that demand is nonlinear; specifically, the demand has a function of the following general form:

$$D = kx^a$$

(2-11)

where D is the demand, x is an attribute of interest, and k and a are estimable parameters. For this type of nonlinear demand, elasticity can be generally estimated as follows:

$$e_x(D) = a = \frac{\log D_0 - \log D_1}{\log x_0 - \log x_1}$$

(2-12)

where the subscripts 0 and 1 correspond to the before and after situations, respectively. Rearranging terms, the new level of demand, which results from a change in the attribute of interest, can be generally estimated as follows:

$$D_1 = D_0 \left(\frac{x_1}{x_0}\right)^{e_x(D)}$$

(2-13)

In this problem, the attribute of interest is not the permit fee itself but the total logistics costs. Therefore, the demand to be estimated is as follows:

$$D_1 = D_0 \left(\frac{TLC_0 - S}{TLC_0}\right)^{e_{TLC}(D)}$$

(2-14)

where TLC_0 is the initial total logistics cost, S is the total logistics cost savings, D_0 is the initial or latent demand, and $e_{TLC}(D)$ is the elasticity of demand with respect to total logistics cost. As previously discussed, the TLC_0 was estimated using the ITIC model software to be $844,491,655.

2.3.7.9 Previously-Estimated Elasticity Values

Freight demand elasticity estimates vary widely due to the different demand and attribute measures, estimation methods, commodities studied, and locations studied. Recent research has also collated and compared empirical freight demand elasticity measures from multiple studies. Abdelwahab (1998) used data from the US Commodity Transportation Survey conducted by the Census Bureau in 1981. Abdelwahab estimated truck price elasticity of demand between -0.956 and -2.489. Clark et al. (2005) surveyed both aggregate and disaggregate mode choice models to compare elasticity estimates across modes and estimation methods. Among the multiple estiamtes reported from other studies, Clark et al. (2005) note the work by Oum in 1989 which found a log-linear own price elasticity for truck freight of -1.341. Clark et al. (2005) also provided appropriate ranges for various commodities transported using various modes based on their survey of other works. For corn, wheat, and other agricultural commodities transported by trucks, the range surveyed was -0.99 to -0.73. For primary metals and metallic products, the range surveyed was -1.36 to -0.18. These are the most appropriate ranges for the agricultural and metal commodities permitted under HEA-1481. Li et al. (2011) also conducted a meta analysis of 12 previous elasticity studies completed between 1978 and 2010 to explore sources of variation among estimates; they reported translog elasticity ranges of tonne-kilometers of travel in the United States between -0.9299 and -1.3034 for natural resources and between -0.7127 and -1.0861 for other products. More recently, McCoullough (2013) specifically estimated the effect of TS&W limits on the rail and truck markets in the United States (McCullough, 2013). McCullough (2013) based his analysis on the classic work of Friedlaender and Spady (1980) which considered specific key commodities such as food, wood products, automobiles, etc. In McCullough's (2013) updated work using the Commodity Flow Survey and Economic Census data from 1997, 2002, and 2007 (all after Friedlaender and Spady's original analysis), the truck elasticity for agricultural products was -0.786. The truck elasticity for primary metal manurfacturing was -0.822. These values are lower in absolute magnitude than those originally reported by Friedlaender and Spady.

For the multiobjective optimization, Clark et al.'s (2005) reported value of -1.341 was used in the model formulation. Estimates from previous studies indicate inelastic demand for agricultural commodities but elastic demand for metal commodities. In practice, the new overweight commodity permits are primarily used by metal carriers; therefore, the elastic estiamte of -1.341 can be considered more appropriate than an inelastic value. Additionally, the value of -1.341 is well within the general range reporeted by Abdelwahab (1998) and can be used to determine an upper bound on the increase in demand in response to TLC savings. Clark et al.'s (2005) value was estimated for all truck freight using a log-linear elasticity demand model which is easier to apply to demand estimation than translog elasticity-demand models and models with lagged structures. Finally, although recent research projects have focused on commodities separately, the analysis herein does not distinguish between agricultural and metal commodities in determining the total logistics cost savings, the demand, or the cost of highway infrastructure consumption.

2.3.7.10 Initial Demand

Finally, the initial or latent demand for overweight vehicle permits, D_0, was estimated to be 35,000,000 ESAL-miles annually. The term latent demand is used here because prior to HEA-1481, carriers were not able to purchase overweight commodity permits although a demand for these permits existed (as evidenced by the purchase of permits after enactment). The records queried from the INDOR database indicated that over 40,000,000 ESAL-miles of travel is expected to be permitted annually for both overweight commodity and Special Weight vehicle permits (Everett et al., 2014); however, this value is for a permit fee of \$0.07/ESAL-mile. As discussed in the preceding paragraphs, demand can change based on the total logistics cost. Therefore, the initial demand value was calibrated to reflect higher demand in the presence of cost savings which occurs at \$0.07/ESAL-mile.

2.3.8 Multiobjective Optimization Formulation for Indiana

The general multiobjective optimization outlined in Equations (2-1) through (2-5) can be replaced with the estimated parameters above to specifically formulate the multiobjective optimization for overweight commodity permits in Indiana as follows:

$$\text{minimize } z_1 = (0.84 - x)D_1 \tag{2-15}$$

$$\text{and maximize } z_2 = 108137615e^{-0.597x} \tag{2-16}$$

$$\text{subject to } D_1 = 35000000\left(\frac{844491655.19 - 108137615e^{-0.597x}}{844491655.19}\right)^{-1.341} \tag{2-17}$$

$$\text{and } x \leq 0.84 \tag{2-18}$$

$$\text{and } x \geq 0$$

(2-19)

where z_1 is the objective to minimize uncompensated consumption, z_2 is the objective to maximize total logistics cost savings, x is the ESAL-mile based permit fee, and D_1 is the resulting demand for overweight vehicle permits in ESAL-miles.

2.3.9 Optimization Results

The formulation presented in Section 2.3.8 includes an equality constraint for the demand function because the demand is not a choice made by the decision maker, but rather an effect of market decisions that are consequences of the decision maker's choice. Two analysis tools were used to solve the multiobjective optimization problem formulated herein, one involved an inequality constraint and the other used an equality constraint.

2.3.9.1 General Algebraic Modeling System (GAMS) Analysis Results

First, the General Algebraic Modeling System (GAMS) was used to mathematically model the problem. GAMS is a high-level modeling system designed for optimization problems (Rosenthal, 2014). High-level refers to the type of language used in GAMS. In GAMS, the model is defined using algebraic equations. Then a command is issued to solve the model using the appropriate third-party optimization solver. GAMS is capable of modeling and solving linear, non-linear, and mixed integer optimization problems. In addition to the capabilities included in GAMS, the publicly available

GAMS Model Library contains 403 (as of January 2015) models that are selected for inclusion because of either the importance of the model problem or the modeling capabilities they represent. Models included in the Model Library are developed by individuals but may be used by others to solve similar problems. Mavrotas (2009) developed one such model for the augmented ε-constraint method described in Section 2.2.5.

The model formulation in Section 2.3.8 was modified to allow demand to vary. The demand constraint in Equation (2-17) was broken into two separate constraints as follows:

$$D_1 \leq 35000000\left(\frac{844491655.19 - 108137615e^{-0.597x}}{844491655.19}\right)^{-1.341}$$

(2-20)

$$\text{and } D_1 \geq D_0$$

(2-21)

where x is the ESAL-mile based permit fee, D_1 is the resulting demand for overweight vehicle permits in ESAL-miles, and D_0 is the latent demand.

This way, demand is made to vary between the upper bound defined by the elasticity-demand function and the lower bound of the latent demand which always exists. All other variables and inequalities in the original formulation were used without modification.

The GAMS program developed by Mavrotas (2009) uses two models: first, a model of the system of interest, and second, a modification of the initial model to modify the epsilon constraints to improve the efficiency of the solution mechanism. Mavrotas'

(2009) original GAMS input was modified to represent the present problem by changing the set of objective functions, parameters, variables, and equations in the first model. The second model which augments the first was not changed, as outlined in Mavrotas' (2009) explanation for using his sample.

Additionally, Mavrotas' (2009) original GAMS input called for a linear programming algorithm. The present multiobjective optimization includes non-linear inequalities; therefore, the command to call up the solver was replaced with one to a non-linear programming algorithm.

The GAMS output is presented in Appendix B. The termination message, "`** Optimal solution. There are no superbasic variables`" typically indicates the solution is a locally optimal corner point. This is not surprising given that minimizing the first objective function, in the absence of the second objective function, would result in a corner point solution in which the ESAL-mile fee is equal to the cost of consumption. Similarly, given that the savings monotonically decreases with ESAL-mile based fees, if the second objective function were maximized, in the absence of the first objective function, the optimal point would again be a corner solution in which the ESAL-mile based fee is equal to zero.

2.3.9.2 Simultaneous Equations Solution

In addition to the GAMS model, the multiobjective optimization problem can be visualized using simultaneous equations when demand is exactly equal to the elasticity-demand curve, as formulated in Section 2.3.8. Equations (2-15) through (2-17) were rearranged to determine and graph the Pareto frontier using sequential equations.

2.3.9.3 Pareto Frontier Visualizations

Figure 2.3 presents a three-dimensional plot of the uncompensated consumption cost, total logistics cost savings, and the decision variable—the price per ESAL-mile of travel to charge for overweight commodity permits. As the amount charged per ESAL-mile increases, both the savings and the uncompensated consumption cost decrease. Similarly, as the amount charged per ESAL-mile decreases, the total logistics cost savings increases but so does the uncompensated consumption cost.

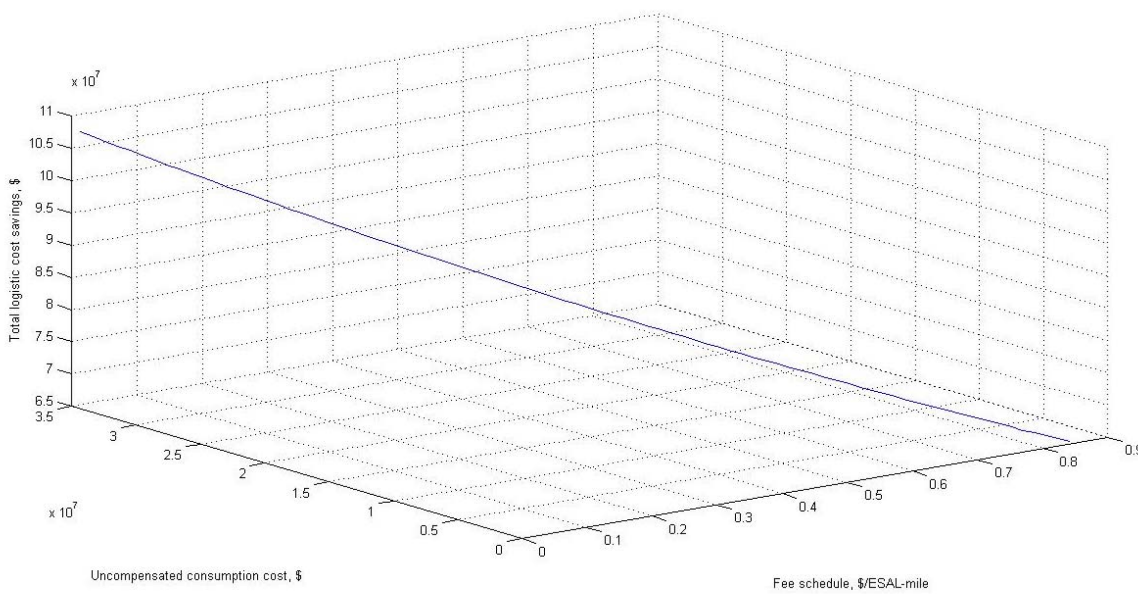

Figure 2.3 Three-Dimensional Plot of the Pareto Optimal Solutions for the Multiobjective Optimization Problem

The Pareto optimal frontier is more easily visualized in two-dimensions where the objective function values are projected onto the plane of the ESAL-mile fee, as shown in Figure 2.4. Again, when the logistics cost savings are high, the uncompensated consumption cost is high as well and when the logistics cost savings are low, the uncompensated consumption cost is also low.

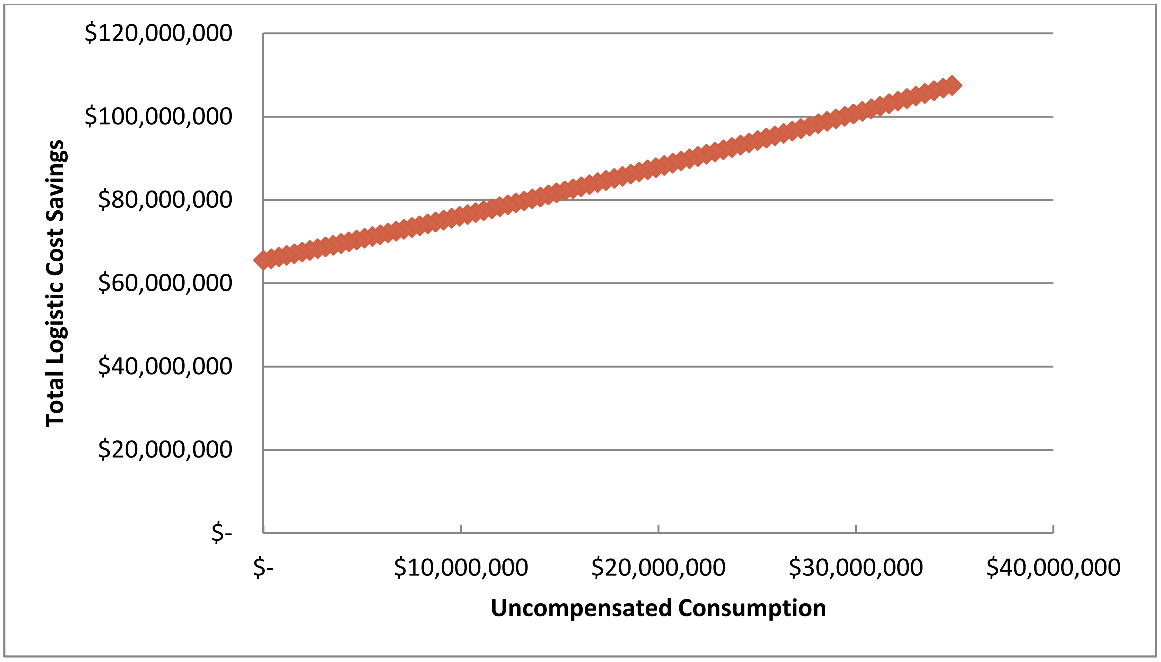

Figure 2.4 Two-dimensional Pareto Optimal Frontier for the Multiobjective Optimization Problem

2.3.9.4 Tradeoff Analysis

In addition to visualizing the Pareto frontier, trade-off analysis provides additional information to the decision maker. Branke et al. (2008) define the tradeoff, $T_{ij}(x^1, x^2)$, involving two objective functions, f_i and f_j between two feasible solutions x^1 and x^2 as follows:

$$T_{ij}(x^1, x^2) = \frac{f_i(x^1) - f_i(x^2)}{f_j(x^1) - f_j(x^2)}$$

The trade-off value quantifies the loss in one objective function for a gain in another objective function. As expected from the definition above, for two objective functions, the tradeoffs between the two are related as follows:

$$T_{ji}(x^1, x^2) = \frac{1}{T_{ij}(x^1, x^2)}$$

Figure 2.5 presents the calculated tradeoffs for uncompensated consumption cost and total logistics cost savings. In the figure, the tradeoff “unit UCC per unit Savings” represents the reduction in uncompensated consumption achieved for a unit reduction in cost savings. These values are less than one for the full range of the decision variable. This indicates that reduction of $1 in uncompensated consumption requires more than a $1 loss in total logistics cost savings (or more than a $1 increase in total logistics cost). The tradeoff “unit Savings per unit UCC” represents the increase in savings possible for an increase in uncompensated consumption. These values are greater than one for the full range of the decision variable.

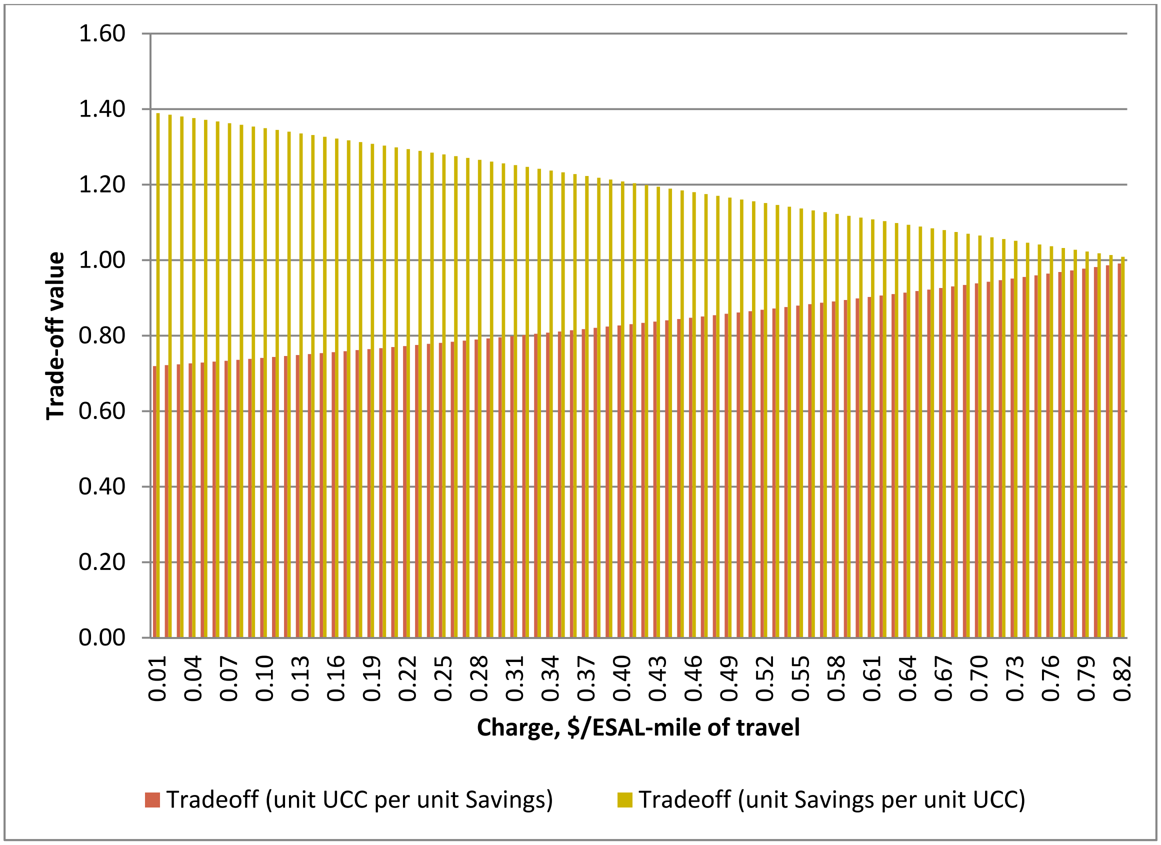

Figure 2.5 Tradeoffs for Uncompensated Consumption Costs and Total Logistics Cost Savings

2.4 Chapter Summary

This chapter presented a mathematical programming approach that can greatly improve the efficiency of traditional permitting mechanisms. Currently, the revenues collected from traditional overweight vehicle permits are significantly less than the actual cost of consumption. Multiobjective optimization addresses this gap while also incorporating the need for transportation agencies to establish overweight vehicle permitting programs that facilitate economic activity.

In contrast to previous efforts to optimize overweight vehicle permitting fees, both the general formulation and the specific model using Indiana-specific parameters represent the problem more accurately with respect to the options available to both decision makers (the transportation agency) and the carriers who use the system. The choice of permit price as the decision variable directly corresponds to the transportation agency's choice in determining a fee schedule. As a result, the actual uncompensated consumption cost, rather than a percentage of that cost, is determined for every possible level of permit fee imposed by the agency.

Additionally, the objective function to maximize the total logistics cost savings is more indicative of the way carriers operate. Trucking companies determine which vehicles to use based on the total logistics cost, not simply the cost of permit acquisition. Therefore, the agency's goal to establish overweight permitting regulations that are not a burden to the trucking industry is met when the agency seeks to maximize total logistics cost savings.

The results of the multiobjective optimization were expressed, or visualized, in the form of a Pareto optimal frontier and associated tradeoffs. Pareto optimality is important in multiobjective optimization because not all the decision makers' conflicting objectives can be satisfied simultaneously. Points on the Pareto optimal frontier cannot be improved for one objective without a loss in at least one other objective. The Pareto optimal frontier and trade-off values inform the decision makers of the possible outcomes for different levels of permit price, in terms of the uncompensated cost of consumption and the total logistics cost savings experienced by the trucking industry. The tradeoffs specifically provide information about the effects of incrementally increasing or decreasing the permit fee.

Future work in this area can include additional improvements to the multiobjective optimization formulation and parameter estimation specific to other states. Additional model forms for the total logistics cost savings and the relationship between savings and additional demand should be explored in future studies. Finally, researchers in other states can estimate parameters appropriate to the regulations and practices in their locations to inform state and local decision makers who regulate TS&W limits and permitting systems.

CHAPTER 3. INCENTIVES FOR INFRASTRUCTURE-FRIENDLY VEHICLE USAGE

3.1 Introduction

For purposes of this research, infrastructure-friendly vehicles refer to overweight vehicles that are configured and loaded to reduce the amount of damage to highway infrastructure. The use of infrastructure-friendly vehicles can be mandated through TS&W limits and oversize/overweight permit regulations or incentivized through a variety of mechanisms including low cost permits, reduced taxes, rebates, and/or bonuses.

Infrastructure-friendly vehicles are desirable because they reduce the cost of highway asset consumption and increase freight productivity. The key to achieving these competing goals is that carriers receive the full benefits associated with higher GVW allowances, such as increased productivity and lower transportation costs, if and only if they exercising responsible loading behavior. Responsible loading behavior refers to the use of equipment that minimizes the loads imposed on pavement and bridge assets, therefore reducing consumption.

The use of infrastructure-friendly vehicles may not be applicable in all cases for overweight operations. In one of the earliest studies of infrastructure-friendly vehicles, a TRB study committee determined that prototypes for infrastructure-friendly vehicles would most likely be attractive to “bulk commodity haulers” and “less-than-truckload freight traffic" carriers, but would not serve as adequate replacement vehicles for full truckload carriers (Morris, 1989).

Two truck loading concepts are useful here: *cube-out* and *weigh-out*. These concepts are applicable to divisible loads and refer to the limiting factor in loading a vehicle, truck size limits or truck weight limits. Low-density goods *cube-out*, or fill up the volume of the trailer before reaching the GVW limit. High-density goods *weigh-out*—the GVW limit is reached even though there is physical space left in the trailer for more goods. Infrastructure-friendly vehicles are most likely to be used by bulk commodity carriers who weigh-out because there is volume left in the trailer (thus, less-than-truckload) that does not contain goods. Carriers that regularly carry cubed-out goods (full truckload) would not benefit from higher GVW limits without changes to truck size limitations because additional cargo cannot be added if there is not additional volume.

3.2 Framework

In practice, the term infrastructure-friendly vehicles has been used to refer to a number of vehicle requirements and other voluntary measures that increase the safety and decrease the pavement and bridge consumption often associated with overweight vehicles. In addition to axle loading and spacing, characteristics that influence safety and asset consumption include the number of tires, tire pressure, suspension, coupling, and vehicle dimensions. This chapter is primarily devoted to axle loading and spacing characteristics; however, agencies should also be aware of the other factors.

The number of tires and tire pressure directly impacts pavement consumption. Typically, the steering axle has two single tires (one on each side) while all other axles have dual tires on each side for a total of four tires per axle. More recently, single wide-base tires, also called super-single tires, have been used in place of dual tires on load-carrying axles. Additionally, tire inflation pressures have increased from between 75 and 85 pounds per square inch (psi) in the 1950s when the original AASHO Road Test was conducted to approximately 100 psi in the 1980s where they have remained (USDOT, 2000). The use of super-single tires and higher inflation pressures effectively reduces the "footprint" of the tire, concentrating the load on a smaller area of pavement. Concentrated loads generally result in greater damage to pavement infrastructure compared to those spread out over a larger area.

Suspension systems distribute loads across an axle group and dampen vertical dynamic loads such as those that occur when heavy vehicles travel along a highway. Dynamic loads refer to the fluctuations in axle loadings above and below average values. Fluctuations occur because of pavement roughness, speed of the vehicle, tire stiffness, and particularly the vehicle suspension. Good suspension dampens the fluctuations and equalizes the load between axles. In addition to affecting pavement wear, suspension systems impact vehicle handling which in turn impacts safety.

Coupling and vehicle dimensions impact the safety of infrastructure-friendly vehicles. Coupling between the tractor and the trailer, and between trailers in double-trailer configurations, affects stability and offtracking. Offtracking occurs when the rear wheels of a combination vehicle deviate from the path of the front wheels on curves. Similarly, the vehicle dimensions affect the maneuverability of vehicles in the traffic stream because the distance between points of articulation and the rear axles, as well as the spacing between axles, affect stability and offtracking.

For tire, suspension, and coupling characteristics, agencies are most likely to mandate requirements rather than encourage voluntary adoption of infrastructure-friendly practices, if they are considered at all. For example, the New York State DOT (NYSDOT) adopted infrastructure-friendly vehicle requirements for all vehicles with a model year 2006 or later and intends to impose similar regulations for earlier model year vehicles beginning January 1, 2020. NYSDOT's infrastructure-friendly vehicle requirements mandate the use of dual tires for all non-steering axles, prohibit the use of lift-axles that are not steerable or trackable, require that air pressure controls for lift axles are located outside of the cab to ensure that lift axles are used properly, and require uniform distribution of load so that no single axle in a multi-axle group carries less than 80% of the load of any other axle in the group (NYSDOT, 2011). In Ontario, Canada, the Ministry of Transport phased in Safe, Productive, Infrastructure Friendly (SPIF) vehicles over a ten-year period between 2001 and 2011. Ontario's SPIF vehicles are fully described vehicle configurations including the axles, suspension, and other requirements, designed to provide stability and control, minimize damage to roads and bridges, and to be as productive as possible (Government of Ontario, 2011).

The impacts of tires, suspension, coupling, and dimensions on pavement and bridge consumption are lower in magnitude than the actual axle loadings and spacing which directly impact the deformation of pavements and the moments applied to bridges. Thus, through the remainder of the chapter, infrastructure-friendly vehicle usage measures will only refer to those regulations or incentives which address axle weights and spacing.

Whereas the infrastructure-friendly vehicle requirements of NYSDOT and the Ontario Ministry of Transport do not provide any productivity benefits to users, axle weight and spacing measures typically provide benefits through higher GVW allowances. The general framework for the use of infrastructure-friendly vehicles begins with a definition of the typical vehicles or vehicle limits that are considered infrastructure-friendly, and then either mandates or incentivizes their use. Three examples of this framework are the Turner truck limits, Michigan TS&W limits, and INDOT's ESAL-mile based multi-trip annual permits.

3.2.1 Turner Proposal

In a 1984 address to AASHTO, former Administrator of the FHWA, Francis C. Turner advocated for truck size and weight limits based on lower individual axle weight limits, longer vehicle length limits, and higher GVW limits. The increase in length limits is necessary for operators to add sufficient extra axles to reduce the load carried by each individual axle. The proposal is now commonly referred to as the "Turner Proposal" and the prototype vehicles as "Turner trucks." Turner advocated for the altered limits as a potential win-win situation: truck operators would benefit from higher GVWs and agencies would benefit from reduced pavement damage due to the lower axle loads.

Turner originally proposed the following TS&W limit changes (Morris, 1989): single axle load limit of 15,000 lbs; tandem axle load limit of 25,000 lbs; greater vehicle lengths; and maximum GVW of 112,000 lbs.

Turner's prototypical truck was a 9-axle double trailer combination with a steering axle and four tandem axles. He estimated that the pavement consumption would be approximately 1/3 that of an 80,000 lb 5-axle vehicle for every ton-mile of travel (Morris, 1989).

In 1989 and 1990, TRB evaluated the Turner Proposal in conjunction with an ongoing study of TS&W limits and alternatives (TRB, 1990a; TRB, 1990b). The results of both analyses were released in 1990. TRB expanded the Turner truck analysis to include four different prototype vehicles—a 7-axle tractor trailer, a 9-axle double, an 11-axle double, and a 9-axle B-train double—with higher GVW limits than Turner proposed. Unlike Turner's original prototype vehicle, not all of the vehicles analyzed met Federal Bridge Formula B regulations; Turner's prototype did. Researchers also considered a voluntary system which did not prohibit use of vehicles previously in use; a variety of policy alternatives including thicker pavements, redesigned trucks, and user fees; and alternative tax treatments to encourage operators to use Turner trucks (TRB, 1990b).

TRB (1990b) determined that any new vehicle options must be voluntary. Turner originally proposed that the lower axle weights apply to all vehicles; those that could not practically meet new lower maximums might purchase special permits and/or pay higher registration fees. TRB (1990b) advocated for a voluntary system because forcing operators to adopt the Turner truck configurations goes against the spirit of the proposal to benefit both trucking companies and agencies. A mandatory system would effectively burden those companies who do not shift voluntarily to the Turner truck configurations.

The Turner proposal directly addressed pavement consumption. Pavement consumption is reduced when the axle weights limits are reduced. As previously discussed, bridge consumption depends on the bending moment produced when a vehicle traverses a bridge and is a function of the span length, bridge materials, and the distribution of the vehicle weight on its axles. The Turner proposal did not address bridge consumption (Morris, 1989). The Turner truck limits would overstress thousands of bridges that have a lower design capacity. As a result, bridges would need to have posted weight limits, be strengthened, or replaced. Posting weight limits on bridges reduces the available roadway network that Turner trucks are able to use. Strengthening or replacing bridges costs the agency money.

TRB (1990b) estimated that approximately 23% of vehicle miles traveled by combination trucks would ultimately be attracted to Turner trucks. Based on this level of expected market penetration, the authors estimated there would be $729 million annual savings to maintain pavements in their current condition. When the additional bridge costs to strengthen or replace deficient bridges (due to the higher Turner truck limits) were incorporated, the annual agency savings to maintain the network in the same condition without adoption of Turner trucks were reduced to $326 million. Similar to previous research, TRB (1990b) determined that freight cost savings would far exceed the agency savings at approximately $2.0 billion annually.

TRB also discussed the potential tax treatment of Turner trucks to provide “incentives to choose trucks that are truly the most efficient” (Morris, 1989). Adjustment via alternative tax treatments is important for cases where use of a Turner truck might lead to lower highway agency costs but would require the operator to pay higher taxes via higher purchasing prices, registration fees, and/or fuel taxes. The higher taxes might discourage adoption of Turner trucks. The authors recommended some form of tax adjustment to equate the operator’s cost whether he or she used a Turner truck or a typical 5-axle, 80,000 lb vehicle is used.

Although TRB (1990b) determined that adoption of the refined version of the Turner proposal would result in overall savings to highway agencies and even larger freight cost savings, the lower axle weight limits were never adopted. In its report, TRB (1990b) recommended that each state consider the Turner proposal as a supplement to existing state and national TS&W limits, yet no state studies explicitly considered the Turner proposal. Notably, the alternatives studied in the more comprehensive 1990 study of various TS&W limits and options were not adopted either. National TS&W limits were not significantly altered following the 1990 studies.

3.2.2 Michigan's TS&W Limits

The Michigan DOT (MDOT) did adopt the philosophy of lower axle weights outlined in the Turner proposal in its unique state TS&W limits. Michigan does not have a GVW limit, but rather limits the individual axle weights as follows (MDOT, 2014): single axles (spacing over 9 feet): 18,000 lbs for GVW over 80,000 lbs, 20,000 lbs otherwise; axle groups with spacing between 3 ½ and 9 feet: 13,000 lbs for all vehicles; axle groups with spacing less than 3 ½ feet: 9,000 lbs for all vehicles; tandem axle assembly: one assembly with 16,000 lbs per axle for GVW over 80,000 lbs, two assemblies with 16,000 lbs per axle otherwise; maximum load on any given wheel not to exceed 700 lbs per inch width of tire; and maximum of 11 axles on a combination vehicle.

The effective maximum allowable GVW in Michigan is 164,000 lbs using an 11-axle vehicle, with most axles carrying 13,000 lbs (MDOT, 2013). Heavy vehicles in Michigan do not need a permit when the GVW exceeds 80,000 lbs as long as the vehicles meet all Michigan state TS&W limits. Michigan is allowed to apply its unique TS&W limits through the grandfather clause.

The Michigan TS&W limits are an example of mandated use of infrastructure-friendly vehicles. Carriers are not simply encouraged to limit the individual axle spacings but are required to do so. The higher GVWs result in higher payloads which reduces the number of vehicle trips necessary to move the same amount of goods. MDOT (2013) estimates that approximately 5% of vehicles in Michigan operate above 80,000 lbs but these vehicles provide substantial benefits to a few basic industries such as manufacturing, forestry, mining, agriculture and construction. In addition to the pavement repair and maintenance cost savings, MDOT experiences savings through the reduced transportation costs for goods such as cement and asphalt used to construct roadways. MDOT (2013) predicts that changes to the current state TS&W limits to align with federal limits would result in more vehicle miles traveled, more congestion, increased costs for consumers (due to higher transportation costs), decreased industrial competitiveness (for industries such as manufacturing and forestry), and increased consumption of pavements. The unique TS&W limits demonstrate the benefits experienced by both the agency and the trucking industry.

3.2.3 INDOT's Annual, Multi-Trip Permit Incentive

As detailed in Chapter 1, the Indiana House Enrolled Act 1481 (HEA-1481) created overweight commodity permits for divisible metal and agricultural loads in Indiana. INDOT issued Emergency Rules to supplant the fee structure defined in HEA-1481 which took effect January 1, 2014. In the Emergency Rules, INDOT created a new subset of overweight commodity trip permits called “annual, multi-trip permits” available after February 1, 2014 (INDOT, 2013). The annual, multi-trip permits are the only annual permit for overweight vehicles in Indiana and are available to those eligible for overweight commodity permits—carriers transporting metal and agricultural commodities up to 120,000 lbs and 97,000 lbs, respectively, along with additional requirements.

When trucking companies apply for overweight commodity permits, the ESALs are calculated using the process defined in the Emergency Rules, individual axle weights and spacing, and standard weights for each axle group. The standard weights and calculation procedure outlined in the Emergency Rules are consistent with previous transportation research on the relationship between ESALs and weight in pounds. In general, the weight of an axle or axle group is divided by the standard weight and that value is raised to the fourth power. The standard weights for single, tandem, tridem, quad, and five-axle groups are 18,000 lbs; 33,200 lbs; 46,000 lbs; 57,000 lbs; and 65,000 lbs, respectively.

If the calculated ESALs are less than or equal to 2.40, the applicant is eligible for an annual multi-trip overweight commodity permit. The INDOR system automatically generates annual, multi-trip permits for those who are eligible. Annual, multi-trip overweight commodity permits are both vehicle and route specific. The permit fee is $20 and the permit is valid for an unlimited number of trips by that vehicle on that route for 364 days from the requested start date for the permit. Carriers that request permits for vehicles exceeding 2.40 ESALs are charged the $20 administrative fee plus the ESAL-mile based fees (ESALs above 2.40 multiplied by the distance traveled in miles) for every single trip. For carriers who have multiple vehicles that are less than 2.40 ESALs traveling multiple routes, each vehicle and route combination must be permitted at a cost of $20 annually for each vehicle/route combination.

Unlike Michigan's mandated compliance with state TS&W limits, Indiana's new annual, multi-trip overweight commodity permits are voluntary, thereby serving as an incentive for trucking companies to use infrastructure-friendly vehicles. Those who are willing to purchase new equipment, retrofit existing equipment, and to load vehicles to less than 2.40 ESALs can take advantage of the low-cost annual permits. Those who cannot practically configure their loads to less than 2.40 ESALs, or those who choose not to do so due to their business models, must pay at least a portion of the additional consumption of highway resources. In contrast to Michigan's TS&W limits, Indiana's incentive program is more consistent with TRB's (1990b) voluntary Turner proposal mechanism. The voluntary nature of the Indiana system does not prohibit users of the system from using non-infrastructure-friendly vehicles but also will not result in full adoption of new vehicle configurations. Only those trucking companies that can increase productivity, reduce overall costs, or offer lower cost services to shippers within the new regulations will use vehicles that take advantage of the annual, multi-trip permits. The new Indiana annual, multi-trip permits are used for the case study later in this chapter.

3.3 Advantages and Disadvantages

The primary advantage of infrastructure-friendly vehicles is a win-win operating environment for the trucking industry and for state transportation agencies. Trucking companies benefit from higher GVWs to transport the same quantity of goods more efficiently. Industries that feed into the truck freight network also potentially experience some of these savings along with consumers, as savings are passed from carriers to shippers. State DOTs benefit from lower individual axle loads which causes the cost of pavement maintenance and rehabilitation to decrease substantially.

The primary disadvantage of the Turner proposal, Michigan's efforts, and Indiana's efforts to encourage or mandate the use of infrastructure-friendly vehicles is that they do not include an explicit measure of bridge consumption. All three approaches rely on the premise of controlling the cost of infrastructure consumption by lowering the individual axle weights, which has a direct relationship to pavement consumption. Individual axle or axle group weights are less related to the bending moment produced in bridges because there are a variety of other explanatory variables including the span length, the axle spacing, and the total GVW. In Indiana, the measure used to determine the cut-off point for infrastructure-friendly and non-infrastructure-friendly vehicles is based on ESALs, a pavement consumption measure.

MDOT states that bridges in Michigan are "designed to carry the concentrated weight of Michigan trucks" (MDOT, 2013). The "considerable investment…to carry heavier, more productive trucks" (MDOT, 2013) is similar to the approach of using some cost savings from pavement consumption to fund the cost of posting weight limits, strengthening, and/or replacing deficient bridges (due to the heavier loads) advocated by TRB (1990b). No such measures were included in INDOT's Emergency Rules, but it is both possible and likely INDOT will address this issue in the future.

Inherent in each of the infrastructure-friendly vehicle approaches described above is the premise that axle weights are the most important consideration. Axle weights are important to carriers because individual axle weights and GVW are interdependent and

GVW dictates payload capacity. Axle weights are important to transportation agencies because pavement stress is caused by individual axle loads applied to the pavement—pavement consumption is a monetized value of this repeated stress. However, axle spacing and total vehicle length, again interdependent elements, are also extremely important, particularly for bridge stress (USDOT, 2000).

Axle spacing has divergent impacts on pavement and bridge distress. Placing individual axles close together creates a group that distributes the load along the pavement, or increases the "footprint" discussed earlier, causing less pavement stress than the same weight on each axle spaced far apart, approximately 9 feet or more. In contrast, bridge distress depends on the bending moment due to point loads applied to the bridge at each axle. The bending moment is greatest, and causes the most stress, when the axles are closest together. The Federal Bridge Formula B controls the maximum amount of weight that can be put on any axle group, without overstressing bridges, based on the number of axles in the group and the length of the axle group.

The USDOT (2000) explicitly demonstrated this concept when it addressed the optimal allowable weight and spacing of tridem axles. The research team demonstrated the decrease in bridge stress as axles in the tridem were spread apart, and the corresponding increase in pavement stress for the same spreads. By plotting the allowable loads for different spacings using both pavement and bridge stress limits, the Department recommended an optimal total weight for tridem axle groups with 4.5 feet between each axle of 44,000 lbs, as shown in Figure 3.1. For closer axle spacings, the Federal Bridge Formula B overstress criteria dictate lower weights. For greater axle spread, the pavement stress significantly increases (USDOT, 2000).

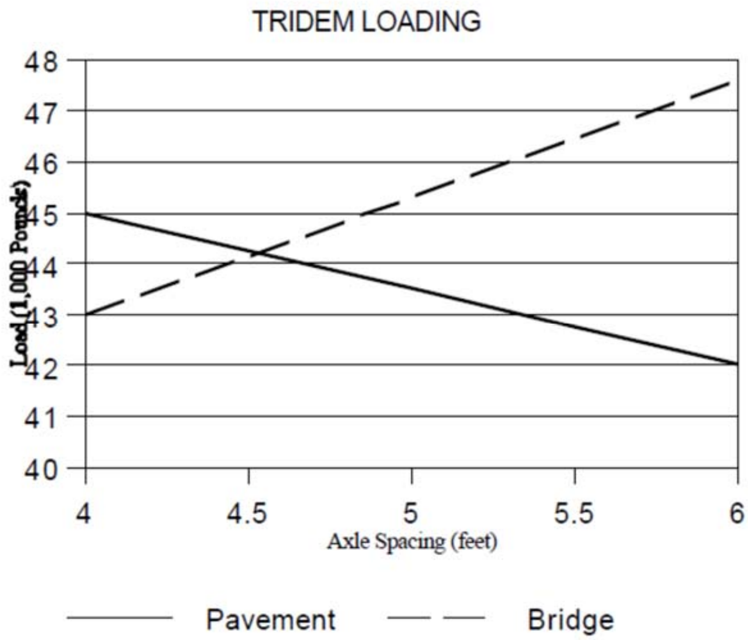

Figure 3.1 Allowable Loads for Tridem Axles vs. Axle Spacing (Source: USDOT National TS&W Study, 2000)

The Turner proposal, Michigan's TS&W limits, and INDOT's ESAL calculation all include some consideration of axle spacing; unfortunately, each focuses primarily on the side of pavement consumption. Francis Turner recognized that longer vehicle lengths are necessary to add sufficient axles to lower individual axle weights to remain within the confines of the Federal Bridge Formula B; he therefore recommended increases in length limits to accommodate the bridge requirements. Although Turner advocated a truck design that met the Federal Bridge Formula B requirements, AASHTO expanded the scope for the larger TRB (1990b) study to include some configurations that overstress long-span steel bridges more than what is allowed in the Federal Bridge Formula B, contrary to Turner's original proposal. The overstress from these vehicles is the impetus for recommendations in the report to post weight limits, strengthen, and replace bridges used by Turner. Inherent in the use of ESALs, INDOT's annual, multi-trip permits are most beneficial to users who can add more axles, typically resulting in closely-spaced axles, to reduce the pavement consumption. More closely-spaced axles cause more damage to bridges compared to longer axle spacings. The annual, multi-trip permits do not account for efforts that carriers might undertake to limit the amount of bridge consumption.

The recent Indiana study estimated that the cost of bridge consumption exceeded the cost of pavement consumption by at least an order of magnitude. While the annual pavement consumption attributable to the additional weight carried by overweight vehicles was estimated to be approximately $2 million, bridge consumption was estimated to be approximately $42 million annually under the assumption that the share of bridge consumption attributable to load (called the load-share) was approximately 30% while the remaining 70% of the cost of bridge consumption was common for all users (the non-load-share) due to the weight of the bridge itself and environmental factors (Everett et al., 2014). If the load-share is increased, the discrepancy between pavement consumption and bridge consumption also increases.

Incentives and mandates to encourage the use of infrastructure-friendly vehicles are commendable when they can reduce the agency's cost of maintaining highway infrastructure and providing acceptable levels of service. Unfortunately, to date, actions in Michigan and Indiana to reduce axle weights and ESALs lead to minor pavement consumption cost savings when bridge consumption is the higher cost. Future research that addresses highway infrastructure asset consumption more holistically might indicate that overweight vehicle configurations different than those espoused by Turner and advocated in Michigan and Indiana are more infrastructure friendly.

3.4 <u>Willingness to Pay for Investment in Infrastructure-Friendly Vehicles</u>

As previously mentioned, the Indiana overweight commodity permits introduced in HEA-1481 served as a case study for each of the alternative overweight vehicle permitting mechanisms described herein. The annual, multi-trip permits introduced in the Emergency Rules specifically served as the case study for infrastructure-friendly vehicles in Indiana.

The trucking permitting questionnaire used to solicit information and opinions from truck users as part of the HEA-1481 mandated study was leveraged to include opinion questions about carriers' willingness to pay (WTP) for investment in infrastructure-friendly vehicles. Previous state TS&W and oversize/overweight studies including recent efforts in Minnesota, Wisconsin, and Texas also used expert opinions and surveys of shippers and carriers (Cambridge Systematics, Inc. and SRF Consulting Group, Inc., 2006; Cambridge Systematics, Inc., 2009; Bienkowski & Walton, 2011; Prozzi et al., 2012).

3.4.1 Permitting Questionnaire Design

Any shifts in the distribution among multiple vehicle configurations are expected occur mostly over the long term as carriers replace vehicles in their fleet, retrofit existing vehicles, and purchase new vehicles in response to changes in permitting regulations and technology improvements. The nature and magnitude of these changes result from choices made by both shippers and carriers. The shippers choose the transportation mode—rail, water, air, or truck. The carrier makes decisions such as investments in the truck fleet and the operating configurations and weights for each vehicle in the fleet. The decisions made by shippers and carriers are often symbiotic: for example, a carrier's decision to invest in additional or new equipment that enables the use of a more cost-effective vehicle configuration may translate into lower shipping costs and therefore attract business from other shippers who previously used either another trucking company or transportation mode. Furthermore, some companies own and operate their own trucking fleet, serving as both shipper and carrier. In such instances, investments that increase the cost-effectiveness of shipping translate into increased profits. Finally, shippers and carriers often enter into contracts to transport goods over a period of time. Carriers may choose to delay investment if they are uncertain whether they will continue transporting a particular shipper's goods after the contract period. The permitting questionnaire was designed to elicit information about carriers' fleet choices.

Methods for studying choice behavior can be categorized revealed preference (RP) and stated preference (SP) methods. RP methods are used to study choices that have already been made, thus the individual's preference is revealed through their actions. SP methods are used to elicit information on individual preferences when the actual choices cannot be observed because the decisions have not yet been made. This typically occurs when the decision environment is physically non-existent at the time of the survey. SP methods include the contingent valuation (CV) approach and stated choice (SC) experiments. Traditionally, CV uses data from a survey instrument to place an economic value on one or more public goods (Carson & Louviere, 2011). Often, the survey instruments use dichotomous (yes/no) choices; although a binary choice task is not synonymous with CV. Historically, CV has been used to estimate residents' willingness to pay (WTP) for applications in a wide range of sectors including water supply, renewable electricity, solar energy systems, and other public or quasi-public goods or services (Carson & Mitchell, 1993; Guo et al., 2014; Radmehr et al., 2014). In contrast, SC experiments are a type of elicitation method where respondents are presented with a finite number of discrete hypothetical alternatives in which one or more attributes are systematically varied. SC experiments have been used in a wide variety of past transportation studies: for example, to determine the value of time (VOT) and the value of reliability (VOR) of travel time for light auto users by varying the cost and travel time between origin-destination pairs. In this manner, SC experiments can be used in conjunction with CV to place economic value on a public good (travel time or reliability).

3.4.2 Hypothetical Bias

The major criticism of stated preference methods is that choices made in a hypothetical setting do not always reflect the actual choices made in real-life settings. RP data, which are observed actions rather than pronounced intentions, do not suffer from this hypothetical bias. Unfortunately, observed data are not always available.

People tend to value goods at an amount higher than they are truly willing to pay. Typically, the hypothetical bias can be as much as a factor of two or three, although higher and lower values are possible for different goods and among different individuals (Norwood, 2005; Murphy et al., 2005). In 1996, a National Oceanic and Atmospheric Administration (NOAA) study suggested dividing hypothetical bids by two to calibrate bids, a recommendation that prompted research into why and by how much people misstate their actual preferences (List & Gallet, 2001). In addition to the uncertainty people experience about their preferences in natural setting, in choice questions regarding public goods, some individuals may strategically overstate the value they place on that good with the hope that those goods will be somehow subsidized (Norwood, 2005). This *strategic bias* can be treated the same as general hypothetical bias resulting from individual uncertainty.

3.4.3 Mitigation Techniques for Hypothetical Bias

Recent research has addressed possible mitigation techniques to address hypothetical bias. These techniques are categorized as *ex ante* techniques incorporated into the elicitation method or *ex post* techniques applied to the collected data. Carson and Groves (2007) found that consequentiality, defined as the respondent's belief that survey results will influence policy decisions and the respondent's interest in the outcomes of those decisions, is absolutely necessary for participants to reveal their true preferences. Whenever possible, ex ante techniques should be used to create incentive compatibility, or a link between actions and rewards that encourages participants to answer truthfully. Typically, SP methods do not have direct incentives because any incentives for participation are provided regardless of the truthfulness of an individual's response (Fifer et al., 2014). Thus, researchers must establish consequentiality (and therefore an incentive-compatible experiment) by including only participants who have a stake in the agency's actions and by creating the feeling that participants' responses may influence agency actions.

3.4.3.1 Cheap Talk Scripts

"Cheap talk" is an ex ante method shown to mitigate hypothetical bias by appealing to consequentiality (Fifer et al., 2014). Cheap talk scripts are text scripts presented to participants prior to completion of the survey. The scripts range from a few sentences to a few paragraphs that provide essential pieces of information: first, an alert about the potential bias associated with hypothetical situations, and second, an emphasis on the importance of truthful answers.

In the trucking permitting questionnaire, following demographic questions about their company and immediately prior to answering questions about hypothetical situations, respondents were shown a cheap talk script, seen in Figure 3.2. The cheap talk script designed for this study includes information that has been demonstrated effective in past research: a brief explanation of bias that could occur and why it occurs, and encouragement and assurances that the survey results will be used in policy making. The policy making assurances develop consequentiality. The researchers balanced the need to adequately explain information without tiring the respondents, or providing so much information that would discourage the respondents from reading the script. This was accomplished through a two-paragraph script on a single screen.

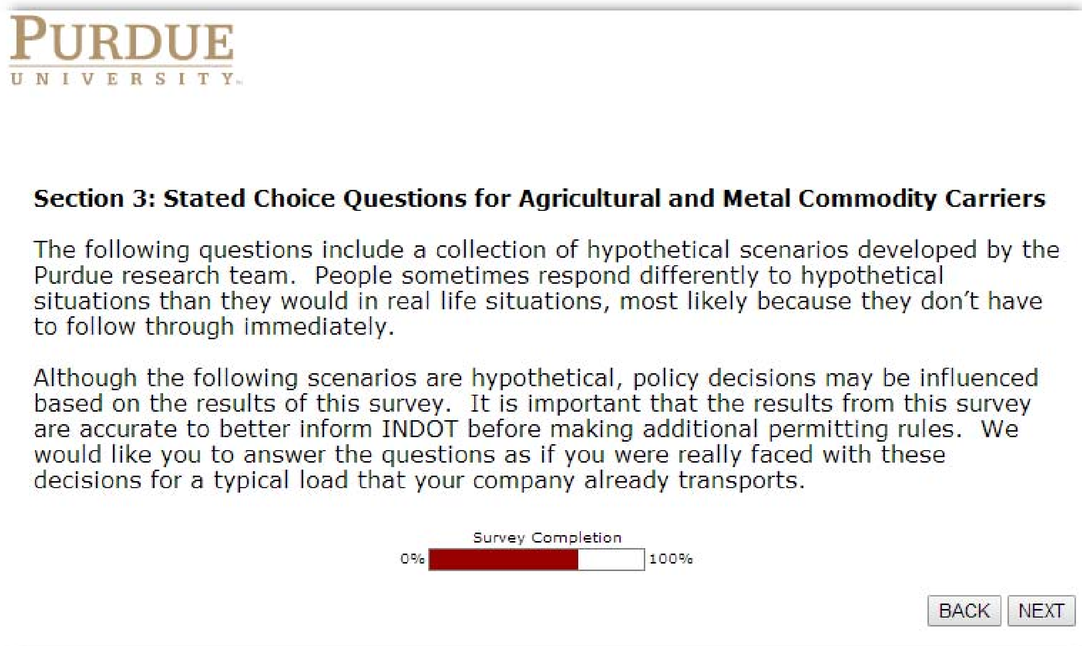

Figure 3.2 Cheap Talk Script Shown to Respondents Prior to Hypothetical Situation Questions

3.4.3.2 Certainty Calibration

In addition to establishing an incentive-compatible experimental design prior to survey administration, there are several ex post calibration techniques to account for hypothetical bias. These include the use of general calibration factors, certainty calibration, and frontier calibration. In addition to the NOAA rule to divide by two, List and Gallet (2001) then Murphy et al. (2005) quantified calibration factors for both public and private goods using meta-analysis of several SP studies. Certainty calibration has been used extensively in CV experiments. In addition to the choice question, respondents are also asked, either qualitatively or using a certainty scale, about their level of certainty regarding their choice. Norwood (2005) reported that when a scale of 1 to 10 (where 10 means “very certain”) was used and the “yes” response of all individual who reported certainty less than 8 were re-coded as “no” responses, the hypothetical bias disappeared. Certainty scales are preferable to qualitative questions or categorical lists because researchers can use the numerical scales to define uncertain responses and calibrate results. Frontier calibration has been used address bias in hypothetical auction data. Frontier calibration assumes that individuals with similar deomgraphics will submit similar bids in an auction; any differences in bids among individuals in the same demographic are due to the hypothetical nature of the auction. Thus, the true bid amount is the lowest hypothetical bid for each demographic group (Norwood, 2005).

In the trucking permitting questionnaire, respondents were asked follow-up certainty scale questions regarding the choice they have made using the five-level Likert-type scale shown in Figure 3.3. In addition to a numerical scale, each possible response included a qualitative description of the level of certainty/uncertainty. The qualitative information may have aided respondents while the quantitative responses provided flexibility in subsequent analysis. Respondents were asked a certainty scale question after every hypothetical scenario question.

Figure 3.3 Example of Certainty Scale Question Posed Subsequent to Question on Future Investment

3.4.4 Online Survey Instruments

Two surveys were administered online using Qualtrics, a web-based survey software licensed at Purdue University. The first survey, developed specifically for the HEA-1481 study, is outlined in Appendix C. Representatives from the Indiana Motor Truck Association (IMTA), the Agribusiness Council of Indiana (ACI), INDOT, and INDOR facilitated with the development of the survey questions and advertisement of the survey to potential respondents. Links to the online survey instrument were provided on various INDOT and INDOR websites related to oversize/overweight vehicles.

In the first survey, respondents were initially asked several questions about their company and operations including descriptions of their truck fleet, company location, number of employees, type of goods hauled, average trip distances, total annual tonnage shipped, and past and current permit purchases. The company and operations information questions could be answered by all respondents. Next, the cheap talk script introduced the hypothetical scenario questions. Only respondents who carried metal or agricultural commodities were asked additional SP questions. Several hypothetical permit fee questions addressed each respondent's intent to purchase permits on a quarterly or annual basis, willingness to invest in infrastructure-friendly vehicles (consistent with the annual, multi-trip permits established in the Emergency Rules), and an alternative scheme for blocks of ESAL-mile permits to determine a self-reported value for each ESAL-mile of travel.

A follow-up survey was developed to encourage additional participation. The questions included in the follow-up survey are detailed in Appendix D. To reduce the amount of time necessary for participants to complete the survey, questions related to past and current permit use were eliminated because they were not relevant to the willingness to pay analysis. Survey respondents who took the follow-up survey were presented with select demographic and operational questions and SP questions. The texts of questions in the follow-up, including descriptions of hypothetical scenarios, were not altered from the original survey. For both versions of the survey, all SP questions were followed by certainty scale questions.

Responses for the original HEA-1481 survey were accepted via the online survey system between May 21 and June 17, 2014. The original survey and the follow-up version of the survey were re-opened and opened, respectively, via Qualtrics beginning August 11, 2014. Additional responses were accepted through September 5, 2014. During the initial period, 64 participants answered some or all of the questions posed. During the second response period, 12 more participants answered some or all of the questions in the original survey while 8 respondents answered some or all of the questions in the follow-up survey. The total number of respondents was 84. Responses that were not complete (for either version of the survey) were not entirely rejected due to limited sample size. In the following discussion of the survey findings, the number of responses for each individual question is indicated where appropriate.

3.4.5 Demographic and Operational Characteristics of Respondents

Table 3.1 outlines the demographic and operational characteristics of the respondents' companies. Survey participants were asked to describe their fleet in terms of both the number of vehicles and the average age of the vehicles. The results indicate that the most common vehicle, by far, is the five-axle single-trailer truck. There is a large range in the fleet size of the individual participating companies. The overall vehicle age range is from brand new (0 years) to 25 years old. Different vehicle types have different age ranges. The number of employees was used as a second measure of company size. Nearly all of the respondents employ a majority of full-time employees with relatively few part-time employees. Again, there was a large range in the responses of individual participating companies.

Table 3.1 also includes approximations of the annual weight of goods transported and distances traveled. In the original survey, the average distances were not asked directly but were derived using the average distances traveled for each type of good and the number of trips made in a typical month.

Table 3.1 Trucking Company Demographics and Operational Characteristics

Variable	**Average**	**Std. Dev.**	**Min.**	**Max.**	**No. of Responses**
Fleet size characteristics					
Number of single-trailer trucks with five axles	88.83	283.45	0	2249	84
Number of single-trailer trucks with size or more axles	7.75	18.89	0	90	84
Number of multi-trailer trucks with five or fewer axles	2.13	10.93	0	92	84
Number of multi-trailer trucks with six axles	2.65	12.25	0	90	84
Number of multi-trailer trucks with seven axles	1.43	5.38	0	34	84
Number of multi-trailer trucks with eight axles	1.04	4.57	0	38	84
Number of multi-trailer trucks with nine or more axles	2.45	12.40	0	100	84
Total number of vehicles	106.29	315.20	0	2525	84
Fleet age characteristics					
Average age of single-trailer trucks with five axles	8.94	4.64	1.5	25	71
Average age of single-trailer trucks with six or more axles	6.15	4.13	0	15	30
Average age of multi-trailer trucks with five or fewer axles	7.22	7.52	0	20	18
Average age of multi-trailer trucks with six axles	2.40	3.29	0	10	15
Average age of multi-trailer trucks with seven axles	3.25	3.57	0	10	16
Average age of multi-trailer trucks with eight axles	4.15	4.45	0	12	13
Average age of multi-trailer trucks with nine or more axles	2.64	3.37	0	8	14
Employment characteristics					
Number of full-time employees	107.92	181.40	0	1200	83
Number of part-time employees	15.60	29.73	0	150	65
Total number of employees	133.40	212.02	0	1210	65
Operational characteristics					
Approximate annual pounds of goods moved (in billions)	6.31	34.2	0	250.0	75
Approximate annual miles traveled (in millions)	4.11	10.7	3600	63.4	76

Figure 3.4 presents the number of years after purchase at which companies replace their vehicles. The results indicate that nearly three-quarters of companies replace vehicles within 10 years. Another significant fraction replaces their vehicles between 10 and 15 years while a very small proportion of respondents do so after 15 years or more. The typical vehicle replacement age is an important consideration for carriers altering their fleet to changes in TS&W limits and oversize/overweight regulations. Carriers are likely to make adjustments at times that are concurrent with their cycles for fleet maintenance and replacement.

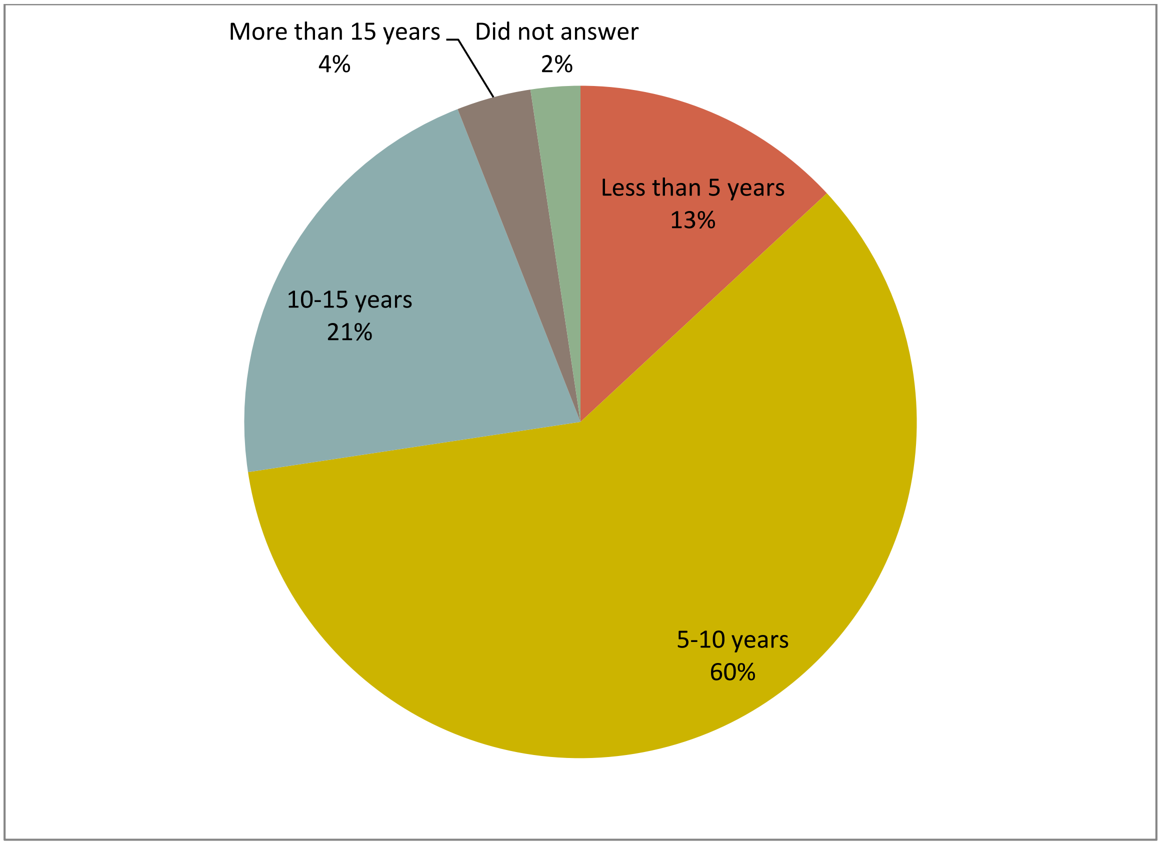

Figure 3.4 Typical Vehicle Age at Time of Replacement

3.4.6 Willingness to Pay Model Estimation

The remaining questions on the survey solicited information about industry stakeholders' preferences regarding overweight divisible load permits and their likely actions in hypothetical situations. Figure 3.5 indicates that approximately 40% of respondents were interested in some form of annual ESAL-mile based overweight divisible load permits, while 31% were not sure and 24% would not want an annual permit tied to tax filings. Four respondents did not indicate a preference. The low number of "yes" responses is inconsistent with repeated comments expressed by representatives of the trucking industry at various industry forums advocating for annual permits. The large portion of "Don't Know" answers could be due to the suggested framework of tying an annual system to tax filings for mileage reporting purposes.

The concept of annual permits tied to tax filings was brought forward as a survey question following feedback that the waiting time between permit requests and permit approval or acquisition is burdensome for the industry, particularly for companies who repeatedly purchase single-trip permits. Annual permits tied to tax filings reduce the time and labor necessary for companies requesting multiple permits for the same vehicle and route. Similarly, INDOR might also have time and labor savings in approval efforts for repeated requests using the same vehicle and route.

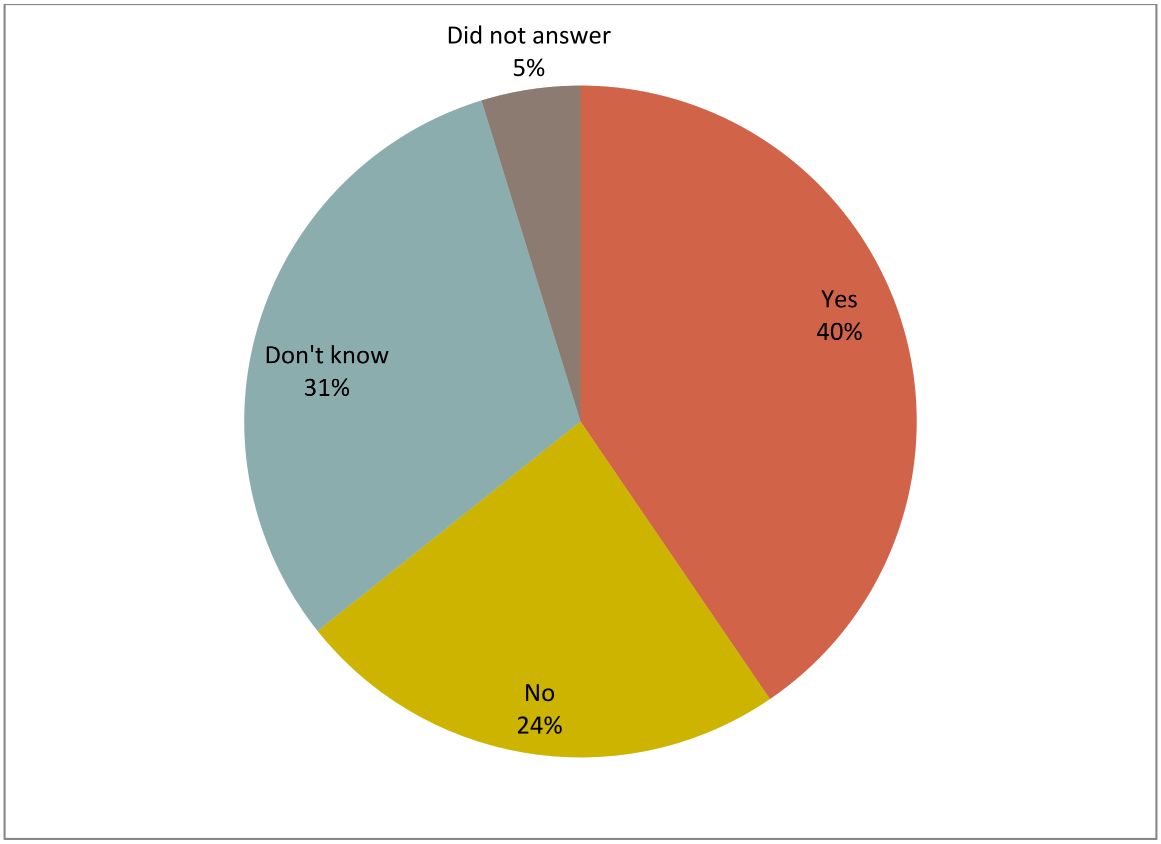

Figure 3.5 Responses to the Question, "Would you be willing to purchase an ESAL-based annual permit for overweight divisible loads that is tied to your quarterly tax filings (for reporting mileage)?"

Prior to the cheap talk script and hypothetical scenarios, all respondents were asked if they would consider changing their fleet to take advantage of permits for overweight divisible loads without any indication of cost. Figure 3.6 indicates that 71% of respondents would be willing to invest at least some amount of money in vehicles necessary to use overweight divisible load permits. One respondent did not indicate a response and four were not sure if they would invest or not. When presented with hypothetical scenarios involving dollar amounts, the respondents exhibited reduced willingness to invest money for this purpose.

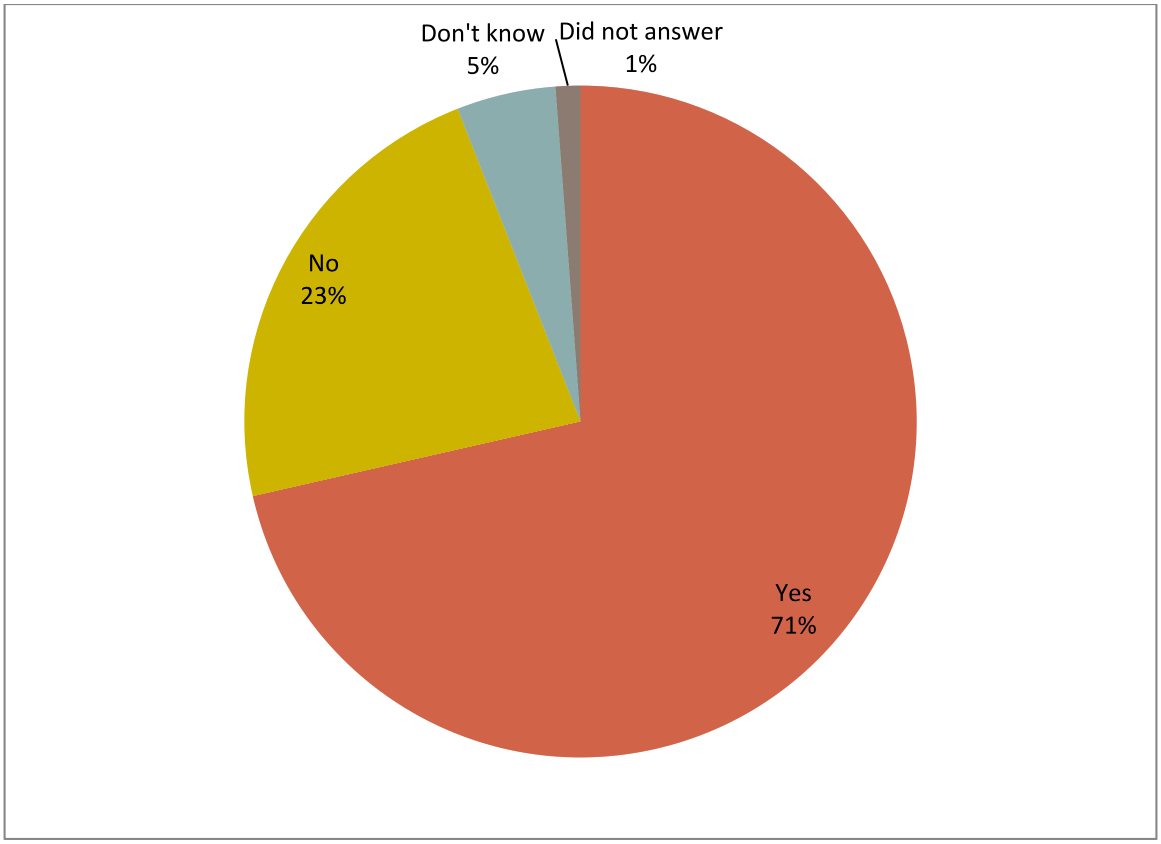

Figure 3.6 Responses to the question, "If divisible load permits were available for your industry, would you consider investing in new equipment or altering your existing equipment to take advantage of these permits?"

The willingness to pay hypothetical scenario of interest was framed as follows:

> “Suppose INDOT plans to offer annual overweight divisible load permits free of any ESAL-mile based fee for those vehicles which do not cause additional damage to pavements and bridges beyond that of 80,000-lb. vehicles (which do not require permits). INDOT would charge an annual administrative fee of $20.00 per vehicle per route to verify the ESAL-equivalent of the vehicle, address the load rating of any bridges on the route, etc. Your company would need to

purchase, retrofit, or otherwise own vehicles that could be configured and loaded to 2.4 ESALs or below."

In actuality, this scenario is consistent with the annual, multi-trip permits created in the Emergency Rules and available since February 1, 2014. The CV question and certainty scale question followed the scenario development. Based on conversations with industry representatives, three investment amounts were selected: $5,000, $10,000, and $15,000. Each participant was presented with a randomly-assigned amount.

Participants who took the full HEA-1481 survey were presented with a number of follow-up questions including the certainty scale (the first follow-up question). Participants who took the later version of the survey were only asked the certainty scale follow-up question.

As previously mentioned, Norwood (2005) determined that recoding the "yes" responses to "no" for all individuals who indicated a certainty of less than 8 on a 1 to 10 scale eliminated hypothetical bias in estimation results. Similarly, for the present research, all individuals who responded "yes," indicating they are willing to invest the specified amount and less than "4 certain" on the certainty scale question were re-coded "no," they are not willing to invest. The actual and certainty calibrated responses are outlined in Table 3.2. There were 80 participants who responded to the CV question. The actual and calibrated responses suggest that when a monetary amount is included and respondents are encouraged to think about their actual operations, their willingness to invest in new equipment or alter existing equipment was much less than indicated for the open-ended question that did not include a dollar amount. In contrast to the 71% that indicated in the open-ended question that they would invest in equipment, only 32.5%

indicated they would do so when a monetary amount was associated with the investment. Even at the lowest level of investment included in the CV question, $5,000, less than half of respondents indicated “yes,” they would invest.

Table 3.2 Raw and Calibrated Responses to WTP for Investment Question

Investment Amount	**Actual Responses**			**Calibrated Responses**		
	Yes	**No**	**% Invest***	**Yes**	**No**	**% Invest***
$5,000	17	20	45.9%	14	23	37.8%
$10,000	7	17	29.2%	2	22	8.3%
$15,000	2	17	10.5%	1	18	5.3%
Total	26	54	32.5%	17	63	21.3%

*% Invest means the percentage of respondents who were willing to invest in infrastructure-friendly vehicles

Table 3.3 presents the results of the selected logit estimation of WTP for investment in new equipment or alterations for existing equipment among truck carriers. The binary logit model was used because respondents were only able to respond “yes” or “no”. The underlying assumption of the binary logit estimation is that the outcome (choice) is a linear function of independent variables. The model results suggest that, in addition to the dollar amount of investment, the number of vehicles in the existing fleet and the respondent’s interest in annual permits tied to quarterly tax filings are significant predictors of their willingness to make such investments. As expected, the parameter estimate for investment amount has a negative sign. As the amount of investment increases, the company is less likely to be willing to invest. The positive sign for the parameter estimate for the number of vehicles indicates that those with larger fleets are more inclined to invest in equipment that meets the requirements for the annual, multi-trip permits. This result is also consistent with expectations because larger companies, using fleet size as a proxy measure, are more willing and/or able to invest in equipment for a particular application—in this case using the annual, multi-trip permits. Smaller companies are likely unable to make investments for a niche market. The last of the statistically significant predictors of WTP for investment is the willingness to use annual permits tied to tax filings. The positive sign of the variable suggests that those respondents who are interested in annual permits are also more likely to invest in infrastructure-friendly vehicles. This likely occurs because the trucking companies that advocate for annual permits do relatively large amounts of overweight freight movement; these companies are likely to benefit the most from annual permits in general and less expensive multi-trip permits specifically.

Table 3.3 Logit Estimation Results for WTP for Investment in Infrastructure-Friendly Vehicles

Variable Description	**Estimated Parameter**	***t* statistic**
Investment in dollars	-0.000495	-4.33
Number of vehicles in fleet	0.00799	3.17
Annual permits indicator (1 if willing to purchase annual permits tied to quarterly tax filings, 0 otherwise)	2.539	3.31
Number of observations	80	
Log-likelihood	-23.084	
McFadden pseudo-R^2	0.442	

Model fit statistics indicate that the logit model is satisfactory. The log-likelihood of the estimated model indicates the model's improvement over a naïve model with only a constant term. The higher the log-likelihood (or less negative), the better the model accounts for heterogeneity in the sample. McFadden's pseudo R^2 is another goodness-of-fit measure that indicates the model accounts for a portion of the heterogeneity. The significance of variables, log-likelihood, and pseudo R^2 were used to select the model presented in Table 3.3 over other estimated models. Other variables such as the average age of vehicle replacement, amount of goods transported annually, and average distances were not found to be statistically significant predictors of willingness to pay for investment.

Figure 3.7 presents the WTP curves for the uncorrected raw data, the certainty calibrated data, and the estimated average WTP curve. The difference between the uncorrected data and the certainty calibrated data reflects the hypothetical bias. The calibrated data indicate that the WTP to invest is lower after the hypothetical bias is accounted for. The estimated average WTP curve represents companies with an average number of vehicles (approximately 107) and an average value for interest in annual ESAL-based permits tied to quarterly tax filings (0.425). In actuality, companies will either be in favor or not in favor of annual ESAL-based permits tied to quarterly tax filings and could have any number of vehicles in their fleets.

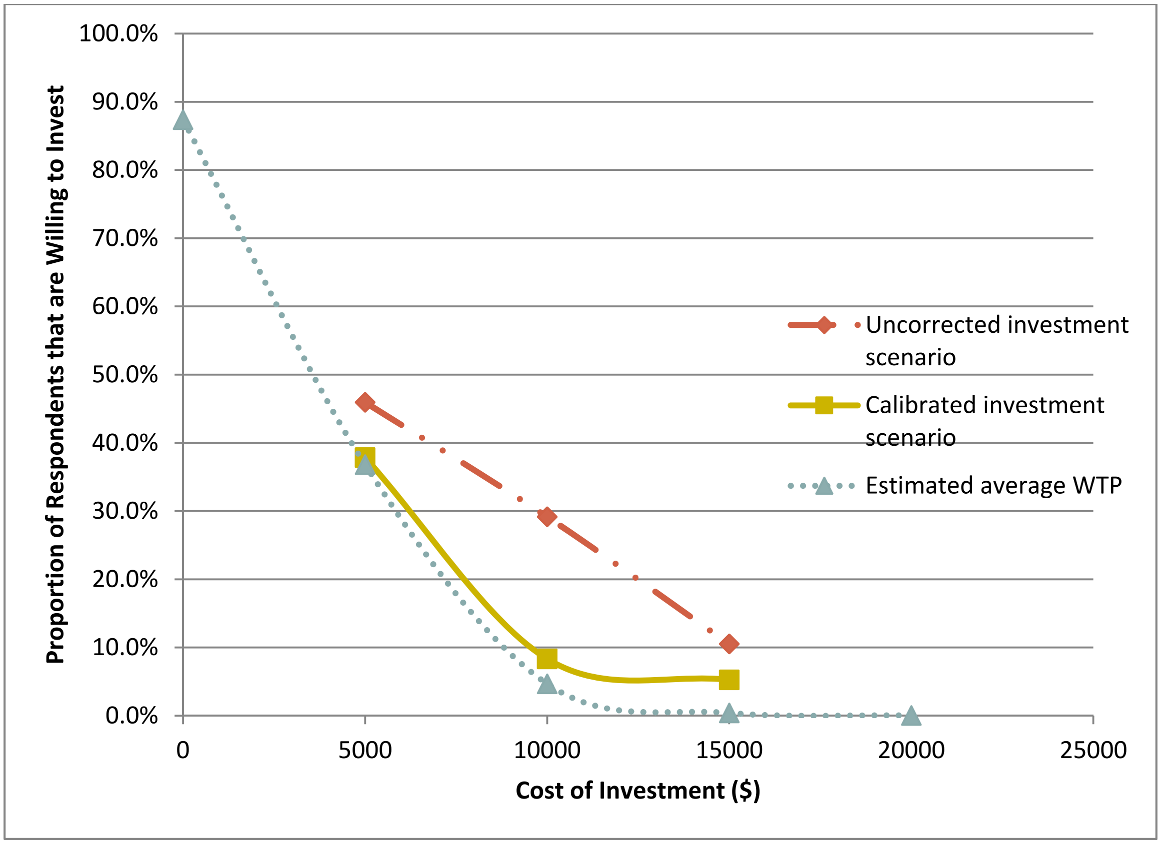

Figure 3.7 WTP Curves for Investment in Infrastructure-Friendly Vehicles

For any given company, the estimated likelihood of the respondent's willingness to pay for investment changes based on the number of vehicles in their fleet and whether or not they are in favor of ESAL-mile based annual permits tied to their tax filings. Figure 3.8 presents the change in the WTP curves when indicator values of 0 (not in favor) and 1 (in favor) are used instead of the mean value 0.425 for whether respondents are in favor of annual permits tied to their tax filings.

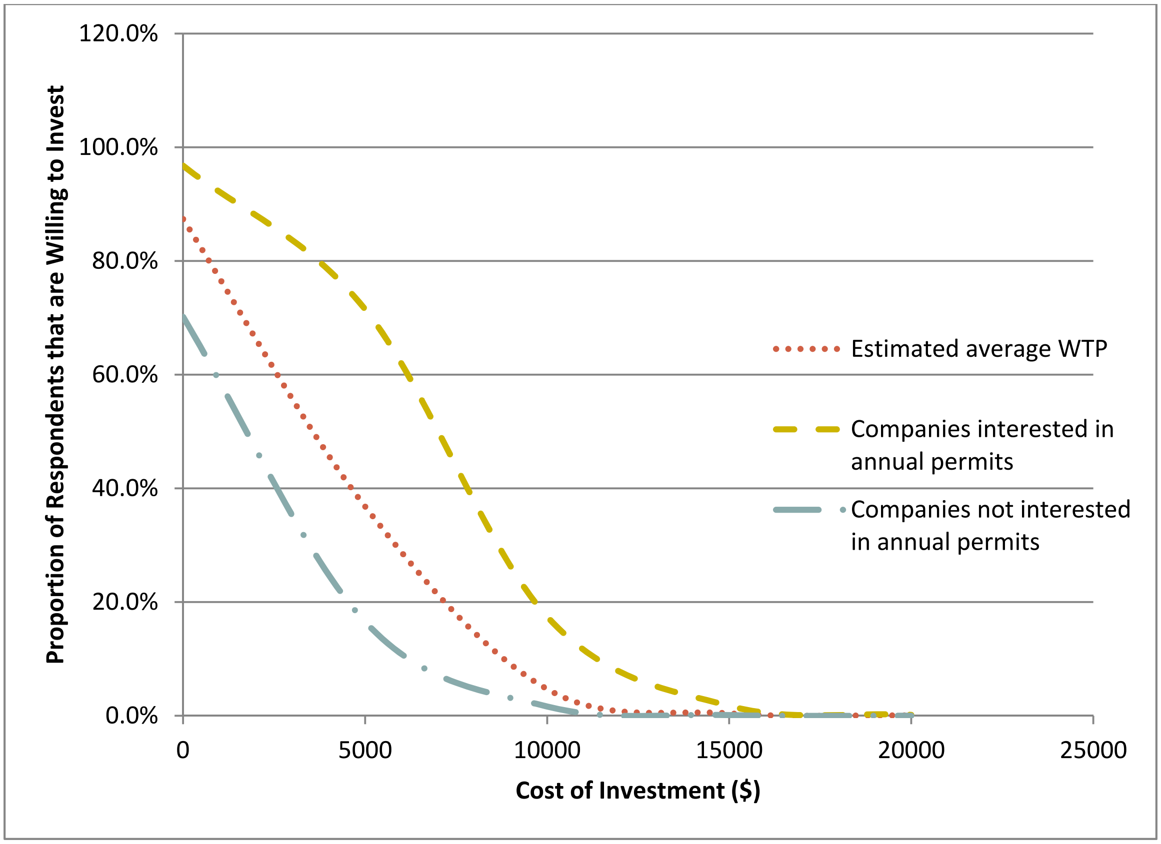

Figure 3.8 WTP Curves for Different Annual Permit Preferences

None of the WTP curves (Figure 3.7 and Figure 3.8) indicate that 100% of carriers would opt to invest even if the cost of investment were dropped to zero (y-axis in the figures). Although this might not seem intuitive, this is consistent with previous CV studies; even at no cost, some individuals are not willing to change current practices because they find current practices acceptable. In the open-ended question without a dollar amount, this type of behavior is captured by some respondents who answered “no” they would not invest any money to take advantage of overweight divisible load permits.

3.4.7 Parametric Results

The results of the logit regression model were also used to estimate the mean WTP using the following equation:

$$Mean\ WTP = \frac{-\beta_C}{\beta_1}$$

where β_1 is the estimated coefficient for the investment amount variable and β_C is the grand constant calculated as the sum of the products of each estimated coefficient and their respective means.

The mean WTP for investment in infrastructure-friendly vehicles is estimated to be $3,907.72 for each company. This is lower than $5,000, the lowest randomly-selected investment amount included in the questionnaire. This result corroborates the observation that a very low percentage of respondents (regardless of uncorrected data or certainty calibrated data) stated they are willing to invest in equipment that would ensure loading of 2.40 ESALs or less.

3.5 Additional Incentive Program Structures

Indiana's annual, multi-trip permits embody an incentive structure where the reward for using infrastructure-friendly vehicles is lower costs for permit acquisition. The annual, multi-trip permits are significantly less expensive at $20 annually compared to the tens of thousands that might be spent on single-trip permits for vehicles above 2.40 ESALs. Michigan's TS&W limits embody an incentive structure where the reward for using infrastructure-friendly vehicles is an increase in GVW. Other mechanisms besides those used in Indiana and Michigan can be used to incentivize the use of infrastructure-friendly vehicles.

The TRB (1990b) Turner proposal study considered one mechanism—special tax treatment. The research committee acknowledged that the taxes paid to own and operate Turner trucks might exceed those for a 5-axle, 80,000 lb vehicle. The increased taxes could come from the sales tax associated with a higher purchase price and the additional fuel taxes associated with a decrease in fuel economy. TRB (1990b) determined that if the Turner proposal were implemented, individual states would need to adjust tax fee structures as appropriate to incentivize the use of vehicles that benefit both the trucking industry and the state agency that maintains the infrastructure.

Another mechanism to incentivize ideal behavior is the use of rebates or bonuses. The estimated mean WTP for investment in infrastructure-friendly vehicles in Indiana is likely much less than the actual expenditures necessary to obtain infrastructure-friendly vehicles (either new or through retrofits). Rebates could be returned to carriers based on the number of infrastructure-friendly vehicles they purchase. Similarly, bonuses could be provided for carriers who can demonstrate that they replaced a number of trips by vehicles over 2.40 ESALs with trips by vehicles loaded at or below 2.40 ESALs, although this likely would be more difficult to verify.

On the opposite end of the spectrum from incentives, penalties can be used to discourage the use of non-infrastructure-friendly vehicles. Inherent in Indiana's overweight commodity permits for vehicles above 2.40 ESALs are the time and labor penalties associated with requesting multiple single trip permits. The acquisition time can jeopardize just-in-time delivery requests. Additionally, trucking companies must pay an employee for the time to repeatedly request permits. Harsher penalties, in terms of the approval time or permit price, for vehicles over 2.40 ESALs may encourage carriers to invest more money in infrastructure-friendly vehicles.

3.6 Chapter Summary

This chapter detailed the use of incentives and mandates for use of infrastructure-friendly vehicles. Infrastructure-friendly vehicles are configured, loaded, and operated in a way to minimize, or at a minimum reduce, the consumption of highway infrastructure assets.

Three examples of proposed and existing initiatives to encourage the use of infrastructure-friendly vehicles were described. The Turner proposal, which was to decrease the federal axle load limits and increase the federal vehicle length limits, would cause less damage to pavements and would have higher GVWs resulting in productivity gains for the trucking industry. Michigan's unique set of TS&W limits are based on a similar philosophy of limiting individual axle weights. Unlike an incentive program, Michigan's TS&W limits require carriers to comply with lower axle weight limits to take advantage of higher GVWs. Indiana recently introduced annual, multi-trip overweight commodity permits for metal and agricultural carriers who load their vehicles to 2.40 ESALs or less. Indiana's program is a perfect example of an incentive program because individual carriers can choose to use infrastructure-friendly vehicles for a minimal permit fee or pay more in permit fees to account for some of the additional consumption of the highway infrastructure.

A stated preference survey was conducted to determine carriers' willingness to pay for investments in infrastructure-friendly vehicles for use in Indiana. Although the majority (71%) of respondents indicated they would invest in equipment to take advantage of divisible load permits, when a monetary value was associated with investment, respondents were less willing to invest (32.5% willing to invest). The mean willingness to pay for investment in infrastructure-friendly vehicles was estimated to be slightly less than $4,000. Future research is necessary to determine if carriers' willingness to pay changes after the incentives have been in place for a longer period of time. Finally, the chapter discussed other initiatives to encourage the use of infrastructure-friendly vehicles for overweight movements, including rebates, special tax treatment, and penalties for non-compliant vehicles.

CHAPTER 4. OVERWEIGHT VEHICLE QUOTAS WITH AUCTION ALLOCATION

4.1 Introduction

Traditional overweight vehicle permits, even when optimized, and incentives for infrastructure-friendly vehicles address the issue of excessive pavement and bridge consumption from overweight vehicles by collecting revenues to offset some or all of the damage that occurs, independent of the total amount of that consumption. Neither of these strategies limits the total amount of consumption—as long as carriers pay appropriate fees and operate within the regulations, there is no upper limit on the amount of overweight vehicle trips that may be permitted. Quotas on the other hand directly limit the amount of allowable consumption from overweight vehicles.

Manheim (1979) defined the total transportation system to include all modes of transportation, the people and goods being transported, the vehicles used, and the networks over which people and goods flow. In focusing this total transportation system definition to the context of overweight vehicles, the overweight vehicle system includes the goods being carried, the various vehicle configurations used to move those goods, and the highway infrastructure the vehicles traverse. The overweight vehicle system is a subset of the total transportation system because the highway infrastructure is shared by both overweight vehicles, non-overweight trucks, and passenger vehicles. Another way to consider the total transportation system is supply. Specifically, the total transportation system components of infrastructure and vehicles using the infrastructure supply the ability to move the people and goods—collectively, the demand.

Manheim (1979) also observed that the total transportation system can be varied through technological improvements, changes to the network, vehicle improvements, and policy changes. Incentives for infrastructure-friendly vehicles exemplify the type of vehicle improvements that alter the overweight vehicle system. The infrastructure can accommodate more trips by infrastructure-friendly overweight vehicles than non-infrastructure-friendly overweight vehicles that consume additional highway infrastructure assets.

Traditional overweight vehicle permit fees are a policy option, but also, ideally, the revenues collected through permit fees are used for improvements to the network via routine maintenance, rehabilitation, and reconstruction of highway infrastructure assets. Unfortunately, the revenues collected from permit fees are typically insufficient to account for consumption of the infrastructure assets. Without intervention, the network of highway infrastructure deteriorates, which results in less available supply.

Quotas are another policy option that approaches the overweight vehicle system from the other direction. Instead of modifying supply through vehicle improvements or improvements to infrastructure, quotas account for the total amount of damage that can be tolerated by the existing highway infrastructure given the available vehicle configurations and do not let that amount be exceeded. Although overweight vehicles improve the productivity of the trucking industry, the existing infrastructure was not designed for these loads. Quotas are a way to manage the infrastructure damage.

To date, quotas have been used in transportation primarily to mitigate congestion by limiting the demand for travel that is supplied. In the context of overweight vehicles, a quota mechanism would also manage the amount of demand for overweight vehicle trips that is being supplied; however, the goal is not to limit demand specifically but to limit highway asset consumption.

In quota mechanisms, the agency defines the supply as either a minimum or a maximum and does not allow usage to fall below the minimum or exceed the maximum, as appropriate. For the proposed overweight vehicle quota, the supply is the amount of infrastructure consumption attributable to overweight vehicles which can be tolerated. Quotas also require the decision maker to allocate the limited supply. Allocation techniques include first-come-first-serve, lotteries, cap-and-trade, merit-based, and auctions.

4.1.1 Quota Allocation in the Road Use Sector

As noted, quotas in the road transportation sector have premoninantly been used as a transportation demand management tool; however, there are lessons to be learned from the allocation methods used in these real-world quota examples.

Driving restrictions in Mexico city limit use of personal vehicles to specific days based on an individual's license plate. This is an egalitarian system because license plates are randomly-assigned. One negative consequence of the license plate restrictions in Mexico City is that the system indirectly encourages slightly increased vehicle ownership, as opposed to use, for individuals to have access to enough vehicles to travel on any given day.

Quotas in Asia have used both egalitarian lottery systems and auctions to allocate limited supply. Singapore first introduced its vehicle quota system (VQS) in May 1990 when it became apparent that large increases in import duty, vehicle registration, gasoline tax, and road use tax, combined with a cordon for travel into the city center, were ineffective at limiting demand (Chu, 2012; Phang, 1993). Although there have been numerous small changes to the system since May 1990, the VQS has always issued certificates of entitlement (COEs) allowing the individual holder to own and operate a vehicle for ten years through an auction. The road transport agency determines the quota as the number of vehicles that will be deregistered, (i.e., taken off the roadway network and exported or scrapped) plus an allowance for growth rate. Successful high bidders pay the market clearing price which is equal to one Singapore dollar more than the highest unsuccessful COE bid price. When several individuals enter the same reserve price, it is possible to have fewer successful bidders than the quota. These “extra” unclaimed COEs are rolled into the following month’s quota.

Although some of the COE categories have been combined, separate groups of COEs for smaller cars, larger cars, and motorcycles have always been used as an effort to protect owners of small vehicles and motorcycles from being outbid by the “richer” owners of larger cars (Phang, 1993; Chu, 2012). Similar efforts may be necessary for application to overweight vehicle permits to protect smaller companies that might not be able to afford permits via an auction.

The city of Shanghai also implemented a quota system using auction allocation for private car license plates (PCLPs). In 2008, the auction system was changed from single sealed bids to a two-round open auction system in which bid revisions can occur during the second round within a small range above and below the prevailing price (Song & Zhou, 2010; Chu, 2012). Unlike the Singapore system, in the Shanghai PCLP auction, successful bidders pay their bid amount. Chu (2012) found that the constraint on bid revision amounts helped mitigate the “winner’s curse” phenomenon, or the idea that the winners who pay the most are worse off because they paid more than other winners who paid only slightly more than the prevailing price. Essentially, the bid revision constraint prevents bids from continuing to escalate so that all winners remain within a narrow price band.

Additionally, throughout its history, the Shanghai governent has used minimum bids for foreign and domestic cars to achieve various policy objectives (Song & Zhou, 2010). Minimum bid prices may be useful in the context of auctioning overweight vehicle permits to ensure a minimal amount of revenue is collected to offset the cost of consumption, particularly if the number of participants is low.

In contrast to Shanghai, Beijing uses an egalitarian lottery system to allocate its quota of license plates. The consequence of a lottery system is inefficient collection of funds from the sale of license plates. In Shanghai, the license plates are purchased by the individuals who most value the PCLP. This generates the greatest funds for the transportation agency.

4.1.2 Auction Allocation for Non-Road Use Transportation

Beyond the realm of road use, auctions have also been used to allocate other limited transportation resources. Both pipe lines and rail lines are used to transport goods over long distances. Unlike the previous road use quota examples, pipe and rail transport is physically constrained by pipe capacities and rail car volumes. Pickl and Wirl (2011) explored different allocation strategies for auctioning the rent on the capacity of the Nabucco Gas Pipeline Project in western Europe. The authors considered allocating similar to a traditional auction where the highest bidders win, allocating capacity to each bidder until there was not enouch capacity for the next ranked bid. Unfortunately, this type of sequential allocation can result in unused capacity of the pipeline. As alternatives, Pickl and Wirl (2011) evaluated the likely allocation using both a pro rata system and optimization. Under the pro rata system, every bidder gets a portion of the total pipeline capacity relative to their bid compared to all other bids. For the optimization approach, the objective was to maximize the total revenue for the auctioneer.

Auctions have also been explored for allocating rail resources. Affuso (2003) detailed some of the advantages and disadvantages of auction allocation for rail capacity. One large disadvantage is the extremely high capital costs of creating rail capacity. Affuso (2003) determined the revenues from the auctions would be small compared to the capital costs necessary for investment. The advantages of auction allocation include clear indications of locations of scarce rail resources (where there are the highest auction prices) and information about the actual market value of rail capacity, which is different than the cost of constructing the rail infrastructure. Research is currently underway on auction allocation strategies for shared rail infrastructure in the California High Speed Rail (HSR) and Northeast rail corridors in the United States (Levy et al., 2014). One unique aspect of rail capacity auctions is that the value an individual places on using one link or terminal at a designated time is directly linked to the ability to use another link or terminal at a different designated time. This results in combinatorial auctions where bid prices are likely contingent on getting portions or all of the capacity for which an individual is bidding.

4.1.3 Cap and Trade Initiatives in the Transportation Sector

In addition to auctions, cap and trade mechanisms have been explored as a transportation demand management tool to curb traffic congestion. Yang and Wang (2011) created a hypothetical tradable mobility credit scheme in which the government initially distributes a given amount of travel credits to all users. Users can buy or sell additional credits to meet their individual travel needs among themselves in a competitive market. The authors found that selection of the total number of travel credits in the system could be used to achieve optimal traffic flows. Markose et al. (2010) demonstrated similar results on an existing transportation system using the transportation demand model of the Gateshead borough roadway network in North East England. The authors observed that a cap and trade scheme provided an incentive to all individuals, including those who were priced out of the system, to change travel patterns. In the cap and trade scheme, those who cannot afford the price of using credits can sell their credits in the trading market for additional income. Markose et al.'s (2010) tradable credit scheme employed a sealed-bid uniform Dutch auction for the initial allocation of credits. In a sealed-bid uniform Dutch auction, the bids are collected secretly and the credits are allocated sequentially to the highest bids at the price the participants bid. The cap and trade scheme has not been explicitly applied to the right for vehicle ownership (like the auctions in Singapore, Shanghai, and Beijing), but rather only the extent of usage of a system. The mobilitiy credits in these schemes are typically tied to the cost of using an individual link in the system, similar to a toll.

4.2 Framework

A overweight vehicle permit quota using an auction allocation process, similar to the Singapore VQS, can be applied to cap highway asset deterioration attributable to overweight vehicles. Instead of issuing COEs for car ownership, the overweight vehicle permit auctioneer issues blocks of usage to auction winners. This will limit the extent of infrastructure consumption.

Barter (2005) proposed a similar usage based scheme to replace the Singapore VQS. In contrast to flat fees, via registration and licensing or purchasing COEs in the case of Singapore, usage charges are much closer to the ideal Pigouvian pricing that accounts for the marginal externalities. Additionally, flat fees that are not associated with transportation infrastructure usage are inherently inequitable for those who use the assets less but must pay the same amount. Barter (2005) noted that the high cost of COEs in Singapore undermines the existing road pricing system because the tolls and cordon charges were insignificant compared to the large cost of purchasing a COE. As a remedy, a transition from COEs for ownership only to usage based COEs was proposed, which continue to entitle purchasers to own a vehicle, tied to an established amount of usage. Instead of a COE being held for a period of ten years, the COE would be valid until the usage was spent. Therefore, instead of bidding for and buying a COE every ten years, continuous auto owners would bid for additional usage every time they were close to the allowance tied to their COE. Those who use the infrastructure least would have the most time between bidding events while though who use the infrastructure most would participate in the auctions more frequently.

A usage scheme for the overweight vehicle permitting quota and auction is more appropriate than auctioning a number of blanket, or unlimited usage, permits as the measure of supply because it allows the agency to control consumption of the highway infrastructure. The agency doesn't necessarily want to curb the demand for overweight permits, only the consumption attributable to those types of operations. For the present overweight vehicle permit auction framework, the transportation agency (or a third-party auctioneer acting on behalf of the transportation authority) defines the usage measure, determines auction parameters such as the quota, the minimum bid price (if necessary), and auction schedule, and determines permit parameters such as the amount of usage and the time limit for which a permit is valid. Trucking companies and permit service providers then bid on the permits. Auction winners receive the permits while those who are unsuccessful must comply with state and federal limits for vehicles without a permit.

This mechanism would most likely be applicable only to overweight *divisible* loads which can be broken apart into multiple smaller loads; this is how those who do not obtain a permit in the auction would be required to move goods. Carriers of *non-divisible* goods, which cannot be broken into smaller units to be below state and federal TS&W limits, would not be required to participate in the auction because they would not be able to move the load without a non-divisible overweight load permit.

Auction allocation is more appropriate for overweight vehicle permitting than egalitarian lottery, first-come-first-served, or cap and trade systems. In both egalitarian lotteries and first-come-first-served allocation, the permits are not put to their most efficient use. Some companies will value the overweight vehicle permits more than others. The additional value, which is captured in an auction but not in a lottery, is additional revenue that the transportation agency would have available to invest in infrastructure maintenance. In a cap and trade system the usage credits would likely end up in the hands of those who most value them through the trading market; however, this does not necessarily mean that the transportation agency would receive the revenue from the trading market. Additionally, in a cap and trade system, the agency must identify all users. In a general road use context, this is rather evident because all vehicles use the highway infrastructure. Full user identification and allocation is not straightforward in the context of overweight vehicle permits because not all trucking companies use overweight vehicles and not all vehicles owned and operated by any given company are used for overweight operations. In an auction, participants identify themselves by submitting a bid.

4.3 Case Study: Divisible Load Permit Auction in Indiana

In practice, the proposed quota and auction framework does not necessarily preclude other permitting strategies. In particular, the incentives for infrastructure-friendly vehicles can easily be implemented in tandem with the auction system. If the same usage measure is applied in both contexts, ESAL-miles of travel in Indiana for example, those who are below a certain limit would be exempt from the auction while any company which decides to operate above the limit would have to participate in the auction. Auction participants either pay for usage with a successful bid or operate within state and federal TS&W limits with an unsuccessful bid.

In the present case study, it is assumed that INDOT will continue to allow any users who configure their vehicles to 2.40 ESALs or below to obtain an annual, multi-trip permit for $20 for each vehicle and route. For all other vehicles, those configured and loaded to more than 2.40 ESALs, the trucking companies would have to participate in an auction.

For purposes of analysis, the usage measure will be defined as ESAL-mile blocks of travel. ESALs are already used to determine who is eligible for annual, multi-trip permits and ESAL-miles include the distance component of consumption. For a given ESAL-mile block, the trucking company is able to use fewer ESALs or travel fewer miles to maximize their own use of individual ESAL-mile blocks; that aspect of use is not controlled by the state agency.

For the present study, each block corresponds to 500 ESAL-miles of travel. Although the agency could set each block to more or fewer ESAL-miles of travel, 500 ESAL-miles is enough to cover several trips without being so much that carriers would not want to participate. If the amount of travel included with each permit is too high, carriers may not want to bid for a block that they will not use entirely. In contrast, if the amount of travel included is too low, carriers will bid for hundreds or even thousands of blocks.

4.3.1 Cap on Infrastructure Consumption

The fundamental necessity of an auction is whether there is something finite to be allocated. In the case of overweight divisible load trucking, there is an increasing demand for using Indiana’s pavement and bridge assets with limited funds available to maintain those assets. The enactment of HEA-1481 indicates that there is a demand which, prior to enactment, was not being met. An auction scheme would allow INDOT to control the consumption attributable to overweight vehicles carrying divisible loads by setting a quota of permitted ESAL-mile blocks to be auctioned. INDOT would also be able to increase the number of ESAL-blocks available in a given period based on the anticipated investment into the highway network.

4.3.1.1 Determination of Quota

There are many different methods for INDOT to determine the appropriate quota. First, INDOT may choose to calculate supply as the total ESAL-miles the pavements and bridges in Indiana can support minus the loading expected from passenger vehicles, trucks up to 80,000 lbs, and overweight non-divisible loads. The total ESAL-miles of use that can be supported depends on the existing inventory and condition of pavement and bridge assets. The deterioration curves for bridges and pavements are nonlinear; assets that are in worse condition deteriorate faster. INDOT may determine supply based on the actual condition of assets or on the projected condition based on investment in the network.

Alternatively, INDOT may determine the quota based on past or present budgets. Initially, INDOT might set the quota using historical maintenance, rehabilitation, and reconstruction budgets. INDOT might also base the quota on an estimate of projected revenues using either the minimum bid price or some estimate of the resulting equilibrium auction prices. Another budget based option is for INDOT to set a floating quota based on the revenues from the previous auction. In each case, the funding supports a given amount of maintenance, rehabilitation, and reconstruction which maintains or improves the condition of the pavements and bridges. As noted, pavements and bridges in better condition deteriorate at a slower pace and can withstand the stress and strains of overweight vehicles.

Finally, INDOT might set the initial quota equal to the current demand, or just below to encourage a small amount of competition, then control demand growth in the future. This is potentially the best option because initially the prices for overweight divisible load ESAL-mile blocks will be low, or close to the minimum bid, then rise as demand for overweight vehicle permits increases. Initially, the revenues collected through the auction would be similar to the revenues from the current overweight commodity permits, particularly if the minimum bid is set equal to the current price of overweight commodity permits. Over time, additional companies will become aware of the permits, realize the benefits of overweight vehicle operations, and seek to participate. The current overweight commodity permit system does not account for increasing awareness of the permits or increasing use of the permits. A quota that is set on the basis of meeting current demand with controlled growth in the future would have two benefits. First, it would prevent exponential increases in the ESAL-miles of travel by overweight vehicles and the associated consumption of highway infrastructure. Second, over time, it would result in higher permit bids in the auction which would result in higher revenues for INDOT to maintain, rehabilitate, and reconstruct pavement and bridge assets.

4.3.1.2 Initial Annual Supply in Indiana

For this research, initial supply is estimated on the basis of existing demand for overweight commodity permits. After determining the intitial quota for the first year, the annual quota can be updated each year based on a low growth rate between 1% and 3%.

Permit records for 33,721 overweight commodity permits sold between January 1, 2014 and June 29, 2014 were queried from the INDOR database. These records contain the start date, mileage, individual axle weights, and axle spacing for each overweight commodity permit. ESALs and ESAL-miles were calculated for each permit record using the algorithm defined in the INDOT Emergency Rules and used by INDOR in approving permit requests. Table 4.1 outlines the total number of ESALs, the number of ESALs above 2.40, and the number of ESALs above 2.40 multiplied by the miles of travel, summed for all overweight commodity permits each month. The increasing number of ESAL-miles (above 2.40 ESALs) each month correspond to more activity in the summer months compared to winter months of January and February.

Table 4.1 ESALs and ESAL-miles of travel for Overweight Commodity Permits, January to June 2014

Month	**Total ESALs**	**ESALs Above 2.40**	**ESAL-miles (above 2.40 ESALs)**
January	38,624	25,968	3,529,437
February	37,290	26,164	3,803,633
March	42,816	28,947	4,110,938
April	45,815	31,354	4,437,441
May	44,713	30,436	4,321,203
June	46,564	32,196	4,452,933
Total	255,822	175,065	24,655,586

Based on the total number of ESAL-miles in the first six months of 2014, shown in Table 4.1, a suggested initial quota is 48,000,000 total ESAL-miles which is equal to

96,000 blocks of 500 ESAL-miles each. In Chapter 2, an initial annual demand of 35,000,000 ESAL-miles was used to perform the multiobjective optimization. This is much lower than the actual demand seen in the overweight commodity permits obtained in 2014—approximately 24,000,000 ESAL-miles in the first six months alone. However, in the multiobjective optimization, the initial demand did not include the demand that would result from increased total logistics cost savings. The initial supply set by INDOT for the auction mechanism should not equal the initial demand used in the multiobjective optimization because many companies will be attracted to the permits by the additional cost savings that can be achieved by operating overweight vehicles.

4.3.1.3 Auction Parameters: Frequency and Minimum Bid Price

INDOT also must set the other auction parameters. For demonstration purposes, it is assumed INDOT will hold auctions once each month. Therefore, the total annual quota is achieved by auctioning 8,000 blocks each month. If in a given month, all of the 8,000 blocks are not allocated during the auction, the remainder roll over to the following month. The initial minimum bid price can be set at $35 per block, which is equal to the product of $0.07 per ESAL-mile (the HEA-1481 fee) and 500 ESAL-miles (the block size). Initially, INDOT can expect to collect a total revenue corresponding to the minimum bid on each block, or $3.36 million; over time, however, the expected increase in demand for overweight vehicle permits will result in increasing revenue per block. The quota ensures that the increase in demand does not also result in huge increases in consumption. Instead controlled increases in allowable consumption are offset by auction revenues.

As previously discussed, INDOT can continue to offer multi-trip annual permits for individuals who configure and load their vehicles to 2.40 ESALs or less. Table 4.2 presents the number and percentage of overweight commodity permits that were eligible for annual, multi-trip permits between January and June 2014. The percentage of permits for vehicles configured and loaded to 2.40 ESALs or fewer is very small, less than 3% in all months and typically hovering around 2%. As a result, most trucking companies who wish to transport overweight divisible loads would be required to participate in the auction. Over time, the auction and incentives are expected to collectively encourage adoption of infrastructure-friendly vehicles at a faster rate compared to the incentives alone.

Table 4.2 Overweight Commodity Permits for Vehicles at or Below 2.40 ESALs

Month	**Permits under 2.40 ESALs**	**Total Number of Permits**	**% Multi-trip**
January	55	5,283	1.04%
February	94	4,648	2.02%
March	108	5,791	1.86%
April	74	6,033	1.23%
May	158	5,967	2.65%
June	128	5,999	2.13%
Total	617	33,721	1.83%

4.3.2 Carriers' Utility of Operating Overweight

The original HEA-1481 survey and the follow-up survey contained questions aimed at eliciting the value individual carriers place on ESAL-miles of travel. This information is important because the permit price depends on the amount that carriers will bid in the overweight permit auction, which depends on their valuation of acquiring permits to operate overweight. Each carrier's valuation is a measure of how much utility each will derive from using overweight vehicles compared to non-overweight vehicles.

The self-reported valuation questions were set up similar to the auction framework but did not specifically mention an auction mechanism (to prevent bias from carriers).

The hypothetical auction scenario was phrased as follows:

> "Suppose INDOT plans to offer permits for a limited number of blocks of 500 ESAL-miles for carrying overweight divisible loads over 2.4 ESAL. Your company could use the block(s) you purchase in any combination so that the total number of ESAL-miles used does not exceed the number of blocks multiplied by 500 ESAL-miles—for example, you could choose to lower the ESAL-value of your vehicles or travel fewer miles as appropriate to maximize your use of the purchased block(s). The first 2.4 ESAL for any vehicle is not counted toward using your block."

The scenario outlines the salient points of the auction for eliciting bid-type responses: the limited number of blocks, the 500 ESAL-miles of usage associated with each block, and the 2.40 ESAL mile credit for all vehicles.

Following the scenario description, survey participants were asked to estimate the total number of 500 ESAL-mile blocks their company would be likely to request and the total amount of money their company would be likely to pay for those blocks. As with the willingness to pay analysis, participants were also asked to indicate their certainty (for both the number of blocks and the total amount of money) using a scale from 1-very uncertain to 5-very certain (similar to the question in Figure 3.3). The number of blocks, multiplied by 500 ESAL-miles, and the total amount were used to estimate a self-reported value in $/ESAL-mile that each respondent placed on overweight vehicle permits.

4.3.2.1 Value per ESAL-mile of Travel

Figure 4.1 depicts a histogram of the $/ESAL-mile from all 31 participants who included both a number of blocks and an amount of money for those blocks. Over half of the self-reported values were between $0.00 and $0.02 per ESAL-mile. Of those, nine bids were less than or equal to the current $0.07 per ESAL-mile charged for overweight commodity permits.

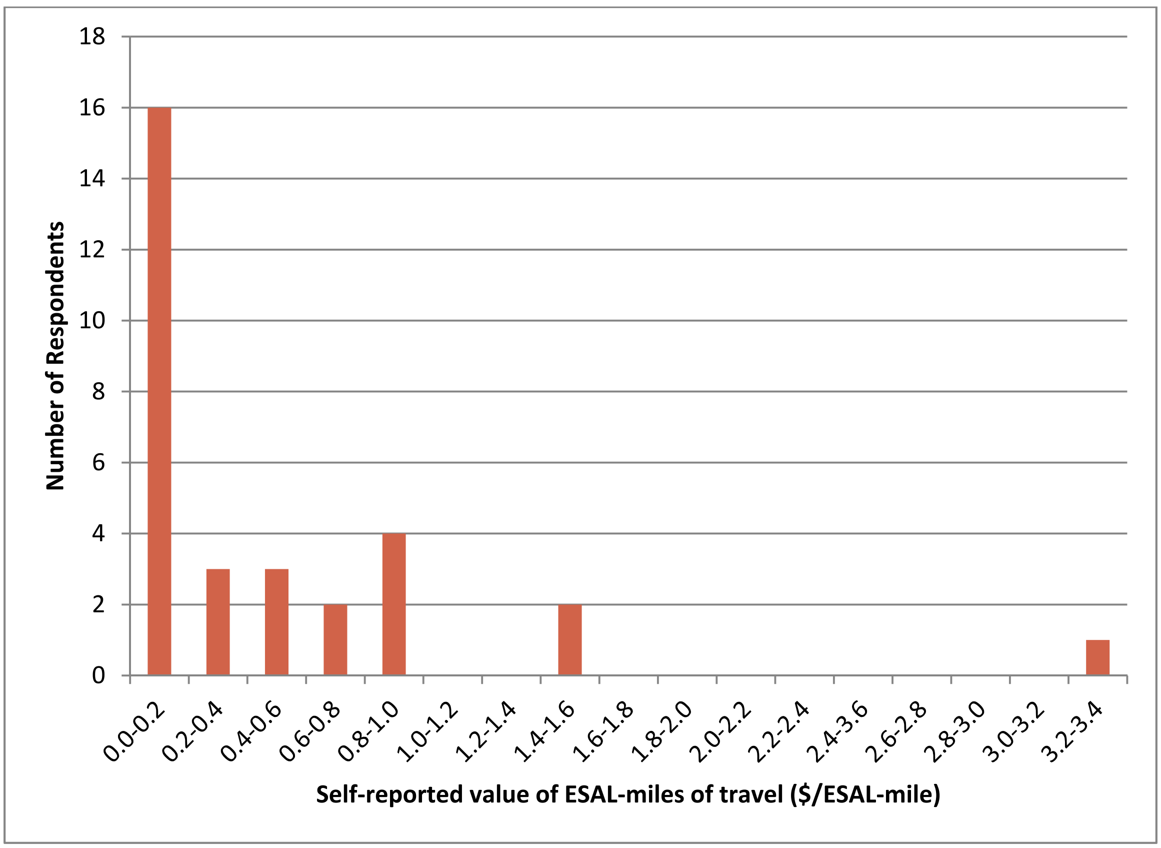

Figure 4.1 Distribution of Self-reported Valuation of Permitted ESAL-miles of Travel

4.3.2.2 Certainty of Self-reported Values

Table 4.3 outlines the descriptive statistics of the corrected and certainty calibrated responses to the two auction scenario questions. Similar to the willingness to pay analysis, individuals who indicated less than "4 certain" on the certainty scale question were assumed to present hypothetical bias. Instead of recoding these data, as was done with the willingness to pay analysis, these observations were removed from the valuation analysis to estimate calibrated values.

Table 4.3 Descriptive Statistics for Auction Scenario Questions

Variable	**Average**	**Std. Dev.**	**Min.**	**Max.**	**No. of Responses**
Uncorrected					
How many 500 ESAL-mile blocks would you purchase?	317.81	1218.12	0	8600	59
How much are you willing to pay for these blocks?	$8,507.75	$24,709.80	$0.00	$156,000.00	52
Certainty calibrated					
How many 500 ESAL-mile blocks would you purchase?	356.96	811.87	0	3120	22
How much are you willing to pay for these blocks?	$11,488.10	$31,708.90	$0.00	$156,000.00	27
Uncorrected					
Value of ESAL-mile	$0.49	$0.69	$0.00	$3.33	31
Certainty calibrated					
Values of ESAL-mile	$0.49	$1.08	$0.00	$3.33	9

Table 4.3 indicates that approximately half of the individuals who answered each question were certain about their responses. Additionally, while 31 participants answered both auction questions, only 9 were certain about both the number of blocks their company would request and the amount of money their company would be willing to pay

for those blocks. Although the average did not change, the certainty calibration resulted in a larger standard deviation because the number of responses is fewer.

4.3.3 Equilibrium Auction Price as a Proxy for Market Value

Auctions are used to allocate items when the value of the good is unknown—if the value is known for certain, the seller will provide the good at the highest known price (Krishna, 2010). If INDOT knows for certain the value individual trucking companies place on ESAL-miles of travel, INDOT can sell permits at the highest price which maintains economic competitiveness with other states to maximize revenues to maintain deteriorating highway infrastructure. Unfortunately, the value individual companies place on ESAL-miles of travel for overweight divisible loads is not known. In the above discussion, even among survey participants, only 9 of the 84 total survey participants—or approximately ten percent—were certain of both the number of ESAL-mile blocks their company would request and the amount of money their company would pay. The permit prices in Texas for 4,000 lbs of additional GVW are low enough that trucking companies were almost unilaterally willing to purchase permits—the Texas permits are most likely underpriced because TxDOT did not know the true value of permits to permit holders (Murphy et al., 2012).

Given sufficient data, game theory can be used to estimate the market clearing price of permits in the auction based on the bids of individual carriers and the auction parameters, including the number of blocks being auctioned and the minimum bid. In the quota context, the game is the auction and each participating carrier is a different player. Each carrier places a bid to maximize the company's utility based on the private value of

ESAL-miles of travel for overweight operations. Unfortunately, the nine responses from carriers who were certain of their choices is insufficient to estimate bid vectors for potential participants. If sufficient data could be collected, bids could be estimated for a each of a number of players based on demographic characteristics; then based on those bids, the winners could be identified and the amount of permit revenues collected through the auction could be determined.

In the absence of such data, the following section details the equilibrium bidding behavior for various auction formats. Auction equilibrium bidding behavior can reveal some information about the value bidders place on auctioned items, depending on the auction format.

4.3.4 Equilibrium Bidding Behavior

In auction research, *private values* refer to the known value an individual bidder places on having an object himself, regardless of the values of other bidders (Levin, 2004; Ausubel, 2008; Krishna, 2010). In contrast, *interdependent values* are based on the individual's own information as well as the value of other bidders (Ausubel, 2008). Interdependence is not used in auction literature in the same manner as in statistical analysis. Values can be interdependent in terms of auction research, but statistically independent; they can also be private as previously defined but statistically correlated (Krishna, 2010). In the overweight vehicle permit auction framework, individual trucking companies have private values for ESAL-mile blocks of travel. Although the companies may not know with absolute certainty the value of a block for their operations, the value is not likely to be influenced by information from other bidders, in this case, competing trucking companies.

The private value assumption is necessary to make conclusions about equilibrium bidding behavior. There are different dominant equilibrium bidding strategies for private value goods depending on whether a single unit is auctioned or multiple units and on the auction format.

4.3.4.1 Single-Unit Auctions

Single-unit auctions are important for the present consideration of auctions of multiple overweight ESAL-mile blocks because the bidding behavior for multiple-unit auctions are abstractions of the behavior for single-unit auctions.

The two primary auction formats for single items are first-price and second-price. The highest bidder pays his or her bid in a first-price auction. In a second-price auction, the highest bidder receives the item, but only pays the price of the second-highest bid (Levin, 2004; Ausubel, 2008; Krishna, 2010). The dominant strategy for second-price auctions for a single unit is to bid truthfully, or for each bidder to submit a bid equal to his or her private value. This auction has also been cited as a Vickrey auction (Levin, 2004), although for purposes of this research, Vickrey auctions will only refer to a specific format for multiple-unit auctions. In a first-price auction, the dominant strategy is to bid slightly lower than the actual private value to maximize an individual's utility—if the bidder pays the full value, he has zero change in utility because he received the value of the good but paid the full cost (Levin, 2004).

4.3.4.2 Multiple-Unit Sealed-Bid Auctions

Properties of first-price and second-price auction formats can be extended to sealed-bid auctions for multiple units. In multiple-unit auctions, participants submit bids for more than one from a collection of homogeneous or complementary goods. When every participant desires exactly one unit, the auction simplifies to a single-unit auction. In the case of overweight vehicle permits, the blocks of ESAL-miles are perfectly homogenous goods. In all multiple-unit auctions, it is assumed that bidders have a nonincreasing bid vector describing the amount he or she is willing to pay for each additional unit of goods. Figure 4.2 depicts a set of possible bid vectors from three participants in a hypothetical auction. All of the bid vectors are nonincreasing, but for Bidder 2, the marginal value for each unit up to four units is constant. As shown in the sample bid vector diagram, not all of the participants need to bid for the same number of goods.

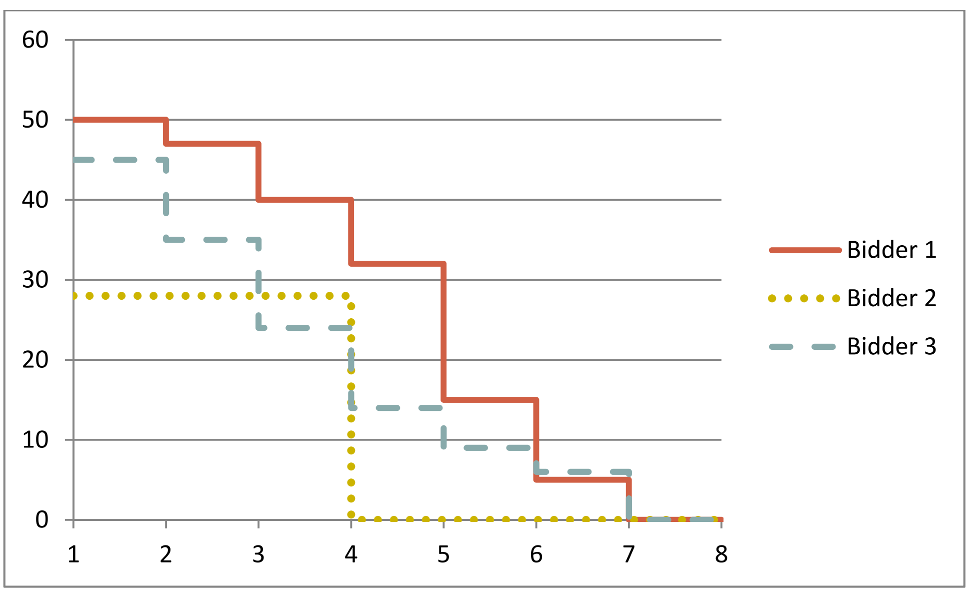

Figure 4.2 Sample Bid Vectors for Three Participants

Three sealed-bid multiple-unit auction format extensions include the discriminatory, uniform-price, and Vickrey auctions. In each of these auctions, the n items are allocated to the individual(s) who submitted the n highest bids in order, but the price each winner must pay for his or her items is different. These auctions are all called *standard auctions* and multiple bidders can win multiple items in each but are not guaranteed to receive the total number of items for which they submitted bids (Krishna, 2010). There are other forms of allocation which are not considered here (see the discussion of Pickl and Wirl's 2011 work on pipeline capacity auctions in Section 4.1.2 for alternative allocation methods).

4.3.4.3 Discriminatory Auctions

The discriminatory auction is a direct extension of the first-price single-unit auction. In a discriminatory auction, each bidder pays his or her bid price for each individual unit. Although Shanghai has implemented some additional aspects with two rounds of bidding, in essence, the Shanghai PCLP auction is discriminatory but has open bidding.

4.3.4.4 Uniform-price Auctions

The uniform-price and Vickrey auction formats are extensions of the second-price single-unit auction. The uniform-price is an intuitive extension of the second-price auction. The Singapore VQS is an example of a uniform-price auction with open bidding. In a uniform-price auction, the n items are allocated to the n highest bids but at a price that is between the nth highest bid and the $(n+1)$th highest bid. Any price between those bids will ensure that the demand supplied is equal to the number of items auctioned.

In practice, the highest losing bid is often used as the price and is referred to as the *market clearing price*. Although this appears similar to the second-price single-unit auction, the dominant strategy is not the same.

4.3.4.5 Vickrey Auctions

The Vickrey auction is the direct extension of the second-price auction which maintains the dominant strategy of truthful bidding. In a multiple-unit Vickrey auction, the price each winner pays is equal to the opportunity cost for each item that would have gone to another bidder (Ausubel, 2008). The opportunity cost is the alternative value of having other bidders win those units. In other words, the winner pays for the externality he or she caused for other bidders (Krishna, 2010). In practice, the bidder pays the amount that the other bidders would have paid had the winning bidder not been present; this calculation is completed for each bidder (Krishna, 2010).

4.3.4.6 Dominant Strategies and Efficiency

The Vickrey multiple unit auction is not widely used, even though the dominant strategy for Vickrey auctions is efficient while the equilibrium bidding strategies of other auction formats are not (Krishna, 2010). Vickrey multiple unit auctions are efficient because the dominant strategy for each participant is to bid truthfully and given truthful bids, the objects always go to those who value them the most. The same is true for second-price single-unit auctions. In contrast, the dominant strategy for uniform-price multiple-unit auctions is to bid truthfully for the first unit but to shade bids for successive units (Ausubel, 2008; Krishna, 2010). Figure 4.3 depicts the lower bids a participant might submit for the second through sixth units which are lower than the individual's actual private value.

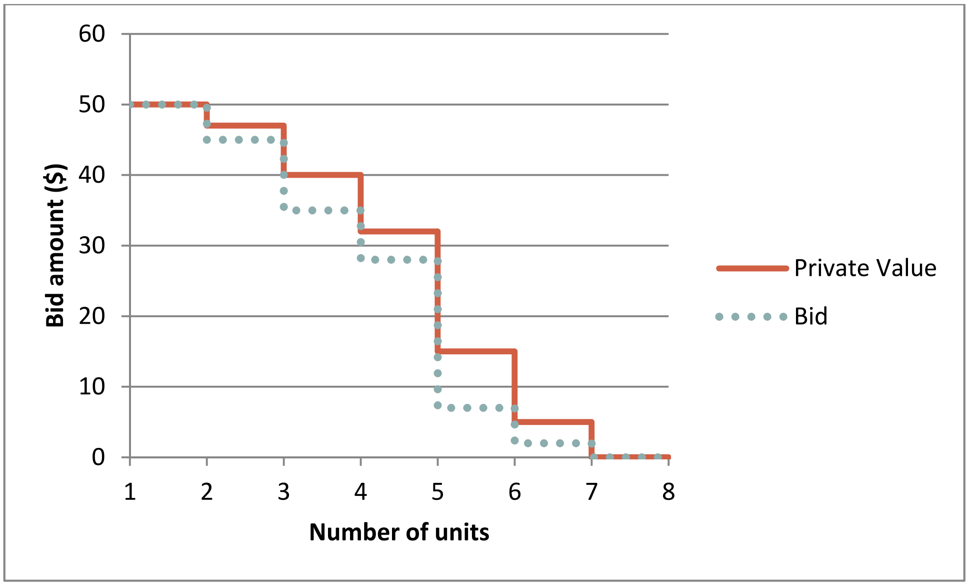

Figure 4.3 Example of Bid Shading in Uniform-Price Auction

The bid vector depicted in Figure 4.3 is an example of dominant auction strategy for the bidder in a uniform-price auction because the truthful bid for the first unit determines whether the bidder will receive any units while all successive bids determine the price he or she pays for any units won. If the bidder's first truthful bid sets the market clearing price, i.e., is the highest losing bid, the bidder does not receive an item but would also not have a reason to increase his or her bid above the private value. If the bidder does win at least one item, his or her other bids influence the market clearing price. For example, if one of the bidder's successive bids, i.e., any value in the bid vector except for the bid for the first unit, sets the market clearing price, he or she could have bid a lower amount for that successive bid and reduced the total price for both him or herself and all other individuals who won an item. Bid shading, as depicted in Figure 4.3, is inefficient because some individuals shade more than others; therefore, items are not always allocated to the participants who most value them. Vickrey multiple-unit auctions are the only efficient type of multiple-unit standard sealed-bid auction.

4.3.4.7 Multiple Unit Open-Bid Auctions

Until now, the discussion has focused on sealed-bid auction formats. The assumption of private values is important because when bidders have private values, in contrast to interdependent values, the dominant equilibrium bidding behavior is the same for open- and sealed-bid auction formats (Krishna, 2010). Filiz-Ozbay et al. (2014) demonstrated that the equilibrium bidding behavior is less efficient for uniform-price auctions when the private values assumption does not hold. Specifically, there are three open-bid auction formats that directly correspond to sealed-bid formats when the private values assumption is true. These three formats are considered for use in overweight vehicle quota auctions.

4.3.4.8 Dutch Auctions

Dutch auctions, where the auctioneer begins at a high price and incrementally decreases the bid amount until each item is claimed, are equivalent to discriminatory sealed bid multiple unit auctions for private values. When the values are interdependent, the claim price of one bidder may influence another bidder's value of the item.

4.3.4.9 <u>English Auctions</u>

English auctions have the same dominant bidding strategy as sealed-bid uniform-price auctions. In English auctions, similar to the format used in Singapore, the price is gradually increased until the number of units demanded above the market clearing price is equal to the number of items supplied. Again, the formats have the same equilibrium with private values but information gleaned during the auction may alter bidder's valuation when the values are interdependent. The open English auction is superior to the sealed-bid uniform-price auction because of subtle differences in bid shading behavior (Kagel & Levin, 2008). In actual practice, Chu (2011; 2012) found that the open-bid format for Singapore's VQS is more efficient than the sealed-bid format used from 1990 until 2001.

4.3.4.10 <u>Ausubel Ascending Price Auctions</u>

Ausubel ascending price auctions are equivalent to Vickrey multiple-unit auctions for private value items. In the Ausubel ascending price auction format, bids are collected similar to the English open auction format, but the pricing structure is similar to the externality costs used in the Vickrey sealed-bid multiple-unit auction (Krishna, 2010).

4.3.5 Desirable Bidding Behavior

As shown in the preceding sections, the auction format affects equilibrium bidding behavior which influences both the efficiency of the auction and the amount of revenue that can be collected. In the case of overweight vehicle permit auctions in Indiana, INDOT should use the open English auction format, similar to that employed in the Singapore VQS. Although the equilibrium bidding behavior is not as efficient as in the Ausubel or Vickrey auctions, the results are likely more transparent and understandable to trucking companies participating in the auction. An open English format is recommended over a uniform-price format due to indications that the open-bid format is more efficient than the sealed-bid format. Additionally, in the open system, bidders are provided with information which likely decreases the occurrence of collusion among parties. It is difficult for trucking companies to collude to keep prices low if all bidders are provided full information about the market clearing price, and therefore the claims of other participants. In the sealed-bid format, INDOT would have to address potential collusion among bidders.

Bid vectors from the companies would likely take one of two forms. They would either submit bids of constant marginal value for all of the ESAL-mile blocks they are likely to request; or, submit decreasing bids where the bids for the first (or first few) units is close to the private value and successive bids are shaded. The participating trucking companies do not necessarily need to all use one form or the other (constant marginal value versus decreasing); there may be a mix of both. In either case, the highest marginal value is likely to be equal to the self-reported $/ESAL-mile value collected in the HEA-1481 and follow-up surveys.

Future research should consider the likely bidding behavior of participating trucking companies using private values. At present, the trucking companies are not certain of their valuation, as discussed in Section 4.3.2.2. In addition to constructing bid vectors, using the valuation method employed in the HEA-1481 survey or by soliciting bid vectors from trucking companies, the willingness to pay for investment in infrastructure-friendly vehicles can be used as a proxy variable. The typical trip VMT, the typical number of trips in a year, and the dollar amount of investment could be used to calculate an approximate annual amount that the trucking companies would spend to avoid the cost of permit acquisition. Based on the assumption that companies would spend the lesser amount of money—either the amount necessary to invest in infrastructure-friendly vehicles or the cost of acquiring permits in the auction—the total bid amount for all blocks would be equal to the willingness to pay for investment. The total amount a company is willing to pay for ESAL-mile blocks and the willingness to pay for investment can be altered similarly to construct bid vectors of either constant marginal value or decreasing values for each company.

4.3.6 INDOT Auction Synopsis

The previous sections provided rationales for the auction framework, including some parameter values, for overweight divisible load permits in Indiana. The state would supply approximately 8,000 permits, each for 500 ESAL-miles of travel, through monthly open English auctions. During each auction, the participating truck companies would bid on the number of ESAL-blocks they desired. The minimum bid, set by INDOT, would start at $35 per 500 ESAL-mile block, equivalent to $0.07 per ESAL-mile. At the same time, all companies would have the option of using infrastructure-friendly vehicles to acquire permits for $20 for each vehicle and route annually. The market clearing price of the auctioned permits would provide an indication to INDOT the actual value that trucking companies place on having overweight divisible load permits (although the clearing price would be somewhat less than true private value due to the inefficiency of the dominant bidding strategy). The auction would also allow INDOT to exercise direct control over the extent of infrastructure usage through the supply provided.

4.4 Auction Implementation Considerations

In addition to the topics explored in the case study (quota, minimum bids, and auction format), the highway agency administering the auction will need to consider a number of issues prior to implementation.

4.4.1 Sealed vs. Open Bids

The first issue to address is whether to use sealed or open bids. In 1990 when the VQS was first introduced, the Singapore Land Transport Authority solicited sealed bids. The auction system was changed to open-bids in July 2001. Chu (2011) found that switching from the sealed- to open-bid system reduced the COE premium by approximately 16%. One caveat of Chu's (2011) findings was that although the market price for COEs was lower under open bids, the system favored late action bidding where bidders would not increase bids to the amount they were actually willing to pay (or enter a bid at all) until the final moments of the auction. The city of Shanghai similarly switched to an open-bid system in January 2008. Song and Zhou (2010) found that the switch to open bids in Shanghai also resulted in a reduction in the average price of license plates.

4.4.2 Secondary Trading Markets

The second consideration is whether to use a bid-only system or allow a secondary trading market, which would work similar to the trading market in cap and trade allocation. The bid-only system is easier to implement because no additional market needs to be created and monitored; however, those persons priced out of permits for overweight vehicles must identify other forms of transportation. As noted previously, this would be easier if the permit auction program was used only for divisible loads because those priced out can still use non-overweight vehicles. This would be a salient consideration if overweight non-divisible load permits were included in the auction.

4.4.3 Effects on "Winners" and "Losers"

In addition to generating additional revenue for the transportation agency, the auction mechanism has unique consequences for auction winners and losers compared to other overweight vehicle permitting alternatives. Obviously, those who are priced out of permits via the auction mechanism must continue to move their goods using non-overweight vehicles. In the other options considered in this study, no individuals are priced out.

For the auction winners, there are added benefits in addition to the operating cost savings. In a quota system, the market is necessarily closed to all parties except for the auction winners. Although this could create a monopoly, it also protects the operations of the auction winners. The companies that are allocated usage blocks will be able to offer overweight vehicle permitting to shippers when others cannot. This can provide an incentive to participate in the auction.

Additionally, there may be concerns that larger, or “richer,” companies are better able to absorb the cost of permits in the auction system and would therefore prevent smaller companies from winning permits through the auction (through higher bids). Agencies may consider having stratified auctions, possibly for different industries, to promote social welfare among those participating in the auction. In the context of Indiana, this may warrant having separate overweight divisible load permit auctions for haulers of steel and agricultural commodities.

4.4.4 Enforcement

Enforcement efforts for overweight divisible loads are likely to be simplified using a quota system, regardless of allocation. The current overweight commodity permits issued in Indiana are valid for a single trip. In Indiana, drivers of overweight vehicles stopped by the Indiana State Police (ISP) must produce a valid permit. Some companies choose to operate outside of the law and illegally use a single-trip permit to make multiple trips. There is currently no way to prevent this illegal behavior. Under a proposed quota, individual trips do not need to be permitted. Individuals who are allocated usage under the quota will have the permit until their usage is spent. Trucking companies have already adopted GPS technologies and keep detailed records about the extent of travel for registration and fuel tax purposes. ISP, or other enforcement agencies, would only need to determine if the driver holds a valid overweight permit.

4.4.5 Dedicated Source of Revenue

Finally, transportation agencies must consider the appropriate use of additional revenues collected via the auction compared to other allocation mechanisms. The most transparent and equitable method is to create a dedicated fund for improvements to those facilities that are most frequently used by overweight vehicles. Additional revenues can reduce the current gap between consumption and revenues that has resulted from traditional overweight vehicle permitting. Increased funding for infrastructure improvements and maintenance on the routes used most often offsets additional deterioration of highway infrastructure due to overweight loading. The improved conditions will also benefit trucking companies through lower vehicle operation costs. In the extreme, if additional revenues collected via the auction are invested in bridge improvements which raise the load carrying capacity of bridges across the state, overweight vehicles may be able to use bridges which previously did not have the load carrying capacity for the higher vehicle loads but which result in shorter trip distances, improving the overall efficiency of the system.

4.5 Chapter Summary

This chapter provided a theoretical framework for using an overweight vehicle quota with auction allocation to limit the amount of infrastructure consumption allowable from overweight vehicle travel. Quotas have been used in other contexts to limit travel demand but have not been used explicitly to limit consumption of highway assets from overweight vehicles. Auctions have also been used to allocate pipe and rail capacity.

Using knowledge gained from previous applications of quotas and auctions, an auction mechanism to allocate overweight divisible load permits was developed. The auction mechanism is most practical for overweight divisible loads because trucking companies have options to transport goods via another mode or using vehicles that comply with state and federal limits; the same is not always true for overweight non-divisible goods.

In the quota and auction framework, the state agency determines the supply of highway asset consumption which can be used by overweight vehicles—this is the quota. Then participating trucking companies bid for permits for defined amounts of consumption. High bidders claim permits for usage while low bidders must operate non-overweight vehicles.

Sample auction parameters were determined for Indiana. The usage measure was defined to be blocks worth 500 ESAL-miles of travel each. ESAL-miles were used in accordance with the existing overweight commodity permits and the 2.40 ESAL value used to define infrastructure-friendly vehicles. Future research should consider alternative usage measures which reflect bridge consumption. Although the revenues from the auction can offset some of the consumption of bridge assets, ESAL-miles are a measure of pavement consumption and do not accurately account for the bending moments overweight vehicle impose on bridges.

Based on overweight commodity permit purchases in the first two quarters of 2014, the initial quota was determined to be 8,000 blocks of 500 ESAL-miles each month, for a total of 96,000 blocks annually or 46,000,000 ESAL-miles of travel. The recommended auction format is the open English auction.

Survey responses were used to determine preliminary estimates of the valuation individual carriers place on ESAL-miles of travel using overweight vehicles. This information would indicate the market clearing price for auctions. Presently, individual carriers are uncertain about the private values they place on overweight vehicle permits. Future research should establish the private values carriers have for overweight vehicle permits to simulate an auction to determine the market clearing price.

The two primary benefits of implementing a quota and auction system for overweight vehicle permits are additional information about the value trucking companies place on overweight divisible loads and the direct control the transportation agency has over infrastructure consumption. Information about the market clearing price could be used to better price all oversize and overweight permits; currently, state agencies do not know the actual maximum amount carriers would be willing to pay. Controlling the amount of allowable infrastructure consumption is also important in light of limited budgets. When traditional permitting mechanisms and infrastructure-friendly vehicles initiatives fail to protect deteriorating infrastructure from additional loadings, quota policies can enforce the ceiling on the repeated loads that the infrastructure can sustain.

CHAPTER 5. REGIONAL AND NATIONAL HARMONIZATION TO INCREASE EFFICIENCY

5.1 Introduction

The previous chapters explored various alternatives for overweight vehicle permitting. Aside from explicit permit structures, regional or national harmonization of TS&W limits and/or overweight permitting practices can also provide efficiency and economic competitiveness benefits.

As mentioned in Chapter 1, TS&W limits and oversize/overweight permitting practices in the United States have changed over time in a fragmented manner because each individual state agency has exercised grandfather rights separately to balance the competing needs of infrastructure preservation, safety and mobility, and economic development concerns specific to its particular circumstances or industries. This has resulted in both size and weight differences as well as differences in permitted oversize/overweight operations.

Inconsistent TS&W limits and overweight permitting practices among the 50 United States results in inefficient operations for any vehicles moving between multiple jurisdictions. Carriers who operate in jurisdictions with multiple different TS&W limits and overweight permit structures must make one of three choices: 1) maintain separate fleets which meet the operational requirements of each jurisdiction, 2) choose the "lowest common denominator" vehicles that meet the requirements of all jurisdictions simultaneously, or 3) operate in other jurisdictions which do not have conflicting regulations.

In the first case, the carriers face several additional costs. Most obviously, there are the capital costs associated with purchasing and maintaining separate vehicle fleets. In addition, there are time and labor costs associated with breaking down the load and transferring in onto other vehicles at the jurisdiction boundaries. Related to this consideration, carriers must have access to facilities where the breakdown can take place. Either the state or local agency must provide these facilities or private entities, the carriers or another group, can finance for these facilities.

In the second case, carriers forfeit the efficiencies of longer lengths, higher gross vehicle weights, or higher axle weights in more permissive jurisdictions. Typically longer or heavier vehicles (depending on whether the goods cube-out or weigh-out) result in more payload per trip. Additional trips are necessary to move the same amount of goods using the vehicle configuration appropriate for the most restrictive jurisdiction.

Finally, some but not all carriers may choose to relocate their business or alter their routes to avoid more restrictive jurisdictions. In some instances, this may not be practical or even possible depending on the location of the origins and destinations. For example, vehicles originating in Florida must travel through Georgia or Alabama to reach any other state by truck; those in Michigan must choose between Indiana, Ohio, and Wisconsin, go through Canada, or make use of waterways to reach other states. This possibility of TS&W limits and oversize/overweight regulations acting as a barrier to trade was explicitly recognized in the 1982 STAA when the federal TS&W limits were applied as *minimums* in addition to maximums for the National Network. The National

Network includes the Interstate System and other federal-aid highways critical to the trucking industry. This aspect of the 1982 STAA was a direct response to several states in the Mississippi valley that imposed lower TS&W limits than the federal TS&W limits.

The 1982 STAA was the first United States surface transportation authorization legislation to both define a transportation network (the National Network) critical for interstate freight movements and recognize the importance of effectively harmonized limits on that network so that select vehicle configurations could travel anywhere on that critical network. The limits are effectively harmonized because there are not any single states or small groups of states that significantly impede interstate freight truck movement though TS&W limits lower than the federal limits; but they are not truly harmonized because nearly every state allows its own overweight loads above the federal limits. Since 1982, various surface transportation authorization laws have established alternative networks including the Primary System, the NHS, and the Strategic Highway Network, among others. The federal TS&W limits apply to each of these federally-funded roadway networks.

5.2 Truck Size and Weight Limits Harmonization Experiences

Regional or national harmonization of TS&W limits and overweight vehicle permitting practices is not a new concept. It simply has not been applied successfully in the United States, although there have been advances internationally.

5.2.1 Attempt by the Western Governors' Association

In conjunction with the USDOT Comprehensive TS&W Limits Study in 2000, the Western Governors' Association (WGA) requested that the authors apply the same framework used in the comprehensive study to an additional scenario identified as the "Western Uniformity Scenario" to harmonize TS&W dimensions for LCVs operating in western states (USDOT, 2004). The final report was intended to complement the Comprehensive TS&W Limits Study report. The ideal of harmonized LCV size and weight dimensions among eligible states in the Western Association of State highway and Transportation Officials (WASHTO) has not been achieved.

The proposed Western Uniformity Scenario included lifting the LCV freeze and harmonizing weights among the thirteen Western states using LCVs through grandfather rights. The proposed scenario assumed that federal axle weights, the Federal Bridge Formula B, and a maximum GVW of 129,000 lbs would apply to two different LCV twin-trailer configurations. One of the two configurations was consistent with a twin trailer with 45-foot trailers included in the WASHTO *Guide for Uniform Laws and Regulations Governing Truck Size and Weight Among the WASHTO States* in effect at that time. The WASHTO (2009) guide is a "living document" published since 1990 aimed at "promoting uniform laws, regulations, and practices" among the WASHTO states. The second configuration included in the Western Uniformity Scenario was a longer twin trailer combination with 48-foot trailers specifically requested by the WGA.

The USDOT (2004) determined that individual states would vary in their use of increased flexibility in setting TS&W limits allowed through adoption of the Western Uniformity Scenario. Some states would immediately increase state TS&W limits to those included in the analysis, some would change some but not all of their existing state TS&W limits, and some might not change state TS&W limits. Although the goal was to promote uniformity, USDOT (2004) concluded that uniformity would not necessarily be achieved via the proposed Western Uniformity Scenario.

The USDOT also addressed TRB recommendations for a systematic process to optimize TS&W policy in the Western Uniformity Scenario report. TRB *Special Report 267* advocated for federal oversight of a national permit program including quantitative analysis of the impacts of permitted vehicles above the federal TS&W limits (TRB, 2002). In the Western Uniformity Scenario report, the USDOT (2004) stated that it "does not favor change in federal truck size and weight policy" on the grounds that there was not sufficient State support for changes to federal policy or the TRB recommendations.

At the same time, the USDOT (2004) indicated that it also does not support the current fragmented approach via grandfather rights for the following reasons:

- "It makes enforcement and compliance with truck size and weight laws more difficult
- It often contributes little to overall productivity
- It may have unintended consequences for safety and highway infrastructure
- And it reduces the willingness to work for more comprehensive solutions that would have much greater benefits."

Based on limited political support from the relevant states, the USDOT recommended against the Western Uniformity Scenario because it could result in further polarization between the states that would adopt the uniform TS&W limits and those that would not.

Furthermore, although the continuing goal of the WASHTO Guide is to promote uniformity among member states, harmonization has not been achieved to date. The authors of the guide itself include a note that individual states who participate reserve their rights to make exceptions to the recommendations included in the guide. Similar to the federal TS&W limits, but more permissive in terms of higher GVWs and vehicle lengths, the Guide seeks to establish minimum standards which apply to the Interstates and National Network in each of the states to facilitate interstate freight movement, particularly using LCVs (WASHTO, 2009).

5.2.2 International Harmonization Efforts

Internationally, there have been several efforts at harmonization within and among nations with varying levels of success. Canada is typically considered the premier example of both harmonization and performance-based consideration of TS&W limits (Fekpe et al., 2006; Mercier, 2007; Woodrooffe et al., 2011; Reimer et al., 2014). Australia and New Zealand have also applied performance-based decision making to their TS&W limits; however, they have not achieved complete harmonization (Fekpe et al., 2006). The member nations of the European Union (EU) have also demonstrated some success at multi-national TS&W harmonization (Walton, et al., 2010). In contrast, the three NAFTA nations (United States, Canada, and Mexico) have not been able to achieve harmonization (Mercier, 2007).

5.2.2.1 Canada

Similar to the United States, TS&W regulations in Canada are under the jurisdiction of the ten provinces and three territories; however, unlike the United States, the Canadian provinces and territories established national agreement on select TS&W

limits in 1988. Woodrooffe et al. (2011) provide an extensive history of the creation of the "Federal-Provincial-Territorial Memorandum of Understanding on Interprovincial Weights and Dimensions" (also called the MOU) and its five amendments.

The Canadian approach to developing the MOU was a "performance-based" systematic method to identify and test model vehicles for both productivity improvements (compared to existing vehicles) and performance criteria related to safety, mobility, and infrastructure damage. Vehicles that are more productive are only approved if they demonstrate better performance than the less productive vehicles they would replace (Fekpe et al., 2006).

Canada's performance-based approach is contrasted against the "prescriptive" approach. In the United States, prescriptive TS&W limits outline the height, width, and length of vehicles, the GVW, and maximum axle or axle group weights. As long as a vehicle is within the prescriptive limits, it is a legal vehicle. Unfortunately, many different configurations meet both the federal and individual state TS&W limits but handle differently and consume more or less of the common highway infrastructure assets. The performance-based approach defines more specifically the various vehicle configurations that can operate including the dimensions, the performance thresholds vehicles must meet, the types of connections that can be used, axle weights and spacings, etc. The MOU vehicles are defined specifically by the aspects of vehicle configuration that affect the dynamic handling of the vehicle—whether or not the vehicle meets performance standards.

5.2.2.2 Australia and New Zealand

Australia and New Zealand have also applied performance-based approaches to TS&W regulations. Walton et al. (2010) outlined the history of TS&W regulation in Australia in the appendices of their 2011 report on LCV use in Texas, with a particular emphasis on Australian road train regulations. Road trains are multi-trailer units, typically much longer than LCVs seen in the United States and elsewhere. The Australian performance based framework was established in 1999 and allows vehicles that meet each of 16 performance standards to exceed prescriptive TS&W limits. Unfortunately, harmonization has not been fully achieved in Australia (Walton, et al., 2010), possibly due to the combination of both prescriptive and performance-based approaches. The Australian performance-based system is a national program separate from individual state and territory permitting systems. It does not replace those systems but is offered as an alternative to those systems. New Zealand has focused more on safety gains rather than productivity improvements in its performance-based system but tends to follow the TS&W approaches implemented in Australia (Fekpe et al., 2006). In both Australia and New Zealand, the performance-based systems indicate which networks, or functional road classes, and locations the approved vehicles can operate over.

5.2.2.3 North American Free Trade Agreement Countries

The North American Free Trade Agreement (NAFTA) was entered into in 1994 to remove existing barriers and promote trade of goods and services among partner countries: the United States, Canada, and Mexico. The majority of goods moved between these three countries are carried by heavy trucks; and, of those the largest volume is moved over highways in the United States (Mercier, 2007). Therefore, it is not surprising that harmonization of TS&W regulations between NAFTA partners is a significant step toward removing existing barriers. Discrepancies between Canadian, Mexican, and United States TS&W regulations result in the same consequences of discrepancies between individual states, provinces, and territories. Carriers moving goods between two countries must choose between using lowest common denominator vehicles that meet each country's regulations or maintain separate fleets. The NAFTA recognized the importance of uniform trucking regulations by requiring uniform standards and technical measures related to vehicle weights and dimensions within a 3-year period (Mercier, 2007). Twenty years since NAFTA was entered into, this has not been achieved.

There are a variety of reasons why the NAFTA has not resulted in uniform TS&W limits among partner countries. First, there is a lack of uniformity within each country. The United States has federal TS&W limits that are much lower than the limits of either Canada or Mexico; however, individual states (including those at the border) do permit loads higher than the U.S. federal legal limits. As previously discussed, the provinces and territories of Canada have entered the MOU that harmonizes most of the TS&W regulations in Canada; although, again individual provinces are able to permit vehicles outside of the MOU on roads in their jurisdiction. Unlike the United States and Canada, Mexico does have uniform national TS&W limits. Although the individual state governments of Mexico have the authority to establish their own TS&W limits, similar to

Canada, none have done so. Both Mexico and Canada allow unpermitted vehicles longer and heavier than those in the United States (Mercier, 2007).

In addition to the difficulties associated with reconciling 66 different sets of TS&W regulations in North America, Mercier (2007) identified four reasons harmonization has not been achieved via NAFTA which have been adjusted and combined as follows: 1) lack of political will, 2) disagreement over technical standards, 2) jurisdictional and stakeholder issues, and 4) issues inherent to the NAFTA.

1. Lack of political will is quite often a difficulty in changing regulations or implementing new regimes. Although TS&W regulations are intrinsically linked to trade barriers/open trade, there are a number of other political issues that have been of greater interest to NAFTA partner countries than TS&W regulations.
2. In addition to the different TS&W regulations, each country uses different technical engineering standards for design, construction, and maintenance of highway infrastructure. Specifically, the three countries use different assumptions and safety factors in bridge design and analysis. The United States uses more conservative assumptions and safety factors; therefore, vehicles that are acceptable in Canada and Mexico are not likely to comply with Federal Bridge Formula B in the United States.
3. A number of interested parties focus on different aspects of TS&W regulation. Railroad lobbyists often oppose increases to TS&W limits that would allow longer and heavier vehicles for two reasons. First, vehicles do not pay the full capital cost of construction and recurring maintenance costs

of roadway infrastructure. In contrast, railroads pay the full costs for the construction and maintenance of the rail infrastructure. Second, greater TS&W allowances may attract business from rail to truck. Safety advocacy groups are concerned about the safety implications of allowing longer and heavier vehicles. Individual government agencies differ in their considerations for state exceptions to federal TS&W regulations. In the United States, states that have higher limits through grandfather rights often seek to protect these rights to maintain economic activity. States in populated areas may place greater emphasis on the safety impacts and concerns about infrastructure preservation.

4. Finally, disharmony has continued partly due to the legal requirements of the NAFTA itself. Each country is able to apply any technical standards as long as they meet two main requirements: "national treatment" where other countries are under the same regulations as the regulating country and "most favorite nation treatment" where one other country is under the same regulations of any other country. As long as the United States applies the same TS&W limits to interstate travel and vehicles to and from Canada and Mexico, these requirements are met. Furthermore, the legal process to determine if a country is using any regulation as a barrier to trade (even if it is disguised) is cumbersome and may not result in a resolution.

Given these difficulties, there has not been any substantial movement toward harmonization of TS&W regulations among the NAFTA partner countries. The first three barriers to NAFTA harmonization also apply to regional harmonization within the

United States. Although the fourth barrier, legal aspects contained in NAFTA, would not necessarily be present, there may be implementation barriers that would similarly burden harmonization efforts regionally.

5.2.2.4 European Union Countries

In contrast, the European Union (EU) has achieved substantial harmonization of TS&W regulations among member countries (Walton et al., 2010). Similar to the relationship between individual states and the federal government, in the EU, individual member countries are permitted to allow longer and heavier vehicles within their borders. The key difference is that the EU restricts this practice if the allowance of longer and heavier vehicles impacts international competition. In effect, the majority of EU member countries agree to the same vehicle dimensions and weights allowed to travel among all of the EU countries except for special "gigaliners" permitted in Sweden and Finland (Walton et al., 2010). Gigaliners are longer and heavier vehicles used to move goods over very long distances in low density population areas of Sweden and Finland but not in other EU member countries. Similar to the performance-based system in Australia, the EU does allow some exceptions for infrastructure-friendly vehicles. Although the relationship between member countries and the EU is somewhat similar to the individual states' abilities to permit vehicles above U.S. federal TS&W limits, the EU has had significant success in harmonizing regulations.

5.3 Framework

In the United States, incremental TS&W harmonization at the regional level that is focused on aligning prescriptive limits included in oversize/overweight permitting programs is likely to be the most effective approach to achieve uniform regulations.

Although the performance-based approach used in Canada, Australia, and New Zealand would likely yield a more optimized national vehicle fleet, performance-based systems are a drastic change from the entrenched system of individual states in the USA exercising their grandfather rights. There would likely be significant pushback from states that currently permit vehicles that may not meet specified performance standards. Any provisions to grandfather-in vehicles that do not meet standards or phase them out over time would prolong the discrepancies between individual state regulations. There would also likely be significant disagreement over the appropriate performance measures and the numerical standards for different regions of the country. Instead, the first step should be to foster cooperation in the current prescriptive TS&W atmosphere.

A national system would also face many more hurdles to implementation than less structured regional cooperation. When TRB (2002) recommended a national performance-based system, the authors recognized the importance of significant oversight and evaluation. The USDOT (2004) also agreed that significant national oversight would be necessary to implement a performance-based system. Both TRB and USDOT recognized the importance of national uniformity and oversight in line with the strong federal role in TS&W regulation; however, many of the differences in state TS&W limits and oversize/overweight procedures have occurred in response to the individual needs of each state. Trucks used most often in the densely populated states in the Northeast are very different from the vehicles used for long-distance trips across the larger, less populated states in the West. LCV use is not limited to Western states (Indiana, Ohio, New York, and Florida all permit some types of LCVs on some routes) but is concentrated in those states prior to the LCV freeze included in the 1991 ISTEA legislation. The permitted vehicles are also often related to industries that differ in various regions of the country. For example, steel production is primarily centralized in the Midwestern region of the country.

Thus, an incremental approach focused on aligning practices within each region is more likely to be accepted by individual states than a complete overhaul at a national level or a performance-based system. A nationwide system could be approached after substantial harmonization has been achieved at a regional level.

5.4 One-Stop Shopping for Overweight Permits

Two tools that are already used to monitor and collect fees from large trucks can be leveraged to implement regionally uniform overweight vehicle programs: the International Registration Plan (IRP) and the International Fuel Tax Agreement (IFTA). As a first step, an integrated overweight vehicle permit collection and distribution procedure, based on existing IRP and IFTA fee collection, would allow for one-stop shopping for carriers requiring overweight vehicle permits in multiple jurisdictions. Following the establishment of streamlined permit acquisition, states DOTs could turn to the issue of harmonizing the TS&W limits and which vehicle configurations can be permitted to exceed those limits. A single permit collection and distribution tool would have small, but real, productivity gains while true harmonization would be even more efficient.

5.4.1 International Registration Plan

The International Registration Plan (IRP) is an agreement among the individual states in the United States, Washington, D.C., and the ten provinces of Canada to streamline the vehicle registration process (IRP, 2012). The IRP is a reciprocity system based on the distance traveled in each jurisdiction. Any vehicle that travels in two or more of the member jurisdictions must register their vehicles with IRP license plates. Carriers who travel interstate must register with IRP but those who operate exclusively intrastate may choose to register with IRP or a state specific system.

The amount of IRP registration fees that a carrier pays to a given state is dependent on the distances traveled in each jurisdiction and the registration fees for that vehicle if it were to operate exclusively in that jurisdiction. For example, if a vehicle travels 25% of the total annual distance in Jurisdiction A, 50% in Jurisdiction B, and the remaining 25% in Jurisdiction C, the IRP for that vehicle is 25% of the cost of the vehicle registration in Jurisdiction A plus 50% of the registration in Jurisdiction B plus 25% of the registration in Jurisdiction C. When a carrier is registering his vehicle fleet, he first contacts the base jurisdiction, which is the state or province where the business is established, then pays the IRP to the base jurisdiction. IRP handles the transfer of money amongst jurisdictions based on the distances traveled in each jurisdiction. The carrier receives a single plate for each vehicle which allows that vehicle to operate between multiple jurisdictions, instead of a license for each state or province. The participating jurisdictions have lower administrative costs because there are fewer registrations to handle—only those for whom it is the base jurisdiction and a transfer via IRP.

The IRP framework could easily be extended to regional overweight vehicle permitting where states use fixed fees because registrations are also based on fixed fees. Although the total amount of registration with IRP is based on the distances apportioned to each jurisdiction, each individual jurisdiction's registration fees are based on the vehicle. The registration fees themselves do not depend on the amount of mileage. Similarly, fixed fees for overweight vehicle trips are typically for a single trip or a number of trips in a set period of time. The primary disadvantage of fixed fee permits is that there is limited relationship between the fee and the actual cost of asset consumption. This also typically results in only a small fraction of cost recovery.

The IRP framework could still be appropriate for incentivizing the use of infrastructure-friendly vehicles. In the Indiana context, overweight vehicles that are loaded to less than 2.40 ESALs are considered infrastructure-friendly and thus eligible for annual, multi-trip permits at a low cost. If states can agree on the vehicles that are infrastructure-friendly and thus eligible for multi-trip or blanket permits using fixed fees, the notion of a base state and apportioned fees could be used to streamline overweight permit fee collection. The same base state that applies for IRP registration could collect the apportioned overweight permit fees for multiple jurisdictions. A third party could then redistribute the apportioned permit fees among jurisdictions. This framework would save the carriers time and money by avoiding having to apply to and pay each state independently. The framework would not pose any additional burdens on the individual states because only those vehicles determined to be infrastructure-friendly, which would qualify for multi-trip or blanket permits anyway, would participate in the harmonized permit system.

5.4.2 International Fuel Tax Agreement

Alongside IRP, the International Fuel Tax Agreement (IFTA) is another agreement among the United States and Canadian provinces (but not territories) used to streamline operations. While IRP collects and redistributes registration fees, IFTA collects and redistributes fuel taxes from motor vehicle carriers. IFTA uses the same concept of base jurisdiction and allows each jurisdiction authority to determine the appropriate tax rates and exemptions. Similar to the single license plate issued with IRP registration, companies file a single tax return each quarter with the base jurisdiction and make one tax payment or receive one tax refund. IFTA jurisdictions similarly benefit from having fewer taxpayers, lower administrative costs, increased audit coverage, and increased enforcement.

IFTA differs from IRP because fuel taxes are paid at the pump and adjusted after-the-fact using tax return data. The IFTA tax returns from the carrier to the base jurisdiction include the fuel taxes paid in each jurisdiction and the miles traveled in each jurisdiction. Each base jurisdiction then processes the information and provides reports and payments (as appropriate) to the other jurisdictions. After processing the data and payments from all of the other jurisdictions, the base jurisdiction either provides a tax refund or requests additional taxes, as appropriate, from each carrier in its jurisdiction.

The IFTA framework with per-mile fees (or, more specifically, per-gallon fees which are related to miles traveled through vehicle fuel economies) is more conducive to the overweight permit fees that are based on actual consumption. The IFTA framework may also be more flexible for harmonization among states that want to charge overweight vehicles different amounts based on the distance traveled. For example, Indiana's overweight commodity permits which are based on $/ESAL-miles can be converted into $/mile using simple ESAL calculations for each vehicle. If other Midwestern states moved toward distance based fees (instead of current annual, fixed fees in Ohio and Kentucky), each state could collect the permit fees from the carriers within their jurisdiction and transfer fees as appropriate to the other states based on distances traveled in each state.

For both IRP and IFTA, harmonization only requires that the vehicle dimensions and weights permitted in each state be consistent. The fees associated with overweight vehicle trips can still differ from one jurisdiction to another. IRP and IFTA are example tools that can be used to administer permit programs, collect fees, and redistribute collected revenues among multiple jurisdictions, not methods to determine what the harmonized vehicle dimensions and weight should be. Thus, IRP and IFTA type tools for streamlining overweight vehicle permitting administration are an incremental step toward harmonization

5.5 Requirements for Consistent Truck Size and Weight Limits

Consistent TS&W limits and oversize/overweight limits can provide more efficiency over the one-stop shopping of an IRP or IFTA based permitting program; however, they are substantially more difficult to attain. An added benefit of, and an incentive for states to pursue, consistent limits within regions and ultimately nationally is that carriers would have a larger market to operate overweight vehicles within, which would result in more efficient operations. With a larger market, states can also work collectively to influence carriers to use vehicles that are less damaging to highway infrastructure.

The first requirement to achieve TS&W and overweight size and weight regulation harmonization is significant political will to accomplish the objective. The USDOT (2004) indicated that lack of state support was a significant and valid reason for not implementing the Western Uniformity Scenario in 2004. Lack of political motivation is a leading factor for lack of uniformity among NAFTA nations (Mercier, 2007). In contrast, strong national agreement from multiple stakeholders that non-uniform size and weight regulations contribute to economic inefficiencies was a significant factor in the creation of the MOU in Canada (Woodrooffe et al., 2011; Walton et al., 2010).

Interestingly, federal TS&W limits were first established out of a need for uniformity. Uniform TS&W regulations protect infrastructure from deterioration beyond the loads for which it was designed; however, at the same time, trucking companies benefit from a network they can reliably use to move goods within the federal vehicle limits. The periodic national TS&W limit studies indicate a continued interest in federal TS&W limits. Alternative scenarios in those studies, which include longer and heavier vehicles, indicate interest in vehicles that are more economically efficient. Unfortunately, states' use of grandfather rights to allow vehicles beyond the federal TS&W limits has significantly limited the ability to establish uniformity as more and more states exercise their rights for specific industries.

TRB (2002) describes this process as "ratcheting" up of vehicle regulations. A given industry gains more permissive regulations in one state. This creates pressure on neighboring states to also increase limits or risk economic disadvantages. Over time, any neighboring states that do not increase limits are labeled as barriers. Over the longer time period, that can result in universal increases above the previously more restrictive "uniform" requirements. Unfortunately, the ratcheting up of TS&W regulations does not necessarily result in uniformly-ratcheted TS&W regulations.

The metal transport industry in the Midwest is a prime example of this process. Compared to other Midwestern states, Michigan has axle weight limits that are more permissive from the perspective of total GVW compared to other Midwestern states. The largest GVW in Michigan is 164,000 lbs when all of the axle weight regulations are followed. In response, Kentucky and Ohio have permitted overweight divisible loads up to 120,000 lbs to move steel coils. The new Indiana overweight commodity permits now allow similar loads of metal goods up to 120,000 lbs in Indiana. Although Indiana, Kentucky, and Ohio now have similar maximum GVW limits for overweight metal divisible loads, they are much lower than Michigan's limits.

TRB (2002) also recognized that the ratcheting process has occurred in primarily political arenas with limited engineering involvement. The overweight commodity permits in Indiana were first introduced through the state legislature and then INDOT was tasked with performing an engineering evaluation. The economic political interests were evident in the requirement that the comprehensive study of impacts include an evaluation of the economic competitiveness compared to other Midwestern states. The ratcheting up of TS&W regulations indicates that elected officials are currently more concerned with maintaining competitiveness and economic advantages over neighboring states rather than cooperative efforts at increasing productivity while preserving infrastructure and maintaining safety and mobility. Infrastructure-friendly vehicles provide a basis for a win-win scenario. A paradigm shift is necessary to generate the political will necessary to pursue these types of solutions.

In addition to the political will, a second requirement for successful harmonization is input from all interested stakeholders. Representatives from all interested state departments of transportation, state governments, the federal government, and interested industries must be involved. State transportation officials are best able to provide technical input on the amount of asset consumption attributable to overweight vehicles. State and federal government representatives are able to identify and pursue any enabling legislation necessary to move toward harmonization. Finally, industry representatives are best able to indicate configurations that are likely to be adopted by the industry. Often there is a disconnect between the transportation departments (whose perspective is asset consumption) and trucking companies (whose perspective is the allowable payload). Inclusion of all interested parties throughout the harmonization process helps ensure that desired outcomes, in terms of productivity improvements and transportation system preservation, are achieved and undesirable consequences are prevented or mitigated.

An example of successful collaboration of both officials in multiple jurisdictions and industry representatives to improve oversize-overweight vehicle permitting is the Manitoba experience accommodating increased truck traffic from the petroleum industry (Reimer et al., 2014). Advances in technology caused a boom in petroleum extraction in Southwest portions of Manitoba, Canada, near the border with Saskatchewan (Canada) and North Dakota (United States). Uniquely configured heavy vehicles carrying both non-divisible and divisible loads are necessary at different points in the petroleum production process which cannot be paused once started. Often, the vehicles are oversize or overweight and require permits from the Manitoba government. Also, the only routes to and from the petroleum wells often include rural roads historically used for farm-to-market trips which were not designed for the new vehicles used by the petroleum industry.

The Manitoba government brought together a stakeholder committee including industry representatives and various Manitoba government agencies responsible for transportation, water resources, and planning to address the need for streamlined permitting. The Manitoba government also collaborated with representatives from Saskatchewan and North Dakota to reduce administrative barriers for overweight vehicle operators traveling through the three jurisdictions. The result of these interactions is a special permitting program for oversize/overweight vehicles routinely used by the petroleum industry in Manitoba. The special program expedites permitting by issuing annual blanket permits for service rigs, winch-bed trucks, concrete trucks, and pumper trucks specific to petroleum extraction without requiring a bridge assessment for each single trip. The Manitoba government decided to offer these permits following an extensive data collection program and a quantitative assessment of the truck traffic associated with the petroleum industry (Reimer et al., 2014).

In addition to political will and engagement from multiple stakeholders, Woodrooffe et al. (2011) identified several other lessons in the creation of the Canadian MOU that could apply to regional harmonization of TS&W regulations in the United States. Although a truly performance-based system for establishing TS&W limits and exceptions in the United States is likely far off, conversations among regional stakeholders interested in harmonization should have a sound technical basis. Decision makers should have engineering support for the amount of infrastructure consumption attributable to various vehicle configurations, the dynamic handling of those vehicles, and the number of vehicle trips necessary to move the same amoung of goods using each vehicle configuration.

Woodroofe et al. (2011) also highlighted the incentives inherent in the Canadian MOU to develop and use vehicles that are more productive and have as good as or better dynamic handling than existing. The Indiana annual, multi-trip permits provide such an incentive while the Kentucky and Ohio blanket permits do not. Efforts at regional harmonization should maintain some incentive structure for development of vehicles that are beneficial for industry while protecting highway infrastructure assets.

Finally, Woodrooffe et al. (2011) highlighted the formal structures in place to both ccreate and oversee a uniform set of TS&W regulations in Canada. In addition to the stakeholders participating in harmonization efforts, either the same body or a third party should be established to oversee implementation. Implementation is not a one-time issue because constant monitoring is neccesary to ensure that the desirable outcomes of increased productivity, increased safety, reduced environemntal impacts, and reduced asset consumption continue to be achieved. Without routine monitoring, the ratcheting up of TS&W limits or discrepancies among multiple jurisdictions can recur.

5.6 Advantages of Regional Cooperation

The advantages of regional harmonization include increased understanding of vehicle-infrastructure interactions, increased economic efficiency, less administrative efforts, and easier enforcement efforts and compliance with TS&W regulations.

The current regulatory environment has resulted in significant subsidization of truck freight. Individual states must balance the needs to preserve deteriorating infrastructure and promote economic interests at the state level. Typically, the balance favors the economic interests as states continue to exercise grandfather rights to compete against one another by permitting more oversize/overweight operations without recovering the cost of using the system. International experience has shown that it is possible to address both infrastructure preservation and economic productivity. Regional harmonization would address both of these needs by placing them collectively above the notion of competing with neighboring states.

Uniform oversize/overweight regulations for industries of regional significance would streamline efforts for both the trucking companies and state agencies. The carriers would benefit by using the same equipment with the same load in multiple states. A common permit program administered by multiple states could provide a single type of permit which is easier for state enforcement agencies to identify. Similarly, if permits were easier to obtain through a common permit program, there is one less reason (among many) for violators to operate without permits. Finally, both trucking companies and transportation agencies save time and money when multiple single trip permits for the same few vehicles and routes are replaced by a single request. Using the IRP and IFTA frameworks for reciprocity, each state is only responsible for the carriers that identify it as the base state.

5.7 Chapter Summary

This chapter provided a qualitative discussion about harmonization of oversize/overweight permitting practices. Although the United States has officially articulated uniform federal TS&W limits, the grandfather rights included in all surface transportation authorization legislation has created a fragmented network of less than optimal state TS&W limits and oversize/overweight permitting programs. Performance-based systems which look at both the productivity and the dynamic handling of vehicles have been used to allow longer and heavier vehicles in Canada, Australia, New Zealand, and the European Union. Canada and the member countries of the European Union have achieved a high degree of uniformity in their TS&W regulations. Although the performance-based approach would result in more optimal vehicle fleets, the United States can still make incremental improvements through regional harmonization of permitting practices. Harmonization is beneficial both to the overweight permit users and to the states that choose to coordinate with neighboring jurisdictions.

CHAPTER 6. SUMMARY AND FUTURE WORKS

6.1 Four Options for Overweight Vehicle Permitting

The primary benefit of using overweight vehicles is that the same amount of goods are moved with fewer trips, which translates into fuel cost savings, vehicle operation and maintenance cost savings, lower driver wages, less congestion and emissions, and so on. The monetary savings may be passed on by the carriers to the shippers in their negotiated contracts. Unfortunately, the damage to highway infrastructure due to overweight trucks is significant and has a sharply increasing non-linear relationship with weight. In the case of pavement consumption, doubling the weight on an individual axle does more than sixteen times the damage. Past research has identified a wide gap between the actual cost of consumption attributable to overweight vehicles and the amount of revenues collected to offset the damage. The status quo where individual states exercise grandfather rights to permit overweight divisible loads has generally resulted in significant subsidization of the trucking industry. The sizeable amount of uncompensated consumption of highway infrastructure assets attributable to overweight vehicles is a problem consistent with the classic issue referred to as the Tragedy of the Commons.

In addition to the ongoing transportation tragedy of the commons, the current system of individual state regulations for oversize and overweight vehicles beyond the federal TS&W regulations has resulted in a non-optimal piecemeal network of regulations. Thus, for interstate commerce, trucking companies that are able to operate more efficiently using overweight divisible loads must choose between vehicles that are less productive because their configuration represents the least common denominator across different state regulations, or configure vehicles and purchase permits to meet the requirements of multiple jurisdictions. In some cases, for the same load being transported, different vehicles are used in the different states along the route to take advantage of more efficient overweight operations. Additionally, the requirements among "competing" jurisdictions are not optimal for asset preservation from a national standpoint when states use more favorable overweight practices to attract economic activity from neighboring states.

The current study has explored four alternatives to the traditional overweight vehicle permits issued by individual states: optimization of traditional vehicle permitting mechanisms, incentives for infrastructure-friendly vehicles, a quota system with auction allocation, and regional and national harmonization of overweight vehicle permitting practices. These four alternatives are not mutually exclusive and can be combined to improve overweight vehicle permitting.

6.1.1 Optimization of Traditional Permitting Mechanisms

Highway agencies must balance the competing needs of preserving the taxpayer-funded highway infrastructure and supporting continuing economic activity within their borders. If the permit fees are too low compared to the cost of consumption, the rate of highway infrastructure deterioration is exacerbated. In the long term, this has negative impacts on both the trucking companies and the general traveling public in terms of vehicle operating costs and safety. In contrast, a general argument from various industries against permit fees that recover the full cost of consumption (or advocating for exemptions and exceptions to existing permits) is that the high costs of permit acquisition raises the cost of doing business in those industries. Industries indicate that the increases would necessarily be passed through the economy to consumers. In one instance in Virginia, construction industry representatives indicated that if exemptions were not issued, or if permit fees were increased, the added cost would be passed back to the state through higher construction costs (VTRC, 2008). Similar sentiments from other industries were detailed in other state TS&W and overweight vehicle studies.

Although these conflicting objectives have been identified and addressed separately in previous research, limited quantitative analysis has been completed to optimize permit fees. The present study established a general framework that appropriately models the agency's goals with respect to both asset preservation and ease of trade and commerce, then applied that general framework to Indiana using Indiana specific parameter estimates. In contrast to existing literature, the present study used the permit fee as the decision variable in the multiobjective optimization formulation because the agency has direct control over the permit fee. Additionally, the general multiobjective optimization framework herein is the first to accurately capture carrier decision making by using the total logistics cost savings in the agency's objective to facilitate economic activity.

The general multiobjective optimization formulation developed in the current study minimizes the uncompensated consumption cost and maximizes the total logistics cost savings. The first objective, to minimize uncompensated compensation, protects highway assets from excessive damage above the fees collected through the sale of permits. The second objective, to maximize total logistics cost savings, reflects the substantial cost savings companies can achieve through overweight vehicle operations. The total logistics cost savings reflects all costs savings, both transportation costs and inventory costs, minus any permit expenses. The multiobjective optimization formulation developed in this study also accounts for the additional demand for overweight vehicle permits when the cost of permits is low (and thus the total logistics cost savings are at their highest).

Parameters for the general multiobjective optimization formulation were estimated for the case study of Indiana overweight commodity permits. Indiana overweight commodity permits are a new type of permit for overweight divisible loads in Indiana up to 97,000 lbs for agricultural goods and 120,000 lbs for metal goods. Parameters were estimated using data relevant to Indiana.

In multiobjective optimization, a single optimal solution typically does not exist because the objectives conflict. Instead, there are many (often infinite) Pareto optimal points where the value of one objective function cannot be improved without a loss in at least one other objective function. For the Indiana overweight commodity permits, the Pareto frontier of Pareto optimal solutions was found and graphed for a range of prices in dollars per ESAL-mile. Every point on the Pareto frontier corresponds to the uncompensated consumption cost and total logistics cost savings associated with a particular fee (in $/ESAL-mile).

In addition to the Pareto frontier, tradeoffs can be established from the multiple optimal solutions of multiobjective optimization problems. The tradeoff between uncompensated consumption cost and total logistics cost savings were calculated for discrete levels of the permit fee for the Indiana case study.

Both the Pareto optimal frontier and the tradeoff analysis provide data that are helpful to INDOT in choosing an appropriate fee structure for overweight commodity permits. INDOT can compare the current uncompensated consumption (approximately $32 million) and total logistics cost savings ($103.7 million) with a permit fee of $0.07 per ESAL-mile to the uncompensated consumption and total logistics cost savings at a different fee per ESAL-mile. Based on INDOT's preferences, a higher or lower fee may be appropriate to decrease the uncompensated consumption or increase savings, respectively. The general form of the multiobjective optimization problem can be used by other states with modifications to the estimated parameters to reflect the actual cost of consumption and total logistics cost savings in those states under different permit fee schedules.

6.1.2 Incentives for Infrastructure-Friendly Vehicle Usage

The second alternative considered in the present research is incentives or mandates for vehicles that are less damaging to highway infrastructure assets. Infrastructure-friendly vehicles represent a win-win situation because they consume less of the common highway infrastructure but can still be loaded to carry goods more productively which benefits carriers.

The Turner proposal, first voiced by Francis Turner in 1984, advocated for a decrease in the federal axle load limits but an increase in the federal total GVW and length limits. The lower axle load limits result in less damage to pavements. Michigan's unique TS&W regulations adhere to the spirit of the Turner proposal—lower individual axle weight limits with higher overall GVW limits. Michigan's TS&W limits are mandated rather than incentivized for all vehicles above the federal GVW limit of 80,000 lbs. Indiana has incentivized infrastructure-friendly vehicle operations through annual, multi-trip overweight commodity permits introduced in the Emergency Rules for overweight commodity permits. Vehicles that are loaded and configured to be 2.40 ESALs or less may operate in Indiana for an annual fee of $20 in contrast to the thousands of dollars in single-permit fees a company might pay for several trips made by vehicles above 2.40 ESALs.

A stated preference survey was conducted to elicit information about individual trucking companies' willingness to invest in infrastructure-friendly vehicles. When monetary amounts were not included, the vast majority of respondents indicated willingness to invest in equipment that is less damaging to infrastructure; however, less than a third were willing to do so in a contingent valuation analysis which included monetary amounts. The mean willingness to pay for investment in infrastructure-friendly vehicles was estimated to be less than $4,000 in the state of Indiana.

6.1.3 Overweight Vehicle Quota with Auction Allocation

The framework for an overweight vehicle quota and auction was established to allocate a maximum amount of infrastructure consumption that can be accommodated without additional funds or reconfiguration of vehicles. Quotas give the transportation agency direct control over the amount of infrastructure consumption allowable by overweight vehicles. After establishing an initial quota, the state DOT can control the growth of overweight vehicles, and thus the growth in consumption attributable to those vehicles. This can prevent an exponential growth in uncompensated loadings from overweight vehicles.

The auction allocation mechanism specifically provides an indication of the value of overweight vehicle permits through the market clearing price. Although many industries advocate for lower permit prices or exemptions from permit regulations, the fact that many companies continue to purchase permits indicates that the permits are worth at least as much as the current fees. The results of an auction would help to quantify the amount trucking companies are willing to spend to acquire permits for overweight vehicles. Several auction formats were considered and the open English auction format was recommended. Other allocation mechanisms, such as a cap and trade system, could be implemented but may not give as much information about the value carriers' place on overweight vehicle permits.

Various auction parameters were defined for Indiana. The measure for the quota is blocks of 500 ESAL-miles of travel. ESAL-mile blocks are a useful measure because individual trucking companies can choose to modify either the ESALs of the vehicles or the miles traveled to maximize use of any single block. Based on current demand for overweight commodity permits, the initial supply, or annual quota, is estimated to be 96,000 blocks of 500 ESAL-miles annually, or 8,000 blocks each month.

In addition to the infrastructure-friendly vehicle questions, the stated preference survey elicited information about how many blocks of 500 ESAL-miles of travel a company would request and how much the company would pay. These data were used to estimate a preliminary valuation of overweight vehicle permits in dollars per ESAL-mile of travel.

6.1.4 Regional or National Harmonization of TS&W Limits

Finally, recommendations were made to mitigate the current inefficiencies in the network of TS&W and oversize/overweight regulations in the United States through national, or at least regional, cooperation. The piecemeal network of state TS&W limits and oversize/overweight regulations has undermined the official federal TS&W limits. Although most long-haul and interstate truck freight is carried in 5-axle, 80,000lbs vehicles, overweight vehicles could be more efficient for trucking companies than the lighter vehicles that meet federal requirements. Individual states have increasingly exercised grandfather rights to permit overweight divisible loads in direct response to the more permissive regulations of neighboring states. This has ratcheted up oversize and overweight practices. At the same time, the discrepancies that continue to exist between neighboring states is a burden on trucking companies that operate in more than one jurisdiction.

Regional harmonization among multiple states has several potential benefits. First, states can focus more on preserving infrastructure than on competing with one another through ever more permissive overweight programs to attract industries to the individual state. Coalitions of states can focus on industries that benefit the entire region to find trucking solutions that are beneficial to both those industries and the transportation agencies of each state. Additionally, enforcement efforts can be simplified if there is a single overweight vehicle regime. Trucking companies will be more likely to use the vehicles that are permitted in multiple states to comply with a single set of overweight regulations than attempt to meet as many or all of a number of different limits. Finally, if there is a mechanism similar to the IRP and IFTA, which collect and distribute registration and fuel taxes, respectively, in place for overweight vehicle permit fees, individual states will not need to collect from all users separately and trucking companies can make payments through a single base state. These mechanisms simplify the process of applying and paying for multiple overweight vehicle permits in multiple locations.

6.2 Future Research Directions

The following sections outline improvements and extensions that can be made in the area of overweight vehicle permitting.

6.2.1 Refinements to Overweight Vehicle Permit Optimization

The general framework for optimizing traditional overweight vehicle permits considered only the agency's goals to preserve highway assets and facilitate trade and commerce. The agency is also concerned with safety and mobility. Previous research has not conclusively quantified the impacts of overweight vehicles on safety and mobility. Additional research in this area should inform future multiobjective optimization analysis of overweight vehicle permits. Additional objectives should include maximizing or minimizing the benefits or negative impacts, respectively, with respect to safety and mobility. Additionally, future research should consider different model forms for the objective functions as appropriate for the individual states.

6.2.2 Rationality of Operator Decision Making

The curves representing the willingness to pay for infrastructure-friendly vehicles presented in Chapter 3 do not meet with expectations that trucking companies will typically be risk averse. A willingness to pay curve roughly corresponds to a utility curve. Utility curves are convex for risk lovers, linear for risk neutral individuals, and concave for risk adverse individuals. Therefore, under the assumption that the trucking industry, as a whole, would be risk averse, the expected shape of all estimated willingness to pay curves should be concave. Concave utility curves correspond to decreasing marginal utility, or in this case, decreasing marginal willingness to pay for investment.

The raw data elicited in the stated choice survey, depicted in Figure 3.7, in Chapter 3, is approximately linear indicating relatively risk neutral behavior; however, the data calibrated to remove hypothetical bias are convex, indicated risk taking behavior. Most of the estimated willingness to pay for investment curves are convex. The willingness to pay curve estimated for companies broadly interested in annual permits with an average number of employees is concave from approximately $0 to $7,500 in investment, then convex for values above $7,500. The inflection point indicates that companies with these characteristics are risk averse at low amounts but risk taking at higher amounts. At first glance, these conclusions do not seem consistent with expectation. The discrepancy between the expected and the estimated willingness to pay curves suggests that respondents to the survey potentially were not making rational decisions based on the present value of purchasing permits compared to investing in infrastructure-friendly vehicles. Future research should explore this behavior.

One possible explanation is that the responding companies are generally unwilling to invest, given uncertainties about future permitting mechanisms. The overweight commodity permits introduced in Indiana are new and subject to changes through INDOT's final rulemaking. At industry forums, and in the survey comments, interested trucking company representatives indicated that they might be more willing and able to make decisions about investment if the fee structures were known. Contracts between trucking companies and shippers are often agreed to in advance. Additionally, vehicles in the fleet are replaced after several years of use. Many survey comments indicated that companies would not invest much in the fleet while Emergency Rules are in place for fear that the fee schedules could change and investment could be wasted. The willingness to pay curves may change in the future once trucking companies have more information about the permitting fee schedule for overweight commodity permits and their costs for permit acquisition. Additionally, companies may be more likely to invest in new equipment to replace vehicles that are nearing the end of their service life.

6.2.3 Experimental Economics Methods

The available survey data are not sufficient to simulate the auction framework developed in this study. Unfortunately, many trucking companies have not or cannot quantify what their private value is for holding overweight vehicle permits. Future research should consider the equilibrium market clearing price for overweight vehicle permits.

Experimental economics methods are laboratory methods used to study economic questions that are difficult to observe or solve analytically. Given sufficient reliable data, bid vectors could be calibrated and estimated for many participants in a simulated overweight vehicle auction. Monte Carlo simulations could be used to estimate the market clearing price. A large amount of data would be necessary for this undertaking. In contrast, experimental economics methods could be used to create an auction environment to observe the bidding behaviors of participating trucking company representatives. The bidding behavior and subsequent market clearing price would indicate not only the value of holding overweight vehicle permits, but also any irrational behavior from participants.

The challenge in using experimental economics methods to further study the auction framework developed herein is ensuring the auction experiment sufficiently replicates the auction process that would be put in place. Similar to the cheap talk script used at the beginning of the surveys, setting up the auction similar to the actual mechanism that would be implemented creates consequentiality. Additionally, the participants must be individuals who make investment decisions for trucking companies—CEOs, CFOs, independent owners, etc.—because the general public likely would behave differently than individuals making decisions on behalf of their organization who are knowledgeable about the trucking industry.

6.2.4 Performance-based TS&W Limit Regulation

Finally, additional research into performance-based TS&W limit regulation could help further the goal of regional and national harmonization. One of the biggest disadvantages of individual states exercising grandfather rights is that the piecemeal network of state TS&W limits and oversize/overweight regulations are prescriptive. As long as carriers use vehicles that are within limits, they are in compliance with the laws, even though some vehicles that are within limits are more efficient, safer, or consume less highway infrastructure than others also within those limits. A performance-based approach transitions from prescriptive limits to defined measures that must be met, regardless of vehicle size and weight. The performance-based approach also has the potential to yield more optimal vehicle configurations.

Performance-based TS&W limits and oversize/overweight permit programs would also help address the competing needs of preserving infrastructure and supporting economic activity. Trucking companies would be able to use the most productive equipment that meets performance standards, such as the number of ESALs, braking distance, or handling measures. At the same time, state agencies would have metrics in place to ensure vehicles in use are safe and protect infrastructure from undue deterioration.

Future research in the area of performance-based TS&W regulation among the individual states may include the performance measures that should be used, standard values for those measures, and the relationship between different vehicle configurations or dimensions that influence the value of important performance measures.

6.3 Contributions to the Body of Knowledge

This study considered multiple options for addressing the consumption of highway infrastructure by overweight vehicles which collectively add to the discussion of overweight vehicle permitting. The research makes four major contributions. First, the general multiobjective optimization formulation contained herein is an improvement on previous research because the new formulation more appropriately models choices made by relevant decision makers. Second, the analysis quantified carriers' willingness to pay for infrastructure-friendly vehicles in Indiana. Third, the framework for an overweight vehicle quota and auction allocation has not previously been applied to overweight vehicles. Finally, a qualitative framework was developed to incrementally achieve harmonization by first instituting a one-stop shopping tool for permit administration then moving on to the issue of establishing consistent TS&W limits and overweight vehicle regulations.

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APPENDICES

Appendix A Summary of ITIC Results for Different ESAL-mile Based Permit Fees

This Appendix presents the summary tables for each successive model run of the Intermodal Transportation and Inventory Cost (ITIC) model software. For each run, the ESAL-mile based fee for overweight commodity permits was adjusted.

Table A.1 Summary of ITIC Results for Introduction of Overweight Commodity Permits at $0.01/ESAL-mile

0.01	ESAL-mile Based Divisible Load Permits							Delta
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total	
Number of Records	50	1	205	122	65	0	443	0
Tons Shipped	8252.9315	121.6495	12975086.04	2831081.83	2536450.521	0	18350992.97	0
Number of Shipments	6827.5875	121.6495	10793108.57	2831081.83	61870	0	13693009.64	12841772.64
Truck VMT	198673.809	2878.774488	144396334.5	30805700.02	29150640.67	0	204554227.8	-70835037.69
Logistics Cost ($)	620,912.09	11,281.04	520,144,618.51	113,655,609.76	100,129,013.28	-	734,561,434.68	-109,930,220.51

Table A.2 Summary of ITIC Results for Introduction of Overweight Commodity Permits at $0.02/ESAL-mile

0.02	ESAL-mile Based Divisible Load Permits							Delta
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total	
Number of Records	51	1	205	121	65	0	443	0
Tons Shipped	8777.442	121.6495	12975086.04	2830557.32	2536450.521	0	18350992.97	0
Number of Shipments	7352.098	121.6495	10793108.57	2830557.32	61870	0	13693009.64	12841772.64
Truck VMT	209696.2062	2878.774488	144396334.5	30799153.1	29150640.67	0	204558703.3	-70830562.22
Logistics Cost ($)	648,421.62	11,281.04	520,725,529.25	113,906,322.99	100,129,013.28	-	735,420,568.18	-109,071,087.02

Table A.3 Summary of ITIC Results for Introduction of Overweight Commodity Permits at $0.05/ESAL-mile

0.05	ESAL-mile Based Divisible Load Permits							Delta
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total	
Number of Records	51	2	204	121	65	0	443	0
Tons Shipped	8777.442	234.179	12974973.51	2830557.32	2536450.521	0	18350992.97	0
Number of Shipments	7352.098	234.179	10792996.04	2830557.32	61870	0	13693009.64	12841772.64
Truck VMT	209696.2062	5889.070603	144393640.2	30799153.1	29150640.67	0	204559019.2	-70830246.3
Logistics Cost ($)	648,421.62	22,934.37	522,122,738.16	114,678,036.52	100,129,013.28	-	737,601,143.95	-106,890,511.24

Table A.4 Summary of ITIC Results for Introduction of Overweight Commodity Permits at $0.07/ESAL-mile

0.07	ESAL-mile Based Divisible Load Permits							Delta
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total	
Number of Records	52	2	204	120	65	0	443	0
Tons Shipped	9201.943	234.179	12974973.51	2830132.819	2536450.521	0	18350992.97	0
Number of Shipments	7776.599	234.179	10792996.04	2830132.819	61870	0	13693009.64	12841772.64
Truck VMT	220715.9365	5889.070603	144393640.2	30792607.75	29150640.67	0	204563493.6	-70825771.91
Logistics Cost ($)	675,263.66	22,934.37	523,158,725.51	115,144,996.36	100,129,013.28	-	739,130,933.19	-105,360,722.00

Table A.5 Summary of ITIC Results for Introduction of Overweight Commodity Permits at $0.10/ESAL-mile

0.10	ESAL-mile Based Divisible Load Permits							Delta
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total	
Number of Records	53	3	203	119	65	0	443	0
Tons Shipped	9601.747	399.849	12974807.84	2829733.015	2536450.521	0	18350992.97	0
Number of Shipments	8176.403	399.849	10792830.37	2829733.015	61870	0	13693009.64	12841772.64
Truck VMT	232577.2102	9298.198926	144390588.8	30785562.56	29150640.67	0	204568667.4	-70820598.05
Logistics Cost ($)	702,665.43	36,151.53	524,528,236.74	115,889,574.32	100,129,013.28	-	741,285,641.29	-103,206,013.90

Table A.6 Summary of ITIC Results for Introduction of Overweight Commodity Permits at $0.25/ESAL-mile

0.25	ESAL-mile Based Divisible Load Permits							Delta
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total	
Number of Records	55	6	200	117	65	0	443	0
Tons Shipped	10720.936	1068.648	12974139.04	2828613.826	2536450.521	0	18350992.97	0
Number of Shipments	9295.592	1068.648	10792161.57	2828613.826	61870	0	13693009.64	12841772.64
Truck VMT	262045.8317	23641.45403	144377750.8	30768059.2	29150640.67	0	204582138	-70807127.51
Logistics Cost ($)	772,075.15	84,833.05	531,500,277.46	119,707,822.89	100,129,013.28	-	752,194,021.83	-92,297,633.36

Table A.7 Summary of ITIC Results for Introduction of Overweight Commodity Permits at $0.40/ESAL-mile

0.40	ESAL-mile Based Divisible Load Permits							Delta
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total	
Number of Records	67	16	190	105	65	0	443	0
Tons Shipped	25694.535	5426.2755	12969781.41	2813640.227	2536450.521	0	18350992.97	0
Number of Shipments	24269.191	5426.2755	10787803.94	2813640.227	61870	0	13693009.64	12841772.64
Truck VMT	538636.8207	113991.631	144296882.7	30603773.58	29150640.67	0	204703925.4	-70685340.15
Logistics Cost ($)	1,492,057.57	358,296.27	538,248,111.97	122,835,462.55	100,129,013.28	-	763,062,941.64	-81,428,713.55

Table A.8 Summary of ITIC Results for Introduction of Overweight Commodity Permits at $0.50/ESAL-mile

0.50	ESAL-mile Based Divisible Load Permits							Delta
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total	
Number of Records	79	55	151	93	65	0	443	0
Tons Shipped	55615.365	540726.344	12434481.34	2783719.397	2536450.521	0	18350992.97	0
Number of Shipments	54190.021	540726.344	10252503.88	2783719.397	61870	0	13693009.64	12841772.64
Truck VMT	1076452.14	10192429.52	135276148	30284329.6	29150640.67	0	205979999.9	-69409265.58
Logistics Cost ($)	2,851,047.72	26,865,686.23	516,406,018.98	124,015,927.02	100,129,013.28	-	770,267,693.23	-74,223,961.96

Table A.9 Summary of ITIC Results for Introduction of Overweight Commodity Permits at $0.75/ESAL-mile

0.75	ESAL-mile Based Divisible Load Permits							Delta
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total	
Number of Records	172	132	74	0	65	0	443	0
Tons Shipped	2839334.762	9012122.869	3963084.817	0	2536450.521	0	18350992.97	0
Number of Shipments	2837909.418	9012122.869	1781107.351	0	61870	0	13693009.64	12841772.64
Truck VMT	52063096.31	112712678.7	43515105.69	0	29150640.67	0	237441521.4	-37947744.1
Logistics Cost ($)	129,548,413.34	385,003,790.44	164,170,333.49	-	100,129,013.28	-	778,851,550.55	-65,640,104.64

Table A.10 Summary of ITIC Results for Introduction of Overweight Commodity Permits at $1.00/ESAL-mile

1.00	ESAL-mile Based Divisible Load Permits							Delta
	5-axle (80,000 lbs)	6-axle (90,000 lbs)	6-axle (97,000 lbs)	8-axle (124,000 lbs)	9-axle (140,000 lbs)	7-axle (110,000 lbs)	Total	
Number of Records	172	142	64	0	65	0	443	0
Tons Shipped	2839334.762	10709747.22	2265460.466	0	2536450.521	0	18350992.97	0
Number of Shipments	2837909.418	10709747.22	83483	0	61870	0	13693009.64	12841772.64
Truck VMT	52063096.31	128432716.6	29444840.88	0	29150640.67	0	239091294.4	-36297971.09
Logistics Cost ($)	129,548,413.34	455,679,646.86	93,696,379.39	-	100,129,013.28	-	779,053,452.88	-65,438,202.31

Appendix B GAMS Output for Multiobjective Optimization

```
\\myhome.itap.purdue.edu\myhome\severet\My
Documents\gamsdir\projdir\epscm_
     permitfee3.gms
GAMS Rev 230  WEX-VIS 23.0.2 x86/MS Windows                  10/03/14
18:26:06 Page 4
eps-Constraint Method for Multiobjective Optimization (EPSCM,SEQ=319)
Include File Summary


   SEQ   GLOBAL TYPE      PARENT   LOCAL  FILENAME

     1                 1  INPUT                    0               0
\\myhome.itap.purdue.edu\myhome\severe
                                          t\My
Documents\gamsdir\projdir\epscm_p
                                          ermitfee3.gms
     2             225  EXIT                        1             225
\\myhome.itap.purdue.edu\myhome\severe
                                          t\My
Documents\gamsdir\projdir\epscm_p
                                          ermitfee3.gms


COMPILATION TIME     =        0.000 SECONDS      3 Mb  WIN230-230 Feb
12, 2009
GAMS Rev 230  WEX-VIS 23.0.2 x86/MS Windows                  10/03/14
18:26:06 Page 5
eps-Constraint Method for Multiobjective Optimization (EPSCM,SEQ=319)
Model Statistics    SOLVE mod_payoff Using NLP From line 163


LOOPS                                  kp   ucc
                                 FOR/WHILE   1


MODEL STATISTICS

BLOCKS OF EQUATIONS          6     SINGLE EQUATIONS            6
BLOCKS OF VARIABLES          4     SINGLE VARIABLES            5
NON ZERO ELEMENTS           11     NON LINEAR N-Z              5
DERIVATIVE POOL              8     CONSTANT POOL              22
CODE LENGTH                 68


GENERATION TIME      =        0.062 SECONDS      4 Mb  WIN230-230 Feb
12, 2009
               L O O P S                kp ucc
                                  FOR/WHILE 1

               S O L V E     S U M M A R Y

     MODEL   mod_payoff         OBJECTIVE  obj
```

```
     TYPE    NLP                 DIRECTION  MAXIMIZE
     SOLVER  CONOPT              FROM LINE  163

**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      2 LOCALLY OPTIMAL
**** OBJECTIVE VALUE                0.0000

 RESOURCE USAGE, LIMIT          0.031      1000.000
 ITERATION COUNT, LIMIT         4         10000
 EVALUATION ERRORS              0             0


    C O N O P T 3   version 3.14S
    Copyright (C)   ARKI Consulting and Development A/S
                    Bagsvaerdvej 246 A
                    DK-2880 Bagsvaerd, Denmark

 Using default options.


    The model has 5 variables and 6 constraints
    with 11 Jacobian elements, 5 of which are nonlinear.
    The Hessian of the Lagrangian has 1 elements on the diagonal,
    1 elements below the diagonal, and 2 nonlinear variables.

 ** Optimal solution. There are no superbasic variables.


 CONOPT time Total                             0.004 seconds
   of which: Function evaluations              0.000 =  0.0%
             1st Derivative evaluations        0.000 =  0.0%

 Workspace           =     0.03 Mbytes
    Estimate         =     0.03 Mbytes
    Max used         =     0.01 Mbytes


**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
                             0     ERRORS
LOOPS                                   kp   ucc
                                 FOR/WHILE   2


MODEL STATISTICS

BLOCKS OF EQUATIONS           6     SINGLE EQUATIONS            6
BLOCKS OF VARIABLES           4     SINGLE VARIABLES            5
NON ZERO ELEMENTS            11     NON LINEAR N-Z              5
DERIVATIVE POOL               8     CONSTANT POOL              22
CODE LENGTH                  68
```

```
GENERATION TIME      =        0.110 SECONDS      4 Mb  WIN230-230 Feb
12, 2009
               L O O P S                 kp ucc
                                  FOR/WHILE 2

               S O L V E      S U M M A R Y

     MODEL   mod_payoff          OBJECTIVE  obj
     TYPE    NLP                 DIRECTION  MAXIMIZE
     SOLVER  CONOPT              FROM LINE  163

**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      2 LOCALLY OPTIMAL
**** OBJECTIVE VALUE        108137614.5450

 RESOURCE USAGE, LIMIT          0.023      1000.000
 ITERATION COUNT, LIMIT         4         10000
 EVALUATION ERRORS              0             0


    C O N O P T 3   version 3.14S
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                    DK-2880 Bagsvaerd, Denmark

 Using default options.


    The model has 5 variables and 6 constraints
    with 11 Jacobian elements, 5 of which are nonlinear.
    The Hessian of the Lagrangian has 1 elements on the diagonal,
    1 elements below the diagonal, and 2 nonlinear variables.

 ** Optimal solution. There are no superbasic variables.


 CONOPT time Total                             0.005 seconds
   of which: Function evaluations              0.000 =  0.0%
             1st Derivative evaluations        0.000 =  0.0%

 Workspace           =     0.03 Mbytes
    Estimate         =     0.03 Mbytes
    Max used         =     0.01 Mbytes


**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
                             0     ERRORS
LOOPS                                  kp   tlcsav
                                 FOR/WHILE   1


MODEL STATISTICS
```

```
BLOCKS OF EQUATIONS           6     SINGLE EQUATIONS            6
BLOCKS OF VARIABLES           4     SINGLE VARIABLES            5
NON ZERO ELEMENTS            11     NON LINEAR N-Z              5
DERIVATIVE POOL               8     CONSTANT POOL              22
CODE LENGTH                  68


GENERATION TIME      =        0.062 SECONDS      4 Mb  WIN230-230 Feb
12, 2009
               L O O P S                 kp tlcsav
                                  FOR/WHILE 1

               S O L V E      S U M M A R Y

     MODEL   mod_payoff          OBJECTIVE  obj
     TYPE    NLP                 DIRECTION  MAXIMIZE
     SOLVER  CONOPT              FROM LINE  163

**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      2 LOCALLY OPTIMAL
**** OBJECTIVE VALUE        108137614.5450

 RESOURCE USAGE, LIMIT          0.023      1000.000
 ITERATION COUNT, LIMIT         4         10000
 EVALUATION ERRORS              0             0


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                    DK-2880 Bagsvaerd, Denmark

 Using default options.


    The model has 5 variables and 6 constraints
    with 11 Jacobian elements, 5 of which are nonlinear.
    The Hessian of the Lagrangian has 1 elements on the diagonal,
    1 elements below the diagonal, and 2 nonlinear variables.

 ** Optimal solution. There are no superbasic variables.


 CONOPT time Total                               0.004 seconds
   of which: Function evaluations                0.000 =  0.0%
             1st Derivative evaluations          0.000 =  0.0%

 Workspace           =     0.03 Mbytes
    Estimate         =     0.03 Mbytes
    Max used         =     0.01 Mbytes


**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
```

```
                              0     ERRORS
LOOPS                                    kp   tlcsav
                                    FOR/WHILE   2


MODEL STATISTICS

BLOCKS OF EQUATIONS           6     SINGLE EQUATIONS            6
BLOCKS OF VARIABLES           4     SINGLE VARIABLES            5
NON ZERO ELEMENTS            11     NON LINEAR N-Z              5
DERIVATIVE POOL               8     CONSTANT POOL              22
CODE LENGTH                  68


GENERATION TIME      =        0.062 SECONDS      4 Mb  WIN230-230 Feb
12, 2009
               L O O P S                kp tlcsav
                                    FOR/WHILE 2

               S O L V E      S U M M A R Y

     MODEL   mod_payoff          OBJECTIVE  obj
     TYPE    NLP                 DIRECTION  MAXIMIZE
     SOLVER  CONOPT              FROM LINE  163

**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      2 LOCALLY OPTIMAL
**** OBJECTIVE VALUE               0.0000

 RESOURCE USAGE, LIMIT          0.023      1000.000
 ITERATION COUNT, LIMIT         4         10000
 EVALUATION ERRORS              0             0


    C O N O P T 3   version 3.14S
    Copyright (C)   ARKI Consulting and Development A/S
                    Bagsvaerdvej 246 A
                    DK-2880 Bagsvaerd, Denmark

 Using default options.


    The model has 5 variables and 6 constraints
    with 11 Jacobian elements, 5 of which are nonlinear.
    The Hessian of the Lagrangian has 1 elements on the diagonal,
    1 elements below the diagonal, and 2 nonlinear variables.

 ** Optimal solution. There are no superbasic variables.


 CONOPT time Total                            0.004 seconds
   of which: Function evaluations             0.000 =  0.0%
             1st Derivative evaluations       0.000 =  0.0%

 Workspace           =     0.03 Mbytes
```

```
    Estimate         =     0.03 Mbytes
    Max used         =     0.01 Mbytes


**** REPORT SUMMARY :         0     NONOPT
                              0 INFEASIBLE
                              0  UNBOUNDED
                              0     ERRORS
GAMS Rev 230  WEX-VIS 23.0.2 x86/MS Windows                   10/03/14
18:26:06 Page 6
eps-Constraint Method for Multiobjective Optimization (EPSCM,SEQ=319)
E x e c u t i o n


----    171 no optimal solution for mod_payoff
**** Exec Error at line 171: Execution halted:


EXECUTION TIME       =        1.060 SECONDS      4 Mb  WIN230-230 Feb
12, 2009


USER: GAMS Development Corporation, Washington, DC   G871201/0000CA-ANY
      Free Demo,  202-342-0180,  sales@gams.com,  www.gams.com   DC0000


**** FILE SUMMARY

Input                         \\myhome.itap.purdue.edu\myhome\severet\My
Documents\gamsdir\projdir\
           epscm_permitfee3.gms
Output                        \\myhome.itap.purdue.edu\myhome\severet\My
Documents\gamsdir\projdir\
           epscm_permitfee3.lst

**** USER ERROR(S) ENCOUNTERED
```

Appendix C HEA-1481 Study Survey Instrument

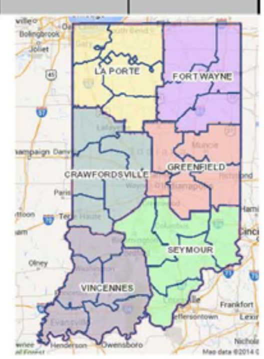
Trucking Permitting Questionnaire

This is the official anonymous survey being conducted by Purdue University, on behalf of the Indiana Department of Transportation, to estimate the impact of House Enrolled Act 1481 (overweight vehicle permit fees) on Indiana's modal distribution and economic development and competitiveness. Please complete this survey as best you can by June 9, 2014.

Section 1: Company Information

1. Please complete the following table to the best of your knowledge with the number of trucks and the average age of those trucks that make up your fleet:

Combination Truck Classification	Description	Approximate # of Trucks	Approximate Average Age
Five-Axle Single-Trailer Trucks	All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit		
Six or More Axle Single-Trailer Trucks	All vehicles with six or more axles consisting of two units, one of which is a tractor of straight truck power unit		
Five or fewer Axle Multi-Trailer Trucks	All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit		
Six-Axle Multi-Trailer Trucks	All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit		
Seven-Axle Multi-Trailer Trucks	All seven-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit		
Eight-Axle Multi-Trailer Trucks	All eight-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit		
Nine or More Axle Multi-Trailer Trucks	All vehicles with nine or more axles consisting of three or more units, one of which is a tractor or straight truck power unit		



2. Based on the adjacent map, where is your company located?
   - ☐ LaPorte district
   - ☐ Fort Wayne district
   - ☐ Crawfordsville district
   - ☐ Greenfield district
   - ☐ Vincennes district
   - ☐ Seymour district
   - ☐ Not in the state of Indiana

3. About how many people do you employ? Full Time ___________, Part Time ___________

4. Does your company own facilities for consolidation, warehousing, and/or distribution of goods?
   Yes ☐ No ☐ Don't know ☐

Section 2: Operations Information

5. Please complete the following table by placing a check mark in the approximate proportion (check one box in each row):

	0-20%	20-40%	40-60%	60-80%	>80%	N/A
a. Proportion of annual trips that are empty haul						
b. Proportion of annual trips that require an overweight vehicle permit						
c. Proportion of operating expenses that covers the cost of overweight vehicle permits						

The next few questions consider the type of goods that you transport and any permits you may be purchasing. Please refer to the following definitions:

Agricultural commodities: Agricultural products in their most basic form going from the farm to the first market. These do not include processed items such as corn syrup, oils, or flour or items used in the production of agricultural products such as fertilizer or seed. Examples include corn and soybeans.

Metal commodities: Metal products in their most basic form going from a mill to the first customer. These do not include manufactured parts going from a manufacturer or a supplier to another customer or items used in the production of metal products such as ore or scrap metal. Examples include metal coils or plates.

Non-divisible goods: Vehicles or loads exceeding the size or weight limits which, if separated into smaller loads or vehicles, would compromise the intended use of the good or vehicle, destroy the value of the load, or require more than 8 work hours to dismantle using appropriate equipment. Examples include construction equipment and wind turbine parts.

Divisible goods: Loads that can be broken down into smaller pieces. Examples include coal, processed goods like cereals, and liquids.

6. Please complete the following table regarding the type of goods/commodities your company carries. For goods that you transport, please indicate the approximate average trip distances.

Good	Does your company transport this good through Indiana? (Yes or No)	Approximate average trip distance through Indiana (miles)
a. Non-divisible overweight goods		
b. Agricultural Commodities		
c. Metal Commodities		
d. Divisible goods other than agricultural and metal commodities		
e. Non-divisible goods that are not typically overweight (i.e. do not require a permit)		

7. About how many pounds of goods do you transport annually? ________________________lbs

8. If you transport agricultural commodities, about what percentage of your total shipments are agricultural commodities? ____%

9. If you transport metal commodities, about what percentage of your total shipments are metal commodities? ____%

10. On average, about how many trips do you make in a typical month? __________________trips

11. On average, how often do you replace a truck in your fleet?
Less than 5 years ☐ 5-10 years ☐ 10-15 years ☐ More than 15 years ☐

12. On average, do most of your loads travel the same route (or the same few routes)?
Yes ☐ No ☐ Don't know ☐

13. Prior to 2013, have you purchased Michigan Train permits (aka Special Weight permits—permits for vehicles up to 134,000 lbs on the Extra Heavy Duty Highway network for a 24-hour period)?
Yes ☐ No ☐ Don't know ☐

    a. If yes, what goods were you transporting most often? ___________________________

    b. If yes, what vehicle configurations did you use? Please check all that apply:
    ☐ 5-axle ☐ 6-axle ☐ 7-axle ☐ 8-axle ☐ 9 or more axle

14. Since the passage of House Enrolled Act 1481, have you purchased Michigan Train permits (aka Special Weight permits—permits for vehicles up to 134,000 lbs on the Extra Heavy Duty

Highway network for a 24-hour period)?
Yes ☐ No ☐ Don't know ☐

15. Prior to this survey, were you aware of new overweight commodity permits—available since June 1, 2013—for overweight divisible loads of agricultural goods (up to 97,000 lbs) or metal goods (up to 120,000 lbs)? Yes ☐ No ☐

16. Since the passage of House Enrolled Act 1481, have you purchased overweight commodity permits for agricultural (up to 97,000 lbs) or metal (up to 120,000 lbs) goods?
Yes ☐ No ☐ Don't know ☐
    a. If yes, were they agricultural or metal commodities? Metal ☐ Agriculture ☐
    b. If yes, about how much do you estimate your company saves annually by using overweight divisible loads? $ ______________________________
    If you wish, you may provide an explanation (optional)
    ____
    ____
    c. If yes, what vehicle configurations did you use? Please check all that apply:
    ☐ 5-axle ☐ 6-axle ☐ 7-axle ☐ 8-axle ☐ 9 or more axle

17. If divisible load permits were available for your industry, would you consider investing in new equipment or altering your existing equipment to take advantage of these permits?
Yes ☐ No ☐ Don't know ☐

Please complete *Section 3: Choice Sets* **ONLY** if you transport metal or agricultural commodities. Otherwise, please proceed to Question 22.

Section 3: Stated Choice Questions for Agricultural and Metal Commodity Carriers

The following questions include a collection of hypothetical scenarios developed by the Purdue research team. People sometimes respond differently to hypothetical situations than they would in real life situations, most likely because they don't have to follow through immediately.

Although the following scenarios are hypothetical, policy decisions may be influenced based on the results of this survey. It is important that the results from this survey are accurate to better inform INDOT before making additional permitting rules. We would like you to answer the questions as if you were really faced with these decisions for a typical load that your company already transports.

Section 3.A: Annual Permit Collection Scenario

18. Would you be willing to purchase an ESAL-based annual permit for overweight divisible loads that is tied to your quarterly tax filings (for reporting mileage)? Yes ☐ No ☐ Don't know ☐

Section 3.B: New Investment Scenario

Suppose INDOT plans to offer annual overweight divisible load permits free of any ESAL-mile based fee for those vehicles which do not cause additional damage to pavements and bridges beyond that of 80,000 lb vehicles (which do not require permits). INDOT would charge an annual administrative fee of $20 per vehicle per route to verify the ESAL-equivalent of the vehicle, address the load rating of any bridges on the route, etc. Your company would need to purchase, retrofit, or otherwise own vehicles that could be configured and loaded to 2.4 ESAL or below.

19. Are you willing to invest **X** dollars per vehicle for retrofits or new equipment to take advantage of the proposed annual permits? (**X** will randomly be assigned $5,000; $10,000; or $15,000. Each respondent will only receive one of the three values) Yes ☐ No ☐

    a. How certain are you that you would actually make this choice (to invest this amount or not) on a scale of 1 to 5, where 1 is "very uncertain" and 5 is "very certain"?
    1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

    b. If yes, how would your company's fleet change? (examples: purchase more 9-axle vehicles, or add axles to existing 6-axle vehicles)
    ____
    ____

    c. If no, why are you not willing to invest?
    ____
    ____

Section 3.C: Block Permits Scenario

Suppose INDOT plans to offer permits for a limited number of blocks of 500 ESAL-miles for carrying overweight divisible loads over 2.4 ESAL. Your company could use the block(s) you purchase in any combination so that the total number of ESAL-miles used does not exceed the number of blocks multiplied by 500 ESAL-miles—for example, you could choose to lower the ESAL-value of your vehicles or travel fewer miles as appropriate to maximize your use of the purchased block(s). The first 2.4 ESAL for any vehicle is not counted toward using your block.

20. How many 500 ESAL-mile blocks would your company be likely to request annually for your entire fleet? ____

    a. How certain are you that you would actually request this number of blocks on a scale of 1 to 5, where 1 is "very uncertain" and 5 is "very certain"?
    1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

21. What is the maximum price you would be willing to pay in total for all of the ESAL-mile blocks you indicated you would likely request in Question 20? $______________________

    a. How certain are you that you would actually pay this amount on a scale of 1 to 5, where 1 is "very uncertain" and 5 is "very certain"?
    1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Section 4: Comments

22. Please provide any additional comments, suggestions, or concerns you may have for the Purdue research team regarding the survey. Comments will be summarized and provided to INDOT.
    ____

Thank you for your participation.

Appendix D Follow-up Survey Instrument

Trucking Permitting Questionnaire

This is the official anonymous survey being conducted by Purdue University, on behalf of the Indiana Department of Transportation, to estimate the impact of House Enrolled Act 1481 (overweight vehicle permit fees) on Indiana's modal distribution and economic development and competitiveness. Please complete this survey as best you can.

Section 1: Company Information

1. Please complete the following table to the best of your knowledge with the number of trucks and the average age of those trucks that make up your fleet:

Combination Truck Classification	Description	Approximate # of Trucks	Approximate Average Age
Five-Axle Single-Trailer Trucks	All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit		
Six or More Axle Single-Trailer Trucks	All vehicles with six or more axles consisting of two units, one of which is a tractor of straight truck power unit		
Five or fewer Axle Multi-Trailer Trucks	All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit		
Six-Axle Multi-Trailer Trucks	All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit		
Seven-Axle Multi-Trailer Trucks	All seven-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit		
Eight-Axle Multi-Trailer Trucks	All eight-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit		

2. About how many people do you employ? Full Time __________, Part Time __________

Section 2: Operations Information

3. About how many tons of goods do you transport annually? ______________________tons
4. About how many miles, on average, does your fleet travel in a year? ________________miles
5. On average, how often do you replace a truck in your fleet?
   Less than 5 years ☐ 5-10 years ☐ 10-15 years ☐ More than 15 years ☐
6. If divisible load permits were available for your industry, would you consider investing in new equipment or altering your existing equipment to take advantage of these permits?
   Yes ☐ No ☐ Don't know ☐

Section 3: Stated Choice Questions for Agricultural and Metal Commodity Carriers

The following questions include a collection of **hypothetical scenarios** developed by the Purdue research team. People sometimes respond differently to hypothetical situations than they would in real life situations, most likely because they don't have to follow through immediately.
Although the following scenarios are hypothetical, policy decisions may be influenced based on the results of this survey. It is important that the results from this survey are accurate to better inform

INDOT before making additional permitting rules. **We would like you to answer the questions as if you were really faced with these decisions for a typical load that your company already transports.**

Section 3.A: Annual Permit Collection Scenario

7. Would you be willing to purchase an ESAL-based annual permit for overweight divisible loads that is tied to your quarterly tax filings (for reporting mileage)? Yes ☐ No ☐ Don't know ☐

Section 3.B: New Investment Scenario

Suppose INDOT plans to offer annual overweight divisible load permits free of any ESAL-mile based fee for those vehicles which do not cause additional damage to pavements and bridges beyond that of 80,000 lb vehicles (which do not require permits). INDOT would charge an annual administrative fee of $20 per vehicle per route to verify the ESAL-equivalent of the vehicle, address the load rating of any bridges on the route, etc. Your company would need to purchase, retrofit, or otherwise own vehicles that could be configured and loaded to 2.4 ESAL or below.

8. Are you willing to invest **X** dollars per vehicle for retrofits or new equipment to take advantage of the proposed annual permits? (**X** will randomly be assigned $5,000; $10,000; or $15,000. Each respondent will only receive one of the three values) Yes ☐ No ☐

   a. How certain are you that you would actually make this choice (to invest this amount or not) on a scale of 1 to 5, where 1 is "very uncertain" and 5 is "very certain"?
   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Section 3.C: Block Permits Scenario

Suppose INDOT plans to offer permits for a limited number of blocks of 500 ESAL-miles for carrying overweight divisible loads over 2.4 ESAL. Your company could use the block(s) you purchase in any combination so that the total number of ESAL-miles used does not exceed the number of blocks multiplied by 500 ESAL-miles—for example, you could choose to lower the ESAL-value of your vehicles or travel fewer miles as appropriate to maximize your use of the purchased block(s). The first 2.4 ESAL for any vehicle is not counted toward using your block.

9. How many 500 ESAL-mile blocks would your company be likely to request annually for your entire fleet? ______________________________

   a. How certain are you that you would actually request this number of blocks on a scale of 1 to 5, where 1 is "very uncertain" and 5 is "very certain"?
   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

10. What is the maximum price you would be willing to pay in total for all of the ESAL-mile blocks you indicated you would likely request in Question 9? $______________________

    a. How certain are you that you would actually pay this amount on a scale of 1 to 5, where 1 is "very uncertain" and 5 is "very certain"?
    1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Section 4: Comments

Please provide any additional comments, suggestions, or concerns you may have for the Purdue research team regarding the survey. Comments will be summarized and provided to INDOT.

____

____

Thank you for your participation.

VITA

VITA

Stephanie R. Everett was born in Tampa, Florida on March 23, 1988 to Janet and Larry Everett. She received her Bachelor of Science in Engineering in May 2010 from Duke University, where she studied Civil and Environmental Engineering and completed a minor in Religion. Stephanie followed in her mother's footsteps (BSCE '76, MSCE '78) when she arrived at Purdue University in August 2010. As a Ross Fellow in the Transportation Engineering and Infrastructure Systems group within the School of Civil Engineering, Stephanie completed her Master of Science in Civil Engineering degree in May 2012. She has conducted research in a variety of areas including performance based programming, ex-post facto program evaluation, lane-use management, and overweight vehicle operations. Stephanie's current interests are focused on transportation funding, investment decision making, and systems evaluation. Stephanie has served as a Young Member on the Transportation Research Board's Standing Committee on Transportation Programming and Investment Decision-Making (ADA50); she is currently the Committee Research Coordinator for that group.

PUBLICATIONS

PUBLICATIONS

Everett, S., Y. Xiong, K. C. Sinha, and J. D. Fricker. Ex Post Facto Evaluation of Indiana's Highway Investment Program: Lessons Learned. *Transportation Research Record 2345*, 24 – 30. 2013.

Everett, S. R., Y. Xiong, J. D. Fricker, and K. C. Sinha. *Measurement and Monitoring of the Performance of Highway Investment*. Publication FHWA/IN/JTRP-2013/16. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2013. doi: 10.5703/1288284315218.

Everett, S. Driver Behavior at Freeway Interchanges with Horizontal Signing. *Compendium of Student Papers: 2009 Undergraduate Transportation Scholars Program*. Southwest Region University Transportation Center. Report No. SWUTC/09/476660-00003-2. October 2009.
<http://swutc.tamu.edu/publications/technicalreports/compendiums/476660-00003-2.pdf>