AN EVALUATION OF THE LIFT AXLE REGULATION (WAC 468.38.280) IN WASHINGTON

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16. ABSTRACT

The lack of uniformity in lift axle regulations and practices among states and provinces hinders the efficiency of commercial vehicle operations. Some jurisdictions ban their use altogether. The objective of this study is to determine whether current lift axle regulations as stated in WAC 468.38.280 are still appropriate, given (1) other state or provincial practices, (2) associated safety concerns, (3) pavement damage due to misuse, and (4) the economic implications of regulatory changes.

On the basis of the conclusions, a number of recommendations can be made. Efforts should focus on improving the use of existing enforcement resources and personnel. Concurrent with the change in enforcement practices, efforts should be made to change the fee/fine structure to reduce or eliminate the benefit achieved from operating illegally. Effort should also be made to establish common specifications among the states or provinces that have comparable regulations. Additional data collection describing lift axle use is recommended.

On the basis of the information collected through this project, a complete ban of lift axles cannot be justified at this time. This conclusion is based on (1) a lack of definitive safety-related data that prove lift axles are a safety risk, (2) a lack of definitive data that prove that lift axles are either being raised inappropriately or are over/underloaded and the extent to which this is occurring, and (3) a lack of quantitative data that describe the economic impacts to the trucking industry of banning lift axles. Additional specifications in the regulation are not recommended because they would only serve to (1) complicate the enforcement procedure, (2) increase the compliance burden for the industry and (3) ultimately lead to non-enforcement of these requirements.

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Lift Axle Regulations

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EXECUTIVE SUMMARY

The lack of uniformity in lift axle regulations and practices among states and provinces hinders the efficiency of commercial vehicle operations. Some jurisdictions ban their use altogether. The purpose of a lift axle is to provide additional axle support when a truck is carrying a load that is heavier than was originally intended for the vehicle configuration. Without a lift axle, the load would have to be carried on a configuration with additional permanent axles or on a larger vehicle(s) (e.g., the load would be carried in two trailers instead of one).

For the trucking industry, lift axles provide several benefits. Lift axles allow the trucker to carry substantially higher payloads for a small increase in vehicle cost. Because lift axles can be raised when the truck is empty or the load is sufficiently light to be supported by the existing fixed axles, they allow the trucker to (1) consume less fuel, and (2) save on tire wear and tear. In addition, lift axles, when lowered, can provide improved traction when better off-road mobility or traction on icy roads or inclines is needed. (1)

Lift axles benefit regulatory agencies in that these devices reduce pavement damage due to repetitive, heavy truck loads. Additional axles help to distribute the truck's load across the pavement surface, thus minimizing damage.

However, several factors may prevent the realization of these positive effects by either group.

- When deployed, lift axles reduce vehicle turning capabilities and may cause the vehicle to jackknife if the roadway is slippery. If the axles are raised through the turn, the truck's stability is compromised, and the chance of a rollover is increased.

- Uneven terrain often results in unintended weight distribution across the axles. If too much weight is supported by the lift axle, safety is compromised.
- The proportion of the load carried by the lift axle is often controlled by the truck driver. If the axle is deployed too far, it may carry too much of the load; if the axle is not deployed far enough, the other axles may be overloaded.
- It is very difficult for regulatory agencies to enforce compliance with lift axle regulations. This is further exacerbated by those in the trucking industry who lower the retractable axle when approaching a weigh facility to meet the legal weight requirements, and raise the axle after clearing the weigh facility.

RESEARCH APPROACH

Data collection was accomplished through several methods. First, a comprehensive literature review provided (1) a description of current lift axle use, including associated safety, pavement, and misuse problems, and (2) a summary of Washington regulations affecting lift axle use. Second, informal interviews provided (1) additional insight regarding lift axle use, and a summary of other state and provincial lift axle practices and regulations. In addition, secondary information was collected at two weigh facilities to quantify the extent of lift axle use.

CONCLUSIONS

A summary of the conclusions reached in this report are provided below.

Vehicle Damage

- No quantitative assessment exists to describe the proportion of repair work that results from lift axle use.

- The collection of these data would be difficult, as repairers see no real benefit from them.

- If substantial vehicle damage problems did result from lift axle use, this issue would most easily be corrected by the trucking industry rather than by regulatory action. High repair costs would decrease the benefit of using lift axles and consequently reduce profit. A reduction in profit would discourage lift axle use.

Safety

- Safety-related information is available regarding vehicular behavior in controlled environments.

- Historical, in-service safety-related data are lacking.

- This additional information,.in-service safety-related data on lift alxes, is needed.

Pavement/Bridge Deterioration

- Theoretical information regarding increases or decreases in pavement/bridge deterioration rates is easily obtainable for a variety of truck configurations.

- Information is lacking on the extent of lift axle use in Washington and, hence, potential increases or decreases in pavement/bridge deterioration rates.

- Information is lacking on the proportion of overweight violations that involve lift axles.

- Information is lacking on overweight violations that involve axle groups that consist of three of more axles with a common suspension system. Thus, neither an assessment of the proportion of lift axle involved in weight violations nor the total weight violations can be determined.

- For a range of pavement structures and using AASHTO load equivalency factors for all axles on a typical concrete truck, the total pavement damage increases by a factor of three when the lift axle is raised when it should be down. When the tandem and lift axles are isolated (steer axle ignored), the estimated change in pavement damage is 7 to 10 times higher for a fully loaded concrete truck (based on pavement elastic analysis). For the rear tandem and associated lift axles of a fully loaded chip truck, the estimated change in pavement damage is 5 to 6 times higher (again, based on pavement elastic analysis).

Economics

- Current regulatory fines are not high enough to (1) discourage illegal practice and (2) compensate for the pavement damage that results from the heavy load.

- Current regulatory fees (i.e., overweight permits) seem low enough to encourage legal operation but do not compensate for pavement damage that results from the heavy load.

- Theoretical information regarding economic savings or expenditures that results from changes in lift axle use in Canada is obtainable for a variety of truck configurations.

- Information is lacking on the extent of lift axle use in Washington and, hence, the potential economic impacts to various sectors of the trucking industry.

- Lift axle use should not be restricted on the basis of configuration (or more generally, industry type). Such restriction could be viewed as an infringement on the right to attain economic benefits unless definitive safety-related or pavement-related data indicate that lift axle use should be restricted by configuration. Definitive data currently do not exist.

Industry Use

- Definitive, comprehensive data that describe the extent of lift axle use by industry type do not exist. Such data, if obtained, would need to account for operating trends within the trucking industry.

Enforcement

- Enforcement personnel and time are limited and close monitoring of lift axle use is difficult.

Uniformity Among States And Provinces

- Common methods for regulation exist among several states, but these states differ in their specifications under these regulations.

- The benefits that might be attained through uniformity among states and provinces are not well defined.

RECOMMENDATIONS

On the basis of the conclusions outlined above, a number of recommendations can be made.

- Most importantly, efforts should focus on improving the use of existing enforcement resources and personnel. This improvement could include selected random days on which to focus enforcement on lift axle compliance or co-location of portable scale vans so that a sufficient number of portable scales exist to weigh larger configurations. By conducting random spot checks that focus on specific compliance areas (i.e., lift axles, tridems, and quads), non-compliance becomes more challenging, and yet little time is taken away from regular weight enforcement activities.
- Concurrent with the change in enforcement practices, efforts should be made to change the fee/fine structure to reduce or eliminate the benefit achieved from operating illegally. This change in the fee/fine structure may require legislative action. Comprehensive work has been done in Washington state to support these changes.
- Effort should be made to establish common specifications among the states or provinces that have comparable regulations. This would ease the compliance burden for the trucking industry and might simplify enforcement by reducing the number of discrepancies encountered. Effort should not be wasted on achieving uniformity among jurisdictions that have differing methods of regulation, as the degree of benefit that would be obtained through uniformity is unclear.
- Additional data collection is recommended. Data that would be helpful in evaluating lift axle use include (1) the extent of lift axle use by truck type, (2) the proportion of lift axles involved in overweight violations, (3) a

better sampling of overweight violations (to include trucks with axle groups of three or more axles with a common suspension system), and (4) safety-related data. In addition, cooperative efforts should be undertaken with the trucking industry to better define the economic benefit achieved through the use of lift axles.

On the basis of the information collected through this project, a complete ban of lift axles cannot be justified at this time. This conclusion is based on (1) a lack of definitive safety-related data that prove lift axles are a safety risk, (2) a lack of definitive data that prove that lift axles are either being raised inappropriately or are over/underloaded and the extent to which this is occurring, and (3) a lack of quantitative data that describe the economic impacts to the trucking industry of banning lift axles. Partial bans or restrictions on lift axle use are not recommended (even though several states and provinces limit lift axle use in this way). Restrictions by configuration or industry type may be viewed as an unfair economic advantage for certain sectors of the industry.

Additional specifications in the regulation are not recommended. Having additional weight, spacing, configuration, or equipment requirements for the lift axle would only serve to (1) complicate the enforcement procedure, (2) increase the compliance burden for the industry and (3) ultimately encourage non-enforcement of these requirements.

CHAPTER 1
INTRODUCTION

Retractable (lift) axles were introduced in North America in the early 1970s as a means of increasing payload without exceeding regulatory weight limits. Their use has grown steadily. State and provincial governments in the U.S. and Canada have since developed guidelines to regulate their use. However, due to a lack of definitive information about the impacts of lift axles on the safety and pavement wear or the economic impacts experienced by the trucking industry, the result has been a highly variable, non-uniform set of regulations in North America.

The current Washington Administrative Code (WAC) governing lift axles is:

> ***WAC 468.38.280 Special Equipment (Amended 1993)*** *Special equipment employing axle groupings other than the conventional single or tandem axle must first be approved by the department before permits will be granted authorizing the unit to operate on state highways.*
> *A retractable axle carrying weight allowed under RCW 46.44.041 shall have a manufacturer's rating of at least 10,000 pounds, shall be self-steering, and shall have the capacity to be activated only from a location out of reach of the driver's compartment: Provided, the requirement that controls be activated only from a location out of reach of the driver's compartment shall not apply to vehicles equipped with hydraulically or pneumatically loaded lift axles that cannot be activated when the vehicle is in motion. Any variable control used to adjust axle loadings by regulating air pressure or by other means must be out of reach of the driver's compartment; And Provided Further, The requirement that the retractable axle shall be self-steering does not apply to a truck/tractor where the retractable axle equipped with four tires is used to create a tandem and the distance between the drive axle and the retractable axle is no greater than 60 inches. The self-steering requirement shall also not apply to a trailing unit where the distance between a fixed axle and the retractable axle is no greater than 60 inches.*

The Washington State Department of Transportation (WSDOT) conducted this study, to examine current regulations to ensure that they best serve the needs of the trucking industry, protect the state's infrastructure investment, and provide an adequate level of safety.

More specifically, this study includes the following:

- a comprehensive description of lift axle types and configurations,

- a summary of vehicle stability and integrity problems noted with the use of different lift axle types and locations,
- a summary of safety problems associated with lift axle use,
- a summary of pavement impacts caused by the use or misuse of lift axles,
- a comprehensive summary of other state and provincial lift axle practices and regulations, and
- possible recommendations for revision of the current WAC with regard to lift axle use.

BACKGROUND STATEMENT

The purpose of a lift axle is to provide additional axle support when a truck is carrying a load that is heavier than was originally intended for the vehicle configuration. Without a lift axle, the load would have to be carried on a configuration with additional permanent axles or on a larger vehicle(s) (e.g., the load would be carried in two trailers instead of one). While both the trucking industry and regulatory agencies benefit from the use of lift axles, there may also be drawbacks.

For the trucking industry, lift axles provide several benefits. Lift axles allow the trucker to carry substantially higher payloads for a small increase in vehicle cost and weight. Because lift axles can be raised when the truck is empty or the load is sufficiently light to be supported by the existing fixed axles, they allow the trucker to (1) consume less fuel, and (2) save on tire wear and tear. In addition, lift axles, when lowered, can provide improved traction when traveling off-road (on unpaved roadways) or on icy roads or inclines. (1)

Conversely, lift axles may cause serious safety and vehicle damage problems. When deployed, lift axles reduce vehicle turning capabilities and may contribute to a vehicle jackknife if the roadway is slippery. Lift axles may be self-steering, controlled steering, or non-steering; this distinction affects turning capability. If the axles are raised through the turn, the truck's stability is compromised, and the chance of a rollover is increased. This rolling tendency is heightened by the heavier loads that lift axles make possible. Because vehicle length remains constant, the load can be stacked higher; higher loads raises the truck's center of gravity, which in turn increases the rolling tendency. (1)

Additionally, for certain axle configurations, a liftable axle could potentially pose a safety hazard, especially if the lift axle is carrying too much of the overall load. Depending on the lift axle's location, uneven terrain often results in unintended weight distribution across the axles. For example, if the retractable axle is located in the center of the vehicle, and the vehicle crosses a berm, then the retractable axle carries almost all of the vehicle's weight. Under such circumstances, the steering capabilities of the lift axle again may influence the level of safety experienced. (1)

Moreover, this uneven weight distribution can cause vehicle damage, such as cracked vehicle frames, due to load distribution across the frame that defies manufacturer specifications.

Lift axles can benefit regulatory agencies in that these devices potentially reduce pavement damage due to repetitive, heavy truck loads. Additional axles help to distribute the truck's load across the pavement surface, thus minimizing damage. However, two factors may prevent the realization of this positive effect.

First, the proportion of the load carried by the lift axle is often controlled by the truck driver. If the axle is deployed too far, it may carry too much of the load; if the axle is not deployed far enough, the other axles may be overloaded.

Second, it is very difficult for regulatory agencies to enforce compliance with lift axle regulations. This is further exacerbated by those in the trucking industry who lower the retractable axle when approaching a weigh facility to meet the legal weight requirements, and raise the axle after clearing the weigh facility. This practice saves on tire and equipment wear and also improves fuel efficiency. However, illegal travel with the axle inappropriately raised causes increased pavement damage. Representatives of regulatory agencies believe that locating the controls for raising and lowering the lift axle outside the cab may inhibit this practice since current enforcement manpower is too limited to effectively monitor trucks at locations other than the weigh facilities.

Although some states and provinces have banned the use of retractable axles for the reasons described above, Washington allows lift axles (self-steering only) because no *definitive* proof that they should be banned has yet been produced. However, current Washington Administrative Code regulations for lift axle use are based on incomplete knowledge of the axles' impacts.

REPORT PURPOSE AND CONTENTS

The lack of uniformity in lift axle regulations and practices among states and provinces hinders the efficiency of commercial vehicle operations. Some jurisdictions ban their use altogether. Truckers who frequently travel through different states or provinces, with differing regulations, find that the retractable axle quickly loses its benefit. In jurisdictions where the axles are banned or do not meet the state's requirements, the truck must meet legal weight specifications with the axle lifted; drivers who fail to meet these weight specifications are penalized.

The objective of this study is to determine whether current lift axle regulations as stated in WAC 468.38.280 are still appropriate, given (1) other state or provincial practices, (2) associated safety concerns, (3) pavement damage due to misuse, and (4) the economic implications of regulatory changes.

This project will benefit state regulatory agencies and the trucking industry. Regulatory agencies will gain additional information about the safety of lift-axles and their effects on pavement. This information will help policy makers in Washington State and elsewhere.

Insofar as the information gained as a result of this study leads to more uniform lift axle regulations among states and provinces, it will benefit the trucking industry by simplifying operations and allowing them to conform with regulations more easily.

This report includes the following elements: (1) a discussion of current lift axle use, including associated safety, pavement, and misuse problems; (2) a discussion of Washington regulations affecting lift axle use; (3) a summary of other state and provincial lift axle practices and regulations; and (4) possible recommendations for revision of the WAC governing lift axle use.

Following this introductory information, Chapter Two summarizes information obtained through the literature review. Chapter Three reports the findings of the informal interviews with both industry and regulatory representatives. Chapter Four considers the implications of Washington regulations for lift axle use. Chapter Five summarizes lift axle regulations in other states and provinces. Chapter Six considers the potential for increased pavement damage through lift axle misuse. Possible recommendations for WAC revision based on the information obtained through the literature review, industry/regulatory interviews, and the national survey are contained in Chapter Seven.

CHAPTER 2
LITERATURE REVIEW

The literature concerning lift axles is extensive. Much of this research originated in Canada, and is a part of the 16-volume "CCMTA/RTAC Vehicle Weights and Dimensions Study." (2) Canadian researchers conducted comprehensive analyses which included the development of regulatory principles for lift axle use in a number of provinces. An overview of these materials, as well as other sources, follows.

For ease of analysis, this literature review is organized around five topics: (1) lift axle design and use, (2) vehicle damage, (3) safety, (4) pavement and bridge considerations, and (5) economic issues.

LIFT AXLE DESIGN AND USE

Before considering the appropriateness of Washington state's lift axle regulations, it is important to understand (1) lift axle operation; (2) users of lift axles (i.e., those who would be most directly affected by any regulatory change); and (3) how lift axles are used (i.e., common axle configurations). In addition to the general description of lift axle use, specific design or operational recommendations summarized in the literature are examined.

Lift Axle Operation

A lift axle is a non-fixed axle located on a tractor, semitrailer, or trailer that can be retracted or lifted from contact with the road. A literature review uncovered several variations in lift axle design, including the following: (1) method of retraction, (2) steering capability, and (3) additional safety features.

Nearly all lift axles are deployed and retracted with hydraulic cylinder or air bag technology. In both cases, a change in pressure (hydraulic fluid pressure or air pressure) `loads' and `unloads' the liftable axle. Increased pressure in the lift mechanism lowers the lift axle. When it contacts the roadway, the lift axle begins to support a proportion of the total vehicle load. The greater the pressure applied to the lift mechanism, the greater the load proportion supported by the lift axle.

Controls for raising and lowering the lift axle or regulating the proportion of the load carried by the lift axle can be installed in a number of ways. The most common installations include (1) having both the deployment and regulating switch inside the cab of the truck, (2) having both the deployment and regulating switch outside of the cab, and (3) having the deployment switch inside the cab and having the regulating switch outside of the cab. (In Washington, both switches are required to be outside of the cab.) Some lift axles are designed to carry a set amount of weight and, hence, require no regulating switch.

Steering capabilities among lift axles range widely; they may be categorized into three broad types: (1) non-steerable axles, (2) self-steerable axles, and (3) steerable axles.

Because they provide no steering capability, non-steerable axles suffer the greatest resistance as the vehicle turns. Although non-steerable axles adequately support the proportional load, they may encourage the practice of lifting the retractable axle around corners to improve maneuverability. Axle retraction on a vehicle meeting its gross weight limits overloads the fixed and drive axles, and increases pavement damage.

To improve cornering and maneuverability, self-steering axles have wheels that articulate, or steer, under the action of forces developed between the tire and the road surface. In addition to improving maneuverability around corners, self-steering axles reduce trailer off-tracking, reduce tire scrub, extend tire life, improve fuel economy, and reduce stress on the trailer frame and its components. Different designs allow varying degrees of steering capability.

Two common steering mechanisms for self-steering axles are (1) the turntable steering mechanism, and (2) the automotive steering mechanism. A third type, the dual tire with inclined kingpins, has been deemed unsafe. (3) The turntable mechanism uses a large-diameter roller bearing to provide steering. The automotive mechanism uses a vertical kingpin and tie rod assembly.

Self-steering axles come in a range of load capacities and track widths. Load capacities typically range from 13,200 to 33,000 pounds (6 to 15 metric tons). Track widths range from 7.92 to 8.58 feet (2.4 to 2.6 meters), outer dimension. Generally, self-steering axles have a locking mechanism to fix the axle in the `zero steer' position when the vehicle experiences adverse road conditions or travels in reverse. This locking mechanism may be designed to operate in the cab.

For normal operation, self-steering axles should be equipped with a self-centering device or centering force mechanism. Centering mechanisms resist steering until some minimum level of side force on the tire-roadway interface develops. As a result, the self-steering axle behaves as a fixed axle prior to steering. Once steering begins, the axle assumes the self-steer mode. Centering mechanisms return the axle to the `zero steer' position automatically and offset unbalanced braking between wheels. Without this device, the internal friction within the self-steering axle could freeze the axle in a self-steer position.

Steerable axles, the third type, provide a compromise between the improved handling of self-steer axles and the stability and control of non-steer axles. Steerable axles are controlled by a hydraulic steering mechanism coupled to the front axle steering system.

Nearly all lift axles are equipped with single tires. Carriers find that for the amount of weight that is carried by the lift axle, single tires can meet the regulatory requirements for maximum pounds per inch of tire width. Lift axles equipped with dual tires exist but are rare.

<u>Axle Users</u>

The literature review revealed that liftable axles are most commonly used by haulers of heavy, dense freight. Freight haulers that carry lighter materials usually maximize the available cubic space before having to increase their allowable weight limits (i.e., "cubing out" before "grossing out").

A variety of vehicle body styles, including the following, can utilize liftable axles:

- van,
- refrigerated van,
- flat bed,
- tank,
- dump,
- hopper,
- log,
- low bed,
- wood chip, and
- cement.

Axle Configurations

A number of factors, including the following, influence the use of lift axles:

- type of power unit (truck or tractor),
- number and type of trailers,
- number of axles,
- manner of combination (dollies, drawbars, fifth wheels),
- suspension systems,
- axle spreads, and
- wheelbase.

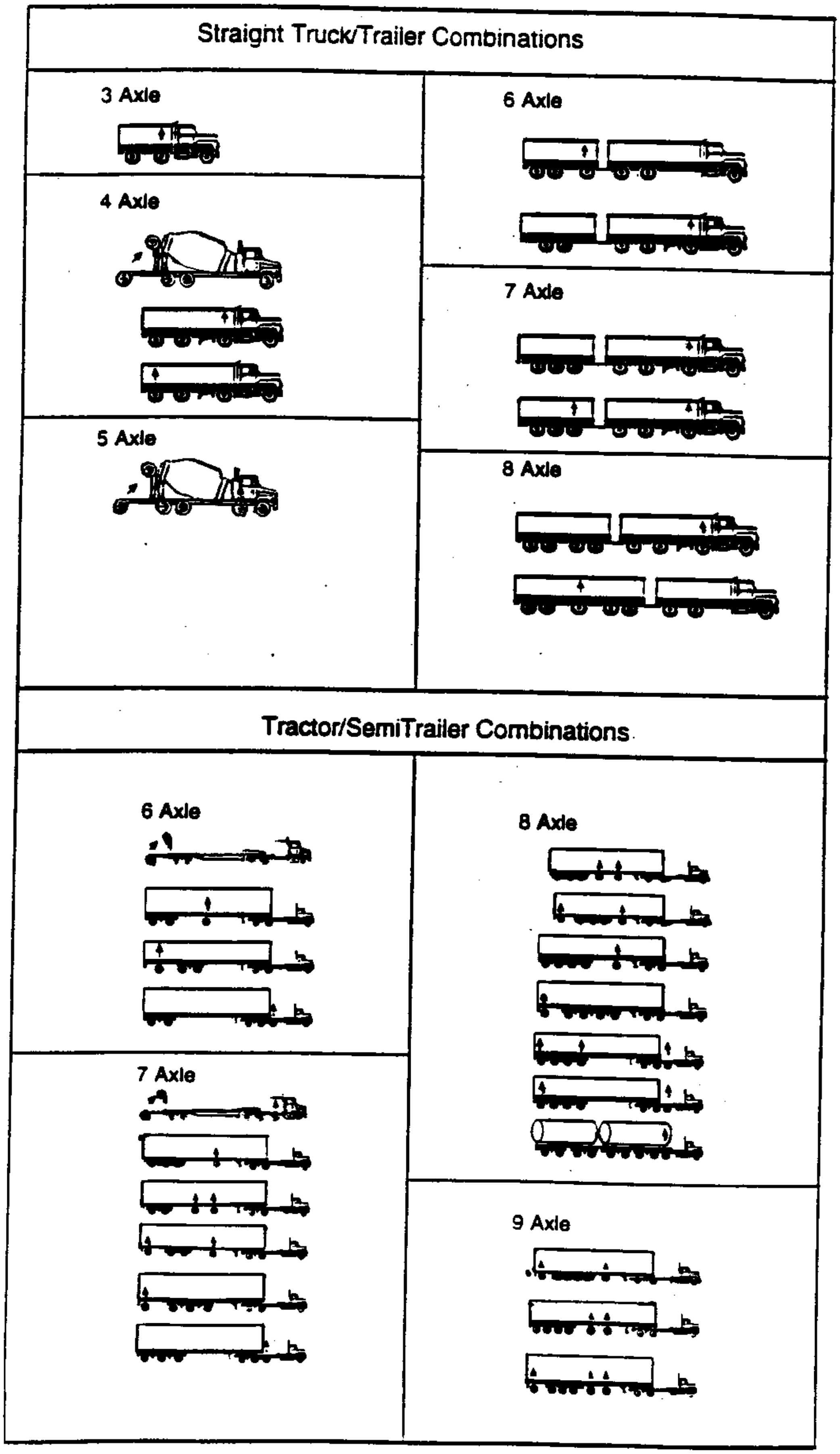
Table 1 provides examples of common lift axle configurations for straight and combination trucks. Note the variety of configurations.

Lift Axle Design and Operation Recommendations

In addition to general descriptions of current lift axle design and operation, the research team found several documents whose purpose is to define an appropriate lift axle design. Ontario Ministry of Transportation, Transportation Technology and Energy Branch, has done extensive work in this area. Two documents in particular have influenced lift axle regulations. They are Billing and Lam's "Development of Regulatory Principles for Straight Trucks and Truck-trailer Combinations," (4) and Billing, Lam and Couture's "Development of Regulatory Principles for Multi-axle Semitrailers." (5)

Both studies rely on computer simulation to assess the performance of a number of truck types and axle configurations. The following variables are considered: lift axle

Table 1. Common Lift Axle Configurations for Straight and Combination Trucks



location, the number of lift axles, and the lift axle's steering capabilities. A number of regulatory recommendations are made based on the performance of each combination.

First, because of compromised vehicle stability, the authors recommend the prohibition of self-steering lift axles for straight trucks, especially if the space between the lift axle and the drive axle is large.

In the case of multi-axle semitrailers, rather than recommending their outright prohibition, guidelines were recommended to account for the compromised vehicle stability. The authors suggest the following:

- Semitrailers should have at least one fixed axle unit.
- Semitrailers should have no more than one liftable axle.
- The liftable axle should be ahead of the fixed axle.

Their recommendations concerning lift axle design and operation follow:

- If the truck is empty, the liftable axle may be raised.
- The lift axle should support an adequate proportion of the load based on the gross weight, number of axles, and axle spacing.
- On uneven roadway surfaces, the lift axle must be capable of controlling its own load automatically. (For example, a bump in the road should cause the air pressure in the lift axle to rise, a hole in the road should cause the air pressure in the lift axle to drop.)
- The lift axle should control its own load over time.
- The lift axle should be self-steering.
- When located at the extreme rear of the vehicle, the lift axle should lift when truck is in reverse to prevent damage to the axle. (Lift axles in this location are designed to trail, but in reverse may turn unexpectedly.)
- The load may be taken off the liftable axle to obtain better traction, but this use should be strictly limited.
- A control device to prevent tampering or misuse of the lift axle should be installed.

For self-steering, as opposed to non-steering lift-axles, the following recommendations apply:

- Steer-centering force requirements should exist.

- The steering mechanism should be able to lock when the truck is traveling at relatively high speeds (greater than 50 km/31 mph), and it should unlock for speeds under 30 km/19 mph.

A related document, "Guide for Maximum Dimensions and Weights of Motor Vehicles and for the Operation of Non-divisible Load Oversize and Overweight Vehicles," (6) has a similar purpose. Produced by the American Association of State Highway and Transportation Officials (AASHTO), this guide defines criteria for lift axle design and operation. These AASHTO guidelines specify that highway-legal vehicles not requiring oversize/overweight permits should be equipped with retractable axles that meet the following criteria:

- All controls must be located outside the cab and inaccessible from the driver's compartment.
- The gross axle weight rating of all retractable devices must conform to the expected loading of the suspension, and shall, in no case, be less than 9,000 pounds (4 metric tons).
- Axles of all retractable devices manufactured or mounted on a vehicle after January 1, 1990 shall be engineered to be self-steering in a manner that will guide or direct the wheels through a turning movement without tire scrubbing or pavement scuffing.
- Tires in use on all such axles shall conform in load rating capacity with relevant state regulations or with Federal Motor Vehicle Safety (FMVS) standards, or with both, as appropriate.
- The retractable axle suspension system shall at all times, for weight computation, distribute the load so that no single axle or combination of axles in the axle group being considered exceeds legal weight limits or the bridge formula ceilings.

Besides AASHTO's effort at the national level, a number of truck manufacturers, lift axle manufacturers, and trucking companies have produced their own literature to recommend design and operation practices. "Boost-A-Load Truck Mixer Operation and Service Manual," published by Challenge-Cook Brothers, Inc., is one example. (7) This document describes the design and proper operation of the lift axles on the mixers in great detail. One feature on these mixers is particularly interesting. For normal operation, the driver must set the calibration knob to agree with the number of cubic yards of material; this calibration regulates hydraulic pressure so that the lift axle carries the appropriate load. Whenever payload is added or removed, the driver must re-adjust the valve setting to ensure that the lift axle continues to support the appropriate load. The Boost-a-Load mixer is designed to remind the driver in case he or she forgets to re-adjust the valve setting. Before the driver can lower the lift axle after dumping all or part of the load, an intercepting electrical circuit requires that the driver depress a reset button next to the load adjustment valve knob. Because the driver must dismount to reset, he or she should also be reminded of the need to adjust the load carried by the liftable axle. This precautionary feature could greatly improve lift axle safety and reduce infrastructure damage due to unequally distributed loads.

VEHICLE DAMAGE CONSIDERATIONS

The literature review yielded little information on vehicle damage as related to lift axle use. Most of the information on this topic was obtained through informal interviews with truck and axle manufacturers, users, and mechanics. This information is found in Chapter Three.

SAFETY CONSIDERATIONS

The configuration and loading of a vehicle influences the level of safety experienced. The addition of a liftable axle, which can affect handling and stability, may reduce safety. A number of specific performance measures can quantify a particular lift axle's impact on safety. (8) The performance measures are defined below.

- **Static roll threshold**—the tractor lateral acceleration at which a vehicle will roll over in a steady turn (it improves as the number of axles increases).
- **High speed off-tracking**—the lateral offset between the path of the tractor's steer axle and the path of the vehicle's last axle in a moderate steady turn improves with longer effective wheelbase and smaller total axle spread. ("Effective wheelbase" is defined as the distance from the

front steer axle to the geometric center of an axle group comprising all non-steering axles in contact with the ground, and "axle spread" is defined as the distance from the first axle group center to the last axle group center.)

- **Load transfer ratio**—the fractional change in load between left- and right-hand tires in an evasive maneuver (indicates how close the vehicle came to lifting off all of the tires on one side, dependent on effective wheelbase).
- **Transient high-speed off-tracking**—the maximum lateral offset between the path of the tractor's steer axle and the path of the vehicle's last axle in a maneuver (indicates potential intrusion into an adjacent lane, dependent on effective wheelbase).
- **Friction demand**—a measure of multiple-trailer axles' resistance to travel around a tight radius turn (describes the minimum level of tire-pavement friction necessary at the tractor drive axles for the vehicle to make the turn without tractor jackknife, dependent on proximity of tires to turn center).
- **Low-speed off-tracking**—the extent of in-board off-tracking of the rearmost trailer from the tractor front axle in a 90°, right-hand intersection turn.
- **Effective overhang ratio**—the distance from the turn center to the rear of the trailer, divided by the semitrailer wheelbase (indicates outswing into adjacent lane when making a 90°, right-hand turn).

These performance measures are referred to in the literature review in the next section. The discussion of safety that follows is divided into three areas: (1) the stability and handling of multi-axle tractor semitrailers, (2) the stability and handling of straight trucks and trucks with trailers, and (3) the safety impacts of axle design.

Multi-axle Semitrailers

The sixteen volume "CCMTA/RTAC Vehicle Weights and Dimensions Study," published by the Roads and Transportation Association of Canada, includes extensive discussion of the safety impacts of multi-axle semitrailers. The "Technical Steering Committee Final Report" summarizes this material. (2)

The stability and control of multi-axle tractor semitrailers are influenced by the following factors:

- Low-speed off-tracking increases as the length of the trailer increases.
- Friction demand increases as the axle spread increases.
- Manufacturer's specifications that limit the load carrying capabilities of lift axles have a greater effect on rollover stability than do specific suspension types.
- Payload center of gravity is the single most powerful determinant of stability and control behavior, static roll stability level, tractor yaw response, high speed offtracking, and braking efficiency.
- Increased axle loading degrades control, static roll stability, tractor yaw response, high-speed off-tracking, braking efficiency, and friction demand.
- The placement of a single liftable (belly axle) near the center of the semitrailer is not observed to degrade control.

Building on these generalized findings, the Roads and Transportation Association of Canada considered the effects of single lift axle as opposed to dual lift axles in its study "Demonstration Test Program: Five, Six and Seven Axle Tractor Semitrailers." (8)

Canadian researchers found that with one axle lowered, vehicle stability is high. More effort was required to maneuver the truck, but these maneuvers could be accomplished in less space than if the axle were raised. However, they felt that the truck style in this case, one with a low center of gravity, had more impact on stability than did axle location. When both axles were lowered, researchers again found that stability was good, but attributable to the low center of gravity, rather than the axles. Maneuvering was more difficult, but again, required less space.

"The Influence of Weights and Dimensions on the Stability and Control of Heavy Trucks in Canada—Part 1" (9) considered the effect of mounting a self-steering, liftable belly axle onto the B-train configuration. (A B-train configuration is a combination vehicle consisting of a tractor and two or three semitrailer where the towed trailer is hitched to a fifth wheel on the frame of the preceding trailer. The results were as follows:

- little impact on the static rollover threshold,
- little impact on high speed off-tracking, however, off-tracking improves mildly if axle is made more resistant to steering,
- little impact on load transfer ratio (if lift axle is made more resistant to steering, load transfer ratio increases),
- little impact on transient high-speed offtracking with belly axle on rear trailer; transient high-speed offtracking is substantially higher with belly axle mounted on lead trailer,
- little impact on low-speed off-tracking, and
- little impact on friction demand with belly axle on rear; severe increase in friction demand with belly axle on lead trailer.

Billing, Lam, and Couture's "Development of Regulatory Principles for Multi-axle Semitrailers" (5) provides guidelines for lift axle use on multi-axle tractor semitrailers. This study uses computer simulation to compare seven different performance characteristics for a variety of axle combinations and configurations.

The Canadian researchers identified two of these performance criteria, friction demand and the effective overhang ratio, as the most important for comparing vehicle stability and ensuring proper axle loading. Rather than developing a vehicle capable of meeting all of the performance criteria (all combinations failed to meet at least one of the performance criteria by a wide margin), they decided that it made more sense to develop a vehicle that would minimize the two most important factors: friction demand and effective overhang ratio. Minimizing these factors confers several benefits:

- Turning and handling capabilities improve because friction demand is minimized.

- Stability improves because the lift axle can remain deployed without compromising turning capabilities (friction demand is improved if the lift axle is raised through the turn but stability suffers).

- There is no possibility of leaving the axle raised after the turn because it is never raised; this minimizes the potential for pavement damage due to overloaded axles.

The foregoing findings are based on vehicles equipped with a non-steering axle. When the axle was converted to a self-steering mode, friction demand improved. The effective overhang ratio was dependent on axle location. When the self-steering axle was located behind the fixed axle, the allowable effective overhang ratio was exceeded. When the self-steering axle was located in front of the fixed axle, the effective overhang criteria were achieved.

Straight Trucks

Using the same computer simulation methodology employed to develop regulatory principles for multi-axle semitrailers, Canadian researchers then turned their attention to straight trucks equipped with lift axles in "Development of Regulatory Principles for Straight Trucks and Truck-trailer Combinations." (4) Their findings follow:

- The friction demand criteria could not be met with either a non-steer or self-steer lift axle deployed on a straight truck.

- Friction demand is improved if a self-steering axle is used in place of a non-steering axle, but not enough to meet the criteria.

- Vehicle handling capabilities decrease as the distance between a lift axle and another axle (either fixed or liftable) increases.

- Vehicle stability and control decrease as the spacing of the lift axle behind the drive axle increases.

- Liftable or self-steering axles severely degrade the yaw stability of straight trucks.

Equipment Specific

Much of the literature on lift axles examines variation in design as a factor in performance.

For example, the Research and Development Division of the Ontario Ministry of Transportation and Communications conducted "Tests of Self-Steering Axles" (10) to compare the performance of fixed single axles to that of fixed tandem (bogie) axles. While this study does not directly address lift axle use, it does address an important design consideration for lift axles. Results are summarized below:

- Both the single and tandem self-steering axles reduced tire scrub.
- The self-steering tandem axle improved off-tracking, the single axle did not.
- Current self-steering tandem axle design could pose a serious risk in situations involving high speed braking and maneuvering.
- The overall performance of the self-steering tandem axle was worse than that of the non-steerable tandem axle when changing lanes on wet asphalt.
- The single, self-steering axle was equivalent to or slightly better than the non-steerable axle in performance and safety; as such, it should be considered as a possible replacement for lift axles. (This substitution would eliminate the need to raise a non-steerable lift axle to achieve better cornering capabilities.)
- When located at either the rear or front of the trailer, the single self-steering axle reduces tire scrubbing; when located at the rear of the trailer, maneuvering capabilities are also improved.

With regard to vehicle control, the majority of high-speed tests revealed little difference between the performance of non-steering and self-steering axles. Overall, however, the performance of self-steering axles was slightly worse than that of non-steering axles. The self-steering tandem axle tended toward instability, but the manufacturer says that this problem can be remedied.

One cautionary note regarding comparisons of self-steering and non-steering axles: there are considerable differences among various self-steer axle designs; this variation makes generalization from this study, "Test of Self-Steering Axles," to other applications inappropriate.

A second study considering differences between self-steer and non-steer axles is "The Influence of Weights and Dimensions on the Stability and Control of Heavy Trucks in Canada—Part 2" (11) published by the Roads and Transportation Association of Canada.

This study's purpose was to investigate the performance of a tractor semitrailer equipped with a self-steer lift axle in the middle of the second trailer during a variety of maneuvers. Examined in that study was the difference in reaction when the self-steering axle is locked (so it performs as a non-steering axle) and unlocked.

As the vehicle attempted a steady turn, rollover occurred at the same time in both self- and non-steer conditions. However, vehicle response was markedly different. When the axle was operating as a non-steer axle, rollover was very smooth. When the axle was operating as a self-steer axle, the trailer oscillated horizontally as the rear axles slid sideways. This motion did not, however, affect the vehicle's rollover threshold because the oscillations did not begin until rollover was imminent.

Next, the Canadian researchers conducted a braking experiment on a pavement with two surface types; this created two different levels of frictional resistance, one on each side of the vehicle. With the vehicle fully loaded, the researchers noted a small but detectable yaw response with the self-steering axle. There was no yaw response in the case of the non-steer axle. With the vehicle unloaded, the researchers noted yaw response in both self- and non-steer conditions; however, the yaw dampened out more quickly when the axle was acting as a non-steer axle. In one instance testing the self-steer axle, the brakes on one side of the axle locked up and the other kept rolling due to the different surfaces; this posed a serious safety problem.

When braking on a turn with a fully loaded vehicle, the vehicle jackknifed when the axle was in both the self- and non-steer conditions. The researchers assumed that the jackknife was caused by a brake lock-up of the tandem axle due to high brake pressure, not by the self-steer axle. With the vehicle unloaded, the self-steering axle locks up at very low braking pressures due to brake lockup. The response for the non-steer case was nearly identical. This finding implies that the steer-centering properties of the self-steer axle do not have a significant effect on stability *in this maneuver.*

The tests for performance on low-speed, tight-radius curves were inconclusive because the friction level on the test road was higher than that predicted on real roads, especially in snowy or icy conditions.

Tests were conducted on undulated roads to see whether self-steering axles steer to a substantial angle when one side of the axle passes over a bump or hole while the other stays on a smooth surface. Included in this test were cobblestones, irregular bumps, and regularly spaced, uniform potholes. Cobblestones and irregular bumps had no effect on axle performance. Potholes produced a small steer angle in the self-steer axle, but the axle quickly returned to the zero steer angle once past the pothole. It is important to remember that axle performance may vary substantially, depending on vehicle configuration. For example, a self-steer axle centered on the semitrailer on a five-axle tractor semitrailer cannot alter the vehicle's overall response because this configuration is very stable. Other vehicle configurations may, however, become susceptible to stability problems when a lift axle is installed. (11)

The safety of self-steer axles was explored in a third study, "Technical Analysis and Recommended Practice for the Double Drawbar Dolly Using Self-Steering Axles." (3) Again, this study does not directly address lift axles but does address an important design consideration for lift axles. In this study, researchers expressed concern about the safety of self-steer axles based on the devices' reaction to unequal forces from the interaction of tire and roadway. Unequal forces on each side of the self-steer axle can result from frozen or poorly adjusted brakes, brake failure on a single side, or variations in road surface friction at the moment of heavy brake application. When unequal forces are applied to the self-steer axle, its angle may change unexpectedly, shifting the direction of the trailer to which it attached.

To this point, our literature review has focused on the performance of self-steer axles that have some degree of centering force to return them to the zero steer position. The extreme case of the self-steer axle design is the "free-steer" or "castering axle" whose wheels are free to spin based on the interactive forces of the tire and road. "The Influence of Rear-Mounted, Caster-Steered Axles on the Yaw Performance of Commercial Vehicles," (12) presented at the Second International Symposium on Heavy Vehicle Weight and Dimensions, examines the safety of free-steer axles.

Free-steer axles are most common on concrete mixers, but are also used on semitrailers designed to transport construction equipment. Both of these truck types often require high maneuverability in confined spaces; free-steering axles make this possible. However, free-steer axles degrade vehicle handling and yaw stability, especially if the axle is located at the extreme front or rear of the vehicle. (12) Advanced castering axle designs may improve performance.

In this study, a unit vehicle (concrete mixer) and a combination vehicle (tractor semitrailer) were tested, each in both loaded and empty conditions. The addition of a free-steering axle to the loaded, unit vehicle degraded handling. Vehicle response destabilized as the load on the lift axle increased. When the unit vehicle was empty, stability was extremely sensitive to lift axle load. As the load on the lift axle was raised, the unit vehicle tended to understeer. At higher axle loadings (6,000 to 8,000 pounds/2.7 to 3.6 metric tons), the critical velocity for safe travel falls to 20 to 25 mph (40.3 kph), even when traveling straight ahead. (12)

Effects on the combination truck were not as severe. For the loaded tractor semitrailer, an increase in the lift axle load slightly increased the distance off-tracked. When the truck was empty, the distance off-tracked was much greater.

This study's overall conclusions include the following:

- Lift axles at the extreme rear of the vehicle, following long trailing arm (booster axles) with free-steering wheels virtually always degraded vehicle handling.

- When installed on unit vehicles, booster axles tended to oversteer and to compromise yaw stability.
- When installed on combination vehicles, booster axles caused excessive steady off-tracking and sluggish trailer response in transient maneuvers.

In all cases, handling was degraded as the axle load was increased (even in the case of a fully loaded vehicle). The researchers suggested that the handling degradation was more attributable to the *design* of the free-steering axle, as opposed to its *position*.

In their conclusion, the Canadian researchers speculated as to the use of other steering technologies for booster axles. They suggested , for example, that the use of a non-steering axle in place of a free-steering axle would improve vehicle stability, especially if the axle were located at the extreme front or rear of the vehicle (thus increasing the effective wheelbase). This increased stability would be due to the side force on the tire at that location, caused by the interaction between the fixed axle and the roadway. Side force improves vehicle stability. Free-steering axles cause no side force. However, this application of non-steering axles would increase tire scuffing to unacceptable levels and would reduce vehicle maneuverability at low speeds. (12)

Consequently, the researchers do not recommend either the non-steering or the free-steering axle; instead they suggested use of a controlled or steerable axle. Steerable axles provide road-tire interaction sufficient to produce a stabilizing side force, yet they do not compromise maneuverability. (12)

PAVEMENT AND BRIDGE CONSIDERATIONS

As stated earlier, carriers that utilize lift axles are limited by weight constraints rather than space constraints ("gross-out" rather than "cube out"). Since vehicle weight is more difficult and time consuming to monitor than available truck volume, carriers complain that it is difficult to load lift-axle equipped trucks to a level close to their allowable gross weight without exceeding allowable axle weights. The results for the carrier are frequent overweight fines at the scales. In Ontario, it is estimated that over two thirds of all weight infractions occur on trucks with liftable axles. (1) The negative repercussions for state and provincial governments go beyond pavement damage to the bridge infrastructure. Overloaded axles can damage bridge decks and the main longitudinal members of short-span bridges.

A number of studies have sought to quantify the relationship between overweight or non-uniform loads and bridge and pavement damage. Selected findings are summarized below.

The key finding of [the] "Effect of Truck Tire Inflation Pressure and Axle Load on Pavement Performance," (13) by researchers at the University of Texas at Austin, was that "the axle load plays a significant role in causing fatigue cracking and subgrade rutting." A four-inch thick surface pavement provided an example. Researchers estimated from their study that a 20 percent increase in axle load would cause a 36 percent reduction in fatigue pavement life and a 50 percent reduction in subgrade rutting life.

The authors of "Axle Group Spacing: Influence on Infrastructure Damage," (14) determined that axle spacings have a significant effect on pavement damage, and that axles in a tandem, tridem or quad axle grouping that do not share the load equally do more pavement damage than those that share the load equally.

Hajek and Agarwal based two recommendations on these findings. First, to prevent structural damage to pavements and bridges, more attention should be focused on axle location (as opposed to gross vehicle weight, axle load, load contact pressure, and dynamic loading effects). This implies a need for regulations governing lift axle placement.

The second recommendation concerns legal limits for single axles. In Canada, legal limits for single-axle load are currently influenced by pavement damage considerations. However, legal limits for gross vehicle weight are influenced by bridge damage considerations. Canadian researchers recommend that single-axle load regulations take into account potential damage to bridge decks and spans, in addition to considerations of pavement damage.

Billing, Lam, and Couture's "Development of Regulatory Principles for Multi-axle Semitrailers" (5), earlier referenced for its safety findings, also contains a good deal of information on pavements. For example, it considers the effects of inappropriate lift axle use (i.e., raising the lift axle when fully loaded). The results, based on analyses of fourteen different multi-axle semitrailer configurations are summarized below.

With the lift axle properly deployed,

- lift axle weights exceeded the Ontario Bridge Formula (OBF) by *as much as* 6.4 percent.

With the lift axle inappropriately raised,

- the increase in the number of equivalent single axle loads (ESALs) ranged from 50 percent to 296 percent, depending on the configuration,
- the vehicle's OBF allowable gross weight was exceeded by *up to* 27 percent, depending on the configuration,
- the OBF allowable drive axle weight was exceeded by *up to* 52 percent, depending on the configuration, and
- the OBF allowable trailer axle weight was exceeded by *up to* 84 percent, depending on the configuration.

These findings point out the serious implications of lift axle misuse for the rate of pavement deterioration. Depending on the amount of truck travel with raised axles, for improved handling around curves or for other reasons, liftable axle use could greatly accelerate pavement deterioration. Moreover, the findings are also applicable to bridge damage, especially in case of severely overweight loads.

Findings in "On the Use of Liftable Axles by Heavy Trucks" (1) are similar. Researchers in this study predicted that the number of ESALs per truck can increase by a factor of between two and four when liftable axles are raised. (For a constant gross vehicle weight, the pavement damage resulting from the increase in ESALs for an overloaded axle is not equally lessened by the reduction in ESALs for the corresponding underloaded axles.) For a number of vehicle configurations, the allowable gross weight of the vehicle, as determined by the Ontario Bridge Formula, would be exceeded by as much as ten metric tons (22,000 pounds). If the vehicle is already overloaded in excess of its allowable gross weight, or if the load is improperly distributed, then Bridge Formula violation is even worse.

Pavement damage was also considered in the CCMTA/RTAC Vehicle Weights and Dimensions Study "Technical Steering Committee Report." (2) A key finding in this study was that a tandem axle plus a lift axle is approximately 15 percent more destructive than an equally loaded, symmetrical tridem. This is because lift axles have a lower legal load limit than do fixed axles.

Mercer and Billing's "Aggregate Truck On-board Weighing Experiment" (15) was conducted to address the overweight problems associated with lift axles. This study postulated that a number of overweight violations are due to an inability to monitor individual axle loads.

The researchers found that when drivers were able to monitor individual axle loads, they achieved (1) better control of their liftable axle load, (2) a substantial reduction in the number of potential overweight charges, and (3) an improvement in the driver's ability to assess whether the truck was in compliance. It is not clear whether the third benefit, improved driver's ability to assess compliance, actually improved compliance.

ECONOMIC CONSIDERATIONS

Carriers favor liftable axles because these devices allow them to increase payloads. For example, the addition of a lift axle to a typical multi-axle semitrailer can increase its payload by up to 32 percent. (Payloads vary, of course, depending on vehicle age, equipment manufacturer, equipment type (e.g., sleepers and extended range fuel tanks), construction material, construction method (e.g., double-walled stainless or single-walled aluminum). (16)

The potential for payload increase is not as substantial for some configurations. However, although liftable axles may not always increase payload, they do provide more latitude with regard to load placement. This can result in substantial savings in time and other benefits.

Because the benefits afforded by lift axles are variable, it follows that a regulation reducing allowable liftable axle loads is unlikely to have an equal impact on all truck combinations and configurations.

This variability is supported in the "Operating Costs of Trucks in Canada—1988." (17) Axle maintenance costs are highly dependent on the number of axles on the vehicle, miles driven per year, road surface, and gross vehicle weight.

Nix and Boucher's "Economics and Liftable Axles on Heavy Trucks" (16) forecasted the possible impacts of changes in lift axle regulations for the trucking industry in Canada. Five scenarios were considered:

(1) the status quo, made up of current allowable axle configurations and current axle load limits,

(2) a scenario in which the axle load limit is lowered from 10 metric tons (22,000 pounds) to 8 metric tons (17,640 pounds),

(3) a scenario in which the axle load limit is lowered even further, to 6 metric tons (13,230 pounds),

(4) a scenario in which lift axles are banned, and

(5) a scenario in which current lift axle loads do not change, but in which only one lift axle per combination is allowed.

Analysis revealed the following conclusions:

- There are alternative vehicle combinations that can haul freight at comparable costs to liftable axle configurations—however, they may compromise safety.
- None of the regulatory scenarios would have a major impact on *total* trucking costs in Canada—an outright ban on lift axle use would, at worst, increase total trucking industry operating costs by just over 1 percent or approximately $100 million (transition costs aside), and
- Some individual operations may see, at a maximum, operating increases of 10 to 12 percent.

SUMMARY OF PREVIOUS FINDINGS

Because the literature is so varied in its examination of lift axle use, it is difficult to discern the key issues involving the design and safety of liftable axles, as well as the impacts lift axles have on infrastructure and the economy. The purpose of this section is to clarify the key issues in each of these areas.

Common Axle Types and Configurations

In the related section of the literature review, the commonly used axle types and configurations were described. While this information is necessary background for those who are unfamiliar with lift axle use, it is not helpful to those who are making policy changes regarding axle use. Therefore, the key information is summarized below to describe recommended axle design features. These recommended features are related to axle loading, steering capabilities, additional safety features, and misuse avoidance methods.

Design Features Recommended in the Literature

Loading	• Lift axles should be designed to maintain their initial loading regardless of • uneven road surfaces • time • variations in energy
Steering Capabilities	• Lift axles should be self-steering with • sufficient steer centering force devices, and • a lockable steering mechanism to provide non-steer operation for higher speed travel (>50 km/31 mph). • Straight trucks should be prohibited from using a self-steering lift axle, especially if the spacing between the lift axle and the drive axle is large.
Safety Features	• Lift axles should raise automatically when a truck is in reverse.
Misuse Avoidance	• Lift axle controls should be located outside of and be inaccessible from the driver's compartment. • A monitoring device should be added to prove no tampering, misuse, or abuse of the lift axle.

Vehicle Damage Considerations

Little information was found in the literature regarding the relationship between vehicle damage and the use of lift axles.

Safety Considerations

The key conclusions from safety-related literature that should be considered for any policy decisions regarding the use of lift axles are summarized below.

- Payload center of gravity is the single, most powerful determinant of stability and control behavior.
- The handling and stability characteristics of an empty vehicle are much more sensitive to lift axle load than are the characteristics of a fully loaded vehicle.
- Considerable differences exist among various self-steer axle designs and installations, so it is difficult to generalize results to other applications.

In the remainder of this section, the key findings from safety-related literature are summarized to indicate how changing variables will positively or negatively affect safety levels. Changing variables include axle placement, the number of axles, the axle or truck loading, and the steering capabilities of the axles.

Axle Placement

If the allowable *spacing* between the lift axle and a fixed axle *increases*:	
Positive	Negative • vehicle stability worsens • friction demand worsens • low speed offtracking worsens
If the lift axle is installed on the *lead* vehicle of a combination vehicle:	
Positive	Negative • friction demand worsens • high speed offtracking worsens
If the lift axle is installed on the *rear* vehicle of a combination vehicle:	
Positive • friction demand improves	Negative
If the lift axle is installed in *front* of a fixed axle:	
Positive • effective overhang ratio improves	Negative

If the lift axle is installed in *back of a fixed axle*:	
Positive	Negative
	• effective overhang ratio worsens

Number of Axles

If the *number* of lift axles *increases* from *zero to one*:	
Positive	Negative
• maneuvering area improves	• maneuvering effort worsens
	• friction demand worsens
	• offtracking worsens
If the *number* of lift axles *increases* from *a single to a tandem*:	
Positive	Negative
• offtracking improves	• maneuvering effort worsens
• maneuvering area improves	• friction demand worsens
	• high speed braking worsens

Axle/Truck Loading

If the *load* on the lift axle *increases*:	
Positive	Negative
	• vehicle stability worsens
	• unit trucks understeer
	• combinations offtrack severely

Steering Capabilities

If the lift axle is made *less resistant to steering* (i.e. using a self-steer axle instead of a non-steer axle):	
Positive	Negative
• friction demand improves	• yaw stability worsens
• load transfer ratio improves	• offtracking worsens
• tire wear improves	• trailer response worsens
• low-speed maneuvering improves	• braking on differential surfaces worsens
	• high speed control worsens

Pavement and Bridge Considerations

In this section, the key findings from pavement and bridge related literature are summarized to indicate how changing variables will positively or negatively affect pavement and bridge structures. Changing variables include axle spacing, axle loading, and axle load monitoring capabilities.

Axle Spacing

If the allowable *spacing* between the lift axle and a fixed axle *increases*:	
Positive	Negative • pavement damage increases

Axle Loading

If the axle *load* is *increased*:	
Positive	Negative • fatigue pavement life decreases • subgrade rutting life decreases
If the lift axle is *inappropriately raised*:	
Positive	Negative • fatigue pavement life decreases • subgrade rutting life decreases

Axle Load Monitoring Capabilities

If the driver is able to *monitor* the axle *loads*:	
Positive • load accuracy potentially improves • weight fines potentially decrease	Negative

Economic Considerations

In this section, the key findings from economic-related literature are summarized to indicate how changing variables will positively or negatively affect the economic well-being of the trucking industry.

If a *lift axle* is *added* to a vehicle:	
Positive • payload increases • load placement latitude increases	Negative
If *lift axle* use were *banned*:	
Positive • comparable configurations exist	Negative • total industry costs would increase slightly • certain individual carrier costs would increase • transition costs would increase

CHAPTER 3
REVIEW OF REGULATORY AND INDUSTRY EXPERIENCE

In an effort to address both the regulatory and industry aspects of lift axle use, informal interviews were conducted with a number of groups, including the following:

- truck manufacturers,
- lift axle manufacturers,
- lift axle installers and repair personnel,
- industry representatives who use lift axles,
- state patrol troopers responsible for weight enforcement, and
- safety officials.

Information covering the following concerns was collected through these interviews:

- installation practices and usage limitations,
- vehicle damage considerations,
- vehicle manufacturer's warranty implications,
- magnitude of wear and tear on vehicles including maintenance costs,
- operational difficulties that occur when trucks travel through multiple states,
- benefits realized by the trucking industry and regulatory agencies, and
- accident histories involving lift axles.

TRUCK MANUFACTURERS

One of the world's largest Class 8 truck manufacturing companies, PACCAR, was contacted as part of this survey. Based in the Puget Sound region, PACCAR is responsible for producing Peterbilt and Kenworth trucks. A representative from the PACCAR Corporate Office was able to address questions relating to design and installation, warranty and liability implications, and the probable impacts of a change in lift axle regulations. His responses are summarized below.

With respect to design, truck manufacturers generally prefer self-steering axles because they are easier on the truck's components, including the frame and other axles. However, because the weight carried by the lift axle is relatively small, (10,000 to 12,000 pounds or 4,540 to 5,448 kilograms), the additional strain on the truck components caused by the non-steer axle is not significant.

Many PACCAR customers order trucks *equipped* with lift axles. However, several of PACCAR's customers have their lift axles added on "after market," that is, following the sale of the truck. When PACCAR equips its trucks with lift axles, the warranty for both the truck and the axle is comprehensive. However, if the lift axle is retrofitted by some other party, the warranty is limited. If PACCAR representatives have not approved the lift axle, any damage to it or to other truck components due to lift axle use is not be covered under warranty, and the trucker is referred to whomever installed the lift axle.

LIFT AXLE MANUFACTURERS

In considering whom to contact for information, the researchers felt it important to talk with a company familiar with both local issues and national concerns. Harbers and Associates, a lift axle manufacturer based in Oregon, provided this dual perspective. Harbers and Associates serves as the west coast sales affiliate of a much larger nationally based lift axle manufacturing company, Watson and Chalin. The Harbers and Associates representative was able to address both local issues, such as the extent of lift axle use in Washington state (and changes in regulatory policy), and nationwide concerns, such as the problems associated with non-uniformity among states.

Harbers and Associates generally serves bulk haulers who originate or travel through states that provide sufficient economic benefit from the use of a lift axle. When making a sale, Harbers and Associates emphasize several benefits: (1) reduced tire wear, (2) reduced maintenance, and (3) improved safety when unloaded (more weight, and consequently, tractive force on the drive axles).

Two types of lift axles, self-steering and non-steering, are available through this company. Sales trends indicate a movement away from non-steering axles (which usually require deployment controls inside the cab for maneuverability around corners) and a movement toward self-steering axles, a trend that Harbers and Associates supports. It was predicted that sales of self-steering axles had increased from zero to over 50 percent of the lift axle market share. However, for self-steering axles to gain 100 percent of the market share, according to Harbers and Associates, they must either demonstrate definite superiority as compared to non-steering axles, or be required by law. Harbers and Associates anticipates the latter, as states move toward the lift axle guidelines set forth by AASHTO which recommend self-steering axles. These guidelines were summarized in this report's literature review.

Several of the western states have already adopted the AASHTO guidelines as regulation, and states in the midwest and on the east coast are considering their adoption. Harbers and Associates is facilitating the movement toward self-steering axles by allowing the realization of additional benefits. Previously, both the self-steering and non-steering axles came with a warranty of three years or 300,000 miles. Beginning in 1994, the self-steering axle warranty will be extended to be five years or 500,000 miles.

Self-steering axles are more costly than non-steering axles. Self-steering axles cost between \$1700 and \$1800, while non-steering axles cost between \$700 and \$800, depending on options. However, the additional cost for self-steering axles is modest in relation to that of other equipment (e.g., tractor, trailers, etc.), especially if one considers the potential increase in payload that they make possible. Moreover, the extended warranty may ease the cost burden.

The self-steering lift axles manufactured by Harbers and Associates are designed to raise when the truck is in reverse. Problems arise if the self-steering axle remains deployed and the truck backs up since the natural tendency for self-steer or castering wheels is to spin 180° when the direction is changed. Because the self-steering wheels on trucks are not allowed this half rotation, they lock into a position approximately 40° off of the direction in which the truck is traveling. The safety implications are very serious if this axle is supporting a load, moreover it can also damage the equipment. The self-steering lift axle available through Harbers and Associates is linked to the vehicle's transmission, so the raising and lowering of the axle is automatic as the truck moves into and out of reverse. This additional safety feature ensures that the vehicle driver won't forget to raise the axle when in reverse; it is out of the driver's control. This lift axle design is acceptable to most states because (1) the driver cannot control the deployment controls; (2) a truck spends less than one percent of its time in reverse; and (3) this process usually takes place on private property, and therefore enforcement is not a major issue.

With respect to changes in current lift axle regulation, it is unclear how minor changes in lift axle regulations, such as changing the axle's steering requirements, would impact lift axle manufacturers. Impact may vary by company or by region. For example, a trend that was noted during the national survey of state regulations showed that self-steering axles are more prominent on the west coast. In fact, several representatives from eastern states were not even aware that self-steering or steerable axles existed. A change in axle steering requirements might make it more difficult for lift axle manufacturers to meet their east coast customers' needs. An all out ban on lift axle use would obviously have a serious, detrimental impact on lift axle manufacturers.

Lift axle manufacturers appreciate being informed in advance of regulations that require technologies not currently available. When a state sets a regulation, there is often a lag time until the new technology can be designed, manufactured and made available. A Harbers and Associates representative predicted that the design specified in the current version of the Washington Administrative Code 468.38.280 may never come into existence. This regulatory change allows for a deployment switch to be located in the cab as long as it is inoperable when the vehicle is in motion. However, no such design is currently being manufactured, according to Harbers and Associates. Because such a design would require a speed sensing device, both the initial cost and maintenance costs associated with the lift axle would be higher. Harbers and Associates speculates that the additional costs associated with this design would make it less appealing to the trucking industry. Therefore, this company would not pursue its design and manufacture at this time.

LIFT AXLE INSTALLERS AND REPAIR PERSONNEL

Information regarding lift axle installation and repair was acquired by contacting two garages that specialize in truck repair: American Frame and Alignment and Foster's Frame and Axle. Both were questioned as to the most frequent repair work required on lift axles or trucks as a result of lift axle use. A representative from American Frame and Alignment noted no unusual repair patterns when comparing lift axles to fixed axles. In most cases, it is worn out parts, unrelated to the lift axle's lifting or pressurizing mechanism that need replacing. A representative from Foster's Frame and Axle noted that installation and alignment were the most common lift axle service jobs. Lift axles are rarely brought in for repair.

Both garages reported that lift axle repairs and installation make up a very small proportion of their workload. The representative from American Frame and Alignment estimated that only 1 percent of their overall workload involves lift axles. Foster's Frame and Axle's estimate was somewhat higher, at five percent but this is still low. Neither representative believed that a change as drastic as a lift axle ban would have much effect on their operations.

Representatives from both garages volunteered suggestions related to lift axle safety. The representative from American Frame and Axle supports non-steering axles, as opposed to self-steering axles on the basis of additional safety. The representative from Foster's Frame and Axle cited two instances in which truckers had brought their vehicles in, complaining of a lack of steering capabilities. This problem had been caused by excessive pressure in the lift axle, which in turn had reduced the weight on the steering axle enough to impair steering. The representative from Foster's supports the improvement of pressure regulators for lift axles, as opposed to a lift axle ban.

LIFT AXLE USERS

To determine the prevalence of lift axle use in the Puget Sound region, visits were made to two weigh facilities. The first, near Lake Stevens, is a rural facility that serves a high proportion of dump trucks hauling rock products from nearby pits and quarries. The second facility, along Interstate 5 near Everett, is an urban facility that serves a wider variety of truck traffic. An informal survey of truck traffic at the Lake Stevens scale, revealed that more than half of all truck traffic was equipped with one or more lift axles. The most common use was on dump trucks preceding a tandem axle, thus forming a tridem axle. The Everett scale experienced a wider variety of truck configurations, and only about 15 percent of the truck traffic there was equipped with lift axles. A total of 273 trucks were observed at both facilities.

Given the range in experience in terms of lift axle use, industry representatives from three different freight sectors (dump, heavy haul, and general motor freight) were contacted: Cadman, Inc., Gresham Transfer and Yellow Freight, respectively.

Cadman, Inc. is a local hauler whose fleet consists of concrete mixers and dump trucks. A Cadman representative estimated that nearly 95 percent of the fleet is equipped with one or more lift axles. Two lift axles are common on concrete mixers; one following the steering axle and one at the extreme rear of the truck. Dump trucks frequently have a lift axle following the steering axle and one on the trailer, preceding the tandem axle. An all out lift axle ban would clearly have adverse financial impacts on Cadman, Inc.

An example illustrates the financial advantages lift axles provide for Cadman, Inc. A typical three-axle truck can legally carry a 52,000 pound load (23,608 kilograms). The addition of a lift axle allows the same truck to support a load of 70,000 pounds (31,780 kilograms), a payload increase of nearly 35 percent. To achieve the same payload, a lift axle-equipped truck could carry *three* full loads, whereas, a truck without the lift axle would have to carry *four* loads. Cadman, Inc. views this payload increase and time savings as the real benefits of lift axle use. Other potential savings resulting from lift axle use, such as reduced tire wear and improved fuel efficiency when the axle is raised, are negated by the additional lift axle maintenance costs, according to the Cadman representative.

A second representative from Cadman indicated that, when a lift axle is used in combination with a tandem to form a tridem, the lift axle often does not support an adequate share of the weight, even though indicators in the cab notify the driver of the weight supported by the lift axle. Interestingly, with a movement towards more lift axles, Cadman has noted no change in the number of weight-related citations.

Gresham Transfer, a primarily local, large heavy hauler with some operations at the national level, has a fleet of approximately 500 tractors and approximately 1000 trailers. Approximately 20 percent of its tractors are equipped with lift axles as are approximately 10 percent of the trailers. Most of the lift axles used by this company are equipped with dual tires to adequately support heavy loads. A representative from Gresham Transfer indicated that the trucking industry would suffer financially if limitations were imposed on lift axle use. Although Gresham Transfer is a heavy hauler, the representative used a typical concrete truck to demonstrate the potential for profit loss. It was estimated that a typical concrete mixer would have to reduce its load by nearly one-third if the driver were prevented from using a lift axle. This reduction could be substantial, considering the number of concrete mixers in operation and the trips per day made by each. No estimates were provided for other configurations.

Yellow Freight was contacted as a representative of the general motor freight industry and indicated that lift axle use in the general motor freight industry is minimal. General motor freight operations tend to maximize available space before maximizing available weight ("cube out" before "gross out"). Consequently, lift axles do not benefit these operations.

WASHINGTON STATE PATROL

Washington State Patrol troopers from the Commercial Vehicle Enforcement Section were interviewed in the field during their regulatory routine. Some interesting issues, which serve to make the enforcement of lift axle regulations difficult., came to light in the course of this study.

First, the weight enforcement process for trucks equipped with lift axles is time-consuming because common configurations require axle groupings to be weighed individually. For example, some of the more remote scale houses experience a high proportion of trucks equipped with lift axles because of their proximity to rock sources (pits). The most common configuration among rock haulers is a single lift axle followed by a fixed tandem axle on the pup trailer. The weigh pads at these facilities can weigh no more than two axles at a time. Officers must "split weigh" such configurations by first weighing the lift axle and then weighing the tandem axle.

According to WSP representatives interviewed, the practice of split-weighing is acceptable as long as the axle grouping does not have a common suspension system. A fixed tridem axle cannot be split-weighed because of the common suspension system. The only way that a fixed axle grouping with three or more axles can be weighed is if the portable scales are employed. The full three axles can then be weighed on a flat platform if a scale is placed beneath every wheel. This practice is rare for two reasons: (1) troopers must enforce a high volume of trucks and do not have the time to weigh each truck equipped with a tridem or quad axle grouping with the portable scales; and (2) weight enforcement officials are limited as to the number of portable scales they can feasibly transport. In an effort to remedy this enforcement limitation, the WSP/WSDOT are installing longer scale pads at several weigh facilities that will allow the weighing of commonly suspended tridem axles. However, limited resources may slow the installation of these improved scale pads at the more remote weigh stations.

A second issue was raised when talking with weight enforcement officials. Washington state regulations require that the control for deploying and regulating the lift axles be located outside the truck's cab. However, weight enforcement officials are uncomfortable checking the cab's interior for a control switch, even if they suspect a violation. Some WSP troopers feel that in order to cite a trucker for the illegal switch in the cab, the truck should be stopped en route with the axle improperly raised. Then and only then should the trooper investigate the cab for illegal switches. If a switch is found inside the cab, then the trooper may raise the lift axle and re-weigh the truck. The driver can then be cited for the overweight charge determined when the axle is raised. Because WSP weight enforcement troopers usually rotate among weigh facilities, it is difficult to observe trucks traveling illegally with the lift axle raised. Hence, the regulation on the location of the lift axle control is rarely enforced.

SAFETY OFFICIALS

It is difficult to identify safety impacts resulting from lift axle use for several reasons. First, an accident can seldom be attributed directly to lift axle use. For example, if a combination truck jackknifes, a number of factors, including icy roadways, high speeds, hard braking, or tire blowout, may contribute to the accident. If the truck is equipped with a lift axle, this equipment may or may not have contributed to the accident. Because it is difficult to establish a definitive cause, the presence of a lift axle on a truck involved in an accident is seldom recorded. As a result, there is little or no historical data on lift axle accident involvement.

At the national level, commercial vehicle safety databases include the following:

- Fatal Accident Reporting System (FARS),
- General Estimates System (GES),
- Trucks Involved in Fatal Accidents (TIFA), and
- SAFETYNET.

FARS and GES are maintained by the National Highway Traffic Safety Administration (NHTSA). FARS contains information on fatality truck accidents only while the GES covers truck crashes at all levels of severity. Administered by the University of Michigan Transportation Research Institute (UMTRI) and sponsored by NHTSA and FHWA, TIFA contains information on medium and heavy trucks involved in fatal accidents. TIFA combines information from FARS and accident data from, what was previously, the FHWA's Office of Motor Carriers MCS 50-T report, which considers accidents at all levels of severity. The MCS 50-T report has been replaced with the SAFETYNET database which contains commercial vehicle safety-related information. State-level safety data is collected, compiled, and uploaded, either manually or automatically depending on the state's level of automation, to the FHWA's Office of Motor Carriers. Until recently, none of these databases included information about lift axle involvement.

In 1991, TIFA was modified to include information on lift axle involvement. Unfortunately, this information relates only to lift axles *not in use,* it is used to verify weight-related information. Data describing trucks with lift axles not in use would be beneficial from a safety aspect if the data could be sorted to reflect those instances wherein the trucker raised the loaded lift axle to improve maneuverability when turning. According to a UMTRI representative, it would be difficult to sort the data in this way and the results might not be accurate.

Washington state lacks this same type of lift axle-related safety data. Accident information is stored in the Micro Computer Collision Accident Report (MicroCARS) database, which is maintained by WSDOT. The database information is based on accident reports filed by the Washington State Patrol and by local jurisdictions statewide. Currently, this database does not contain information about lift axle use, but it does have the flexibility to accommodate additional information. However, to obtain a comprehensive sampling of lift axle involvement, all jurisdictions statewide would have to agree to collect additional data on lift axle involvement. Additionally, information related to lift axle safety could be collected as part of the Incident Response Database, which is in the final stages of development. The data to be collected should include (1) the presence of a lift axle, (2) its position (i.e., deployed or raised) and (3) its location (e.g., tractor or trailer, before or after fixed axle, etc.).

CHAPTER 4
IMPLICATIONS OF WASHINGTON REGULATIONS

In addition to the Washington Administrative Code on special equipment cited previously, (WAC 468.38.280), a number of other Washington regulations impact the use of lift axles. Below is a summary, including the amended WAC 468.38.280, of regulations impacting lift axle use. These regulations are cited from the Washington Administrative Code (WAC), the Revised Code of Washington (RCW), amendments to the Revised Code of Washington (Washington Laws 1993), and the Code of Federal Regulations (CFR). The regulations are organized into four categories: (1) equipment specifications, (2) weight limits, (3) operating fees (e.g., permits, licensing, taxes), and (4) enforcement. Following each citation is an interpretation of the law and a discussion of some of the regulation's more important implications for lift axle operation and use. At the end of this chapter, the overall implications of Washington regulations affecting lift axle use are discussed.

EQUIPMENT SPECIFICATIONS

Equipment specifications serve to maintain safety and protect the infrastructure. In Washington, equipment specifications for lift axles come from two sources: WAC 468-38-280 and 49 CFR 393.42. A summary of each of these regulations and a discussion of their implications for both regulatory and trucking representatives is provided.

> ***WAC 468.38.280 Special Equipment (Amended 1993)*** *Special equipment employing axle groupings other than the conventional single or tandem axle must first be approved by the department before permits will be granted authorizing the unit to operate on state highways.*
> *A retractable axle carrying weight allowed under RCW 46.44.041 shall have a manufacturer's rating of at least 10,000 pounds, shall be self-steering, and shall have the capacity to be activated only from ((~~outside~~)) <u>a location out of reach of t</u>he driver's compartment: Provided, the requirement that controls be activated only from ~~outside~~ <u>a location out of reach of t</u>he driver's compartment shall not apply to ((~~existing trucks, presently equipped with hydraulically loaded lift axles which presently can be activated inside the driver's compartment~~)) <u>vehicles equipped with</u>*

hydraulically or pneumatically loaded lift axles that cannot be activated when the vehicle is in motion. Any variable control used to adjust axle loadings by regulating air pressure or by other means must be out of reach of the driver's compartment; And Provided Further, The requirement that the retractable axle shall be self-steering does not apply to a truck/tractor where the retractable axle equipped with four tires is used to create a tandem and the distance between the drive axle and the retractable axle is no greater than 60 inches. The self-steering requirement shall also not apply to a trailing unit where the distance between a fixed axle and the retractable axle is no greater than 60 inches.

Interpretation

Under this regulation, the Washington State Department of Transportation (WSDOT) has the authority to require that the lift axle be inspected before issuing any permits. This practice is rarely carried out. Instead, the WSDOT focuses on inspecting unusual dolly systems or configurations. Because no mention is made of axle weight restrictions, it is assumed that the retractable axle may carry the same amount of weight as a single, fixed axle, as prescribed by the Federal Bridge Formula.

The lift axle must also be able to carry a load of at least 10,000 pounds (4.5 metric tons) as prescribed by the manufacturer. This ensures that the equipment will operate safely under typical loads. The minimum manufacturer's rating requirement was spurred by instances in which truckers, knowing that an additional axle would allow them to carry additional weight, were cited using lightweight axles not designed for such heavy loads.

The self-steering requirement is intended to improve vehicle handling and to reduce tire scrub on the pavement when turning. Self-steering axles can be distinguished from non-steering axles at weigh facilities by weight enforcement personnel relatively easily because the steering mechanisms below the vehicle are visible from most scalehouses as the trucker drives through.

The lift axle controls may be located in the vehicle's cab or within the driver's reach only if the lift axle controls are so designed to prevent the raising and lowering of the axle when the vehicle is in motion. In this case (where controls are allowed inside the cab), the regulator, which adjusts the load supported by the fixed axle, must be out of the driver's reach. These requirements, in combination, serve to discourage the trucker from raising the axle inappropriately when loaded and in motion and also from underloading or overloading the lift axle.

The exception to the self-steering requirement was made in an effort to legalize certain truck configurations already in existence. It is assumed for these cases, that the benefit of a self-steering lift axle is negligible when used in combination with the rear drive axle or the truck/tractor to make a tandem or if used on the trailer if the lift axle is within 60 inches from a fixed axle. For these two axle configurations, self-steer axles lose their benefit of improved handling and reduced tire scrubbing.

> ***49 CFR 393.42 Brakes Required on All Wheels.*** *(a) Every commercial motor vehicle shall be equipped with brakes acting on all wheels.*
> *(b) Exception. (1) Trucks or truck tractors having three or more axles- (i) need not have brakes on the front wheels of the vehicle if manufactured before July 25, 1980; or (ii) those manufactured between July 24, 1980, and October 27, 1986, must be retrofitted to meet the requirements of this section within one year from February 26, 1987, if the brake components have been removed.*
> *(2) Any motor vehicle being towed in a driveaway-towaway operation must have operative brakes as may be necessary to ensure compliance with the performance requirements of § 393.52. This paragraph is not applicable to any motor vehicle towed by means of a tow-bar when any other vehicle is fully mounted on such towed motor vehicle or any combination of motor vehicles utilizing three or more saddle-mounts (See § 393.7(a)(3).)*
> *(3) Any full trailer, any semitrailer, or any pole trailer having a GVWR of 3,000 pounds or less must be equipped with brakes if the weight of the towed vehicle resting on the towing vehicle exceeds 40 percent of the GVWR of the towing vehicle.*
> *(4) Trucks or truck tractors having three or more axles and being operated by or under the control of a Mexican motor carrier must be retrofitted to meet the requirements of Paragraph (a) of this section by January 1, 1991 if the vehicle was manufactured on or after July 25, 1980.*

Interpretation

For the purposes of this study, all lift axles should be equipped with brakes under this regulation. None of the exceptions or special conditions cited above affect lift axle brake requirements. Brakes on the lift axle are checked as part of the Motor Carrier Safety Assistance Program when trucks are subject to an equipment inspection.

WEIGHT LIMITS

Regulations governing the loads on the vehicle, groups of axles, individual axles, and tires serve to reduce pavement damage. The enforcement of weight regulations is a very sensitive issue. In Washington, a number of issues make enforcement more difficult. First, weight enforcement personnel are not allowed to split weigh axle groupings that have a common suspension systems due to problems with accuracy (split weighing is the practice of weighing a tridem as a single and a tandem axle). Lift axles can, however, be weighed by splitting the group, because no common suspension exists. Most scale pads are only large enough to handle a tandem axle. This means that weight enforcement personnel have no way to enforce tridem and quad axle group weights.

A second difficulty arises from the trucking industry. Truckers who willingly violate the weight regulations also avoid the permanent weigh facilities. These truckers can only be monitored through the use of portable scales. Many truckers argue about the accuracy of the portable scales, but more so because they are angry at being stopped and at the delay.

Recent changes to the regulations governing weight limits are summarized in Washington Laws 1993, Chapter 102 and 103. Limitations on lift axle use are discussed following a citation from RCW 46.44.047, which considers Log Tolerance Permits.

> ***Washington Laws 1993 Chapter 102 Overweight Permit Fees for Trucks*** *(amending RCW 46.16.070, 46.16.160, 46.44.0941, 46.44.095, 46.44.096, and 46.68.035; reenacting and amending RCW 46.44.041; and repealing RCW 46.44.160.).*
> (See Table 2)...~~*It is unlawful to operate any vehicle upon the public highways equipped with two axles spaced less than seven feel apart unless the two axles are so constructed and mounted that the difference in weight between the axles does not exceed three thousand pounds. However, variable lift axles are exempt from this requirement. For purposes of this section, a "variable lift axle" is an axle that may be lifted from the roadway surface, whether by air, hydraulic, mechanical, or any combination of these means. The weight allowed on the axle is governed by RCW 46.44.042 and this section.*~~...

Table 2: Bridge Formula Weights

	Number Of Axles in Group Being Considered							
ft	2	3	4	5	6	7	8	9
4	34,000							
5	34,000							
6	34,000							
7	34,000							
8	34,000	42.000						
9	39,000	42.500						
10	40,000	43.500						
11		44.000						
12		45,000	50,000					
13		45,500	50,500					
14		46,500	51,500					
15		47,000	52,000					
16		48,000	52,500	~~52,500~~ 58.000				
17		48,500	53,500	~~53,500~~ 58.500				
18		49,500	54,000	~~54,000~~ 59.000				
19		50,000	54,500	~~54,500~~ 60.000				
20		51,000	55,500	~~55,500~~ 60.500	66.000			
21		51,500	56,000	~~56,000~~ 61.000	66.500			
22		52,500	56,500	~~56,500~~ 61.500	67.000			
23		53,000	57,500	~~57,500~~ 62.500	68.000			
24		54,000	58,000	~~58,000~~ 63.000	68.500	74.000		
25		54,500	58,500	~~58,500~~ 63.500	69.000	74.500		
26		55,500	59,500	~~59,500~~ 64.000	69.500	75.000		
27		56,000	60,000	~~60,000~~ 65.000	70.000	75.500		
28		57,000	60,500	~~61,000~~ 65.500	~~61,000~~ 71.000	76.500	82.000	
29		57,500	61,500	~~62,000~~ 66.000	~~62,000~~ 71.500	77.000	82.500	
30		58,500	62,000	~~63,000~~ 66.500	~~63,000~~ 72.000	77.500	83.000	
31		59,000	62,500	~~64,000~~ 67.500	~~64,500~~ 72.500	78.000	83.500	
32		60,000	63,500	~~65,000~~ 68.000	~~65,000~~ 73.000	78.500	84.500	90.000
33			64,000	~~66,000~~ 68.500	~~66,000~~ 74.000	79.000	85.000	90.500
34			64,500	~~67,000~~ 69.000	~~67,000~~ 74.500	80.000	85.500	91.000
35			65,500	~~68,000~~ 70.000	~~68,000~~ 75.000	80.500	86.000	91.500

Table 2: Bridge Formula Weights *(Continued)*

	Number Of Axles in Group Being Considered							
ft	2	3	4	5	6	7	8	9
36			66,000	~~69,500~~ 70.500	~~69,500~~ 75.500	81.000	86.500	92.000
37			66,500	~~70,500~~ 71.000	~~70,500~~ 76.000	81.500	87.000	93.000
38			67,500	~~72,000~~ 71.500	~~72,000~~ 77.000	82.000	87.500	93.500
39			68,000	72,500	~~72,500~~ 77.000	82.500	88.500	94.000
40			68,500	73,000	~~73,000~~ 78.000	83.500	89.000	94.500
41			69,500	73,500	~~73,500~~ 78.500	84.000	89.500	95.000
42			70,000	74,000	~~74,000~~ 79.000	84.500	90.000	95.500
43			70,500	75,000	~~75,000~~ 80.000	85.000	90.500	96.000
44			71,500	75,500	~~75,500~~ 80.500	85.500	91.000	96.500
45			72,000	76,000	~~76,000~~ 81.000	86.000	91.500	97.500
46			72,500	76,500	~~80,000~~ 81.500	~~80,000~~ 87.000	92.500	98.000
47			73,500	~~77,000~~ 77.500	~~81,000~~ 82.000	~~81,000~~ 87.500	93.000	98.500
48			74,000	78,000	~~82,000~~ 83.000	~~82,000~~ 88.000	93.500	99.000
49			74,500	78,500	~~83,000~~ 83.500	~~83,000~~ 88.500	94.000	99.500
50			75,500	79,000	84,000	~~84,000~~ 89.000	94.500	100.000
51			76,000	80,000	84,500	~~85,000~~ 89.500	95.000	100.500
52			76,500	80,500	85,000	~~86,000~~ 90.500	95.500	101.000
53			77,500	81,000	86,000	~~87,000~~ 91.000	96.500	~~91,000~~ 102.000
54			78,000	81,500	86,500	~~88,000~~ 91.500	~~91,000~~ 97.000	~~92,000~~ 102.500
55			78,500	82,500	87,000	~~89,000~~ 92.000	~~92,000~~ 97.500	~~93,000~~ 103.000
56			79,500	83,000	87,500	~~90,000~~ 92.500	~~93,000~~ 98.000	~~94,000~~ 103.500
57			80,000	83,500	88,000	~~91,000~~ 93.000	~~94,000~~ 98.500	104.000
58			84,000	~~89,000~~ 84.000	~~92,000~~ 89.000	~~95,000~~ 94.000	~~95,000~~ 99.000	104.500
59			85,000	~~89,500~~ 85.000	93,500 89.000	~~96,000~~ 94.500	~~96,000~~ 99.500	~~97,000~~ 105.500
60				85,500	90,000	95,000	~~97,000~~ 100.500	~~98,000~~ 105.500
61				86,000	90,500	95,500	~~98,000~~ 101.000	~~99,000~~ 105.500
62				~~87,000~~ 86.500	91,000	96,000	~~99,000~~ 101.500	~~100,000~~ 105.500
63				87,500	92,000	~~97,000~~ 96.500	~~100,000~~ 102.000	~~101,000~~ 105.500
64				88,000	92,500	97,500	~~101,000~~ 102.500	~~102,000~~ 105.500
65				88,500	93,000	98,000	~~102,000~~ 103.000	~~103,000~~ 105.500
66				89,500	93,500	98,500	~~103,000~~ 103.500	~~104,000~~ 105.500
67				90,000	94,000	99,000	~~104,000~~ 104.500	~~105,000~~ 105.500
68				90,500	95,000	99,500	105,000	105.500
69				91,000	95,500	100,000	105,500	105,500
70				92,000	96,000	101,000	105,500	105,500

Interpretation

Table 2 summarizes the changes to the bridge formula table. Changes to this formula allow higher weights to be carried on groups of axles that consist of five or more axles, depending on the spacing. This may encourage the addition of a lift axle to achieve the higher weights without overloading individual axle groups. Until these changes were made, Washington weight enforcement had been governed by a modified bridge table, which restricted trucks to lower weights than those allowed by the federal government. Washington recently agreed to raise its bridge table limits to meet those of the federal weight standards because the state was afraid of losing federal monetary support due to non-compliance.

An increase in a vehicle's allowable gross weight, either through legislation or permit, allows a number of things to occur. Increased gross weight requires that more axles be added to the vehicle; these axles are often liftable. Second, a shift may occur within the industry—now that more weight is allowed, certain truck configurations may hold more appeal than existing configurations. The greater variety in configurations that is allowed by using lift axles makes it more difficult to enforce the weight based on the bridge formula. The more lift axles are used, the greater the risk of damage in the event of misuse. Third, the industry has more flexibility when loading the vehicle to gross because the axles are not at their maximum weights.

Previous regulations required that no axles be spaced less than seven feet apart unless they had been designed to share the load equally (within 3,000 pounds/1.4 metric tons). Lift axles, however, *could* be spaced closer than seven feet from a fixed or second lift axle without carrying the same (within 3,000 pounds/1.4 metric tons) axle load as the adjacent axle. This regulation was deemed unnecessary because it was too difficult to enforce, especially when considering axles with common suspensions systems. Axles now are required to meet only the individual axle grouping (i.e., single, tandem, tridem, quad) weight limitations, regardless of the weight difference between individual axles.

Washington Laws 1993 Chapter 103 Axle And Tire Weight Restrictions*(amending RCW 46.44.042). Subject to the maximum gross weights specified in RCW 46.44.041, it is unlawful to operate any vehicle upon the public highways with a gross weight, including load, upon any tire concentrated upon the surface of the highway in excess of six hundred pounds per inch width of such tire. Other than the non-liftable steering axle on the power unit or tiller axle on fire fighting apparatus, an axle manufactured after July 31, 1993, carrying more than ten thousand pounds gross weight must be equipped with four or more tires. Effective January 1, 1997, an axle, excluding the non-liftable steering axle on the power unit or tiller axle on fire fighting apparatus, carrying more than ten thousand pounds gross weight must have four or more tires, regardless of date of manufacture. Instead of the four or more tires per axle requirements of this section: (1) an axle may be equipped with two tires limited to five hundred pounds per inch width of tire; or (2) in the case of a ready-mix concrete transit truck, the rear booster trailing axle may be equipped with two tires limited to six hundred pounds per inch width of tire. This section does not apply to oversize and overweight permits issued under RCW 46.44.090. For the purpose of this section, the width of tire in case of solid rubber or hollow center cushion tires, so long as the use thereof may be permitted by the law, shall be measured between the flanges of the rim. For the purpose of this section, the width of tires in case of pneumatic tires shall be the maximum overall normal inflated width as stipulated by the manufacturer when inflated to the pressure specified and without load thereon.*

The department of transportation, under rules adopted by the transportation commission with respect to state highways, and a local authority, with respect to a public highway under its jurisdiction, may extend the weight table in RCW 46.44.041 to one hundred fifteen thousand pounds. However, the extension must be in compliance with federal law, and vehicles operating under the extension must be in full compliance with the 1997 axle and tire requirements under this section.

Interpretation

Under this regulation, all axles that carry 10,000 pounds (4.5 metric pounds) or more must be equipped with dual tires, with the following exceptions: (1) the steering axle on the truck/tractor, (2) the tiller axle on a fire engine, and (3) the rear booster axle on a ready-mix concrete truck. Any axle may be equipped with two tires, but the allowable pounds per inch width of tire width is limited to 500 pounds per inch width (8.94 kilograms per millimeter width), rather than 600 pounds per inch width (10.72 kilograms per millimeter width). This consequently, limits the axle load.

If the load per inch width of tire were to increase, the industry could continue to carry the heavier loads on single tires. If the pounds per inch (kilograms per millimeter) width of tire requirements were to decrease, the industry may have to start using dual tires on all axles, including lift axles. This would lead to higher manufacturing costs for the industry, higher operating costs, and would give further motivation to lift axles inappropriately. However, the loads concentrated on the tire area are also governed by the allowable axle load. It is predicted that the trucking industry will continue to equip their lift axles with single tires and to limit the weight on the tires to 500 pounds per inch width (8.94 kilograms per millimeter width).

In addition to the dual tire requirements, this regulation also reserves the WSDOT's right to extend the previous bridge formula limitations of 105,500 pounds (48 metric tons) to 115,000 pounds (52.3 metric tons), as long as the axle and tire requirements provided above are met. It is predicted that this raise in federal bridge formula limitations will not occur any time soon. In addition, if the weight limitations were raised, the WSDOT would grandfather in the requirement that existing trucks meet the existing requirement of 105,500 pounds (48 metric tons).

> ***RCW 46.44.047 Excess Weight-Logging Trucks-Special Permits-County Or City Permits-Fees-Discretion Of Arresting Officer.*** *A three axle truck tractor and a two axle pole trailer combination engaged in the operation of hauling logs may exceed by not more than six thousand eight hundred pounds the legal gross weight of the combination of vehicles when licensed, as permitted by law, for sixty-eight thousand pounds: PROVIDED, that the distance between the first and last axle of the vehicles in combination shall have a total wheelbase of not less than thirty-seven feet and the weight upon two axles spaced less than seven feet apart shall not exceed thirty-three thousand six hundred pounds.*
> *Such additional allowances shall be permitted by a special permit to be issued by the department of transportation valid only on state primary or secondary highways authorized by the department and under such rules, regulations, terms, and conditions prescribed by the department...*

Interpretation

It is stated that a three axle truck tractor and a two axle pole trailer (five axles total) engaged in hauling logs may exceed their licensed gross weight limit of 68,000 pounds (30.9 metric tons) by as much as ten percent (6,800 pounds/3.1 metric tons). If a log truck has an additional lift axle, it no longer fits the prescribed configuration for log tolerance permits requirements. In actuality, this is not a problem because truckers requesting a log tolerance permit rarely have a lift axle as part of their configuration. To carry the additional weight allowable through a log tolerance permit, the lift axle would need extra wide or dual tires, not to exceed the pounds per inch (kilograms per millimeter) width tire requirements. Given the additional cost of tires, lift axles lose their benefit in this instance.

OPERATING FEES

Operating fees, such as licensing costs, taxes and fines, can have a major impact on benefit conferred by lift axle use. If a trucker adds a lift axle to his current configuration to benefit from the additional payload, some of the monetary benefit is lost through additional licensing fees for the increased load, potential overweight permit fees, and potential overweight fines. Washington Laws 1993, Chapter 102 and 123 serve to regulate licensing fees, overweight permit fees, and excise taxes on large trucks. Chapter 403 of the 1993 Washington Laws serves, in part, to regulate the fine structure for overweight or other related violations (i.e., permit violations).

> ***Washington Laws 1993 Chapter 102 Overweight Permit Fees for Trucks*** *(amending RCW 46.16.070, 46.16.160, 46.44.0941, 46.44.095, 46.44.096, and 46.68.035; reenacting and amending RCW 46.44.041; and repealing RCW 46.44.160.).*
> *...(1) In lieu of all other vehicle licensing fees, unless specifically exempt, and in addition to the excise tax prescribed in chapter 82.44 RCW and the mileage fees prescribed for buses and stages in RCW 46.16.125, there shall be paid and collected annually for each motor truck, truck tractor, road tractor, tractor, bus, auto stage, or for hire vehicle with seating capacity of more than six, based upon the declared combined gross weight or declared gross weight thereof pursuant to the provisions of chapter 46.44 RCW, the following licensing fees by such gross weight* (See Table 3)*: ..*
> *...The following provisions apply when increasing gross or combined gross weight for a vehicle licensed under this section: (a) The new license fee will be one-twelfth of the fee listed above for the new gross weight, multiplied by the number of months remaining in the period for which licensing fees have been paid, including the month in which the new gross weight is effective. (b) Upon surrender of the current certificate of registration or cab card, the new licensing fees due shall be reduced by the amount of the licensing fees previously paid for the same period for which new fees are being charged...* (See Table 4)

Table 3: Licensing Fees for Trucks in Excess of 80,000 Pounds

Declared Gross Weight	*Licensing Fee*
4,000 lbs.	*$37.00*
6,000 lbs.	*$44.00*
8,000 lbs.	*$55.00*
10,000 lbs.	*$62.00*
12,000 lbs.	*$72.00*
14,000 lbs.	*$82.00*
16,000 lbs.	*$92.00*
18,000 lbs.	*$137.00*
20,000 lbs.	*$152.00*
22,000 lbs.	*$164.00*
24,000 lbs.	*$177.00*
26,000 lbs.	*$187.00*
28,000 lbs.	*$220.00*
30,000 lbs.	*$253.0)*
32,000 lbs.	*$304.00*
34,000 lbs.	*$323.00*
36,000 lbs.	*$350.00*
38,000 lbs.	*$384.00*
40,000 lbs.	*$439.00*
42,000 lbs.	*$456.00*
44,000 lbs.	*$466.00*
46,000 lbs.	*$501.00*
48,000 lbs.	*$522.00*
50,000 lbs.	*$566.00*
52,000 lbs.	*$595.00*
54,000 lbs.	*$642.00*
56,000 lbs.	*$677.00*
58,000 lbs.	*$704.00*
60,000 lbs.	*$750.00*
62,000 lbs.	*$804.00*
64,000 lbs.	*$822.00*
66,000 lbs.	*$915.00*
68,000 lbs.	*$954.00*
70,000 lbs.	*$1,027.00*
72,000 lbs.	*$1,098.00*
74,000 lbs.	*$1,193.00*
76,000 lbs.	*$1,289.00*
78,000 lbs.	*$1,407.00*
80.000 lbs.	*$1,518.00*
82.000 lbs.	*$1.623.00*
84.000 lbs.	*$1.728.00*
86.000 lbs.	*$1.833.00*
88.000 lbs.	*$1.938.00*
90.000 lbs.	*$2.043.00*
92.000 lbs.	*$2.148.00*
94.000 lbs.	*$2.253.00*
96.000 lbs.	*$2.358.00*
98.000 lbs.	*$2.463.00*
100.000 lbs.	*$2.568.00*
102.000 lbs.	*$2.673.00*
104.000 lbs.	*$2.778.00*
105.500 lbs.	*$2.883.00*

Table 4: Overweight Permit Fees

Weight Over Total Registered Gross Weight	*Fee Per Mile On State Highways*
1-5,999 pounds	*$ .07*
6,000-11,999 pounds	*$ .14*
12,000- 17,999 pounds	*$ .21*
18,000-23,999 pounds	*$ .35*
24,000-29,999 pounds	*$ .49*
30,000-35,999 pounds	*$ .63*
36,000-41,999 pounds	*$ .84*
42,000-47,999 pounds	*$1.05*
48,000-53,999 pounds	*$1.26*
54,000-59,999 pounds	*$1.47*
60,000-65.999 pounds	*$1.68*
66,000-71.999 pounds	*$ 2.03*
72.000-79,999 pounds	*$ 2.38*
80,000 pounds or more	*$ 2.80*

Interpretation

Previously covered by annual additional tonnage permits, trucks can now *license* their vehicles for a weight in excess of 80,000 pounds (36.4 metric tons), up to 105,500 pounds (48 metric tons) (See Table 3). This change in process shifts the responsibility of regulating additional tonnage from the WSDOT's Permits Division to the Washington Department of Licensing (WDOL). The main benefit of this shift is realized by the trucking industry. Many truckers now need to make only one stop to meet the requirements (i.e., at WDOL) rather than having to go to the WDOL for licensing and to the WSDOT for additional tonnage permission.

Based on the fee structures provided in this regulation, loads that are substantially overweight (double that of legal gross weight limits) can be moved relatively inexpensively with an overweight permit (see Table 4). This means that, for a modest fee, a trucker can achieve a sizable increase in payload. This implies two things. First, if the permit fees are kept low, compliance with regulatory requirements is encouraged. Truckers who operate legally by purchasing a permit are not penalized for operating legally. On the other hand, low permit fees do not compensate for the damage caused by overweight trucks. Hence, roadway repair funds must come from other sources (i.e., taxpayers). A balance needs to be struck: truckers should not be penalized for operating legally, and yet the state should receive compensation for the resulting roadway damage.

> ***Washington Laws 1993 Chapter 123 Motor Vehicle Excise Tax - Additional Tax on Large Truck-Type Power Units.*** *...(4) An additional excise tax is imposed on truck-type power units that are used in combination with a trailer to transport loads in excess of forty thousand pounds combined gross weight. The rate of tax shall be forty-eight one hundredths of one percent of the value of the vehicle. Ten percent additional tax collected under this subsection shall be distributed in the manner prescribed in RCW 82.44.110(2). The remainder of the excise tax collected under this subsection shall be distributed in the manner prescribed in RCW 82.44.110(1). This tax shall not apply to power units used exclusively for hauling logs...*(See Table 5).

Table 5: Increased Licensing Fees for Trucks in Excess of 40,000 Pounds

Declared Gross Weight	*Licensing Fee*
4,000 lbs.	*$37.00*
6,000 lbs.	*$44.00*
8,000 lbs.	*$55.00*
10,000 lbs.	*$62.00*
12,000 lbs.	*$72.00*
14,000 lbs.	*$82.00*
16,000 lbs.	*$92.00*
18,000 lbs.	*$137.00*
20,000 lbs.	*$152.00*
22,000 lbs.	*$164.00*
24,000 lbs.	*$177.00*
26,000 lbs.	*$187.00*
28,000 lbs.	*$220.00*
30,000 lbs.	*$253.0)*
32,000 lbs.	*$304.00*
34,000 lbs.	*$323.00*
36,000 lbs.	*$350.00*
38,000 lbs.	*$384.00*
40,000 lbs.	*$439.00*
42,000 lbs.	~~*$456.00*~~ *$546.00*

Declared Gross Weight	*Licensing Fee*
44,000 lbs.	~~*$466.00*~~ *$556.00*
46,000 lbs.	~~*$501.00*~~ *$591.00*
48,000 lbs.	~~*$522.00*~~ *$612.00*
50,000 lbs.	~~*$566.00*~~ *$656.00*
52,000 lbs.	~~*$595.00*~~ *$685.00*
54,000 lbs.	~~*$642.00*~~ *$732.00*
56,000 lbs.	~~*$677.00*~~ *$767.00*
58,000 lbs.	~~*$704.00*~~ *$794.00*
60,000 lbs.	~~*$750.00*~~ *$840.00*
62,000 lbs.	~~*$804.00*~~ *$894.00*
64,000 lbs.	~~*$822.00*~~ *$912.00*
66,000 lbs.	~~*$915.00*~~ *$1,005.00*
68,000 lbs.	~~*$954.00*~~ *$1,044.00*
70,000 lbs.	~~*$1,027.00*~~ *$1,117.00*
72,000 lbs.	~~*$1,098.00*~~ *$1,188.00*
74,000 lbs.	~~*$1,193.00*~~ *$1,283.00*
76,000 lbs.	~~*$1,289.00*~~ *$1379.00*
78,000 lbs.	~~*$1,407.00*~~ *$1,497.00*
80.000 lbs.	~~*$1,518.00*~~ *$1,608.00*

Interpretation

Trucks that weigh over 40,000 pounds (18.2 metric tons) are subject to an excise tax. This shouldn't affect lift axle use because the tax isn't weight-dependent once over 40,000 pounds (18.2 metric tons). No incentive or disincentive exists for their use.

Licensing fees for loads over 40,000 pounds (18.2 metric tons) has increased by a set amount. However, while the increase in licensing fees was uniform, the cost of the additional weight in licensing fees increases exponentially as weight increases, which makes it costly to carry heavy loads. This should discourage the use of lift axles by reducing the monetary benefit. Again, however, higher licensing fees may discourage payment by truckers and may encourage illegal operation.

> ***Washington Laws 1993 Chapter 403 Commercial Motor Vehicle Inspection*** *(Amends RCW 46.32.010, 46.32.020, and 46.44.105). ...(1) Violation of any of the provisions of RCW 46.44.()41, 46.44.042, 46.44.047, 46.44.090, 46.44.()91, and 46.44.095, or failure to obtain a permit as provided by RCW 46.44.090 and 46.44.095, or misrepresentation of the size or weight of any load or failure to follow the requirements and conditions of a permit issued here under is a traffic infraction, and upon the first finding thereof shall be assessed a basic penalty of not less than fifty dollars; and upon a second finding thereof shall be assessed a basic penalty of not less than seventy-five dollars; and upon a third or subsequent finding shall be assessed a basic penalty of not less than one hundred dollars.*
> *(2) In addition to the penalties imposed in subsection (1) of this section, any person violating RCW 46.44.041,46.44.042, 46.44.047, 46.44.090, 46.44.091, or 46.44.095 shall be assessed three cents for each pound of excess weight. Upon a first violation in any calendar year, the court may suspend the penalty lot five hundred pounds of excess weight for each axle on any vehicle or combination of vehicles, not to exceed a two thousand pound suspension. In no case may the basic penalty assessed in subsection (1) of this section be suspended...*

Interpretation

Truckers who violate the weight regulations, including permits, are assessed a minimum fine of $50. Fines increase as a result of repeat offenses (as long as the officer is able to trace the previous offense). Tracing the offenses is difficult when carriers have multiple vehicles and multiple drivers.

Drivers whose loads are assessed as being overweight are penalized three cents for every pound overweight (if a truck is 2,000 pounds [0.9 metric pounds] overweight, the fee is only $60). In a study conducted at Washington State University, it was found that "fines on overweight violations are either initially too low or are lowered by judges in contested hearings to amounts that are less than the profits gained by hauling the extra tonnage, thus encouraging illegal overloading." (18)

Suggested changes to the current penalty system in this study include (1) increasing the penalties for overloads on axles (including bridge/internal axle spacing) rather than on gross overloads because heavy axle loads rather than heavy gross weights are likely to cause excessive roadway damage, and (2) increase the overweight fines exponentially rather than the uniform three cents per pound because damage to the roadway increases exponentially. (18)

ENFORCEMENT

Commercial vehicle enforcement is extremely difficult. First, the enforcement of lift axles is not a priority for the Washington State Patrol (WSP). Other truck-related issues such as safety and crime take precedence. In addition, limits on time and manpower prevent the monitoring of a number of specific lift axles regulations (i.e., no controls in the cab). Chapter 403 of the 1993 Washington Laws discusses aspects of the inspection and weighing process conducted by the WSP.

> ***Washington Laws 1993 Chapter 403 Commercial Motor Vehicle Inspection*** *(Amends RCW 46.32.010, 46.32.020, and 46.44.105). ...The state patrol may inspect a commercial motor vehicle while the vehicle is operating on the public highways of this state with respect to vehicle equipment, hours of service, and driver qualifications.*
> *(3) It is unlawful for any vehicle required to be inspected to be operated over the public highways this state unless and until it has been approved periodically as to equipment.*
> *(4) Inspections shall be performed by a responsible employee of the chief of the Washington state patrol, who shall be duly authorized and who shall have authority to secure and withhold, with written notice to the director of licensing, the certificate of license registration and license plates of any vehicle found be defective in equipment so as to be unsafe or unfit to be operated upon the highways of this state, and it shall be unlawful for any person to operate such vehicle unless and until it has been placed in a*

condition satisfactory to pass a subsequent equipment inspection. The police officer in charge of such vehicle equipment inspection shall grant to the operator of such defective vehicle the privilege to move such vehicle to a place for repair under such restrictions as may be reasonably necessary.
...(6) It is a traffic infraction for any person to refuse to have his motor vehicle examined as required by the chief of the Washington state patrol, or, after having had it examined, to refuse to place an insignia, sticker, or other marker, if issued, upon the vehicle, or fraudulently to obtain any such insignia, sticker, or other marker, or to refuse to place his motor vehicle in proper condition after having it examined, or in any manner, to fail to conform to the provisions of this chapter.
(7) It is a traffic infraction for any person to perform false or improvised repairs, or repairs in any manner not in accordance with acceptable and customary repair practices, upon a motor vehicle...
...The chief of the Washington state patrol may adopt reasonable rules regarding types of vehicles to be inspected, inspection criteria, times for the inspection of vehicle equipment, drivers' qualifications, hours of service and all other matters with respect to the conduct of vehicle equipment and driver inspections.
...(10) For the purposes of determining gross weights the actual scale weight taken by the arresting officer is prima facie evidence of the total gross weight.
(11) It is a traffic infraction to direct the loading of a vehicle with knowledge that it violates the requirements in RCW 46.44.(141, 46.44.(142, 46.44.047, 46.44.090, 46.44.091, or 46.44.095 and that it is to be operated on the public highways of this state...

Interpretation

Under this regulation, troopers may both inspect a vehicle and examine the driver and his or her credentials. However, this process is performed in an effort to maintain adequate levels of roadway safety. Inspecting the vehicle for equipment that is illegal, such as a deployment switch in the cab, would not be permissible under this regulation. The main focus of the lift axle inspection is on the brakes and wheels. Little attention is paid to whether the lift mechanism is operable.

IMPLICATIONS

Based on the regulations provided above, there are two ways of discouraging the illegal use of lift axles. First, enforcement efforts can be increased or redirected to focus on the specifications of the lift axle regulations (i.e., control location, steering capabilities, etc.). Currently, enforcement manpower is limited and other enforcement priorities exist that prevent the close monitoring of lift axle regulations. A second option is to reduce the monetary benefit derived from lift axle use. This would be accomplished by increasing fines for overweight vehicles or adjusting fees and taxes to compensate for the increase in payload. The most effective regulatory scheme is a combination of these two options.

CHAPTER 5
SUMMARY OF PRACTICES IN OTHER STATES AND PROVINCES

Information regarding lift axle regulations in other states and Canadian provinces was obtained through informal telephone surveys of knowledgeable representatives from each jurisdiction. Specifically, information pertaining to each state or province's regulation or policy was elicited through a series of questions relating to the following issues:

- lift axle bans,
- pre-operation requirements,
- weight specifications,
- equipment specifications, and
- axle deployment requirements.

In addition, representatives were questioned as to the motivation behind the existing regulation or policy.

The information obtained from each jurisdiction is displayed in both tabular and geographic form. Table 6 provides a summary of each jurisdiction's involvement in lift axle regulation. The absence of a check mark (√) indicates that lift axles, in this state or province, are not distinguished from fixed axles; and as such, no special regulatory actions are taken. The jurisdictions without special lift axle regulations are depicted in Figure 1. Under each of the categories below, a geographic map is provided to show which jurisdictions have common regulations. This should provide a better understanding of the disparity in terms of state or provincial regulations with which the trucking industry must contend.

BANS

Lift axle use can be banned entirely, or restricted, based on a number of factors including load, truck type or configuration, and lift axle design. Figure 2 depicts the states and provinces that currently ban lift axle use in one way or another.

Table 6. Summary of Lift Axle Regulation by State/Province (December 1993)

	BAN	PRE-OPERATION REQUIREMENTS		WEIGHT SPECIFICATIONS[1]				EQUIPMENT SPECIFICATIONS						AXLE DEPLOYMENT		MOTIVATION			
				Axle Load		Axle Spacing	Configuration	Steering				Tires[2]	Brakes[3]						
		Permit Required	Approval Required	Set by State	Set by Manufacturer			Must be Non-	Must be Controlled	Must be Self-	Centering Mechanism Required	Must be Dual		Control Must be Outside Cab	Loaded Axle Must be Down	Protect Infrastructure	Improve Safety	Maintain Vehicle Integrity	Obtain Uniformity
Alabama				√												√			
Alaska	√															√			
Arizona			√							√				√	√	√			
Arkansas																√			
California	√																		
Colorado				√															
Connecticut				√															
Delaware																			
Florida	√						√							√	√				
Georgia	√															√			
Idaho			√		√					√				√	√				
Illinois							√												
Indiana												√							
Iowa				√											√				
Kansas	√			√											√				
Kentucky																√			
Louisiana				√										√	√				

[1] Load, spacing or configurations requirements different than those requirements governing fixed axles.
[2] Tire requirements in addition to pounds per inch width requirements.
[3] Brake requirements in addition to federal safety-related brake requirements.

Table 6. Summary of Lift Axle Regulation by State/Province (December 1993) *(continued)*

	BAN	PRE-OPERATION REQUIREMENTS		WEIGHT SPECIFICATIONS[1]				EQUIPMENT SPECIFICATIONS						AXLE DEPLOYMENT		MOTIVATION			
				Axle Load		Axle Spacing	Configuration	Steering				Tires[2]	Brakes[3]						
		Permit Required	Approval Required	Set by State	Set by Manufacturer			Must be Non-	Must be Controlled	Must be Self-	Centering Mechanism Required	Must be Dual		Control Must be Outside Cab	Loaded Axle Must be Down	Protect Infrastructure	Improve Safety	Maintain Vehicle Integrity	Obtain Uniformity
Maine				√			√			√		√			√				
Maryland				√											√	√			
Massachusetts			√												√				
Michigan																√	√		
Minnesota															√				
Mississippi	√																		
Missouri														√	√	√			
Montana															√				
Nebraska				√										√	√				
Nevada															√				
New Hampshire																			
New Jersey																			
New Mexico																			
New York				√															
North Carolina																			
North Dakota																			

1 Load, spacing or configurations requirements different than those requirements governing fixed axles.

2 Tire requirements in addition to pounds per inch width requirements.

3 Brake requirements in addition to federal safety-related brake requirements.

Table 6. Summary of Lift Axle Regulation by State/Province (December 1993) *(continued)*

	BAN	PRE-OPERATION REQUIREMENTS		WEIGHT SPECIFICATIONS[1]				EQUIPMENT SPECIFICATIONS						AXLE DEPLOYMENT		MOTIVATION			
				Axle Load		Axle Spacing	Configuration	Steering				Tires[2]	Brakes[3]						
		Permit Required	Approval Required	Set by State	Set by Manufacturer			Must be Non-	Must be Controlled	Must be Self-	Centering Mechanism Required	Must be Dual		Control Must be Outside Cab	Loaded Axle Must be Down	Protect Infrastructure	Improve Safety	Maintain Vehicle Integrity	Obtain Uniformity
Ohio				√										√	√	√			
Oklahoma																√			
Oregon	√				√									√	√	√	√		
Pennsylvania															√	√	√		
Rhode Island																			
South Carolina															√	√			
South Dakota		√										√		√	√				
Tennessee																			
Texas																			
Utah					√					√				√	√	√	√		
Vermont																			
Virginia																			
Washington					√					√				√	√	√			
West Virginia				√											√				
Wisconsin				√															
Wyoming																			

1 Load, spacing or configurations requirements different than those requirements governing fixed axles.
2 Tire requirements in addition to pounds per inch width requirements.
3 Brake requirements in addition to federal safety-related brake requirements.

Table 6. Summary of Lift Axle Regulation by State/Province (December 1993) *(continued)*

	BAN	PRE-OPERATION REQUIREMENTS		WEIGHT SPECIFICATIONS[1]				EQUIPMENT SPECIFICATIONS						AXLE DEPLOYMENT		MOTIVATION			
				Axle Load		Axle Spacing	Config-uration	Steering				Tires[2]	Brakes[3]						
		Permit Required	Approval Required	Set by Prov-ince	Set by Manu-facturer			Must be Non-	Must be Con-trolled	Must be Self-	Centering Mechanism Required	Must be Dual		Control Must be Outside Cab	Loaded Axle Must be Down	Protect Infra-structure	Improve Safety	Maintain Vehicle Integrity	Obtain Uniform-ity
Alberta	√																		
British Columbia	√																		
Manitoba	√		√	√										√		√			
Ontario	√			√															
Quebec	√	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Saskat-chewan	√																		

1 Load, spacing or configurations requirements different than those requirements governing fixed axles.
2 Tire requirements in addition to pounds per inch width requirements.
3 Brake requirements in addition to safety-related brake requirements.

Regulations/policies address lift axles

Regulations/policies do not address lift axles specifically (i.e., lift axles, when down, are viewed as a fixed axle)

Figure 1. States/Provinces with Regulations or Enforcement Policies Specific to Lift Axles (12/93)

Figure 2. States/Provinces with Lift Axle Bans in Effect (12/93)

Throughout Canada, lift axle use is limited by truck configuration. In 1988, Canadian provinces agreed to recognize six truck configurations that experience sufficient load carrying capacity while maintaining a high level of stability. These configurations are limited by specified axle loads, axle arrangements, axle spacing, and other dimensions. These six configurations, referred to as 'RTAC trucks,' were developed by the Roads and Transportation Association of Canada (RTAC) in an effort to improve the efficiency of truck travel throughout the country. Pre-defined, uniform truck configurations make enforcement easier for the regulatory personnel, and make compliance easier for the trucking industry.

None of the RTAC configurations recognize lift axles as load bearing axles. Therefore, Canadian weight enforcement officials must ensure that the weight carried by the truck does not exceed legal weight limits, notwithstanding the presence of the lift axle. In cases in which a lift axle is used in combination with a tandem axle to create a tridem, the axle grouping is limited to the tandem axle weight limits; the lift axle provides no additional load carrying benefits. Similar reasoning applies to other axle groupings. In each case, the lift axle may support weight, but the permissible weight is governed by the number of fixed axles.

Although the 'RTAC rules' prohibit lift axles on the six RTAC configurations, there is some disparity in regulation with regard to non-RTAC trucks. Some provinces recognize lift axles on non-RTAC trucks, but others ban lift axles completely.

In British Columbia, prior to 1988, weight enforcement personnel recognized lift axles as load carrying axles if they were installed on the trailer. (Lift axles have never been allowed on the power unit.) However, when the RTAC configurations were introduced, officials in B.C. opted to ban lift axles. Today, if a truck with a loaded lift axle is stopped at a B.C. weigh facility, the driver is required to redistribute the load such that the weight supported by the lift axle can be transferred to the fixed axles without overloading (B.C.'s weight limits are substantially higher than U.S. weight limits, so overloading is not usually a problem). An overweight citation is rarely issued in such cases.

In Manitoba, as in B.C., lift axles are not recognized on the power unit of any vehicle. In addition, Manitoba will not recognize a lift axle if it is on a semitrailer, although full trailers may be equipped with lift axles as load bearing axles. The motivation behind lift axle restrictions on semitrailers is infrastructure preservation. Manitoba has no requirements for the steering capabilities of the lift axle (other than on unusual configurations such as concrete trucks), so the axle is often non-steering. When turning, non-steering axles on the semitrailer are thought to cause severe pavement damage because of scrubbing. Full trailers have an additional axle at the front of the trailer that helps prevent this.

In the U.S., the most severe lift axle bans are operative in Alaska, Georgia, and Mississippi. In none of these states will weight enforcement personnel recognize a lift axle as a load carrying axle. If a truck equipped with a lift axle passes through any of these states, weight enforcement personnel require that the lift axle or axles be raised prior to weighing the vehicle. The trucker may then be cited for any overweight fees that may result from the other overloaded axles. This all out ban on lift axle use stems from a desire to maintain the condition of the highway infrastructure. Representatives of these states feel that compliance problems (i.e., raising the loaded axle inappropriately) could not easily be corrected given the limitations on enforcement manpower. Therefore, banning the use of lift axles was seen as the most feasible way of ensuring compliance with the weight laws.

While there is no direct lift axle ban in Florida, use is limited to a single unit, four-axle dump truck hauling less than 70,000 pounds (31.8 metric tons). This configuration was chosen because of the heavy loads it carries and its short axle spread. Moreover, the ability to raise the axle when empty allows improved maneuverability for this vehicle. Lift axles on other configurations are not recognized by Florida weight enforcement personnel. As in Alaska, Georgia, and Mississippi, the driver of any truck not meeting the given configuration, but equipped with a lift axle is required to raise the lift axle prior to being weighed, and is subject to any resulting overweight fines.

In California and Kansas, lift axles are recognized as load carrying axles as long as the truck is carrying a legal load (i.e., load that does not exceed the maximum gross weight that the vehicle is registered to carry). However, lift axles are prohibited on overlegal loads. This policy may limit the use of lift axles, because much of the benefit derived from lift axle installation is the additional payload. If the payload is limited to legal loads, then some of this benefit is lost.

Unlike Florida, California and Kansas, Oregon does not regulate lift axle use based on weight, size or truck type. Instead, Oregon regulates lift axle use based on axle design. Oregon weight enforcement personnel do not recognize lift axles that allow the load supported by the lift axle to increase or decrease (i.e., variable load suspension axles). The lift axle must be set at a fixed load supporting capability and must either be fully raised or fully deployed. Again, this regulation stems from a desire to preserve the infrastructure and to reduce compliance problems associated with inappropriate raising of the axle. However, this regulation , may be relatively difficult to enforce; and as such, less effective.

PRE-OPERATION REQUIREMENTS

Originally, it was thought that several states or provinces would have pre-operation requirements, such as the purchase of a special equipment permit, an equipment inspection, or a brief training requirement, prior to lift axle use. However, few states and provinces even offer such programs and they are almost always voluntary (see Figure 3).

Permit Required

There are no pre-operation requirements governing lift axle use in South Dakota. However, if drivers want to improve their vehicles' turning maneuverability by raising a loaded lift axle, then they must first obtain a permit. Such a permit allows the lift axle to

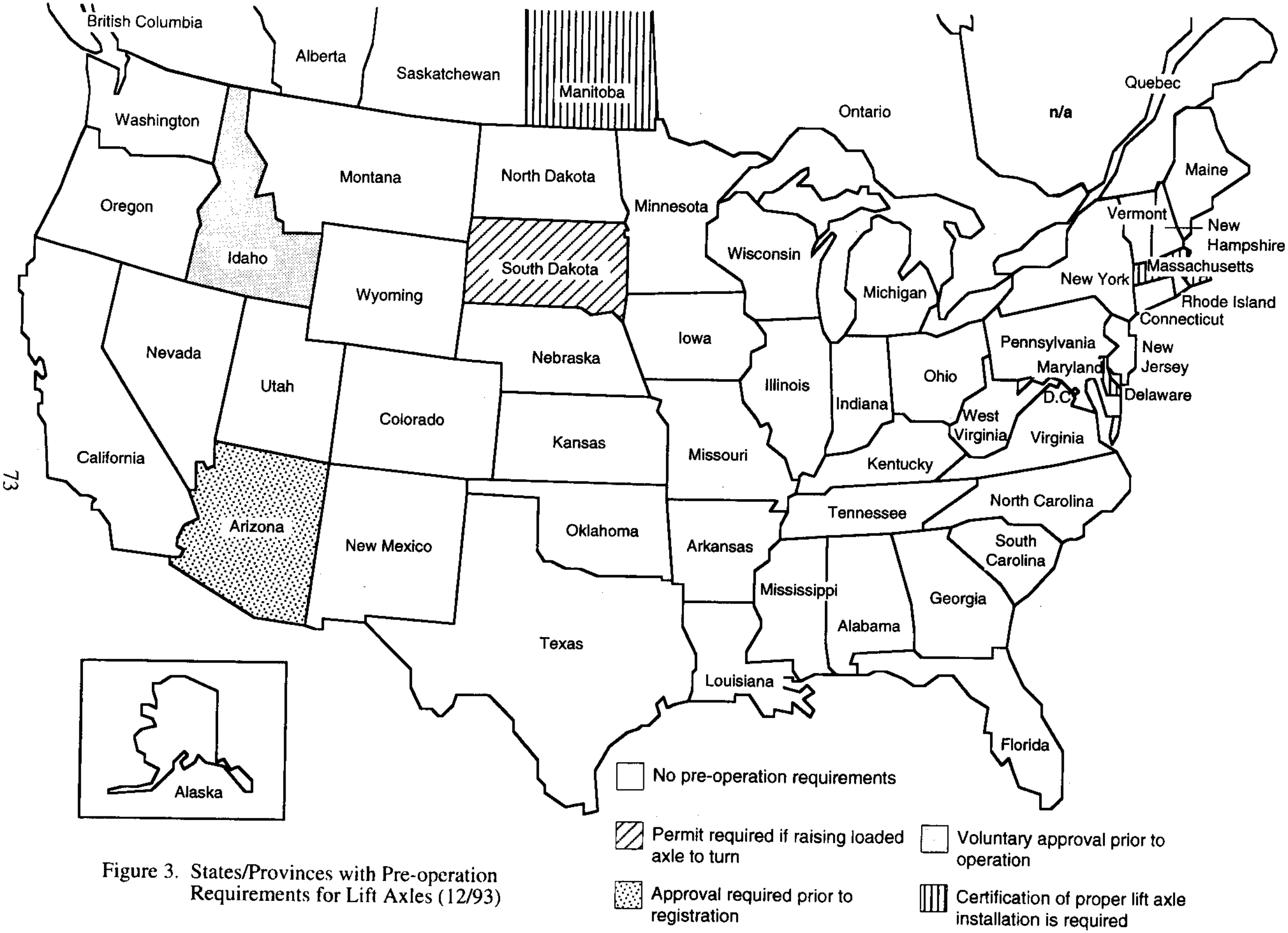


Figure 3. States/Provinces with Pre-operation Requirements for Lift Axles (12/93)

be raised when turning, but it must be lowered again within 100 feet (30.5 meters) of the corner. If a trucker raises the lift axle without a valid permit, or if he or she is not within 100 feet (30.5 meters) of the corner, then he or she may be asked to be weighed at the nearest facility (with the lift axle raised) and may be cited for overweight fines. Unfortunately, enforcement of this policy may result in the delay of legal (permitted) trucks as officers check for permits. A more positive approach would be to ensure compliance without delaying legal drivers.

Approval Required

When a driver brings his vehicle in for registration in Arizona, the vehicle, including the lift axle, is checked to ensure that it can adequately and safely support the proposed registered load. However, this check is aimed more at approval of the allowable weight than at lift axle use.

Idaho does not require, but allows the pre-qualification of configurations with lift axles. Idaho regulations require that the pressure regulator, which controls the amount of load supported by the lift axle(s) be set in advance and be inaccessible to the driver. If a driver or carrier informs the Idaho weight enforcement personnel of the regulator setting in advance, then the weighing process can be speeded up, saving the trucker travel time. This policy is intended to improve the efficiency of weigh scale operations rather than to monitor equipment.

In Massachusetts, when a lift axle is added to a vehicle, the driver must obtain and carry a certification from the installer that states that the lift axle was installed in a manner consistent with the manufacturer's specifications. While this certification is not verified *prior* to operation, it is issued prior to operation, and must be presented if requested by an enforcement officer.

Manitoba and Delaware require similar certification. If a driver or carrier has a lift axle added (retrofitted) to the vehicle after manufacture, then the after-market installer must re-certify the vehicle's gross vehicle weight rating (GVWR) for the additional weight. Delaware representatives expressed their concern regarding installations performed by smaller or less reputable garages that are not willing to assume the responsibility of re-certifying such vehicles because of potential safety or compliance problems.

WEIGHT SPECIFICATIONS

The level of safety experienced by the truck driver and the amount of damage incurred by the infrastructure are highly dependent on the axle load, the spacing between axles, and the location of the lift axles with respect to fixed axles. In most states and provinces, the load and spacing of lift axles are governed by the same bridge formula that governs fixed axles. The vehicle configuration is most often left to the carrier.

The differences in weight specifications are depicted in Figure 4. However, this figure may be misleading. It may appear that the jurisdictions with common shading have the same regulations. However, common shading only indicates that each jurisdiction shares a common *method* of regulation. The specifications in these regulations may differ substantially. The benefit of portraying the information in this way is that, while it does not show jurisdictions that have the *same* regulations, it does show states that have *common approaches* to regulation. It may be easier for these states or provinces to move toward more uniform regulations.

Load

Currently, no jurisdictions differentiate weight limits based on fixed axle as opposed to lift axle use. However, in Oklahoma, changes are being proposed that would limit lift axle loads to 8,000 pounds (3.6 metric tons), or to 650 pounds per inch (11.62 kilograms per millimeter) width of tire, whichever is reached first. Currently, the lift axle can carry as much as a fixed axle (20,000 pounds/9.1 metric tons).

In Connecticut, the allowable lift axle load depends on its proximity to a fixed axle. If the lift axle is placed more than six feet (1.8 meters) from a fixed axle, then the allowable axle load is 18,000 pounds (8.2 metric tons). If the lift axle is placed less than

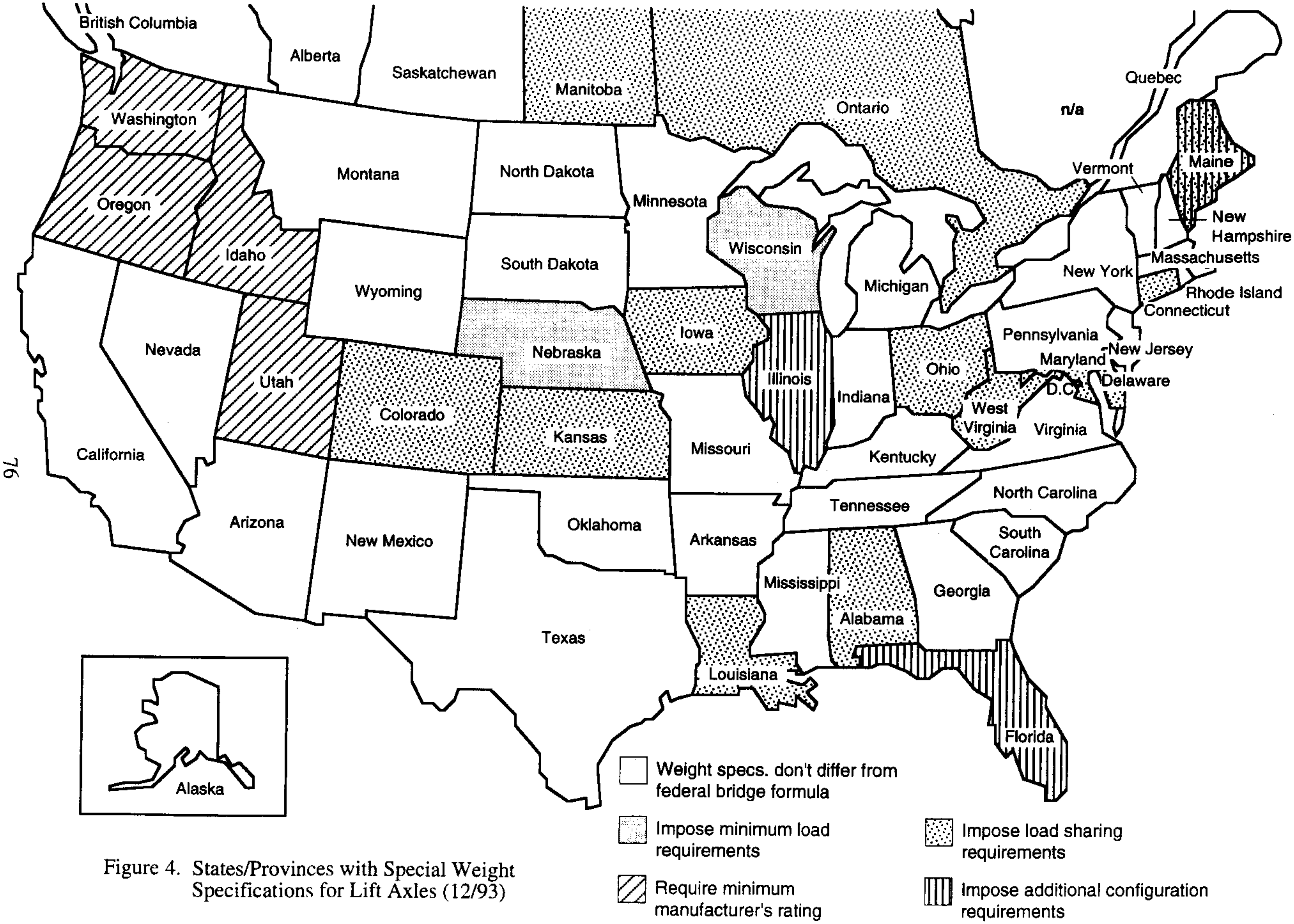


Figure 4. States/Provinces with Special Weight Specifications for Lift Axles (12/93)

six feet (1.8 meters) from a fixed axle, the allowable axle load is 22,400 pounds (10.2 metric tons).

A number of other jurisdictions have regulations or policies governing the proportion of load carried by the lift axle. The intent is to ensure that the lift axle is not supporting too little or too much of the overall load. Unfortunately, significant variability exists among the jurisdictions that require this proportional loading. Alabama, for example, requires that the lift axle carry at least 50 percent of the weight carried by the permanent axles, while both Nebraska and Wisconsin require that the lift axle carry at least 8 percent of the total gross vehicle weight. In Kansas, if a lift axle is used in combination with a tandem to form a tridem, then the lift axle must support at least one-third of the weight supported by that axle group. Louisiana has a similar requirement, but gives an allowance of 2,000 pounds (0.9 metric tons). In Maine, no axle in a tridem can support more than 40 percent of the weight supported by that axle group. For a tandem axle, no axle can carry more than 60 percent, or the weight supported by that axle group. In Iowa, if the lift axle is used to obtain additional load carrying capabilities, then the lift axle is required to carry any additional weight. If it does not support this additional weight, then the lift axle is not recognized, and the driver is assessed overweight fines. While these load sharing regulations are different in their specifications, the actual range of acceptable lift axle weights may be comparable.

A number of states also require that the axle be designed to carry a minimum amount of axle weight safely. This value, defined by the axle manufacturer, is called the manufacturer's axle weight rating. While a number of states are concerned with this rating, the minimum value varies. For example, Idaho requires that the lift axle have a manufacturer's rating of at least 9,000 pounds (4.1 metric tons). Oregon and Washington require a rating of not less than 10,000 pounds (4.5 metric tons). Utah requires a manufacturer's rating of at least 12,000 pounds (5.5 metric tons).

Spacing

No jurisdictions were found to have regulations or guidelines governing the spacing between a lift axle and another axle that differed from federal bridge formula regulations.

Configuration

Some states, such as Michigan, are lax in regulating configurations and will allow as many as four to five lift axles per vehicle. Other states, such as Illinois, limit the number of lift axles on a vehicle. Weight enforcement officials in Illinois honor four axles on a straight truck or six axles on a combination truck. Any number of these axles may be lift axles. However, if a lift axle is added onto one of these configurations as an additional axle in excess of the four- or six-axle limits, it is not be recognized. The additional axle must be lifted prior to weighing and the driver is cited for any overweight charges.

In Maryland, certain lift axle-equipped configurations are given special weight allowances. Maryland features a dump service registration, which allows a three-axle truck equipped with a lift axle to carry 65,000 pounds (29.5 metric tons). However, this registration is being phased out gradually by reducing the operating area of these vehicles, and hence, reducing its operational benefits. Other tractor trailer combinations must adhere to the federal bridge formula.

EQUIPMENT SPECIFICATIONS

Some jurisdictions have specific equipment or design specifications for lift axles that differ from design specifications for fixed axles. Differences have to do with the axle's steering requirements, tire requirements, and brake requirements. Figure 5 depicts states and provinces with additional equipment specifications for lift axles.

Steering

Lift axles can be designed in three ways: non-steering, controlled steering, or self-steering. When surveying the representatives in the U.S., three groups emerged. First,

Figure 5. States/Provinces with Equipment Specifications for Lift Axles (12/93)

several states require self-steering lift axles. A self-steering lift axle provides better maneuverability (reducing the need to raise the axle for turning) and reduces pavement damage. The second and third groups that emerged do not regulate lift axle steering capabilities. The choice of non-steering, controlled steering, or self-steering is left to the carrier or driver. These second and third groups differ in that one group allows the lift axle to be raised when turning (to improve maneuverability and reduce pavement damage) while the second group requires that the lift axle be down at all times, including during turning, if the axle is loaded.

The exception to this grouping is Maine, where self-steer axles are not required on any other configurations except a six-axle, single-unit truck. Beginning with the steering axle and moving rearward on the truck, axles 2, 5 and 6 may be lift axles, but axles 2 and 6 must be self-steering.

In New York, no current regulations specify required lift axle steering capabilities. However, officials there are proposing changes that would require lift axle controls to be placed out of the reach of the driver while still requiring that a loaded lift axle be down at all times, even when turning. Officials in New York feel that this combination of requirements will encourage the trucking industry to opt for self-steering axles to achieve better handling without the need for formal regulation.

Tires

Tire loading is monitored under Federal Motor Carrier Safety regulations, which are based on the tire manufacturer's ratings. In addition, tire loading is often monitored within states by observing the pounds per inch (kilograms per millimeter) width of tire. Several states have a predetermined value, which suggests an appropriate tire loading based on tire size. While this measure was not directly addressed through the survey, information regarding a state's required pounds per inch (kilograms per millimeter) width was often volunteered. Contrary to expectations, this measurement was not consistent, but instead ranged from 500 pounds per inch (8.94 kilograms per millimeter) width to

650 pounds per inch (11.62 kilograms per millimeter) width. The effect that this range of values would have on lift axle violations is unclear.

Few alternate regulations, in addition to the pounds per inch (kilograms per millimeter) width requirement, were discovered. Only three states currently require that lift axles be equipped with dual tires, and then only for certain loads or configurations. Indiana requires that dual tires be used on the lift axle if used in combination with a tandem to create a tridem axle capable of carrying 50,000 pounds (22.7 metric tons). Maine requires that all axles, except the steering axle and the second axle on a six-axle, straight truck capable of carrying 77,200 pounds (35.1 metric tons) gross vehicle weight, be equipped with four tires. South Dakota has more general regulations which require dual tires on the lift axle if the lift axle is being used to support a load which is over the legal weight limits. In Washington, regulations are changing to require all axles (with some exceptions) that carry more than 10,000 pounds (4.5 metric tons) (1) be equipped with dual tires or (2) be equipped with single tires limited to 500 pounds per inch (8.94 kilograms per millimeter) width of tire.

New York is proposing a dual tire requirement for all axles, including lift axles, on three, pre-defined configurations known as "Roadwork vehicles." These configurations include (1) a four-axle straight truck with a 25 foot (7.6 meters) minimum wheelbase and a load capacity of 68,000 pounds (30.9 metric tons); (2) a six-axle combination truck with a 50 foot (15.3 meters) minimum wheelbase and a load capacity of approximately 85,000 pounds (38.6 metric tons); and (3) a seven-axle combination truck with a minimum wheelbase of 50 feet (15.3 meters) and a maximum load carrying capacity of 91,000 to 93,000 pounds (41.4 to 42.3 metric tons). These specially designed vehicle are intended to reduce the equivalent single-axle loads (ESALs) to approximately 1 (federal bridge regulations currently have ESALs approaching 2.5) in an effort to reduce pavement damage resulting from repetitive heavy truck loads. New York regulations do not currently specify dual tires.

Brakes

Most states have adopted federal regulations regarding brakes directly (49 CFR 393.42). The complete citation of this federal regulation is contained in Chapter four of this report. In essence, federal regulations require that all axles on vehicles that carry more than 3,000 pounds (1.4 metric tons) to be equipped with operable brakes. There are several exceptions to this regulation, but none of them directly affect brakes on lift axles.

AXLE DEPLOYMENT

Compliance with the regulations or policies governing lift axles is highly dependent on the accessibility of the controls for deployment. As a result, a number of jurisdictions have specific regulations or policies that govern the location of lift axle controls and lift axle operation (see Figure 6).

Control Location

A number of jurisdictions regulate the location of the controls for raising and lowering the lift axle. If the control is in the cab, it not only allows the driver to raise the lift axle at inappropriate times, but it also compromises the vehicle's safety if the axle is lowered while the truck is in motion. A number of jurisdictions require that lift axle controls be located outside the cab for these reasons. However, in a number of jurisdictions , it is felt that the controls should be in the cab, to allow the driver to benefit from improved maneuverability when turning and to prevent tampering by someone other than the driver.

In Nebraska, lift axle controls on *interstate* trucks must be located outside the cab. It is assumed that interstate trucks do not need the controls inside the cab for maneuvering purposes. Local trucks that are equipped with lift axles may have the controls located inside to allow the axle to be raised around corners (allowing for improved maneuverability). Although Missouri also requires that the controls for the lift axle be located outside the cab, truckers may obtain a permit that allows the controls to be located inside the cab.

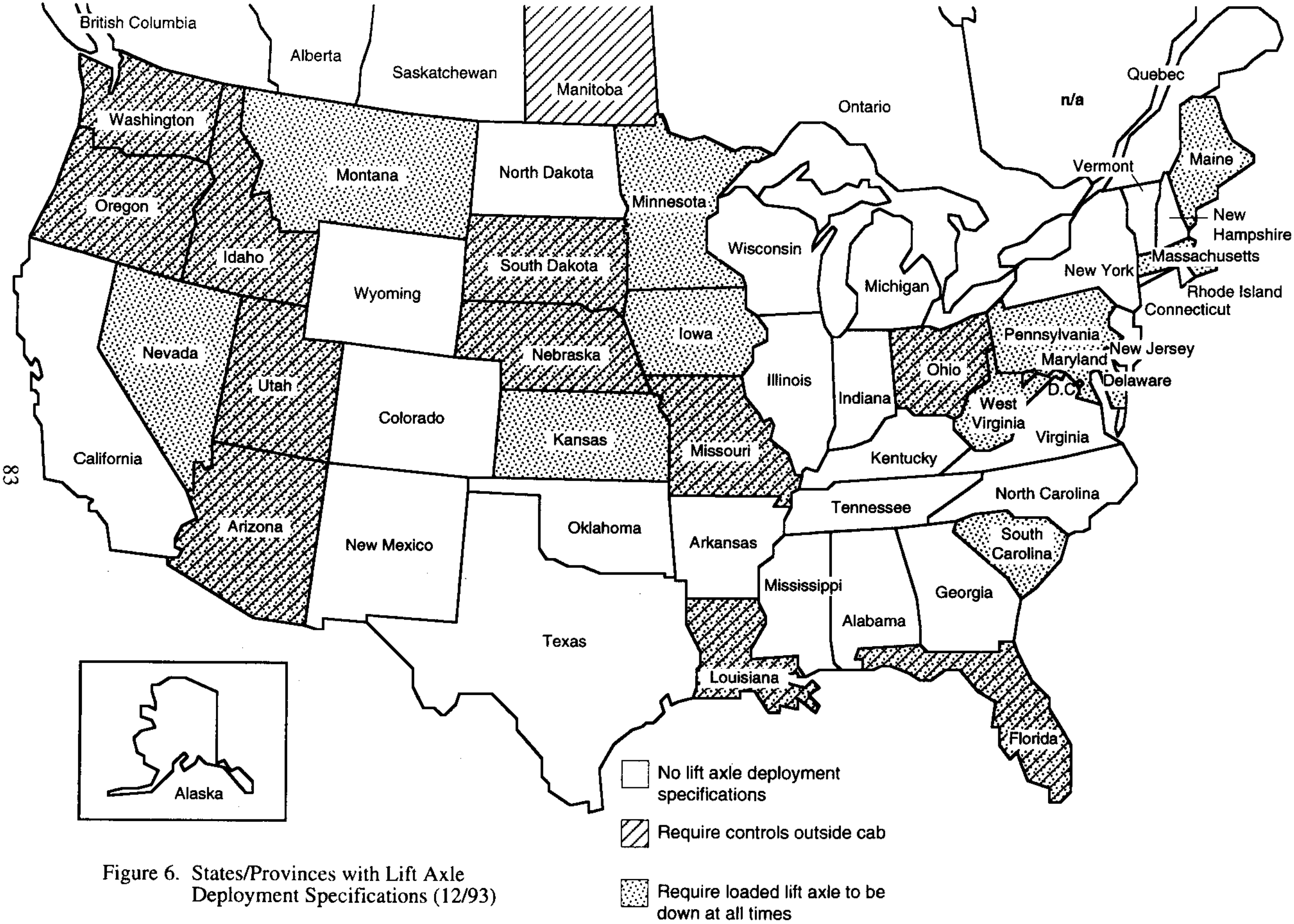


Figure 6. States/Provinces with Lift Axle Deployment Specifications (12/93)

Current regulations in New York do not specify lift axle control location. However, it is being proposed that lift axle controls should be located outside of the driver's reach for three, pre-defined vehicles (four-axle straight truck, six-axle combination truck and seven-axle combination truck).

A number of jurisdictions have tried to address the problem of compliance without compromising safety. Regulations in Arizona, Florida, Idaho, Louisiana, Ohio, South Dakota, and Utah specify that the switch for raising and lowering the lift axle may be located inside the cab. However, the pressure regulator, which controls the amount of weight carried by the lift axle, must be located outside the cab. Wisconsin currently has no regulations governing the location of the controls, but is currently proposing these same requirements.

In Washington, it was recently required that all controls be located outside the cab. However, recent regulatory changes now allow for internal location of the controls for raising and lowering the axle *if the switch is designed to be inoperable while the vehicle is in motion.* In this case, if the control is located inside the cab, then, the pressure regulator must be out of the driver's reach.

In Connecticut, previous practice allowed a trucker to be issued a permit for additional weight only if controls for the lift axle were located outside the cab. If the controls for the lift axle were inside the cab, then the maximum allowable weight was limited. This practice has been discontinued.

Axle Raising

A number of jurisdictions , especially those that have no requirements governing the steering capabilities of a lift axle, allow truckers to raise a loaded lift axle when turning to improve the vehicle's maneuverability and reduce pavement damage. However, some states oppose this practice.

Kansas, Maine, Maryland, Minnesota, Montana, and South Carolina require that a loaded lift axle be down at all times, even when turning. This is especially important if raising the lift axle causes overloading on the other axles. Oregon requires that lift axles be down at all times if the load exceeds 80,000 pounds (36.4 metric tons), or if raising the axle would cause overloading on any of the other axles. In Pennsylvania, the lift axle must be deployed if the truck is carrying at least two-thirds of its normal load (registered weight).

MOTIVATION FOR REGULATION OR POLICY

When information about the motivation behind the regulation or policy was provided, it most often related to preserving the infrastructure as opposed to improving safety, maintaining vehicle damage, or promoting regulatory uniformity among jurisdictions (the exception is the lift axle ban on RTAC trucks in Canada, which is clearly a movement toward uniformity). There is a simple explanation for this. First, when an accident involving a truck occurs, a number of factors, aside from lift axle use, may have had a part in causing the accident. It is not usually clear that the accident resulted from lift axle use.

The same is true for vehicle damage considerations. Problems are not easily linked to lift axle use. No overwhelming evidence suggests that lift axles are unsafe or that they cause undue damage to the vehicle.

However, if pavement problems arise in areas along truck routes with turns, it can easily be attributed to the scrubbing of tires, and can, in part, be attributed to non-steering lift axles that were not lifted around the corner. Few other factors enter into the picture. In such cases, the resulting damage is more obvious and can be attributed more easily to lift axle use.

IMPLICATIONS

The survey of U.S. states and Canadian provinces raises some interesting issues regarding lift axle use and regulation. Specifically, these issues relate to (1) the feasibility of enforcement, (2) differing priorities among jurisdictions, and (3) the lack of definitive solutions.

One of the biggest issues raised by nearly every jurisdiction was enforcement. Limited enforcement manpower prevents the close monitoring of lift axle use. A number of jurisdictions agreed that while their state regulations or practices comprehensively addressed enforcement issues with respect to lift axle use, the time and manpower available limits the extent to which lift axle regulations can be monitored. Other enforcement issues usually take precedence over lift axle regulation. Yet, if the lift axle regulations are not being enforced, then one wonders why the regulations exist. This issue implies a need for more communication between legislators and relevant law enforcement personnel. Additional input from law enforcement personnel in the law-making process may require a greater time commitment initially. However, their early input may ease their burden by simplifying enforcement.

Given the limitations on enforcement, the regulatory differences among the states and provinces may not be as great a concern for the trucking industry as thought initially. When considering the various state and provincial regulations, it is apparent that there are several regulation methods that are common to the jurisdictions. However, there are differences in the specifications or *details* of the requirements. With limited enforcement manpower, many of these 'details' go unchecked. A non-compliant trucker would go unchecked.

Concern over limited enforcement capability varies substantially among jurisdictions. This variability results from a difference in local industry and resources (proportion of heavy-haul commodities), and in state- or province-specific regulations that either directly or indirectly affect lift axle use. While enforcement could be simplified through more uniform requirements for lift axle use, it is difficult to achieve such uniformity when each jurisdiction has different priorities.

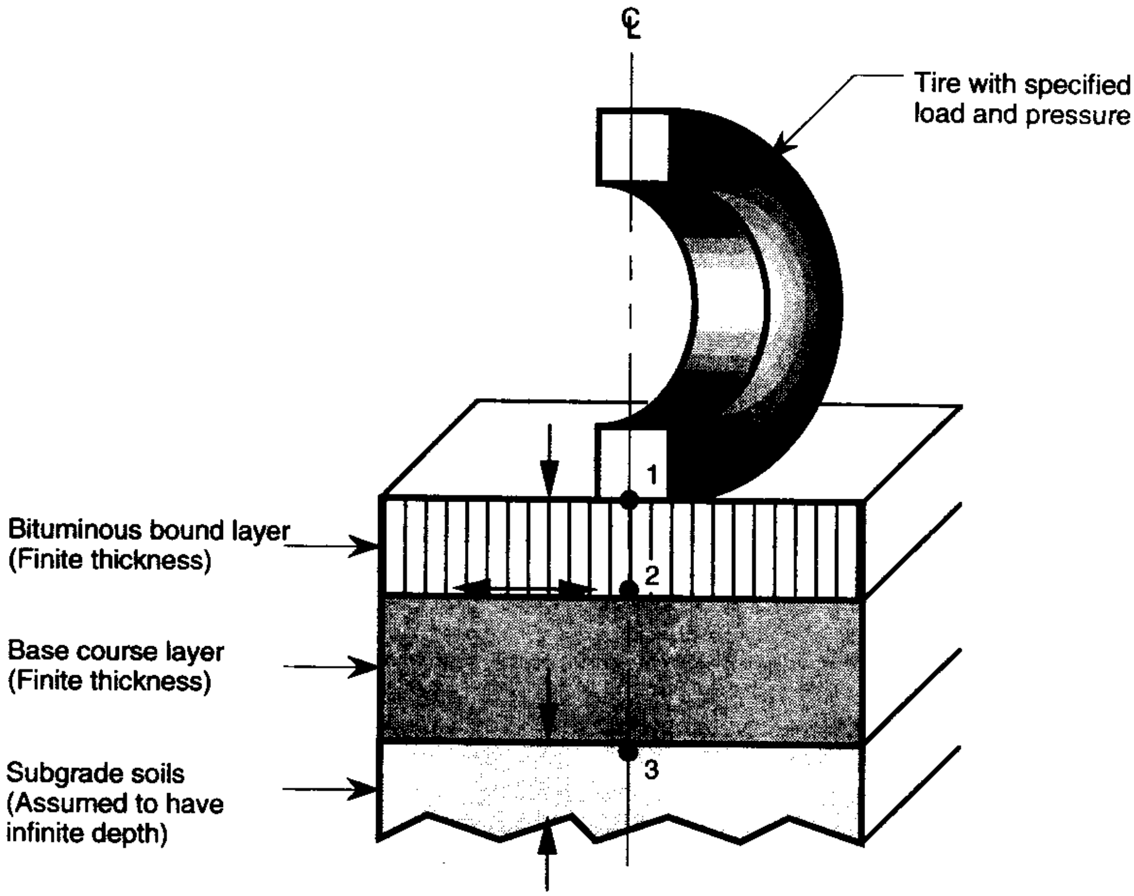
Moreover, it is difficult to achieve uniformity when guidelines regarding lift axle use and operation are few. For example, Washington state, in an effort to improve vehicle maneuverability and to reduce pavement damage, requires that a self-steering lift axle and lift axle controls be located out of the driver's reach. On the other hand, Louisiana approaches vehicle maneuverability and pavement damage reduction differently. Louisiana has no restrictions on the steering capabilities of the lift axle, and allows inside location of deployment controls so that the trucker may raise the axle when turning. Washington state's and Louisiana's regulatory approaches are very different in form, but they are similar in intent. Little definitive evidence exists that indicates one approach is more effective than the other.

CHAPTER 6
PAVEMENT DAMAGE CONSIDERATIONS

Basic elements of pavement structure include the surfacing, base, and subgrade layers. The purpose of the surfacing and base course is to provide a layered structure capable of supporting traffic loads and resisting the effects of climate. Surfacing is generally composed of a combination of aggregate and asphalt cement that is referred to as asphalt concrete pavement (ACP). The base course generally consists of dense, well graded aggregate which helps distribute the load stresses. Subgrade refers to the existing soils upon which the pavement structure is built.

When a load is placed on the pavement, the pavement is deflected downward at the surface. In addition, horizontal tensile forces, or tensile strains (ε_t), develop at the bottom of the surfacing course because of the surface's bending. This kind of strain can be used to predict fatigue cracking. At the same time, the subgrade experiences vertical compressive forces, or compressive strains (ε_v), due to the load and bending action. This type of strain can be used to predict rutting in the wheel path. These pavement responses are depicted in Figure 7.

The thickness of the surfacing and base course layers determines, in large part, the life of the pavement structure. Thicker pavement designs typically withstand more loads, and hence last longest. Thinner pavements experience fatigue cracking or rutting after fewer loads. The environment and weather also degrade pavement, but at a slower rate than do traffic loads. Heavy, repetitive traffic loads have the greatest potential for degrading the pavement structure. It is this type of repetitive, heavy loading that is analyzed in this chapter.



1. Pavement surface deflection
2. Horizontal tensile strain at bottom of bituminous layer
3. Vertical compressive strain at top of subgrade

Figure 7. Forces Acting on Pavement (REF. 19)

METHOD OF ANALYSIS

The researchers used computer software for much of the pavement analysis. This software, ELSYM5, uses layered elastic analysis to determine the displacement, stress, and strain at any vertical or horizontal location of interest which results from load(s). The computer analysis consisted of five steps: (1) selecting the truck configurations to be analyzed, (2) determining representative pavement sections for testing, (3) inputting the required data, including information on axle spacing, axle loading, and pavement sections, (4) inputting evaluation locations, and (5) running ELSYM5. The limiting conditions for both fatigue and rutting were calculated using widely used failure criteria and the strain information from ELSYM5. To further evaluate the ELSYM5 analysis, results were compared using AASHTO axle load equivalency factors.

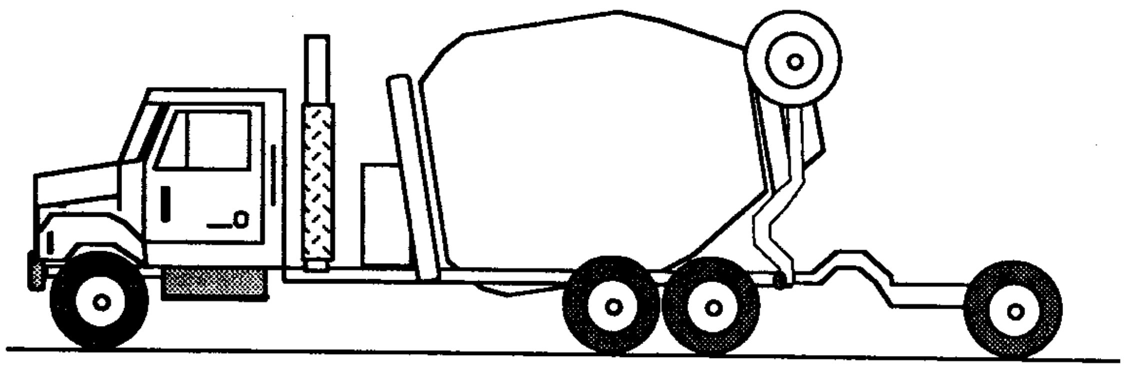
Truck Configurations

Two truck configurations were considered in this analysis: a concrete truck and a chip-hauling truck. A variety of other configurations utilize lift axles and could have been included in this analysis. These two configurations were chosen because (1) information regarding specific truck dimensions was readily available for both truck types, (2) chip-hauling trucks were frequently noted at the weigh facilities, and (3) concern was voiced over the damage that might be done to city streets if concrete trucks raise their booster axles when they should be down. Figure 8 depicts both configurations.

Typical concrete trucks are equipped with either four or five axles (a four-axle truck is shown in Figure 8). Four-axle trucks consists of a steer axle, a tandem axle, and a lift (booster) axle at the rear of the truck.

The second configuration considered was a chip-hauling truck. This type of truck generally has eight axles: a steering axle, a lift axle, a tandem axle, a lift axle, a tandem axle and a lift axle. The two lift axles and the tandem at the rear of the truck are grouped symmetrically to resemble a quadrum axle. When empty, the truck can raise the two rearward lift axles and operate with only a tandem in contact with the ground.

CONCRETE TRUCK



CHIP-HAULING TRUCK

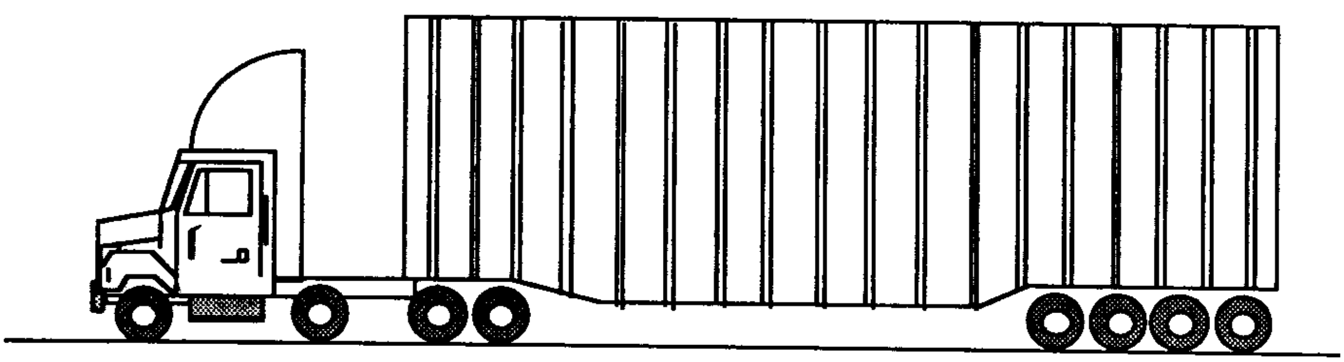


Figure 8. Truck Configurations

Axle Spacing and Loading

Loading conditions are defined in ELSYM5 using two of three parameters, load, contact pressure or the radius of the loaded area. For this analysis, load and contact pressure were entered.

An average tire inflation pressure of 100 pounds per square inch (psi) was assumed. It was also assumed that the tire load is uniformly applied over a circular area, which results in contact pressure that is the same as tire inflation pressure.

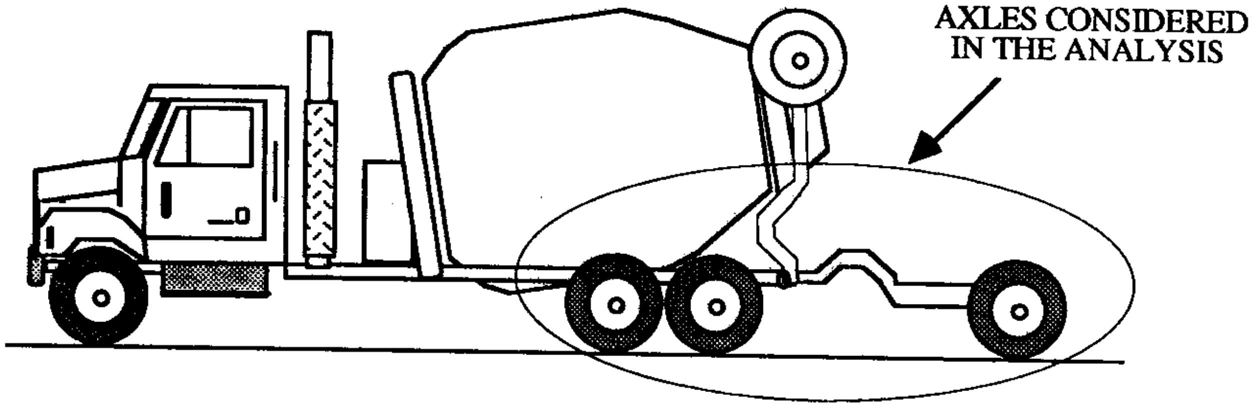
Three loading scenarios were considered in this analysis: (1) a fully loaded concrete truck with approximately 10 cubic yards of concrete, (1) a partially loaded concrete truck with approximately 7 cubic yards of concrete, and (3) a fully loaded chip-hauling truck.

If axles are spaced far apart, axle groups may be isolated for analysis. Axles spaced at large distances have little influence on pavement responses due to other axles. The isolated axle groups considered in this analysis are shown in Figure 9.

The magnitudes of the loads on each axle group when the lift axle is deployed and when the lift axle is raised are provided in Figure 10. Note that the axle group load for the concrete truck increases when the lift axle is raised. Deploying the lift axle extends the truck's wheel base which approximately centers the truck's center of gravity between the front and rear wheels. Raising the lift axle shortens the wheel base which locates the center of gravity near the rear of the truck. This weight imbalance shifts a portion of the weight that was supported by the steer axle to the tandem axle, which increases the load on the tandem axle (see Figure 11).

The specific loads and their locations are provided in Figures 12 and 13 for both the concrete truck and the chip-hauling truck. ELSYM5 allows for a single wheel load to be entered. This means that all wheels are assumed to carry a proportionate share of the total load. This load, applied to each wheel, is denoted by "P" in each of the figures. For the concrete truck, a proportionate wheel load of 4,250 pounds was assumed for the

CONCRETE TRUCK



CHIP-HAULING TRUCK

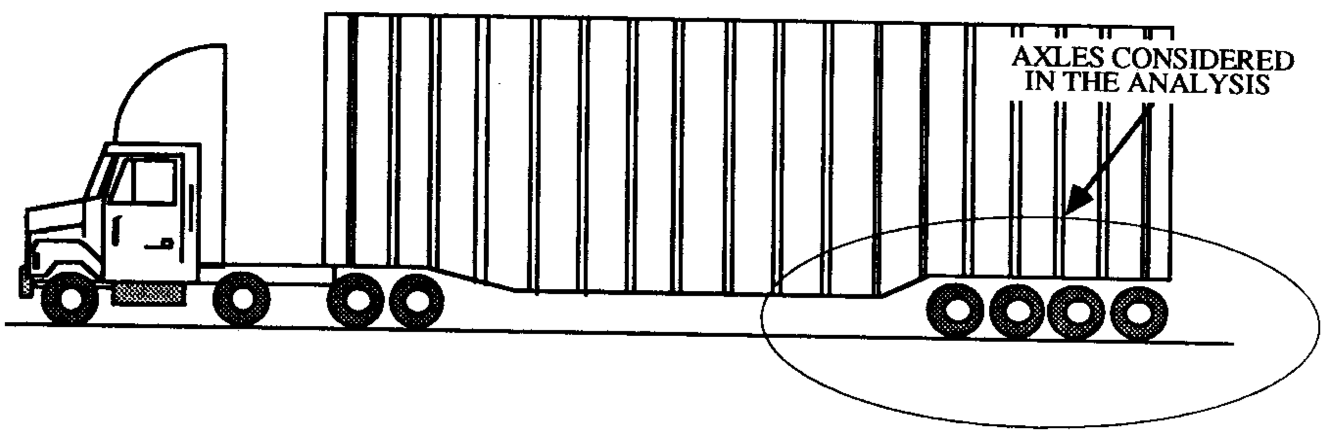


Figure 9. Isolation Of Axles

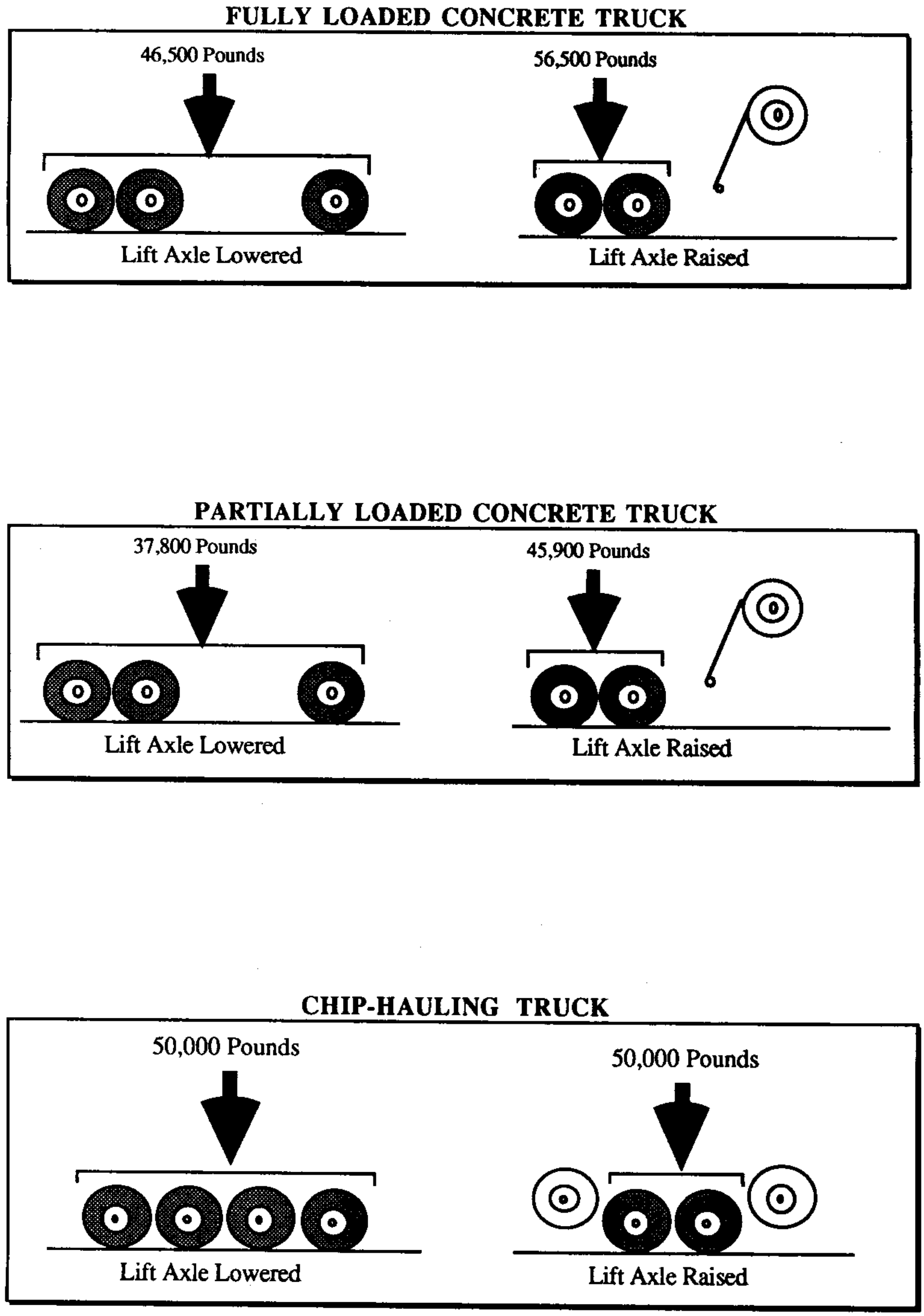
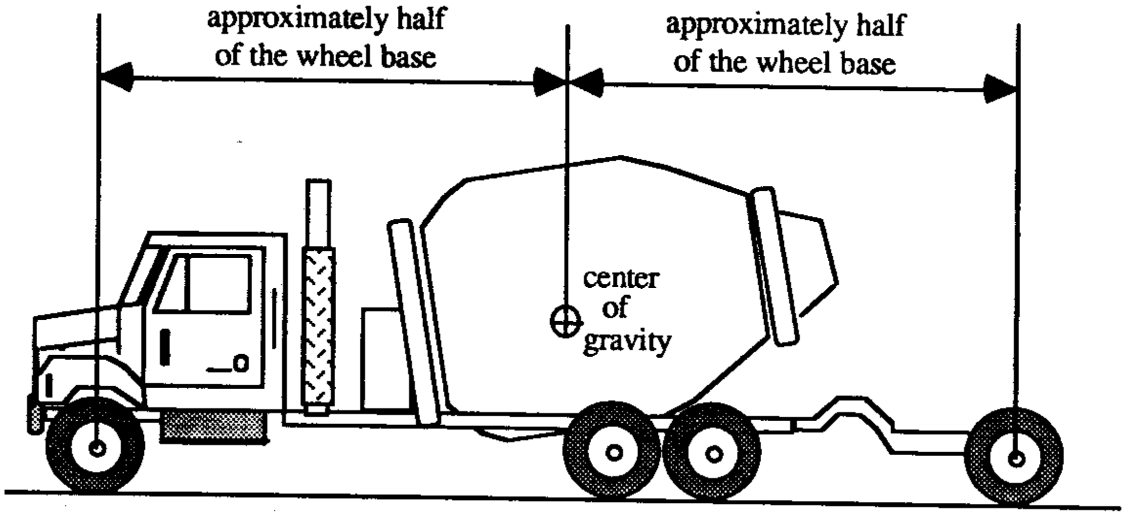


Figure 10. Axle Group Loading



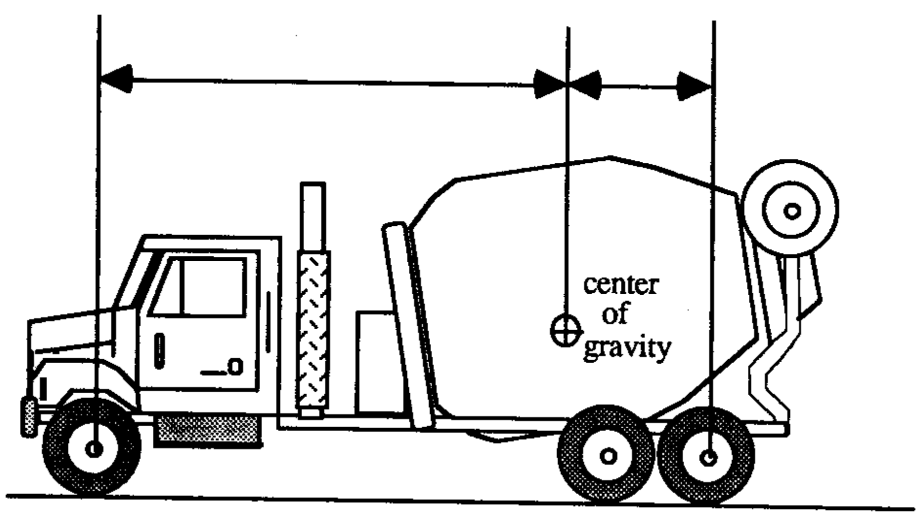
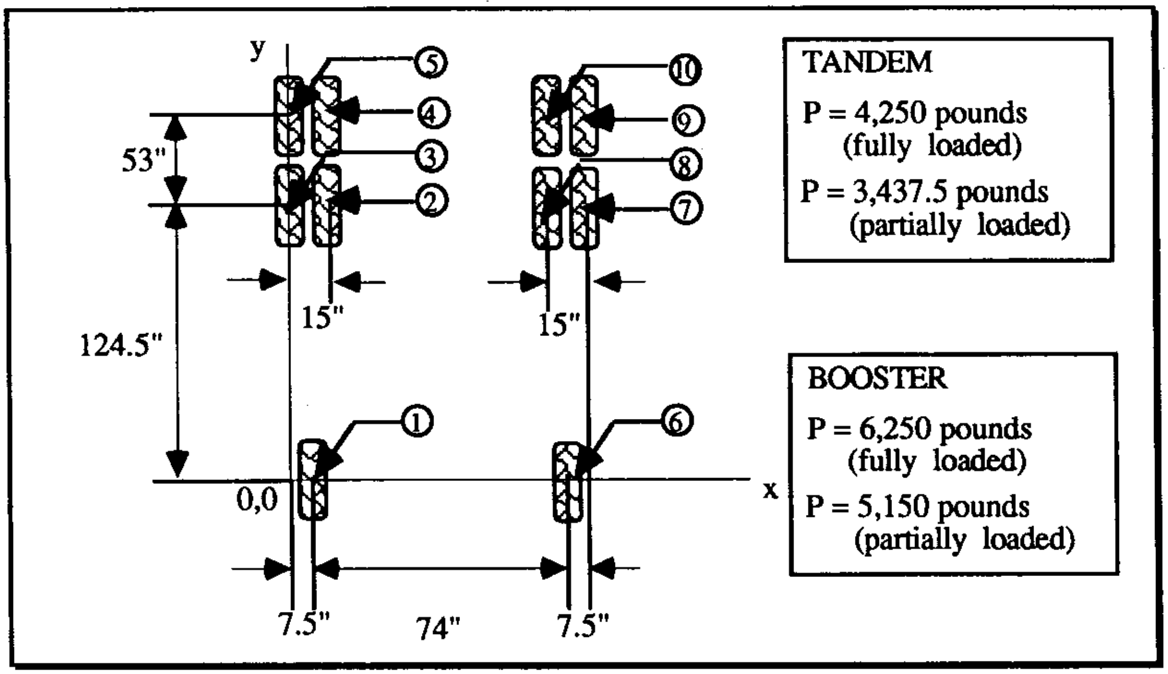


Figure 11. Concrete Truck Center of Gravity

LIFT AXLE LOWERED



LIFT AXLE RAISED

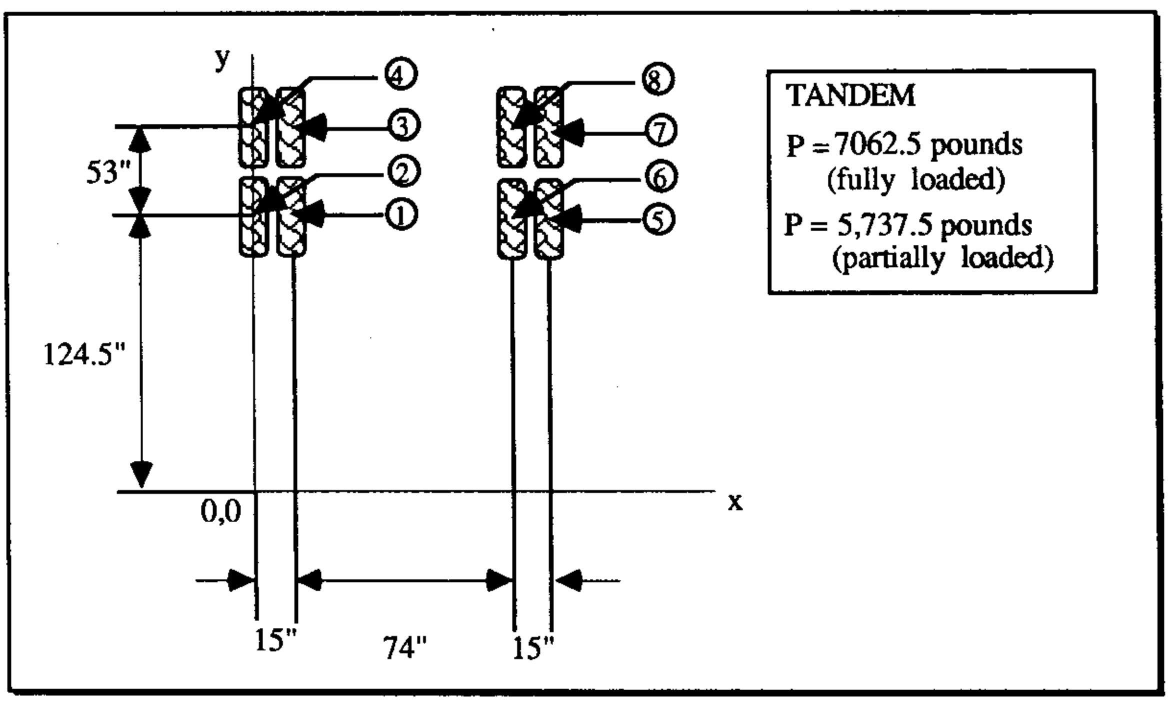
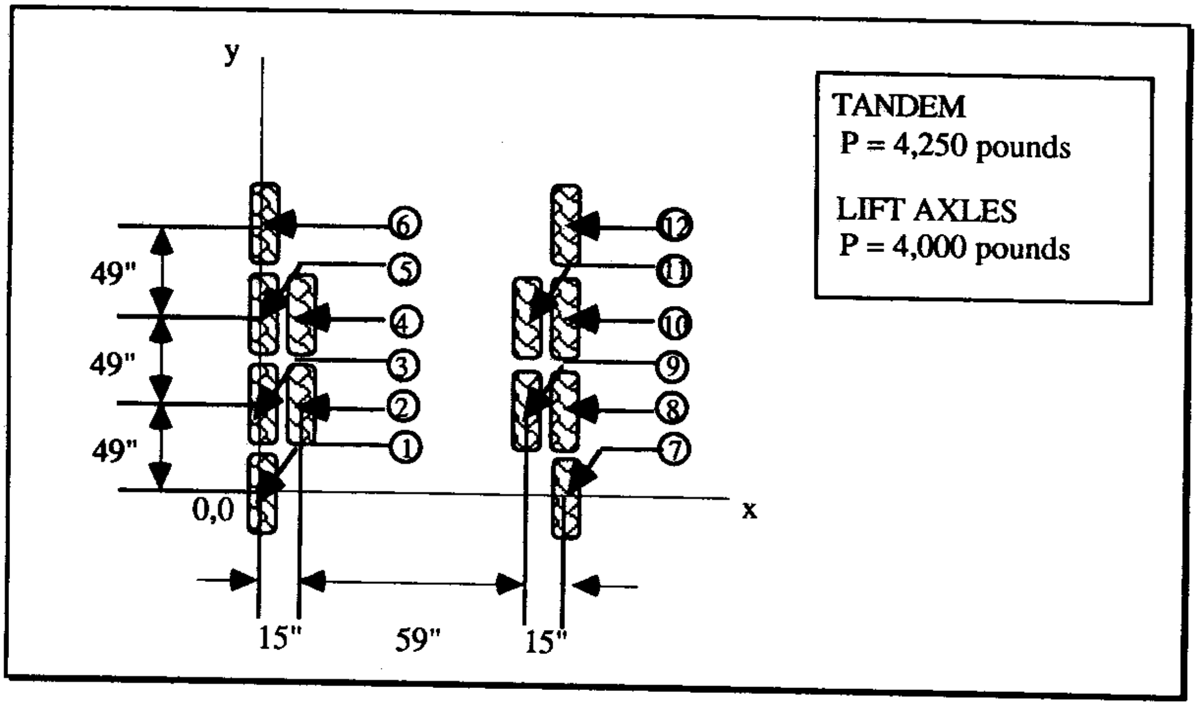


Figure 12. Concrete Truck Load Locations

LIFT AXLES LOWERED



LIFT AXLES RAISED

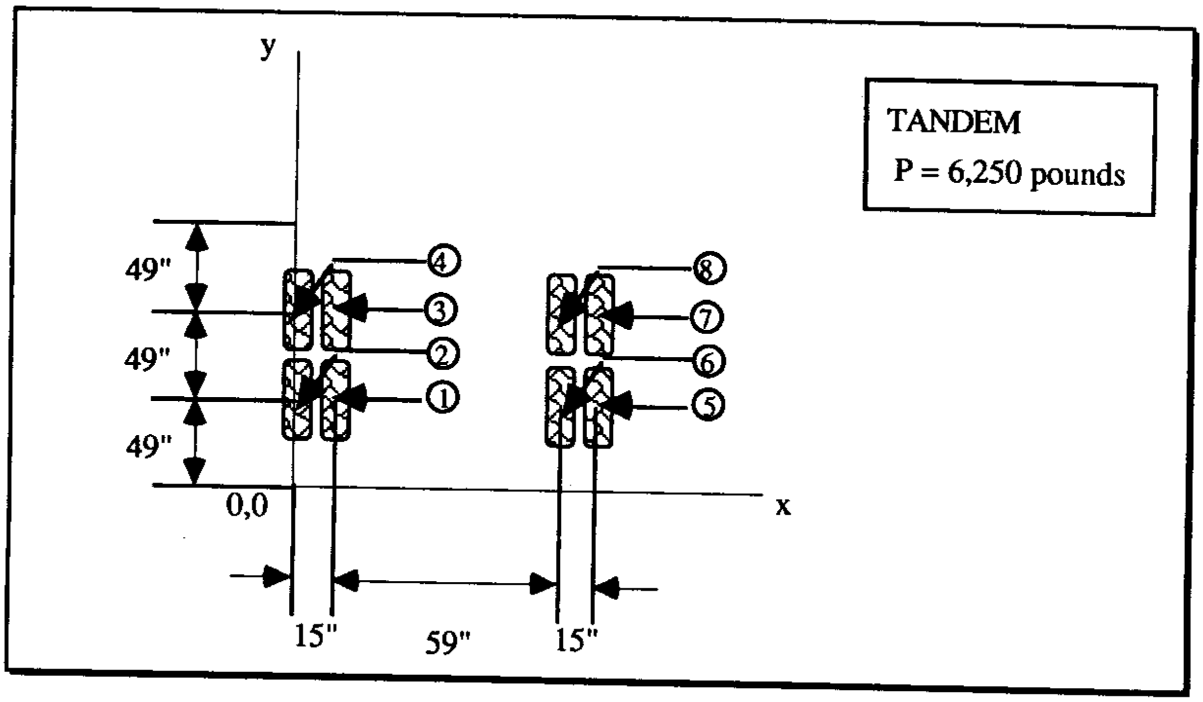


Figure 13. Chip-hauling Truck Load Locations

tandem axle and 6,250 pounds for the booster axle. These wheel loads result in axle group loadings of 34,000 pounds on the tandem and 12,500 pounds on the booster axle. For the partially loaded concrete truck, wheel loads are 3,437.5 pounds and 5,150 pounds for the tandem and booster axles respectively. This results in a load of 27,500 pounds on the tandem axle and a load of 10,300 pounds on the booster axle (a total truck weight of 54,000 pounds was used). For the chip-hauling truck, a proportionate wheel load of 4,250 pounds was assumed for the tandem axle and 4,000 pounds for the lift axles. These proportionate wheel loads result in axle group loadings of 34,000 pounds on the tandem axle and 8,000 pounds on each lift axle.

Pavement Sections

Three representative pavement sections were considered in the analysis. Views of the three pavement sections, including the layer thickness, assumed modulus of elasticity (E) and assumed Poisson's ratio (μ) are provided in Figure 14.

Section A consists of a thin layer of asphalt concrete pavement (ACP), and a base course. Section B consists of a thicker ACP over a slightly thicker base. Section C consists of a very thick ACP layer over a base course. Section A and B pavement types are typically found in city street and arterial designs. Section C pavement types are typically found in freeway designs. In each case, the subgrade layer is assigned a thickness of zero to indicate semi-infinite extent.

Typical values for the modulus of elasticity were assumed. Asphalt concrete pavement has a typical modulus of elasticity of 500,000 psi. The modulus of elasticity for the base course is typically 25,000 psi if crushed stone is used. For soils in the subgrade, the modulus of elasticity was assumed to be 7,500 psi which represents a medium to low "strength" soil (CBR$\cong$5).

The Poisson's ratio for asphalt concrete pavement is typically 0.35. A crushed stone base has a slightly higher Poisson's ratio of 0.40. For fine-grained soil subgrade, 0.45 is typical.

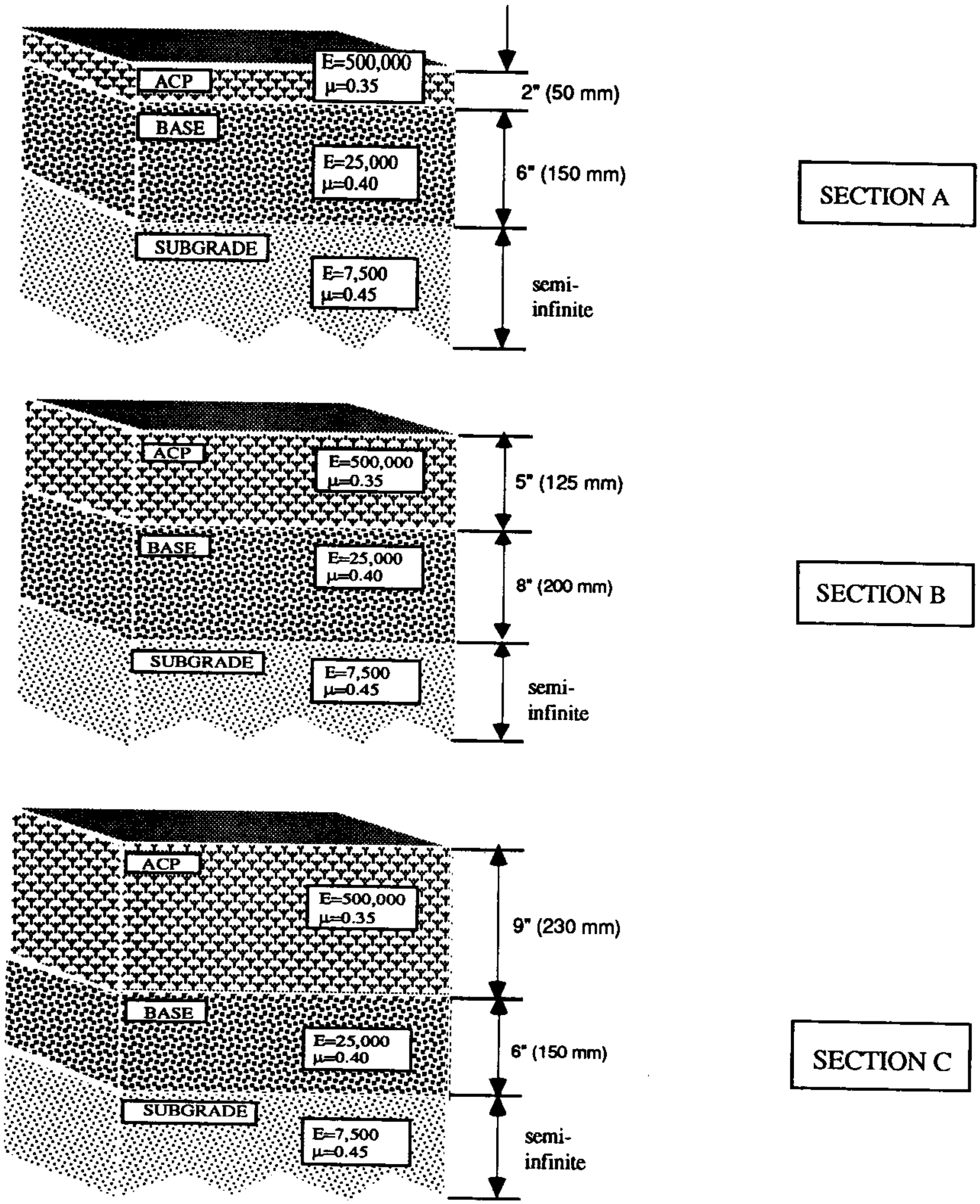


Figure 14. Pavement Sections

Evaluation Locations

Each of the loading scenarios was evaluated at three locations in the x-y plane (horizontal) and the z-plane (vertical). For both the concrete truck and the chip-hauling truck, the evaluation locations in the horizontal plane were as follows: (1) in the center of the tandem axle group along centerline of inside wheels, (2) in the center of the tandem axle group centered between the two wheels, and (3) centered under the rear, inside wheel (see Figure 15). In the z-plane, the evaluation locations for both trucks were at the top of the ACP, the bottom of the ACP, and the top of the subgrade (see Figure 16).

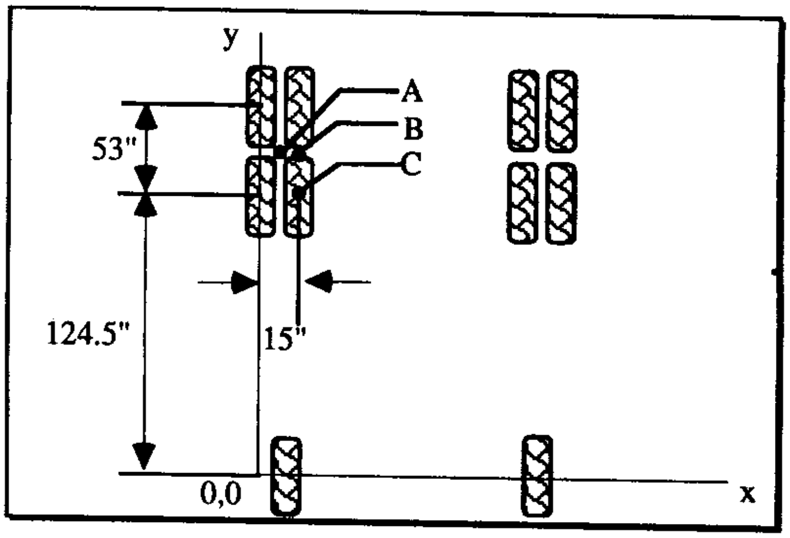
PAVEMENT ANALYSIS RESULTS

Three measures were used to indicate the relative change in pavement deterioration rates when lift axles are deployed and when they are raised. These measures include vertical displacement at the surface of the roadway, the number of loads to fatigue failure, and the number of loads to rutting failure. Pavement displacement, in this analysis, is used only to show how it changes for the various loading conditions evaluated. When considering the estimated number of loads to fatigue failure or rutting failure, the lower number indicates the mode in which the pavement will likely fail first. The changes in these measures attributable to lift axle deployment are provided below. This analysis focuses on the distinction between proper and improper lift axle deployment, not on the distinction between different truck types.

Vertical Displacement

Vertical displacement is the distance that the surface of the asphalt concrete is deflected downward as the result of load application. Vertical displacement increases with the magnitude of the load. Figures 17, 18, and 19 show the change in vertical displacement with the lift axle(s) deployed and raised for each of the truck load and configuration scenarios. Note that the greatest displacement occurs with the fully loaded concrete truck. Also note that in each case, the largest displacement occurs on the

CONCRETE TRUCK



CHIP-HAULING TRUCK

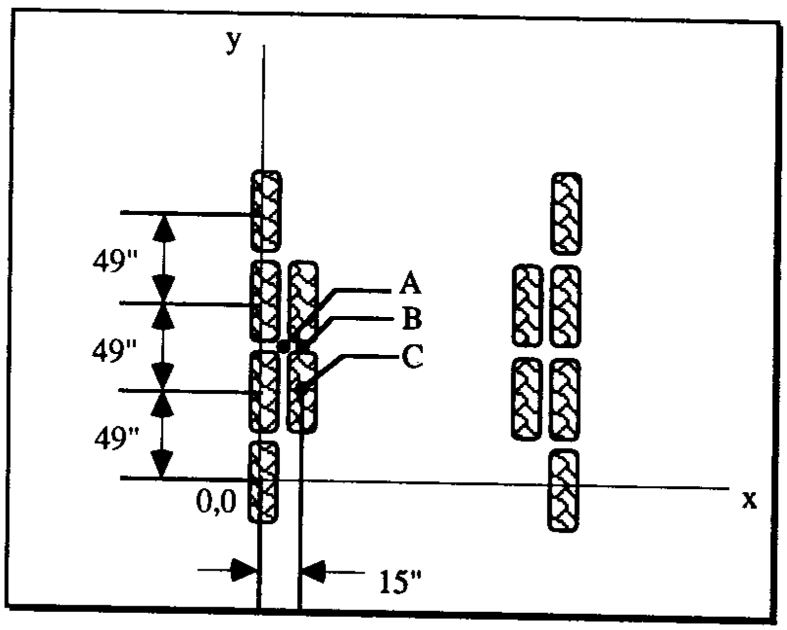


Figure 15. Evaluation Locations In The X-Y Plane

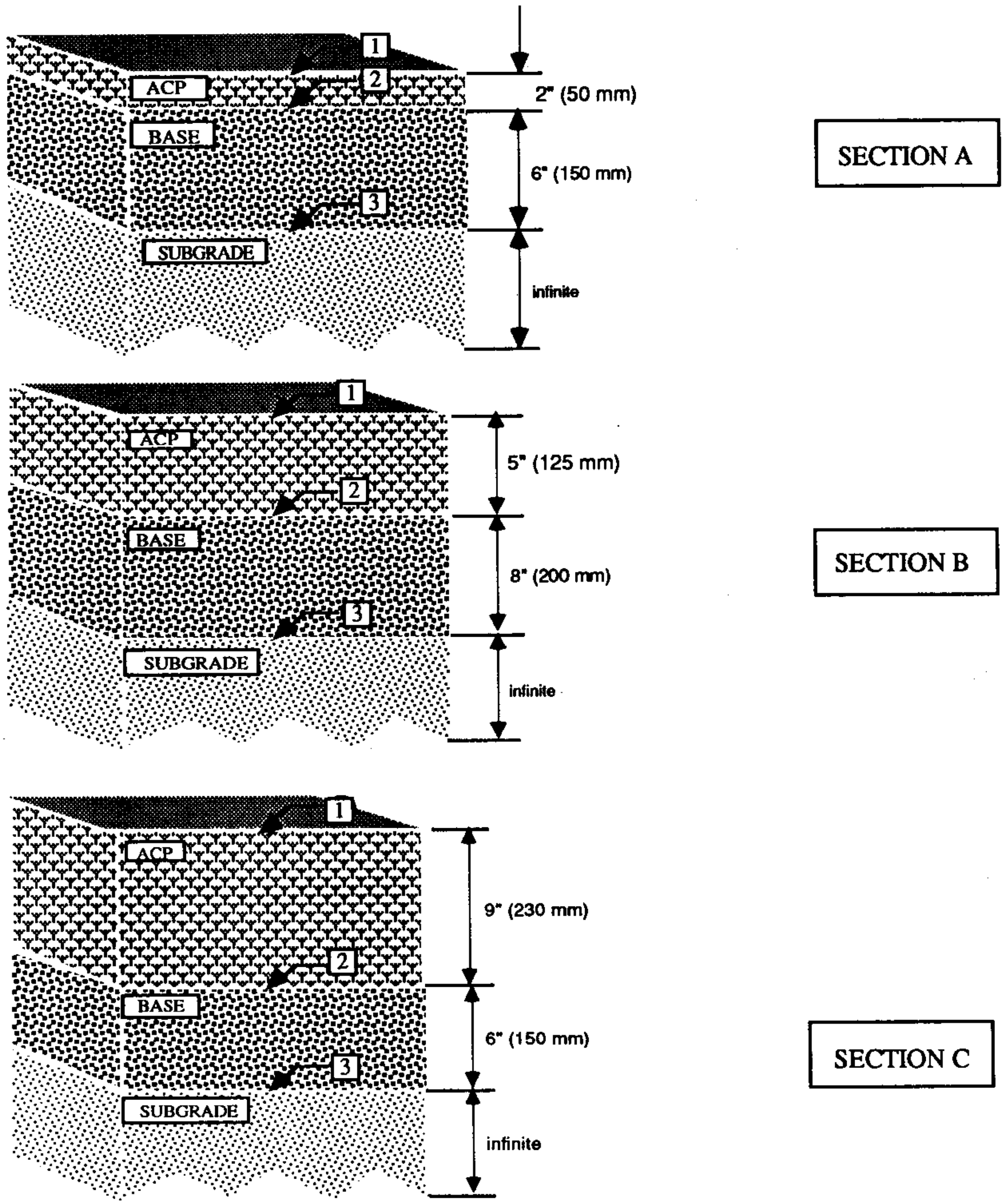


Figure 16. Evaluation Locations In The Z-Plane

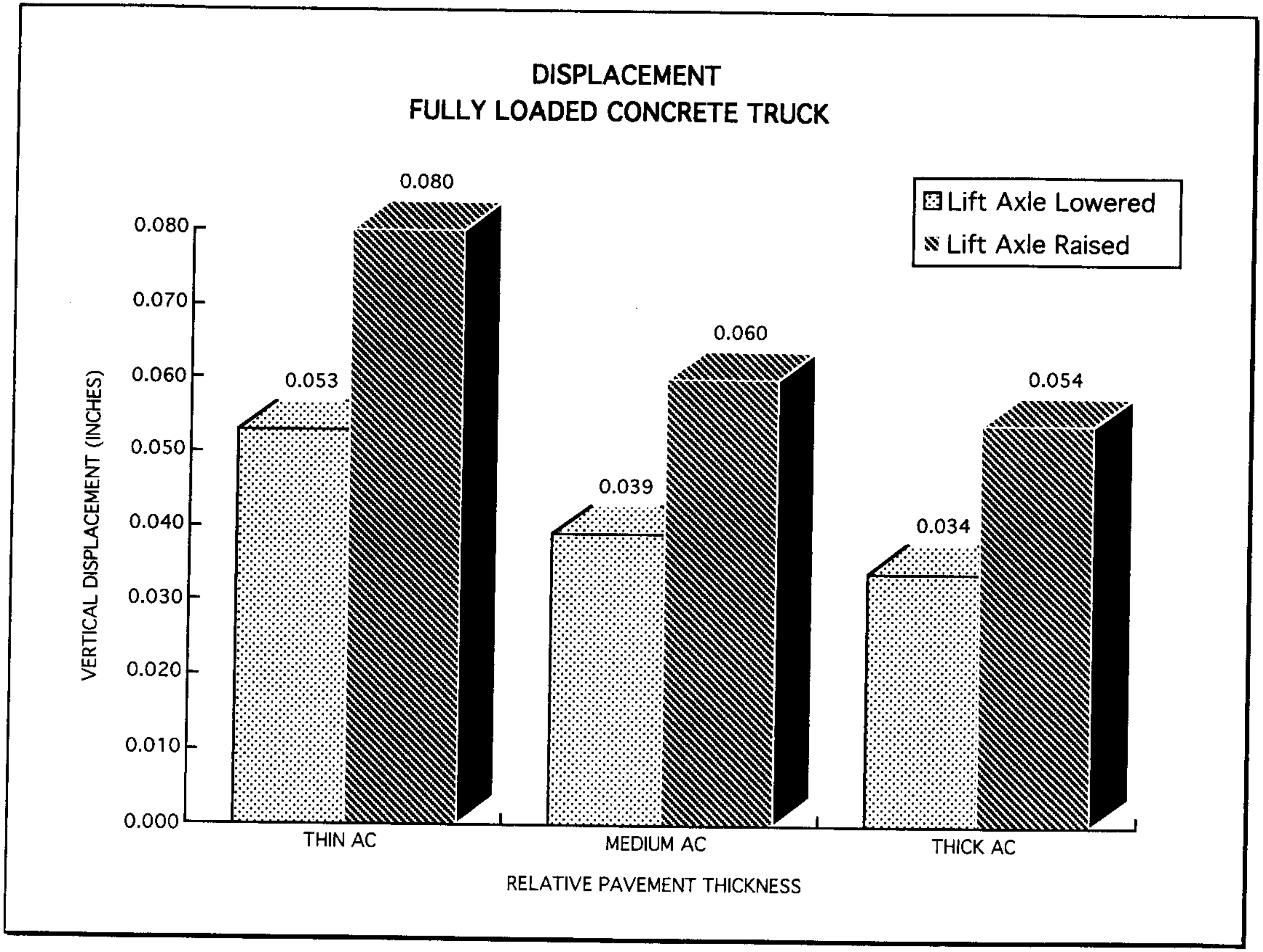


Figure 17. Displacement: Fully Loaded Concrete Truck

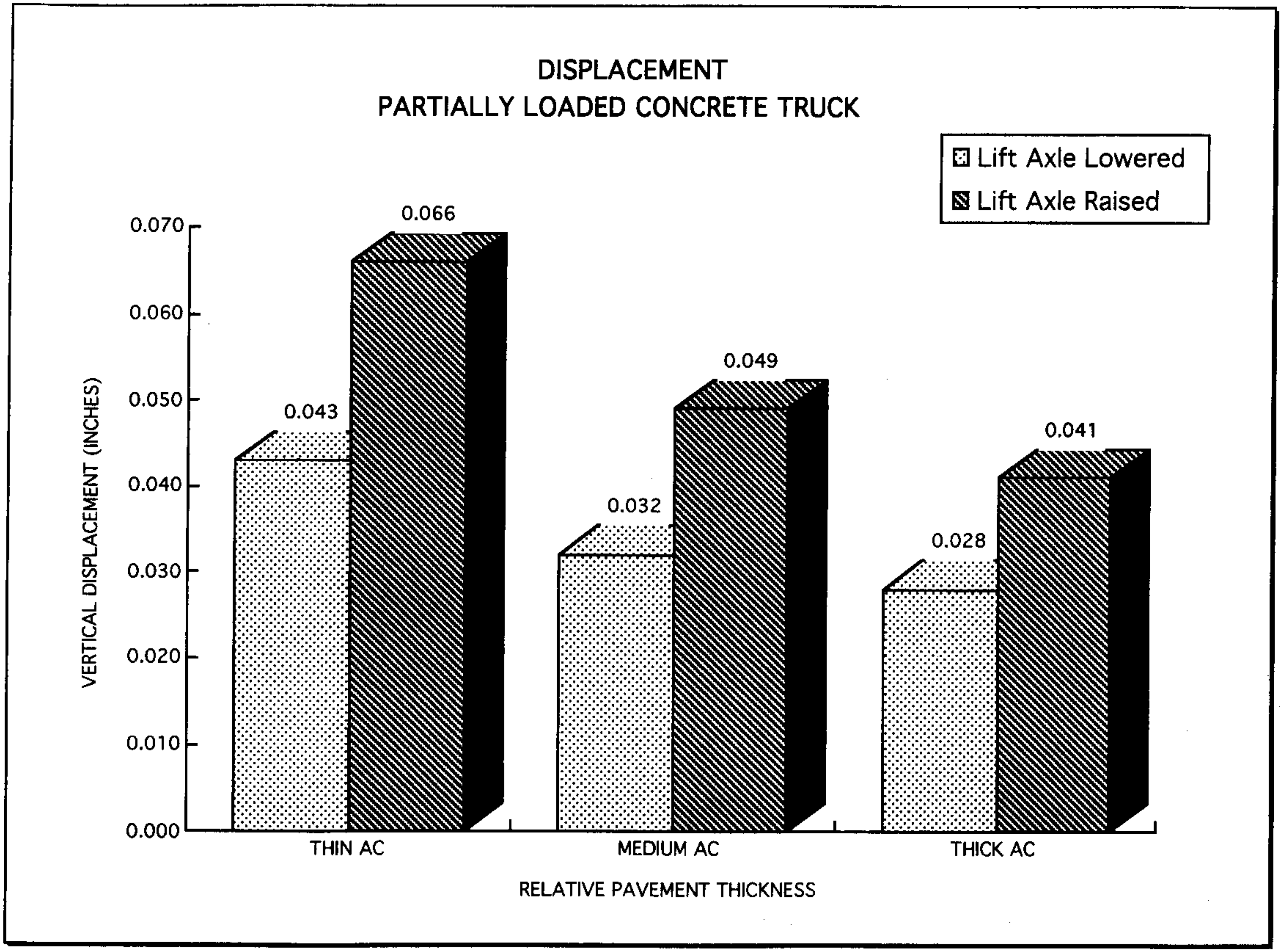


Figure 18. Displacement: Partially Loaded Concrete Truck

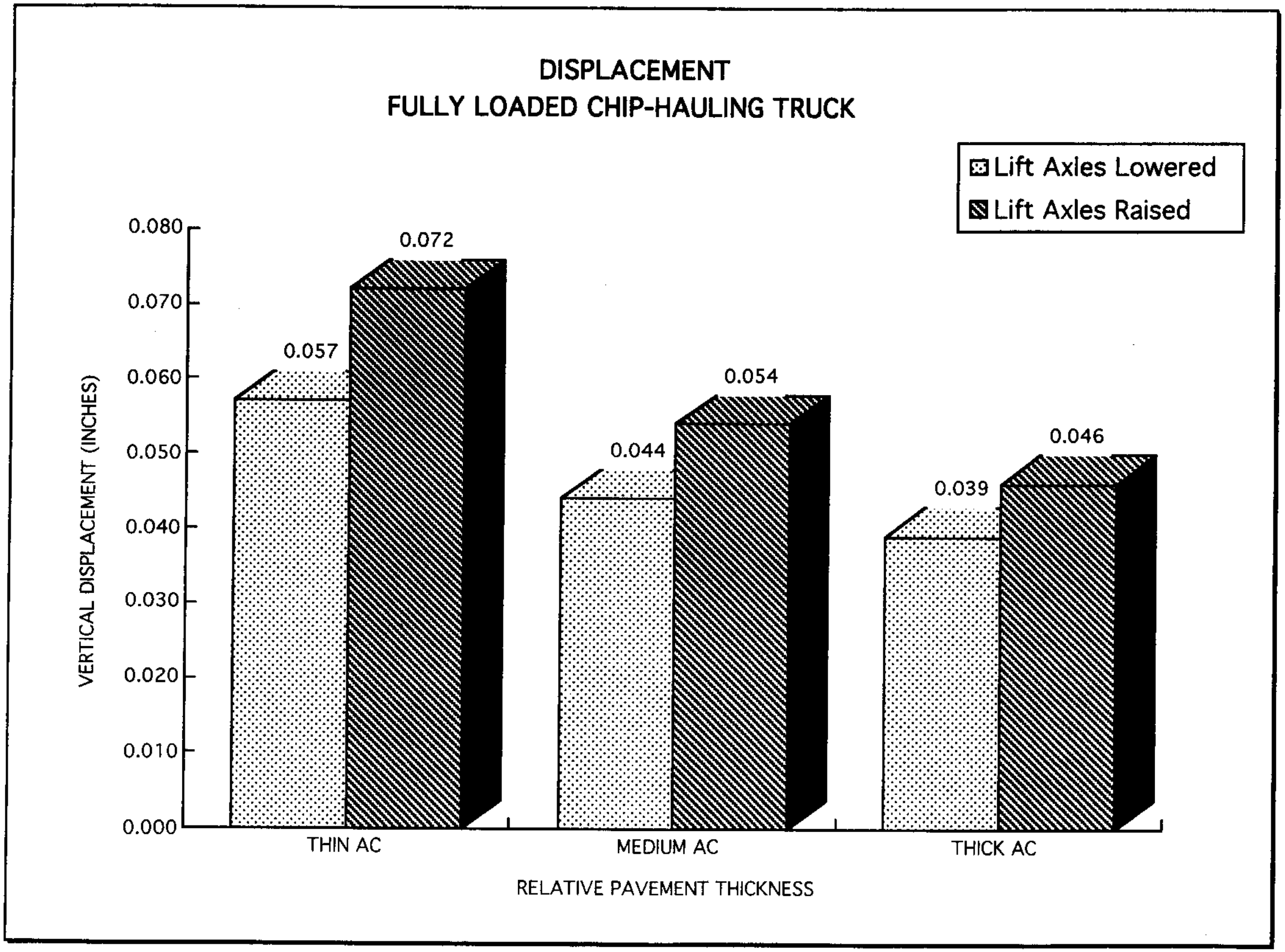


Figure 19. Displacement: Fully Loaded Chip-hauling Truck

pavement section with the thin asphalt concrete layer. The least displacement occurs on the pavement section with the thick asphalt concrete layer.

Loads to Fatigue Failure

The first failure criterion considered in this analysis was the number of loads to failure in the fatigue mode of asphalt concrete. Fatigue cracking failure can be predicted by the horizontal tensile strain (ε_t) at the bottom of the asphalt layer and by the modulus of elasticity (E) for ACP. ELSYM5 provides the critical strain values in this plane. The number of load applications to reach fatigue cracking failure can then be estimated with the following equation:

$$\log N_f = 15.947 - 3.291 \log\left(\varepsilon_t / 10^{-6} \right) - 0.854 \log\left(E / 10^{3} \right) \qquad (20)$$

where ε_t is the horizontal tensile strain, and E is the modulus of elasticity of AC. Using this equation, fatigue failure is defined as fatigue cracking over 10 percent of the pavement's wheel path area.

The number of load applications to fatigue failure under two conditions are depicted in Figures 20-22. The first condition is the number of load applications to fatigue failure when the lift axle is deployed (i.e., down). The second condition is the number of load applications to fatigue failure when the lift axle is raised (i.e., up). This analysis is applied to the three truck configurations described earlier: fully loaded concrete truck, partially loaded concrete truck, and fully loaded chip-hauling truck. Note that the smaller the number, the greater the rate of pavement deterioration. Of the three configurations analyzed herein, a fully loaded concrete truck would cause fatigue failure after the fewest load applications. In each case, fatigue failure occurs first in the case of the thin pavement section.

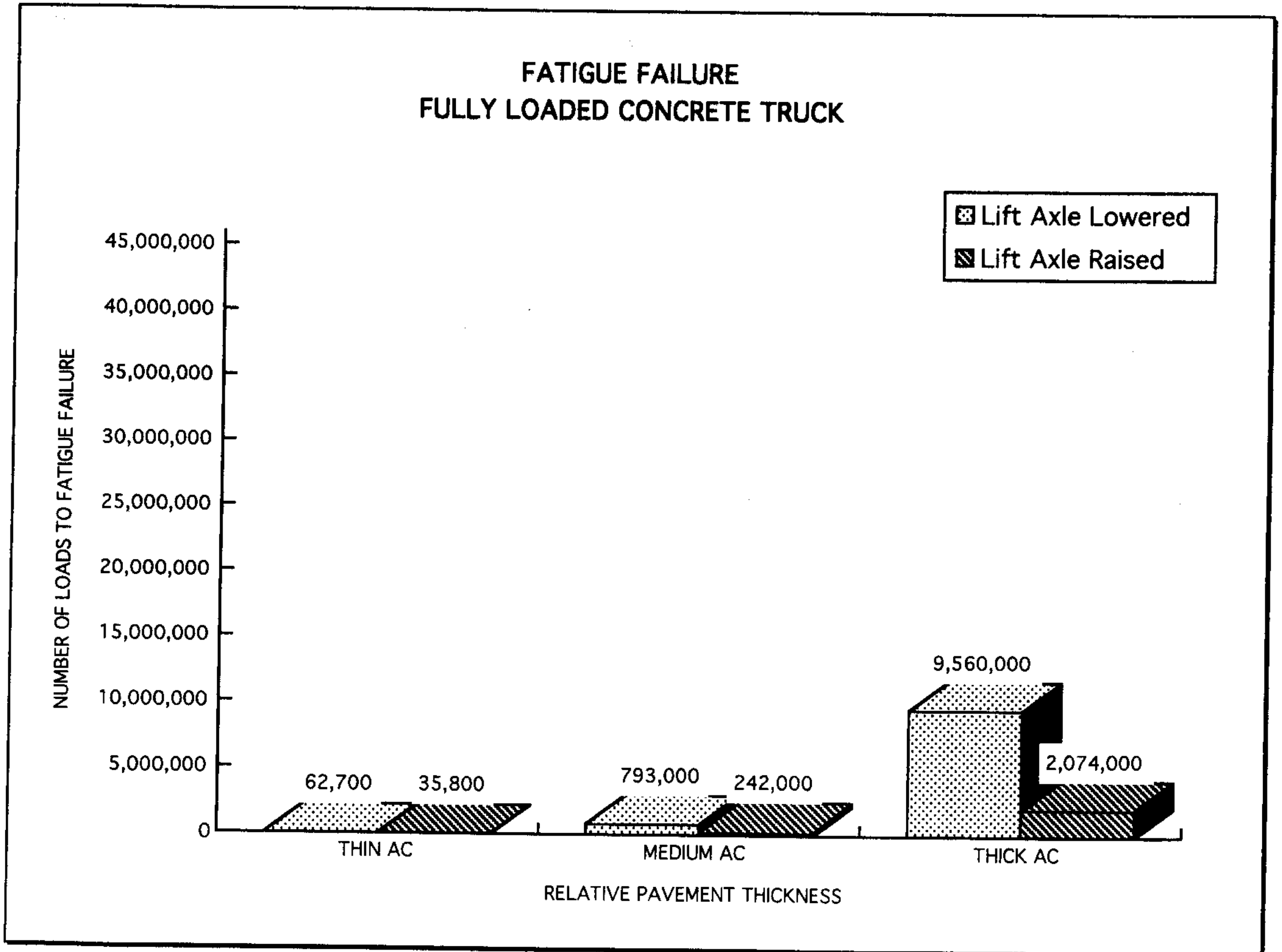


Figure 20. Fatigue Failure: Fully Loaded Concrete Truck

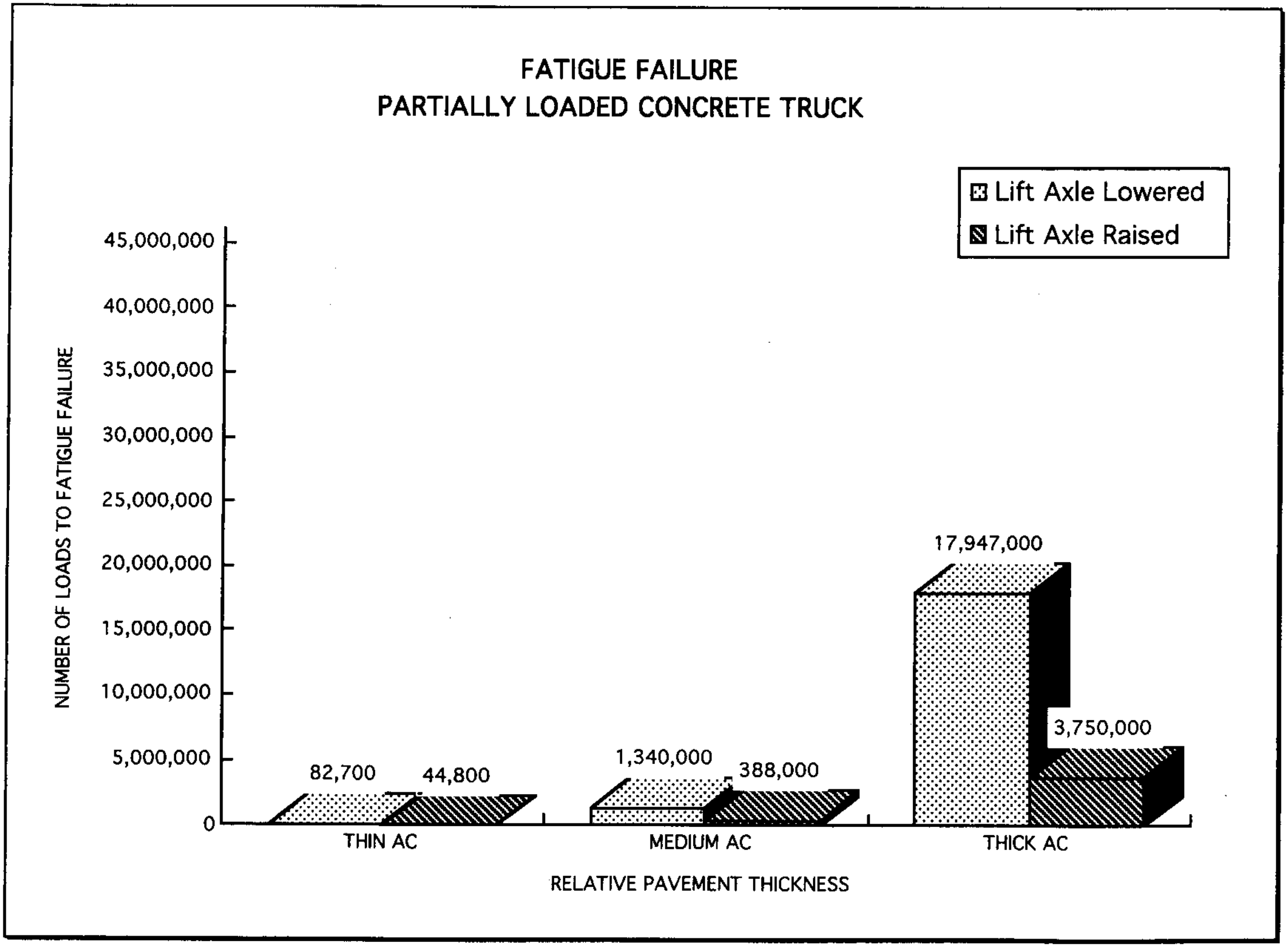


Figure 21. Fatigue Failure: Partially Loaded Concrete Truck

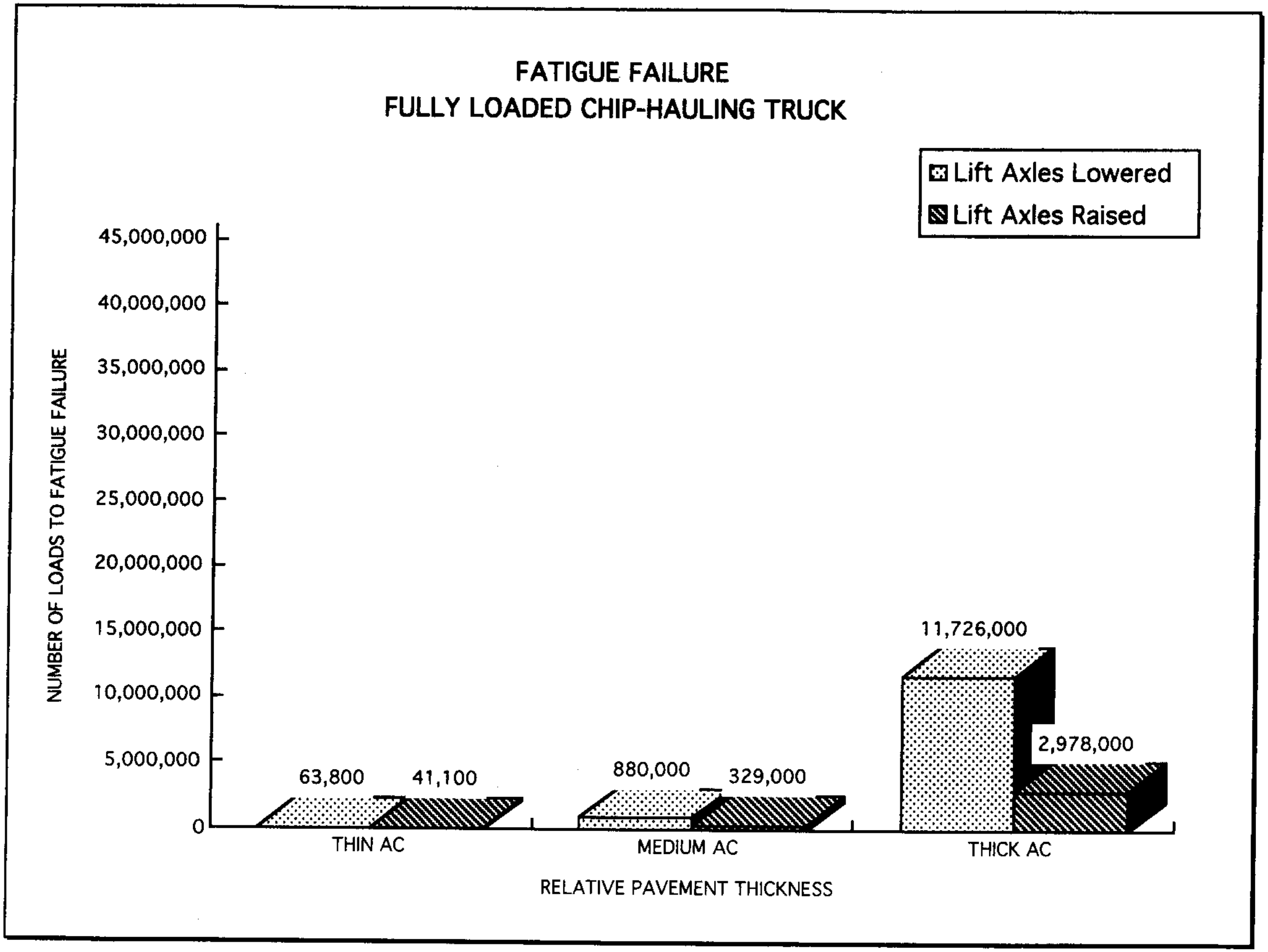


Figure 22. Fatigue Failure: Fully Loaded Chip-hauling Truck

For each of these graphs, it is clear that when the lift axle is raised, fatigue failure results after fewer loads. In the case of a fully loaded concrete truck with its lift axle raised, fatigue failure is reached

- 1.8 times faster for thin pavement,
- 3.3 times faster for medium pavement, and
- 4.6 times faster for thick pavement.

For a partially loaded concrete truck, with its lift axle raised, fatigue failure is reached

- 1.8 times faster for thin pavement,
- 3.5 times faster for medium pavement, and
- 4.8 times faster for thick pavement.

For a fully loaded chip truck with its lift axles raised, fatigue failure will be reached

- 1.6 times faster for thin pavement,
- 2.7 times faster for medium pavement, and
- 3.9 times faster for thick pavement.

These results may be somewhat misleading in that it appears that the most severe problems are associated with thick pavement. However, the ratio of rates of deterioration are greater for thick pavement because the original rate of deterioration is so much higher than that of either the medium or thin pavement (i.e., a pavement subjected to light loads lasts exponentially longer than a pavement subjected to heavy loads).

The emphasis of this analysis however, is on the *relative change* in the rate of deterioration of a pavement structure. Looking only at the number of loads to failure is unreasonable since it is unlikely that thousands of trucks with their booster or lift axles raised improperly will travel the same roadway segment repeatedly. This analysis isn't designed to indicate *how many* load applications are expected before pavement failure but rather how much more damaging a *single* load application is if lift axles are used improperly.

Loads to Rutting Failure

Rutting can begin in any layer of the structure, which makes it more difficult to predict. For the purpose of this analysis, rutting failure is attributed to vertical compressive strain at the top of the subgrade layer in the z-plane. ELSYM5 provides the critical strain values. The number of loads to failure can then be calculated with the following equation:

$$N_f = 1.077 \times 10^{18} \left({}^{10^{-6}}/_{\varepsilon_V} \right)^{4.4843} \qquad (21)$$

where ε_V is the vertical compressive strain. Failure in this case is defined as 0.5 inch (13 mm) depressions in the pavement's wheel paths.

The number of load applications to rutting failure under two conditions (load axle properly deployed and improperly lifted) are depicted in Figures 23–25. Again this analysis is applied to three truck configurations: fully loaded concrete truck, partially loaded concrete truck, and fully loaded chip-hauling truck. The smaller the number, the faster the rate of pavement deterioration.

For a fully loaded concrete truck with its lift axle raised, pavement failure due to rutting will be reached

- 7.0 times faster for thin pavement,
- 9.0 times faster for medium pavement, and
- 9.6 times faster for thick pavement.

For a partially loaded concrete truck with its lift axle raised, pavement failure due to rutting will be reached

- 7.5 times faster for thin pavement,
- 9.3 times faster for medium pavement, and
- 9.9 times faster for thick pavement.

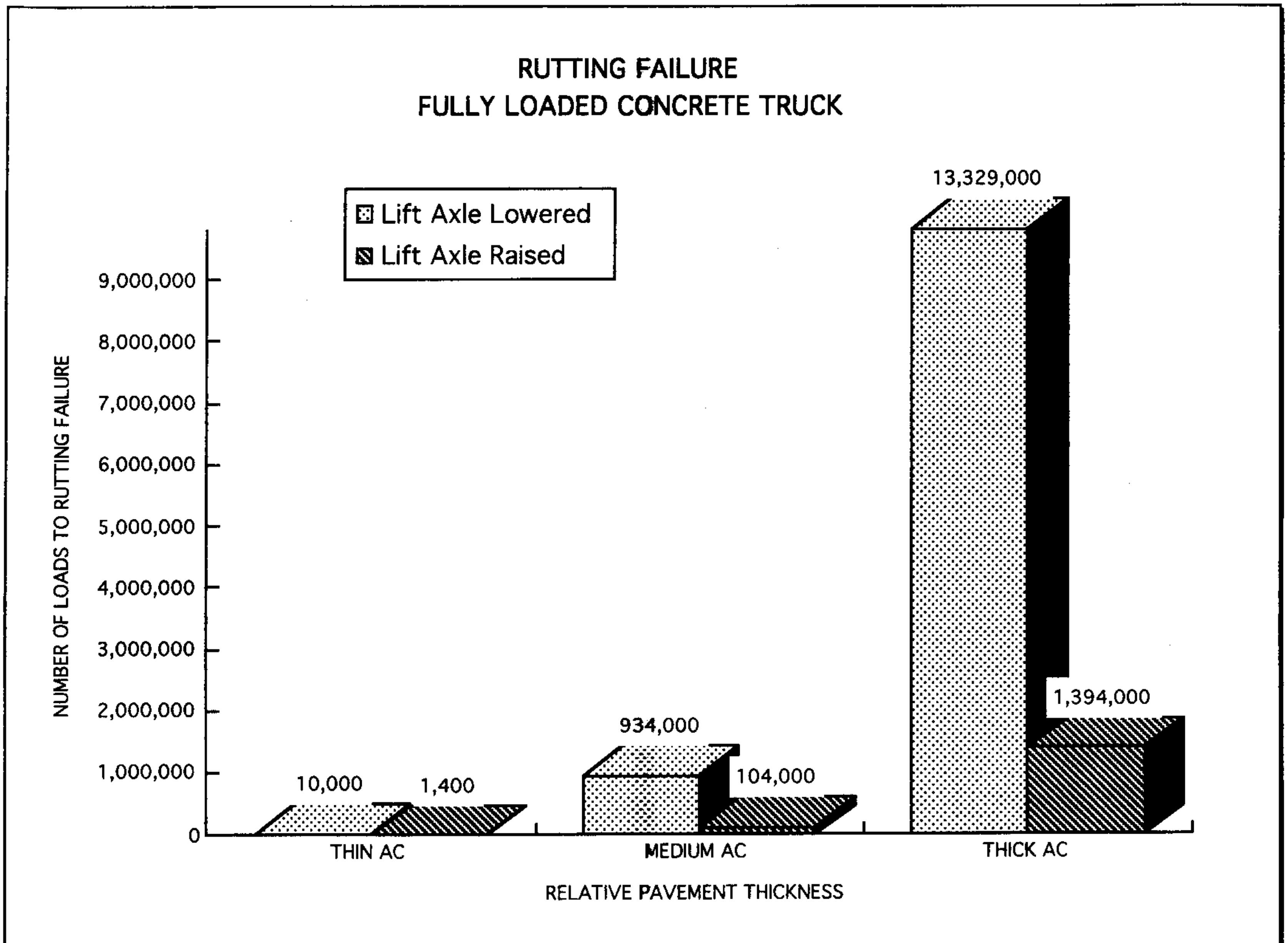


Figure 23. Rutting Failure: Fully Loaded Concrete Truck

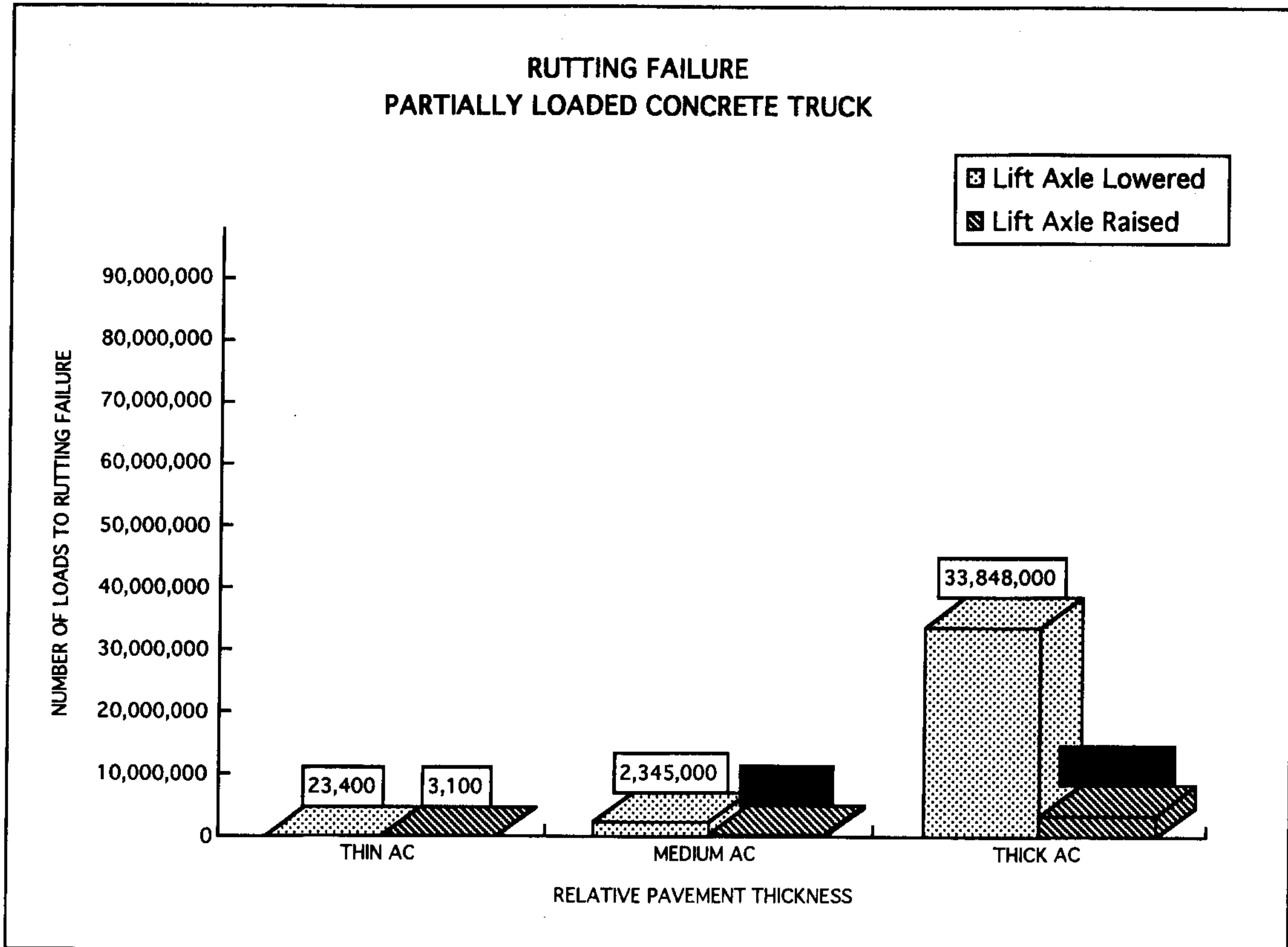


Figure 24. Rutting Failure: Partially Loaded Concrete Truck

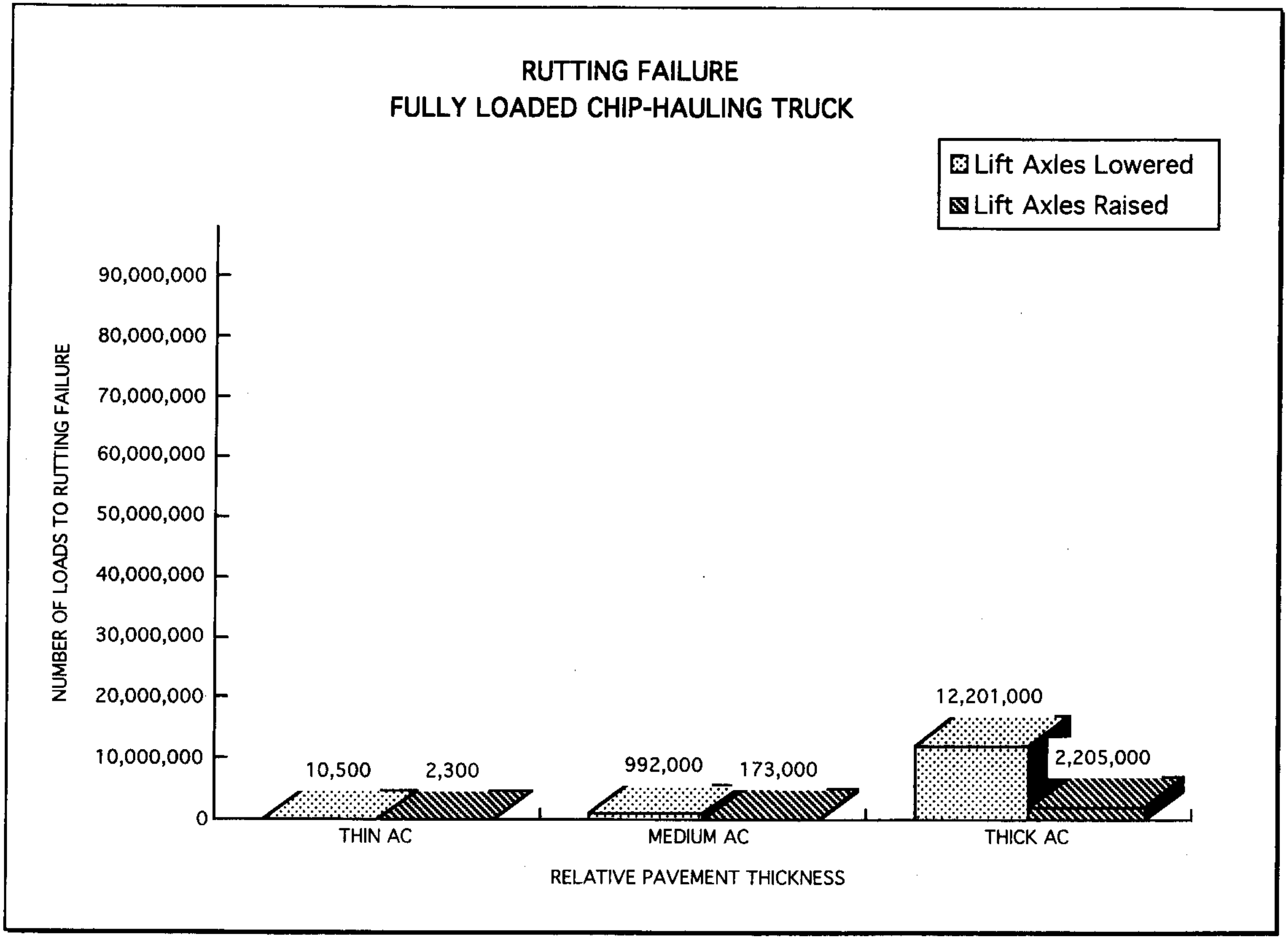


Figure 25. Rutting Failure: Fully Loaded Chip-hauling Truck

For a fully loaded chip truck with its lift axle raised, pavement failure due to rutting will be reached

- 4.6 times faster for thin pavement,
- 5.7 times faster for medium pavement, and
- 5.5 times faster for thick pavement.

Critical Mode of Failure

Up to this point, the analysis has focused on the *difference* in pavement deterioration rates between a truck with its lift axle properly deployed and a truck with its lift axle improperly raised. However, to determine the approximate number of loads that the pavement can withstand without failure, it is important to consider the critical mode in which the pavement will fail. Table 7 summarizes the critical mode of failure for each of the loading and configuration scenarios and indicates the critical number of loads to reach that failure. Note that for the thin pavement section, the number of loads to failure is small compared to the number of loads to failure for the medium and thick sections. Also note the decrease in the number of loads to failure with the lift axle raised improperly.

AASHTO Axle Load Equivalency Factor Method

To further evaluate the results obtained in ELSYM5, a second analytical method was employed. The AASHTO equivalent single axle load method considers the change in equivalent single axle loads (18 kip loads) based on changes in axle loadings. Values are precalculated based on the Structural Number (a measure of the pavement structural section - a larger SN implies a thicker pavement) of the pavement section and on the axle loading for single, tandem and triple axles. The chip-hauling truck was not considered in this analysis because the AASHTO method does not provide values for a quadrum axle.

Structural Numbers were assumed for the pavement sections as follows: 2 for the thin pavement section, 3 for the medium section, and 5 for the thick pavement section. The fully loaded concrete truck was estimated to support 20,000 pounds on the steer axle,

Table 7: Critical Mode and Number of Loads to Failure

Truck	Pavement	Lift Axle Down		Lift Axle Up	
		Mode	Number of Loads	Mode	Number of Loads
Fully Loaded Concrete Truck	Thin AC	RUTTING	10,000	RUTTING	1,400
	Medium AC	FATIGUE	793,000	RUTTING	104,000
	Thick AC	FATIGUE	9,560,000	RUTTING	1,394,000
Partially Loaded Concrete Truck	Thin AC	RUTTING	23,400	RUTTING	3,100
	Medium AC	FATIGUE	1,340,000	RUTTING	252,000
	Thick AC	FATIGUE	17,947,000	RUTTING	3,433,000
Fully Loaded Chip Truck	Thin AC	RUTTING	10,500	RUTTING	2,300
	Medium AC	FATIGUE	880,000	RUTTING	173,000
	Thick AC	FATIGUE	11,726,000	RUTTING	2,205,000

34,000 pounds on the tandem axle and 12,000 pounds on the booster axle when deployed (AASHTO values are provided in 2,000 pound increments). With the lift axle raised, the fully loaded concrete truck was estimated to support 10,000 pounds on the steer axle and 56,000 pounds on the tandem axle. The partially loaded concrete truck was estimated to support 16,000 pounds on the steer axle, 28,000 pounds on the tandem axle and 10,000 pounds on the booster axle when deployed. With the lift axle raised, the partially loaded concrete truck was estimated to support 8,000 pounds on the steer axle and 46,000 pounds on the tandem axle. Based on these values, axle load equivalency factors were determined (see Tables 8 and 9).

For a fully loaded concrete truck with the lift axle raised, pavement failure will be reached using AASHTO load equivalency factors (tandem and lift axle combination only)

- 8.9 times faster for thin pavement,
- 7.3 times faster for medium pavement, and
- 6.8 times faster for thick pavement.

Recall that the ELSYM5 analysis indicated that if the lift axle on a fully loaded concrete truck were raised, failure would occur through rutting, and that this failure would occur (tandem and lift axle combination only)

- 4.6 times faster for thin pavement,
- 5.7 times faster for medium pavement, and
- 5.5 times faster for thick pavement.

Using the AASHTO axle load equivalency factor method, a partially loaded concrete truck with the lift axle raised, pavement failure will be reached (tandem and lift axle combination only)

- 8.0 times faster for thin pavement,
- 6.0 times faster for medium pavement, and
- 7.2 times faster for thick pavement.

Table 8: Axle Load Equivalency Factors for Fully Loaded Concrete Truck with Lift Axle Down and Up

Pavement	Structural Number	Lift Axle Position	Steer Axle	Tandem Axle	Booster Axle	Total ESALs	Change for Total ESALs
Thin	2	Down	1.57	1.08	0.198	2.848	+6.9
		Up	0.102	9.6	0	9.702	
Medium	3	Down	1.49	1.11	0.229	2.829	+5.4
		Up	0.118	8.1	0	8.218	
Thick	5	Down	1.51	1.09	0.189	2.789	+4.7
		Up	0.088	7.4	0	7.488	

Note: Terminal Serviceability Index = 2.5

Table 9: Axle Load Equivalency Factors for Partially Loaded Concrete Truck with Lift Axle Down and Up

Pavement	Structural Number	Lift Axle Position	Steer Axle	Tandem Axle	Booster Axle	Total ESALs	Change for Total ESALs
Thin	2	Down	0.613	0.495	0.102	1.21	+2.8
		Up	0.047	3.98	0	4.027	
Medium	3	Down	0.646	0.598	0.118	1.362	+2.3
		Up	0.051	3.58	0	3.631	
Thick	5	Down	0.623	0.495	0.088	1.206	+2.4
		Up	0.034	3.55	0	3.584	

Note: Terminal Serviceability Index = 2.5

The ELSYM5 analysis indicated that if the lift axle on a partially loaded concrete truck were raised, failure would occur through rutting, and that this failure would occur (tandem and lift axle combination only)

- 7.5 times faster for thin pavement,
- 9.3 times faster for medium pavement, and
- 9.9 times faster for thick pavement.

The similarity between these values indicates that the ELSYM5 analysis is reasonable.

To this point, the analysis has considered the tandem and lift axle combination in isolation. It is also important to consider the truck as a whole (tandem and lift axle combination plus the steering axle). The change in the total number of ESALs for both a fully loaded concrete truck and a partially loaded concrete truck is provided in Tables 8 and 9, respectively. From these values, the change in the pavement deterioration rate based on the entire truck loading can be determined.

For a fully loaded concrete truck with the lift axle raised, pavement failure will be reached using AASHTO load equivalency factors (all axles)

- 3.4 times faster for thin pavement,
- 2.9 times faster for medium pavement, and
- 2.7 times faster for thick pavement.

Using the AASHTO axle load equivalency factor method, a partially loaded concrete truck with the lift axle raised, pavement failure will be reached (all axles)

- 3.3 times faster for thin pavement,
- 2.7 times faster for medium pavement, and
- 3.0 times faster for thick pavement.

Note that the change in pavement deterioration rates is much smaller when all axles of the truck are considered in the analysis (steer, tandem and booster). Examination of all axles reduces the relative rate of pavement deterioration since the positive impacts of reducing the load on the steer axle and eliminating the load on the booster axle are taken into account.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

The conclusions from this study are organized by two levels of detail. First, specific examples of impacts to vehicle damage, safety, pavement and bridge deterioration, and economic impacts to the trucking industry resulting from lift axle use are summarized. Second, broader issues related to lift axle use, such as industry use, enforcement, and uniformity among states and provinces, are discussed.

SPECIFIC IMPACTS ATTRIBUTABLE TO LIFT AXLE USE

A number of formal studies and informal observations provided information related to the specific impacts of lift axle use. These impacts are relevant in the following areas:

- vehicle damage,
- safety,
- pavement/bridge deterioration, and
- economics.

Below is a summary of these impacts. In each case, key issues to be noted are listed separately at the beginning of each section.

Vehicle Damage

Key Issues

- No quantitative assessment exists to describe the proportion of repair work that results from lift axle use, and collection of these data would be difficult.
- If substantial vehicle damage problems did result from lift axle use, this issue would most easily be corrected by the trucking industry rather than by regulatory action. High repair costs would decrease the benefit of using lift axles and consequently reduce profit. A reduction in profit would discourage lift axle use.

Few quantitative data exist that correlate lift axle use with vehicle damage problems. Often, when a truck is brought in for repair, little effort is made to determine the *cause* of the problem; effort instead focuses on the repair. However, if lift axle use causes substantial vehicle damage problems, members of the trucking industry will realize the loss in benefit.

Safety

> **Key Issues**
>
> - Safety-related information is available regarding vehicular behavior in controlled environments.
> - Historical safety-related data are lacking.

Much of the safety-related information focuses on vehicle behavior characteristics when one or more lift axles are employed. Conclusions from safety studies are summarized below.

- Payload center of gravity is the single, most powerful determinant of stability and control behavior.
- The handling and stability characteristics of an empty vehicle are much more sensitive if the lift axle is deployed *as if* carrying a load than are the characteristics of a fully loaded vehicle.
- Vehicle maneuverability and performance suffer (1) as the spacing between the fixed and lift axle increases, (2) if the lift axle is installed behind a fixed axle, (3) if the lift axle is installed on the lead vehicle of a combination vehicle, and (4) as the load on the lift axle increases.
- Vehicle maneuverability and performance suffer (1) if a lift axle is added to a vehicle, and (2) if a single lift axle is replaced with a tandem lift axle.

In terms of specific lift axle design, the following conclusions have been reported.

- Self-steering axles improve vehicle maneuverability, but decrease levels of vehicle control and safety.
- Considerable differences exist among various self-steer axle designs and installations, so it is difficult to generalize results to other applications.

While these conclusions, stemming from tests in a controlled environment, are informative, little historical safety data exist to substantiate these results. These historical safety data may be lacking for several reasons. When an accident occurs, it is difficult to directly correlate the accident with lift axle use. Too many other factors, such as roadway condition, driver reaction, or other equipment, may have contributed to the accident. Because the accident cannot be directly linked to lift axle use, the presence of a lift axle is viewed as extraneous information and is seldom, if ever, recorded.

A second reason for the lack of data on safety and lift axle use is related to motivation. Until recently, there has been little interest in lift axle use in the U.S., as shown by the dearth of lift axle literature published in the U.S. The trucking industry views lift axles as beneficial and interest among regulatory agencies varies from state to state. Regulatory personnel, already overworked in their duties, are not going to ask for more information from accident scenes. Therefore, with no overwhelming interest in the safety of lift axle use, no additional data collection on the subject has been pursued.

Data collection efforts to correlate lift axle use and safety problems will not be as simple as recording whether a truck is equipped with a lift axle. To be most beneficial, the information should include the presence of one or more lift axles, the position of the axle (i.e., raised or deployed) and the position of the lift axle(s) with respect to the fixed axles (i.e., the configuration), and where the lift axle was placed on the truck.

Pavement/Bridge Deterioration

Key Issues

- Theoretical information regarding increases or decreases in pavement/bridge deterioration rates is easily obtainable for a variety of truck configurations.
- Information is lacking on the extent of lift axle use in Washington and, hence, potential increases or decreases in pavement/bridge deterioration rates.
- Information is lacking on the proportion of overweight violations that involve lift axles.
- Information is lacking on overweight violations that involve axle groups that consist of three of more axles with a common suspension system because of weight accuracy problems. Hence, an accurate proportion of lift axle involved weight violations cannot be determined since an accurate number of total weight violations cannot be determined.
- For a range of pavement structures and using AASHTO load equivalency factors for all axles on a typical concrete truck, the total pavement damage increases by a factor of three when the lift axle is raised when it should be down. When the tandem and lift axles are isolated (steer axle ignored), the estimated change in pavement damage is 7 to 10 times higher for a fully loaded concrete truck (based on pavement elastic analysis). For the rear tandem and associated lift axles of a fully loaded chip truck, the estimated change in pavement damage is 5 to 6 times higher (again, based on pavement elastic analysis).

Based on the limited pavement analysis conducted with only two truck types (concrete truck and a chip-hauling truck), it is estimated that raising a lift axle or axle(s) improperly results in 3 to 10 times more pavement damage per truck pass. However, this information means little unless the extent of illegal lift axle use is known.

Axle overloading occurs not only with lift axle use but also with fixed axles. Regulatory personnel in Washington speculate that the banning of lift axles would greatly reduce axle overloading. However, not enough information exists to substantiate this belief. One problem is that when drivers of overweight trucks are cited, the presence of a lift axle is not recorded. Another problem is that regulatory personnel in Washington are unable to accurately weigh axle groupings with *common* suspension systems without using portable scales. Troopers often do not carry enough portable scales to weigh a large configuration. Hence, these trucks remain unweighed. Because of these two practices, it is difficult to determine the proportion of overweight violations that is attributable to lift axles.

Economics

Key Issues

- Current regulatory fines are not high enough to (1) discourage illegal practice and (2) compensate for the pavement damage that results from the heavy load.
- Current regulatory fees (i.e., overweight permits) seem low enough to encourage legal operation but do not compensate for pavement damage that results from the heavy load.
- Theoretical information regarding economic savings or expenditures that results from changes in lift axle use in Canada is obtainable for a variety of truck configurations.
- Information is lacking on the extent of lift axle use in Washington and, hence, the potential economic impacts to various sectors of the trucking industry.
- Lift axle use should not be restricted on the basis of configuration (or more generally, industry type),. Such restriction could be viewed as an infringement on the right to attain economic benefits unless definitive safety-related or pavement-related data indicate that lift axle use should be restricted by configuration. Definitive data currently do not exist.

The economic benefits or detriments associated with lift axle use can be considered from two perspectives: the regulatory perspective and the trucking industry perspective. Several issues arise from the regulatory perspective. First, do the fees or fines associated with the additional weight-carrying ability resulting from lift axle use compensate for the damage the additional loads inflict on the pavement? Evidence indicates that these fees and fines are not compensatory. Second, how high can the fees and fines be raised before a legal trucker is penalized for operating legally and illegal operation is encouraged?

The trucking industry achieves economic benefits if a lift axle is added to the vehicle. If lift axles were banned, trucking industry costs would increase. This increase would be substantial initially because of transition costs. The same would be true even if regulatory requirements were changed only to a smaller degree. This increase in operating cost would not be uniform over the trucking industry but would vary depending on the extent of lift axle use.

It is difficult to determine the direct economic benefit that results from lift axles because the costs and benefits vary depending on the size and the configuration of the truck and the size of the payload. Thus, it is difficult to predict the impact that increases in permit fees, taxes, licensing fees, or fines would have upon the use of lift axles.

BROADER ISSUES ASSOCIATED WITH LIFT AXLE USE

When changes to current lift axle use and operation are considered, a number of broader issues need to be addressed. These include the following:

- the extent of lift axle use within the trucking industry,
- the feasibility of enforcing lift axle use and operation requirements, and
- the importance of uniform regulations among states and provinces.

As previously, the key issues are highlighted at the beginning of each section.

Industry Use

Key Issues

- Definitive, comprehensive data that describe the extent of lift axle use by industry type do not exist. These data would need to account for operating trends within the trucking industry.

Changes in lift axle use and operation requirements not only affect the truck carriers but also impacts truck manufacturers, axle manufacturers, and garages responsible for installing axles and/or repairing trucks. The extent of impacts due to changes in lift axle use would vary substantially throughout each of these industries.

The lift axle manufacturing industry is relatively flexible with respect to meeting state regulations. The same is true of repair and installation garages, which can easily adapt to the required changes.

Initially, disparate lift axle regulations among states and provinces were thought to create problems for the trucks that crossed state or provincials borders. However, while the different regulations regarding lift axles in each state may seem overwhelming, many states are limited in their ability to accurately weigh the configurations and cite a truck with lift axles. Thus, the differences are not as inconvenient for truckers as originally supposed.

Enforcement

Key Issues

- Enforcement personnel and time are limited and other priorities take them away from the close monitoring of lift axle use.

Weight enforcement officials are frustrated with the lack of capabilities they have to enforce lift axle regulations. A number of Washington state regulations and practices encourage the use of lift axles but discourage the enforcement of their operation by being too detailed. The laws related to lift axles are too specific and too disparate among the states and provinces so that many of these regulations are never checked. Equipment is only checked for safety reasons and not to ensure compliance with equipment specifications, as safety takes a priority. Also, the fines associated with misuse of lift axles are not substantial enough to discourage illegal practice. Any changes to Washington's administrative code regarding lift axles should consider the ability of state officials to enforce those requirements.

Uniformity Among States And Provinces

Key Issues

- Common methods for regulation exist among several of states, but these states differ in their specifications under these regulations.
- The benefits that might be attained through uniformity among states and provinces are not well defined.

Little uniformity in lift axle use and operation exists among states and provinces. Lift axle use varies greatly by locality because of differing industries and truck traffic needs, hence, concern about lift axle use also varies. As a result of these differences, it is difficult to move toward national uniformity in lift axle regulations if lift axle use is not recognized as an issue in a number of states.

Common methods of regulation exist among many states and provinces, but differences exist in the specifications or details of these regulations. However, if the details of the regulations cannot be enforced because of time and personnel limitations, these differences may not pose a problem to the trucking industry. States and provinces that share regulation methodologies may have an easier time moving toward uniform regulations if common specifications can be agreed to.

In a number of states and provinces, a common motivation for lift axle regulation exists, but differences in opinion exist regarding the best way to regulate. These states and provinces may have more difficulty in agreeing on uniformity. However, the ability to enforce regulations should take precedence over making regulations uniform, although the uniformity may benefit enforcement personnel by reducing the number of discrepancies encountered.

RECOMMENDATIONS

On the basis of the conclusions outlined above, a number of recommendations can be made.

- Most importantly, efforts should focus on improving the use of existing enforcement resources and personnel. This improvement could include selected random days on which to focus enforcement on lift axle compliance or co-location of portable scale vans so that a sufficient number of portable scales exist to weigh larger configurations. By conducting random spot checks that focus on specific compliance areas (i.e., lift axles, tridems, and quads), non-compliance becomes more challenging, and yet little time is taken away from regular weight enforcement activities.

- Concurrent with the change in enforcement practices, efforts should be made to change the fee/fine structure to reduce or eliminate the benefit achieved from operating illegally. This change in the fee/fine structure may require legislative action. However, comprehensive work has been done in Washington state to support these changes.
- Effort should also be made to establish common specifications among the states or provinces that have comparable regulations. This would ease the compliance burden for the trucking industry and might simplify enforcement by reducing the number of discrepancies encountered. Effort should not be wasted on achieving uniformity among jurisdictions that have differing methods of regulation, as the degree of benefit that would be obtained through uniformity is unclear.
- Additional data collection is recommended. Data that would be helpful in evaluating lift axle use include (1) the extent of lift axle use by truck type, (2) the proportion of lift axles involved in overweight violations, (3) a better sampling of overweight violations (to include trucks with axle groups of three or more axles with a common suspension system), and (4) safety-related data. In addition, cooperative efforts should be undertaken with the trucking industry to better define the economic benefit achieved through the use of lift axles.

On the basis of the information collected through this project, a complete ban of lift axles cannot be justified at this time. This conclusion is based on (1) a lack of definitive safety-related data that prove lift axles are a safety risk, (2) a lack of definitive data that prove that lift axles are either being raised inappropriately or are over/underloaded and the extent to which this is occurring, and (3) a lack of quantitative data that describe the economic impacts to the trucking industry of banning lift axles. Partial bans or restrictions on lift axle use are not recommended (even though several states and provinces limit lift axle use in this way). Restrictions by configuration or industry type may be viewed as an unfair economic advantage for certain sectors of the industry.

Additional specifications in the regulations are not recommended. Having additional weight, spacing, configuration, or equipment requirements for the lift axle would only serve to (1) complicate the enforcement procedure, (2) increase the compliance burden for the industry and (3) ultimately lead to non-enforcement of these requirements.

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