

EVALUATION OF THE IMPACTS OF INCREASING TRUCK WEIGHTS ON TWO PILOT PROJECT ROUTES IN IDAHO

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Prepared by

NIATT

**National Institute for Advanced Transportation Technology
University of Idaho**

Richard Nielsen, Associate Professor
Fouad Bayomy, Associate Professor
Michael Kyte, Professor & Director of NIATT
Melissa Lines, Technical Writer

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EXECUTIVE SUMMARY

Introduction

In 1998 the Idaho legislature amended Idaho Code 49-1001 to allow higher weight trucks to operate on two pilot project routes in Idaho. Currently, the maximum gross vehicle weight (GVW) allowed in Idaho is 105,500 lbs. This amendment allows trucks to operate at gross weights up to 129,000 pounds. The Idaho Transportation Department (ITD) desired an independent analysis, evaluation, and report on the impacts of this legislation on Idaho's bridges, pavement, and traffic safety and operations. ITD requested that the University of Idaho's National Institute for Advanced Transportation Technology (NIATT) conduct this evaluation.

A direct measurement of the physical impacts of the higher weight trucks has not been possible during the first year of this project. Changes to pavement and bridge structures are not measurable over such a short period of time, and the number of trips by higher weight trucks is not currently a significant portion of the overall truck traffic stream.

Therefore, this scoping study accomplishes 3 limited tasks: it outlines current and predicted truck traffic on the two pilot routes, and it provides an examination of the effects of this shift on pavement, bridges, and traffic safety and operations. It also identifies key concerns and areas requiring more investigation.

Current Traffic

Over the past year, truck drivers operating higher-weight trucks on these routes were required to submit pilot project trip logs describing the routes, number of trips, cargo and operating weight of their vehicles. Only 9 overweight trucks have been permitted for these routes, so the data available from the trip logs is very limited.

Future Traffic

To meet the stated objectives, the researchers developed two traffic scenarios predicting future traffic on the pilot routes. The first assumes that higher weight trucks are not allowed, and the second assumes that higher weight trucks are allowed. The second scenario assumes that the higher-weight trucks will operate at the GVW levels experienced in Montana, which currently allows trucks to operate at higher GVWs. We then compared the behavior of the selected pavement segments and the bridges under both scenarios.

Assumptions

For both scenarios, we assumed a 1% annual growth rate in truck traffic on the routes over the next 20 years. We also assumed that the trucks operating at higher weights will be able to carry freight with fewer trips, but heavier loads per trip. We did not shift freight from trucks currently running at lower weights to higher-weight trucks.

Pavement Analysis and Conclusions

We analyzed the effects of these trucks on the two pavement segments corresponding to the traffic data collection sites. The pavements in these two locations are currently in relatively good condition. We calculated fatigue damage and rutting, since they are a function of truck loading.

When we consider the life predicted by the fatigue and rutting models in both scenarios, we find that both pavement segments survive the expected traffic. This is attributed in part to the relatively good conditions of the pavements. However, there is an increase in pavement damage of 3% at the US30 site and 10% for the US93 site. As a result the service life will be reduced by about 3% at the US30 site and 10% at the US93 site. Over a 20-year period, the service life will be reduced about 0.56 years for the US30 site and 1.8 years for the US93 site. It is important to emphasize that these results are based on the assumed future traffic scenario, and the two selected pavement segments.

Bridge Analysis & Conclusions

We analyzed the effects of these trucks on a selection of bridges representing a variety of bridge materials, critical span lengths, and years of service. The bridges were rated using the most current version of the bridge codes. Code-based ratings determine the capacity of the bridge through the duration of its assumed service life (typically 50 years), but they do not directly calculate the remaining service life of a bridge.

The bridges analyzed in this study are capable of carrying the higher weight trucks predicted by the study scenarios. In most cases the rating factor increased by 5 to 15%, with some increasing as much as 20%, indicating an increased ability to carry these trucks. However, longer span bridges experienced a decrease in rating factor of 11 to 19%. These results are based on the analyses of specific bridges on these routes and cannot be readily extrapolated to other routes. Bridge ratings will also change if the volume of higher-weight truck traffic is significantly higher than projected in this study.

Traffic Safety and Operations Analysis and Conclusions

We conducted a literature survey to identify information currently available on the effects of GVW and truck configuration on highway traffic operations and safety. We also examined field crash data from the states of Idaho and Montana, with statistics on the number of accidents, injuries and fatalities in the two states, for single, double and triple trucks.

While data quantifying the effects of heavier trucks on traffic operations and safety are limited, based on national studies it is likely that heavier trucks may decrease safety on Idaho's two-lane rural highways due to higher incidences of truck rollovers, crashes, etc. However, some of this potential safety decrease could be moderated by additional safety-related requirements for higher weight trucks. For example, the new legislation requires brakes on all axles for the higher weight trucks. No accident data are available specifically for higher-weight trucks, but if the experience

with triple trailers in Idaho and Montana is an indicator, then the crash potential may not increase on primary routes such as Idaho's pilot project routes.

General Conclusions

Given the projected future traffic scenario, truck configurations and pavement conditions considered in this study, we conclude the following:

- The remaining service life of the two pavement segments will be shortened by 3% at the US30 site and 10 % at the US93 site, resulting from the traffic volumes predicted by our traffic scenario.
- The bridges analyzed in this study are capable of carrying the higher weight trucks predicted by the study scenarios.
- Traffic safety and operations might be adversely impacted by higher weight trucks. Additional design requirements for these trucks and regulations such as minimum speeds on uphills could mitigate these effects.

Recommendations

Since these conclusions are limited in scope and rely heavily on the traffic predictions we have made, we recommend these additional efforts:

- Continuing to monitor the pilot project trip logs to verify that the truck traffic and the vehicle configurations are consistent with those assumed in this study.
- Making more refined predictions of future traffic and analyzing the bridges and pavements for a range of scenarios.
- Analyzing a broader selection of bridges and pavement segments.
- Developing more detailed analyses of the bridges to determine the changes in remaining service life attributable to heavier weight trucks.
- Estimating the costs and benefits to the state resulting from increased truck weights.
- Continuing to monitor the accident rate and safety performance of higher-weight trucks.

Allowing higher weight trucks on our nation's roads has been a subject of debate for many years. Economic forces, combined with political change, may accelerate the acceptance of this concept. However, questions still remain regarding their effect on the transportation infrastructure. Given the value of the public's investment in that infrastructure, we feel that continued monitoring of bridges, pavements and traffic safety is a critical element of this process.

EVALUATION OF THE IMPACTS OF INCREASING TRUCK WEIGHTS ON TWO PILOT PROJECT ROUTES IN IDAHO

BACKGROUND

House Bill 623, passed by the 1998 Idaho legislature, made several significant changes in law governing the operation of trucks on Idaho highways. The legislation contained, among other things, amendments to Idaho Code 49-1001. The amendments allowed ITD to issue permits for higher weight trucks to operate on two pilot project routes in Idaho. Previously, the maximum GVW allowed in Idaho was 105,500 pounds. This amendment allowed vehicles to operate on specific routes with reducible loads that had gross weights exceeding 105,500 pounds but not more than 129,000 pounds.

The amendment also included requirements for operating these higher weight trucks. It specified that axle and weight combinations must satisfy an extended version of "Bridge Formula B," which assumes that the length of the overall load and the weight on individual axles determine the trucks' effects on the bridges. The permits require that each axle on these higher-weight trucks be equipped with its own set of brakes, in order to provide adequate braking for higher operating weights.

The pilot project routes on which vehicles exceeding 105,500 pounds could operate were identified by the legislature as: (1) Ashton to Kimberly to Twin Falls to Nevada using US-20, US-30, SH-33, US-93, SH-25, SH-50, and SH-74, and (2) Interstate 15 to Wyoming or Utah border using US-30, SH-34, and US-91.

PURPOSE OF STUDY

The Idaho Transportation Department (ITD) desired an independent analysis, evaluation, and report on the impacts of this legislation on Idaho's pavement, bridges and traffic safety and operations. ITD requested that the University of Idaho's National Institute for Advanced Transportation Technology (NIATT) conduct this evaluation.

INTRODUCTION

The study team has recognized from the beginning of this project that a direct measurement of the physical impacts of the overweight trucks on Idaho's roads and bridges is not possible during the first year of this project. There are two reasons for this. First, changes to pavement and

bridge structures are not measurable over such a short period of time. Second, the number of trips by higher-weight trucks is not currently a significant portion of the overall truck traffic stream. Only 9 overweight permits have been issued for these pilot routes since the beginning of this study. This is not a large enough number of overweight trucks upon which to base definitive conclusions.

Instead of direct measurement of the impacts, we focused on two efforts:

- Determining likely scenarios describing the shift to the use of heavier trucks, and
- Estimating the effects of this shift on pavement, bridges, and traffic using standard engineering models.

This is a scoping study. It is not intended to address all the complex issues involved in allowing higher weight trucks on Idaho roads. For example, this study does not directly address such issues as: effects of this legislation on modal shifts for shipment of freight, enforcement procedures, and the overall state economic impact of this legislation. Although these issues are important, they are beyond the scope of this study.

OVERVIEW OF REPORT

The pavement and bridges on the pilot routes must be capable of carrying the current and future truck traffic. The truck traffic data that we used to describe the current traffic is taken from the weigh-in-motion (WIM) data accumulated over the past year at the two permanent WIM data collection sites on the pilot routes. Traffic attributable to trucks operating under the pilot project is estimated from their trip logs. Total truck traffic over the next 20 years is forecasted from the WIM data. The GVW for the future trucks is estimated from the GVW of heavier trucks currently operating in Montana.

Pavement

We analyzed the effects of these trucks on the two pavement segments corresponding to the WIM sites. We calculated the fatigue damage and rutting, since they are a function of truck loading. The results are expressed as a relative change in damage and a relative change in service life for the pavements

Bridges

We also analyzed the effects of these trucks on a selection of bridges representing a variety of bridge materials, critical span lengths, and years of service. The bridges were rated using the most current version of the bridge codes. Code-based ratings determine the capacity of the bridge relative to the loads imposed by the trucks.

Traffic Safety & Operations

We conducted a literature survey to identify information currently available on the effects of GVW and truck configuration on highway traffic operations and safety.

Each of the three sections concludes with a detailed summary of the results and the conclusions drawn. A final section describes the general conclusions and provides recommendations for the future.

METHODOLOGY

Describing Current Traffic

The truck traffic data that we used to describe the current traffic is taken from the weigh-in-motion (WIM) data accumulated over the past year at the two WIM sites on the pilot routes. These are the Flattop site, located on US93 near Milepost 59, and the Georgetown site, located on US30 near Milepost 425 (see Table 1).

The WIM sensors provide information regarding axle loads and spacing, etc. The various axle configurations are grouped into the vehicle classification codes given in column 1 of Table 1 using the FHWA 6-digit code. As seen in column 2 of Table 1, this classification scheme describes the type of vehicle (single truck, truck-trailer, tractor-semi trailer, etc.) and the number of axles on each unit. The WIM data and the vehicle classification scheme cannot distinguish the higher weight trucks permitted for the pilot study, since some trucks operate at these weights under annual permits rather than pilot project permits. Based on the pilot project truck logs (see Table 2) and practical interpretations of the permit legislation, the higher-weight trucks are assumed to have 7 or more axles.

Table 1 - Weight Data on Pilot Routes

| Vehicle Code | Vehicle Category | Flattop WIM Site- US93 | | | Georgetown WIM Site- US30 | | |
|--------------|---------------------------------------|------------------------|---------------|-----------------------|---------------------------|---------------|-----------------------|
| | | Avg. Gross Weight | Vehicle Count | Portion of Population | Avg. Gross Weight | Vehicle Count | Portion of Population |
| 220000 | 2-ax. units | 2411 | 5716 | 6.07% | 22391 | 3997 | 1.62% |
| 230000 | 3-ax. unit | 31833 | 14307 | 15.19% | 30907 | 4608 | 1.87% |
| 240000 | 4-ax. unit | 45158 | 652 | 0.69% | 38602 | 214 | 0.09% |
| 321000 | 2-ax. tract. 1-ax. semi | 27489 | 4223 | 4.48% | 27344 | 2325 | 0.94% |
| 331000 | 2-ax. tract. 2-ax. semi | 36626 | 490 | 0.52% | 38370 | 716 | 0.29% |
| 322000 | 3-ax. tract. 1-ax. semi | 30901 | 2589 | 2.75% | 31006 | 1855 | 0.75% |
| 332000 | 3-ax. tract. 2-ax. semi | 51787 | 33422 | 35.48% | 58774 | 199553 | 80.98% |
| 333000 | 3-ax. tract. 3-ax. semi | 56190 | 6542 | 6.95% | 55766 | 5550 | 2.25% |
| 334000 | 3-ax. tract. 4-ax. semi | 46011 | 1018 | 1.08% | 61532 | 181 | 0.07% |
| 337000 | 3-ax. tract. 7-ax. semi | 0 | 0 | 0.00% | 24200 | 1 | 0.00% |
| 342000 | 4-ax. tract. 2-ax. semi | 74461 | 167 | 0.18% | 71883 | 343 | 0.14% |
| 343000 | 4-ax. tract. 3-ax. semi | 87942 | 500 | 0.53% | 79404 | 974 | 0.40% |
| 344000 | 4-ax. tract. 4-ax. semi | 104630 | 1504 | 1.60% | 86055 | 54 | 0.02% |
| 421000 | 2-ax. truck, 1-ax. trail. | 0 | 0 | 0.12% | 0 | 0 | 0.00% |
| 422000 | 2-ax. truck, 2-ax. trail. | 43440 | 109 | 0.06% | 44124 | 199 | 0.08% |
| 423000 | 2-ax. truck, 3-ax. trail. | 47787 | 52 | 0.06% | 81910 | 11572 | 4.70% |
| 432000 | 3-ax. truck, 2-ax. trail. | 49545 | 879 | 0.93% | 49074 | 2474 | 1.00% |
| 433000 | 3-ax. truck, 3-ax. trail. | 59283 | 67 | 0.07% | 58128 | 1743 | 0.71% |
| 434000 | 3-ax. truck, 4-ax. trail. | 63978 | 1059 | 1.12% | 51608 | 759 | 0.31% |
| 442000 | 4-ax. truck, 2-ax. trail. | 76027 | 11 | 0.01% | 64388 | 34 | 0.01% |
| 443000 | 4-ax. truck, 3-ax. trail. | 0 | 0 | 0.00% | 75500 | 14 | 0.01% |
| 444000 | 4-ax. truck, 4-ax. trail. | 95687 | 64 | 0.07% | 90848 | 89 | 0.04% |
| 521200 | 2-ax. tract. 1-ax. semi, 2-ax. trail. | 48787 | 1011 | 1.07% | 50802 | 1041 | 0.42% |
| 531200 | 3-ax. tract. 1-ax. semi, 2-ax. trail. | 57811 | 429 | 0.46% | 55506 | 920 | 0.37% |
| 532100 | 3-ax. tract. 2-ax. semi, 1-ax. semi | 71117 | 17 | 0.02% | 65245 | 37 | 0.02% |
| 532200 | 3-ax. tract. 2-ax. semi, 2-ax. trail. | 69320 | 12042 | 12.78% | 65718 | 3345 | 1.36% |
| 532300 | 3-ax. tract. 2-ax. semi, 3-ax. trail. | 64927 | 439 | 0.47% | 71690 | 332 | 0.13% |
| 532400 | 3-ax. tract. 2-ax. semi, 4-ax. trail. | 86493 | 6874 | 7.30% | 66896 | 129 | 0.05% |
| 533200 | 3-ax. tract. 3-ax. semi, 2-ax. semi | 52325 | 4 | 0.00% | 43700 | 5 | 0.00% |
| 542200 | 4-ax. tract. 2-ax. semi, 2-ax. trail. | 85100 | 3 | 0.00% | 65718 | 3345 | 1.36% |
| 543200 | 4-ax. tract. 3-ax. semi, 2-ax. trail. | 0 | 0 | 0.00% | 76566 | 3 | 0.00% |
| | | Total Veh. | 94190 | | Total Veh. | 246412 | |

Pilot Project Log Sheet Summary

Truck operators participating in the pilot project are required to keep log sheets detailing the origin, destination, gross vehicle weight (GVW) and cargo for each trip taken by higher weight trucks. The log sheets are submitted to ITD on a quarterly basis. The data from the log sheets received to date are summarized in Table 2. The data are very limited at this point, but they do provide some information regarding the types of trucks operating under the pilot project.

Table 2 - Pilot Project Log Sheet Summary

| Company | GVW | No. Axles | No. Trips Empty | No. Trips Full | Avg. GVW Empty | Avg. GVW Full |
|------------------------|------------|------------------|------------------------|-----------------------|-----------------------|----------------------|
| Circle A Construction | 129,000 | 11 | N/A | N/A | N/A | N/A |
| Circle A Construction | 129,000 | 11 | N/A | N/A | N/A | N/A |
| Western Alfalfa | 115,500 | 7 | 9 | 9 | 35,230 | 111,862 |
| Western Alfalfa | 114,500 | 7 | N/A | N/A | N/A | N/A |
| Western Alfalfa | 115,500 | 7 | 13 | 13 | 34,628 | 101,586 |
| Tim Ridinger | 115,000 | 7 | N/A | N/A | N/A | N/A |
| Circle A Construction | 129,000 | 11 | N/A | N/A | N/A | N/A |
| Circle A Construction | 129,000 | 11 | N/A | N/A | N/A | N/A |
| Handy Truck Line, Inc. | 114,000 | 9 | N/A | N/A | N/A | N/A |

Predicting Future Traffic

Estimating future truck traffic including higher weight trucks is significantly more problematic, since only nine higher-weight truck permits have been issued as of September 1999.

Extrapolation from this small number would be meaningless. Therefore, the researchers have examined the truck traffic distributions in the neighboring state of Montana to predict future truck traffic on the pilot route.

Montana allows higher-weight trucks on its secondary (non-interstate) highways. Its permit requirements are not identical to those of the pilot project; however, they are similar and provide a realistic guide to the practical implementation of higher weight vehicles. The truck weight distributions for a secondary route in Montana and the two Idaho WIM sites are compared in Table 3.

Table 3 - Weight Data, Pilot Routes and Montana

| Vehicle Code | Vehicle Category | Flattop | | | Georgetown | | | Montana | | |
|--------------|---------------------------------------|-------------------|---------------|-----------------------|-------------------|---------------|-----------------------|-------------------|---------------|-----------------------|
| | | Avg. Gross Weight | Vehicle Count | Portion of Population | Avg. Gross Weight | Vehicle Count | Portion of Population | Avg. Gross Weight | Vehicle Count | Portion of Population |
| 220000 | 2-ax. units | 2411 | 5716 | 6.07% | 22391 | 3997 | 1.62% | 18780 | 129 | 12.11% |
| 230000 | 3-ax. unit | 31833 | 14307 | 15.19% | 30907 | 4608 | 1.87% | 32865 | 110 | 10.33% |
| 240000 | 4-ax. unit | 45158 | 652 | 0.69% | 38602 | 214 | 0.09% | 48931 | 29 | 2.72% |
| 321000 | 2-ax. tract. 1-ax. semi | 27489 | 4223 | 4.48% | 27344 | 2325 | 0.94% | 29880 | 5 | 0.47% |
| 331000 | 2-ax. tract. 2-ax. semi | 36626 | 490 | 0.52% | 38370 | 716 | 0.29% | 38300 | 2 | 0.19% |
| 322000 | 3-ax. tract. 1-ax. semi | 30901 | 2589 | 2.75% | 31006 | 1855 | 0.75% | 33500 | 6 | 0.56% |
| 332000 | 3-ax. tract. 2-ax. semi | 51787 | 33422 | 35.48% | 58774 | 199553 | 80.98% | 64188 | 505 | 47.42% |
| 333000 | 3-ax. tract. 3-ax. semi | 56190 | 6542 | 6.95% | 55766 | 5550 | 2.25% | 57371 | 24 | 2.25% |
| 334000 | 3-ax. tract. 4-ax. semi | 46011 | 1018 | 1.08% | 61532 | 181 | 0.07% | 73350 | 2 | 0.19% |
| 337000 | 3-ax. tract. 7-ax. semi | 0 | 0 | 0.00% | 24200 | 1 | 0.00% | 68317 | 6 | 0.56% |
| 342000 | 4-ax. tract. 2-ax. semi | 74461 | 167 | 0.18% | 71883 | 343 | 0.14% | 80167 | 9 | 0.85% |
| 343000 | 4-ax. tract. 3-ax. semi | 87942 | 500 | 0.53% | 79404 | 974 | 0.40% | 91362 | 13 | 1.22% |
| 344000 | 4-ax. tract. 4-ax. semi | 104630 | 1504 | 1.60% | 86055 | 54 | 0.02% | 102600 | 1 | 0.09% |
| 421000 | 2-ax. truck, 1-ax. trail. | 0 | 0 | 0.12% | 0 | 0 | 0.00% | 34800 | 1 | 0.09% |
| 422000 | 2-ax. truck, 2-ax. trail. | 43440 | 109 | 0.06% | 44124 | 199 | 0.08% | 32825 | 4 | 0.38% |
| 423000 | 2-ax. truck, 3-ax. trail. | 47787 | 52 | 0.06% | 81910 | 11572 | 4.70% | 17700 | 1 | 0.09% |
| 432000 | 3-ax. truck, 2-ax. trail. | 49545 | 879 | 0.93% | 49074 | 2474 | 1.00% | 73143 | 77 | 7.23% |
| 433000 | 3-ax. truck, 3-ax. trail. | 59283 | 67 | 0.07% | 58128 | 1743 | 0.71% | 36620 | 5 | 0.47% |
| 434000 | 3-ax. truck, 4-ax. trail. | 63978 | 1059 | 1.12% | 51608 | 759 | 0.31% | 84500 | 4 | 0.38% |
| 442000 | 4-ax. truck, 2-ax. trail. | 76027 | 11 | 0.01% | 64388 | 34 | 0.01% | 83933 | 6 | 0.56% |
| 443000 | 4-ax. truck, 3-ax. trail. | 0 | 0 | 0.00% | 75500 | 14 | 0.01% | 95425 | 8 | 0.75% |
| 444000 | 4-ax. truck, 4-ax. trail. | 95887 | 64 | 0.07% | 90848 | 89 | 0.04% | 105338 | 13 | 1.22% |
| 521200 | 2-ax. tract. 1-ax. semi, 2-ax. trail. | 48787 | 1011 | 1.07% | 50802 | 1041 | 0.42% | 50057 | 7 | 0.66% |
| 531200 | 3-ax. tract. 1-ax. semi, 2-ax. trail. | 57811 | 429 | 0.46% | 55506 | 920 | 0.37% | 59400 | 5 | 0.47% |
| 532100 | 3-ax. tract. 2-ax. semi, 1-ax. semi | 71117 | 17 | 0.02% | 65245 | 37 | 0.02% | 32400 | 1 | 0.09% |
| 532200 | 3-ax. tract. 2-ax. semi, 2-ax. trail. | 69320 | 12042 | 12.78% | 65718 | 3345 | 1.36% | 82886 | 64 | 6.01% |
| 532300 | 3-ax. tract. 2-ax. semi, 3-ax. trail. | 64927 | 439 | 0.47% | 71690 | 332 | 0.13% | 84189 | 9 | 0.85% |
| 532400 | 3-ax. tract. 2-ax. semi, 4-ax. trail. | 86493 | 6874 | 7.30% | 66896 | 129 | 0.05% | 64840 | 10 | 0.94% |
| 533200 | 3-ax. tract. 3-ax. semi, 2-ax. semi | 52325 | 4 | 0.00% | 43700 | 5 | 0.00% | 102217 | 6 | 0.56% |
| 542200 | 4-ax. tract. 2-ax. semi, 2-ax. trail. | 85100 | 3 | 0.00% | 65718 | 3345 | 1.36% | 106400 | 1 | 0.09% |
| 543200 | 4-ax. tract. 3-ax. semi, 2-ax. trail. | 0 | 0 | 0.00% | 76566 | 3 | 0.00% | 84450 | 2 | 0.19% |
| | | Total Veh. | 94190 | | Total Veh. | 246412 | | Total Veh. | 1065 | |

Assumptions

In order to predict changes in Idaho trucks weights from the Montana data, the researchers made several assumptions:

- Vehicles having seven or more axles will carry higher weights. All vehicles that have applied for permits under Idaho's pilot project have seven or more axles. With two exceptions, vehicle classifications with seven or more axles had higher gross vehicle weights in Montana compared to Idaho.
- For these vehicle categories, the average gross vehicle weight under the Idaho higher-weight truck scenario will be equal to the average GVW measured on the selected secondary route in Montana, with two exceptions. Two vehicle categories currently have slightly higher average gross vehicle weights in Idaho compared to Montana; their average weights were not changed. These two categories are designated by vehicle codes 344000 and 532400, vehicles consisting of 4-axle tractors pulling 4-axle semi-trailers and those consisting of a 3-axle tractor pulling a 2-axle semi-trailer and a 4-axle trailer.
- The 7-axle combinations are assumed to have a tare weight of 35,000 lbs, 8-axle combinations, a tare weight of 45,000 lbs and 9-or-more-axle combinations a tare weight of 55,000 lbs. These are arbitrary values based on a comparison of the pilot log sheets and estimated payload information provided by Western Trailers (see Appendix B). The tare weights cannot be determined from the WIM data because they do not identify empty and laden trucks. Likewise, it is difficult to determine empty vs. laden from the histograms of the WIM data because there is significant scatter in tare weights and because trucks can carry partial loads.
- The number of trips required to carry the higher loads decreases in an amount inversely proportional to the relative increase in average vehicle payload (GVW less the tare weight).
- The freight is not shifted between vehicle classifications.

Predictions

To predict the effects of heavier trucks on Idaho's pavement and bridges, two forecasting scenarios were developed:

Baseline Scenario

The first scenario assumes that no higher weight trucks were allowed on the pilot route. This scenario serves as a baseline against which the higher weight truck scenario is compared.

Higher Weight Scenario

The second scenario assumes that higher weight trucks are allowed on the pilot route, with the pilot route extended slightly, i.e., the routes were extended to allow connections to Montana and Wyoming. The extensions to the pilot route are included in the scenario because the current pilot routes have generated only a limited number of permits. Without the extensions and the resulting increase in permits, the baseline scenario and the higher weight truck scenarios would be indistinguishable.

Using the WIM data from the two sites described previously, and Montana's truck traffic data, we have forecasted the truck traffic for the next 20 years (see Table 4). For both the baseline and the higher weight scenario, we assumed a 1% growth in truck traffic each year.

Effect of Assumptions on Predictions

The traffic counts for both scenarios were used in the pavement and bridge analyses to determine the impact of the higher weight trucks. The accuracy of the assumptions and predictions affect the accuracy of the predicted impact. For example, the assumed 1% per year growth rate is applied to both the baseline scenario and the higher weight truck scenario. Since it is applied to both, and since the impacts will be determined from a comparison of the two scenarios, minor changes in the growth factor will not have a significant impact on the outcome.

The bridge strength rating makes only a crude distinction between low truck traffic volume (less than 1000 Average Daily Truck Traffic or ADTT) and high truck traffic volume (greater than 1000 ADTT). Small inaccuracies in the predictions will have little effect on the final strength rating when it is based on such simple classifications. Thus, the predicted traffic counts are sufficiently accurate for the code-based bridge rating system used in this study.

Table 4 - Predicted Truck Traffic

| | | Flattop Site | | | | | | | | | | Georgetown Site | | | | | | | | | |
|----------------------------------|-------------|-------------------|----------------------|--------------------------|-------------------------|-------------------|----------------------|--------------------------|-------------------------|---------------|----------------------|--------------------------|-------------------------|-------------------|----------------------|--------------------------|-------------------------|--|--|--|--|
| | | Baseline Scenario | | | | | Future Scenario | | | | | Baseline Scenario | | | | | Future Scenario | | | | |
| Vehicle Category | Tare Wt lbs | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | | | | |
| | | Avg. GVW (lb) | Truck Factor, (ESAL) | No. of trips In 20 years | Total ESALs In 20 Years | Adj.Avg. GVW (lb) | Truck Factor, (ESAL) | No. of trips In 20 years | Total ESALs In 20 Years | Avg. GVW (lb) | Truck Factor, (ESAL) | No. of trips In 20 years | Total ESALs In 20 Years | Adj.Avg. GVW (lb) | Truck Factor, (ESAL) | No. of trips In 20 years | Total ESALs In 20 Years | | | | |
| 2-ax units | | 2,411 | 1.002 | 151,028 | 151,330 | 2,411 | 1.002 | 151,028 | 151,330 | 22391 | 1.090 | 105,603 | 115,107 | 22,391 | 1.090 | 105,603 | 115,107 | | | | |
| 3-ax unit | | 31,833 | 0.847 | 378,022 | 320,185 | 31,833 | 0.847 | 378,022 | 320,185 | 30907 | 0.988 | 121,765 | 120,304 | 30,907 | 0.988 | 121,765 | 120,304 | | | | |
| 4-ax unit | | 45,158 | 2.271 | 17,219 | 39,104 | 45,158 | 2.271 | 17,219 | 39,104 | 38602 | 1.481 | 5,659 | 8,381 | 38,602 | 1.481 | 5,659 | 8,381 | | | | |
| 2-ax tract 1-ax semi | | 27,489 | 1.319 | 111,592 | 147,190 | 27,489 | 1.319 | 111,592 | 147,190 | 27344 | 1.530 | 61,433 | 93,993 | 27,344 | 1.530 | 61,433 | 93,993 | | | | |
| 2-ax tract 2-ax semi | | 36,626 | 0.937 | 12,947 | 12,132 | 36,626 | 0.937 | 12,947 | 12,132 | 38370 | 1.570 | 18,914 | 29,695 | 38,370 | 1.570 | 18,914 | 29,695 | | | | |
| 3-ax tract 1-ax semi | | 30,901 | 0.970 | 68,413 | 66,361 | 30,901 | 0.970 | 68,413 | 66,361 | 31006 | 0.951 | 49,014 | 46,613 | 31,006 | 0.951 | 49,014 | 46,613 | | | | |
| 3-ax tract 2-ax semi | | 51,787 | 1.006 | 883,094 | 888,393 | 51,787 | 1.006 | 883,094 | 888,393 | 58774 | 1.557 | 5,272,737 | 8,209,651 | 58,774 | 1.557 | 5,272,737 | 8,209,651 | | | | |
| 3-ax tract 3-ax semi | | 56,190 | 1.800 | 172,849 | 311,129 | 56,190 | 1.800 | 172,849 | 311,129 | 55766 | 1.571 | 146,647 | 230,382 | 55,766 | 1.571 | 146,647 | 230,382 | | | | |
| 3-ax tract 4-ax semi | | 46,011 | 1.055 | 26,885 | 28,364 | 46,011 | 1.055 | 26,885 | 28,364 | 61532 | 2.391 | 4,778 | 11,424 | 61,532 | 2.391 | 4,778 | 11,424 | | | | |
| 3-ax tract 7-ax semi | | 24,200 | 0.020 | 22,000 | 0 | 24,200 | 0.020 | 22 | 0 | 24200 | 0.020 | 22 | 0 | 24,200 | 0.020 | 22 | 0 | | | | |
| 4-ax tract 2-ax semi | | 74,461 | 3.114 | 4,404 | 13,713 | 74,461 | 3.114 | 4,404 | 13,713 | 71883 | 2.472 | 9,072 | 22,426 | 71,883 | 2.472 | 9,072 | 22,426 | | | | |
| 4-ax tract 3-ax semi | 35,000 | 87,942 | 5.453 | 13,211 | 72,042 | 91,362 | 6.352 | 12,410 | 78,826 | 79404 | 3.484 | 25,740 | 89,679 | 91,362 | 6.106 | 20,279 | 123,827 | | | | |
| 4-ax tract 4-ax semi | 45,000 | 104,630 | 8.588 | 39,722 | 341,135 | 104,630 | 8.588 | 39,722 | 341,135 | 86055 | 4.779 | 1,431 | 6,840 | 86,055 | 4.779 | 1,431 | 6,840 | | | | |
| 2-ax truck 2-ax trail | | 43,440 | 5.201 | 2,862 | 14,888 | 43,440 | 5.201 | 2,862 | 14,888 | 44124 | 4.829 | 5,263 | 25,413 | 44,124 | 4.829 | 5,263 | 25,413 | | | | |
| 2-ax truck 3-ax trail | | 47,787 | 1.546 | 1,365 | 2,111 | 47,787 | 1.546 | 1,365 | 2,111 | 81910 | 9.257 | 261,718 | 2,422,722 | 81,910 | 9.257 | 261,718 | 2,422,722 | | | | |
| 3-ax truck 2-ax trail | | 49,545 | 1.357 | 23,230 | 31,523 | 49,545 | 1.357 | 23,230 | 31,523 | 49074 | 1.636 | 65,352 | 106,917 | 49,074 | 1.636 | 65,352 | 106,917 | | | | |
| 3-ax truck 3-ax trail | | 59,283 | 2.421 | 1,762 | 4,265 | 59,283 | 2.421 | 1,762 | 4,265 | 58128 | 1.509 | 46,042 | 69,477 | 58,128 | 1.509 | 46,042 | 69,477 | | | | |
| 3-ax truck 4-ax trail | 35,000 | 63,978 | 1.285 | 27,986 | 35,962 | 84,500 | 3.910 | 16,383 | 64,064 | 51608 | 1.040 | 20,059 | 20,862 | 84,500 | 7.475 | 6,730 | 50,306 | | | | |
| 4-ax truck 2-ax trail | | 76,027 | 4.343 | 286 | 1,243 | 76,027 | 4.343 | 286 | 1,243 | 64388 | 2.255 | 903 | 2,036 | 64,388 | 2.255 | 903 | 2,036 | | | | |
| 4-ax truck 3-ax trail | 35,000 | 75500 | 3.650 | 374 | 1,366 | 95,425 | 9.314 | 251 | 2,337 | 75500 | 3.650 | 374 | 1,366 | 95,425 | 9.314 | 251 | 2,337 | | | | |
| 4-ax truck 4-ax trail | 45,000 | 95,687 | 2.771 | 1,695 | 4,698 | 105,338 | 4.070 | 1,424 | 5,796 | 90848 | 3.078 | 2,356 | 7,252 | 105,338 | 5.564 | 1,790 | 9,960 | | | | |
| 2-ax tract 1-ax semi, 2-ax trail | | 48,787 | 1.551 | 26,709 | 41,426 | 48,787 | 1.551 | 26,709 | 41,426 | 50802 | 2.057 | 27,502 | 56,571 | 50,802 | 2.057 | 27,502 | 56,571 | | | | |
| 3-ax tract 1-ax semi, 2-ax trail | | 57,811 | 1.585 | 11,340 | 17,974 | 57,811 | 1.585 | 11,340 | 17,974 | 55506 | 1.726 | 24,309 | 41,957 | 55,506 | 1.726 | 24,309 | 41,957 | | | | |
| 3-ax tract 2-ax semi, 1-ax semi | | 71,117 | 3.048 | 440 | 1,342 | 71,117 | 3.048 | 440 | 1,342 | 65245 | 3.647 | 969 | 3,533 | 65,245 | 3.647 | 969 | 3,533 | | | | |

| | | Flattop Site | | | | | | | | | | Georgetown Site | | | | | | |
|----------------------------------|-------------|---|----------------------|--------------------------|-------------------------|-------------------|---|--------------------------|-------------------------|---------------|----------------------|---|-------------------------|-------------------|----------------------|--------------------------|-------------------------|--|
| | | Baseline Scenario | | | | | Future Scenario | | | | | Baseline Scenario | | | | Future Scenario | | |
| Vehicle Category | Tare Wt lbs | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | |
| | | Avg. GVW (lb) | Truck Factor, (ESAL) | No. of trips In 20 years | Total ESALs In 20 Years | Adj.Avg. GVW (lb) | Truck Factor, (ESAL) | No. of trips In 20 years | Total ESALs In 20 Years | Avg. GVW (lb) | Truck Factor, (ESAL) | No. of trips In 20 years | Total ESALs In 20 Years | Adj.Avg. GVW (lb) | Truck Factor, (ESAL) | No. of trips In 20 years | Total ESALs In 20 Years | |
| 3-ax tract 2-ax semi, 2-ax trail | 35,000 | 69,320 | 2.033 | 318,175 | 646,849 | 82,886 | 4.156 | 228,037 | 947,614 | 65718 | 1.605 | 88,384 | 141,857 | 82,886 | 4.061 | 56,697 | 230,261 | |
| 3-ax tract 2-ax semi, 3-ax trail | 45,000 | 64,927 | 1.338 | 11,604 | 15,526 | 84,189 | 3.782 | 5,900 | 22,318 | 71690 | 1.498 | 8,764 | 13,128 | 84,189 | 2.849 | 5,969 | 17,004 | |
| 3-ax tract 2-ax semi, 4-ax trail | 55,000 | 86,493 | 1.769 | 181,635 | 321,312 | 86,493 | 1.769 | 181,635 | 321,312 | 66896 | 0.796 | 3,413 | 2,717 | 66,896 | 0.796 | 3,413 | 2,717 | |
| 3-ax tract 3-ax semi, 2-ax semi | 45,000 | 52,325 | 1.643 | 110 | 181 | 102,217 | 23.927 | 14 | 337 | 43700 | 0.558 | 132 | 74 | 102,217 | 16.703 | 0 | 0 | |
| 4-ax tract 2-ax semi, 2-ax trail | 45,000 | 85,100 | 2.523 | 88 | 222 | 106,400 | 6.165 | 58 | 355 | 65718 | 1.605 | 88,384 | 141,857 | 106,400 | 11.028 | 29,823 | 328,896 | |
| 4-ax tract 3-ax semi, 2-ax trail | 55,000 | 76,566 | 1.407 | 88 | 124 | 84,450 | 2.082 | 64 | 134 | 76566 | 1.407 | 88 | 124 | 84,450 | 2.082 | 64 | 134 | |
| | | Total ESALs | | | 3,532,089 | | | | 3,876,900 | Total ESALs | | | 12,042,357 | | | | 12,388,835 | |
| | | % Increase in ESALs of the future compared to Baseline scenario | | | | | % Increase in ESALs of the future compared to Baseline scenario | | | | | % Increase in ESALs of the future compared to Baseline scenario | | | | | 2.88% | |

PAVEMENT ANALYSIS

Introduction

Highway infrastructure protection has been an important consideration in determining the parameters of truck size and weight limits. Increased axle weights and the number of trucks operating on the highway system contribute to pavement wear, and consequently the increase in maintenance and rehabilitation costs. While the issue is not a new one, quantification of these impacts is vital to decision-makers before they can allow heavier trucks to operate on state routes.

This study assesses the impacts of increased truck weights on the performance of two pavement segments. The study is limited to the future traffic scenario discussed earlier. The assessment of the impacts is conducted in terms of pavement damage or service life. The study, however, does not address the economic impacts of the maintenance cost or the societal gain of the new truck operation. Thus, the “benefit” is assessed in terms of remaining service life. A scenario will be considered more beneficial over another if it leads to longer service life of the pavement.

Pavement Remaining Service Life Assessment Methodology

Two pavement distresses are considered in this analysis – fatigue and rutting (permanent deformation). While these are not the only distresses in pavements, they are the major load-associated distresses. In addition, they can be evaluated mechanistically, so the effect of various scenarios of axle loads can be evaluated.

The Asphalt Institute models are used in this study, since they are the most commonly used and have been used for the overlay design system in the state of Idaho. Also, the national truck study¹ uses the Asphalt Institute models in its fatigue analysis. Our analysis is also conducted using Shell models, for the purpose of comparison.

Fatigue

Fatigue is the deterioration of a material under repeated cycles of load, resulting in progressive cracking that eventually produces fracture. This type of distress occurs in the asphalt-bound layers under repeated traffic loads. Two truck characteristics lead to fatigue damage: the axle load (weight), and the number of repetitions. The axle load is proportional to the induced strain in the pavement, and the repetitions contribute to the accumulation of the incremental damage that occurs after each axle load passes. There are several fatigue models that incorporate pavement layer modulus of resilience and the induced elastic tensile strain as the independent parameters. The modulus of resilience reflects the pavement structure capacity and the elastic strain reflects the effect of the axle load on the damage to the pavement structure. Most of these models have the general form:

¹ 1997 *Comprehensive Truck Size and Weight Study, Volume II: Issues and Background*, FHWA, U.S. DOT, Draft Final Report, June 1997. <http://www.fhwa.dot.gov/reports/tswstudy/tswfv2.htm>.
Development and Calibration of Mechanistic-Empirical Distress Models for Cost Allocation, Draft Final Report, FHWA Contract DFH61-93-C-00055, March 1977.

$$N_f (\text{fatigue}) = f_1 (\epsilon_t)^{f_2} (E)^{f_3} \quad \text{Eqn. 1}$$

| | | |
|----------|------------------------------|---|
| In which | N_f | Number of cycles to fatigue failure |
| | ϵ_t | Maximum Tensile Strain at the bottom of asphalt layer |
| | E | Asphalt layer elastic modulus |
| | $f_1, f_2, \text{ and } f_3$ | Fatigue model parameters. |

For the Asphalt Institute fatigue model, the parameter f_1 changes with different fatigue Shift Factors (SF). The shift factor is simply a factor that adjusts the laboratory-based fatigue model to correlate more closely with actual field conditions. The original value of the fatigue shift factor, which was proposed by the Asphalt Institute, is 18.4. However, many states have found that this shift factor predicts very long fatigue lives when it is applied to real pavements. Based on its experience in Idaho, ITD uses a shift factor of 8 or 10, especially for old roads. If the pavement is highly aged and cracked, this factor may be reduced to 4. Accordingly, values of the parameter f_1 are determined to be 0.0796, 0.0432 and 0.01728 for SF of 18.4, 10 and 4 respectively. The parameters f_2 and f_3 are -3.291 and -0.854 as originally provided in the Asphalt Institute equation.

Rutting (Permanent Deformation)

As in the case of fatigue, rutting depends on the axle load (weight) and the number of repetitions. However, the mechanism of rutting is different from that of fatigue. The pavement material properties also have different effects on fatigue versus rutting. That is, while a stiff pavement may show high resistance to rutting, it will be more prone to cracking, and this will accelerate its fatigue failure. Both distresses, though, are increased with the increase of axle loads and repetitions. Rutting has been correlated with the compressive strain at the top of subgrade – the foundation materials supporting the pavement. As with fatigue, there are several rutting models, which can be represented by the following function:

$$N_r (\text{rutting}) = f_4 (\epsilon_c)^{f_5} \quad \text{Eqn. 2}$$

| | | |
|----------|------------------------|---|
| In which | N_r | Number of cycles to rutting failure |
| | ϵ_c | Maximum Compressive Strain at the top of subgrade layer |
| | $f_4 \text{ and } f_5$ | Rutting model parameters. |

For the Asphalt Institute rutting model, parameters f_4 and f_5 are $1.37\text{E-}09$ and -4.477 respectively. No shift factors were applied to the rutting model, since rutting is in the subgrade and the shift factors only apply to the asphalt pavement layers.

It is important to emphasize that the proposed models work well for comparison between the two scenarios. However, using the models to calculate the absolute service life may introduce significant error, because of the difficulties in correlating the shift factor to actual pavement conditions. Therefore, it is more appropriate to select a shift factor that provides an arbitrary design life and compare the relative impacts of the assumed scenarios on that arbitrary design life.

Selected Pavement Sites

Two sites were selected for this limited study, US30 MP425-426 and US93 MP 59-60, since they were the only two that have historical truck weight data. Traffic data from Weigh-in-Motion (WIM) stations at these two sites were provided by ITD and are presented in Table 1. The pavement condition data provided by ITD included International Roughness Index (IRI), crack index (CI) and rut-depth data. They indicate that the two pavement sites are generally in very good conditions. The pavement at US30 MP 425-426 was overlaid in 1996 and it has an average crack index of 5 (excellent). The pavement at US93-MP 57-60 was reconstructed in 1992 and it has an average crack index of 4.0 (very good).

Pavement structure capacity is assessed in terms of the layers moduli and the induced elastic strains. This is determined by means of Falling Weight Deflectometer (FWD) testing provided by ITD, and the use of backcalculation procedures. The MODULUS backcalculation software is used to determine layer moduli of the pavements. Finally, the multi-layer elastic theory is employed, using the KENLAYER software, to determine the elastic tensile strain at the bottom of the asphalt layer and the elastic compressive strain at the top of the subgrade layer.

Traffic Loads

Two scenarios were discussed earlier, the Baseline scenario and the Future Heavy-Truck Scenario. Traffic data for both scenarios, and both sites, including average gross vehicle weight and number of trips per year for each category of vehicles, are provided in Table 4.

Baseline Scenario

For the baseline scenario, average truck factors in Equivalent Single Axle Load units (ESALs) are obtained from the WIM data provided by ITD (Columns 5 and 13 in Table 4). The projected total accumulated ESALs over an analysis period of 20 years are estimated using an annual growth rate of 1% (Columns 7 and 15 in Table 4).

Future Scenario

The future heavy-truck scenario assumes that vehicles with seven or more axles will increase their gross weight to that currently observed on a secondary route in Montana. Accordingly, new truck factors for those two vehicle categories were estimated by increasing the original truck factors by the ratio (New GVW/Old GVW) raised to the fourth power. After reducing the number of trips in the heavier truck scenario (based on the relative increase in payload), we determined yearly ESALs for the heavy-truck scenario (Columns 9 and 17 in Table 4). We estimated the total accumulated ESALs over a 20-yr period based on the 1% annual growth rate in this scenario as well (Columns 11 and 19 in Table 4).

Pavement Structure Evaluation

Using the Falling Weight Deflectometer (FWD) results, along with the seasonal factors adopted by the State of Idaho in climatic zone 1, a matrix of pavement layer moduli was established and is presented in the Tables A1 and A2 of Appendix A. With these layers' moduli values, the KENLAYER program was used to calculate the elastic compressive and tensile strains needed for fatigue and rutting analysis. Elastic strain results are also provided in Tables A1 and A2.

Damage and Service Life Analysis

Based on the proposed fatigue and rutting models, the remaining service life of the pavement sections at the two sites were evaluated for both the baseline and heavy truck scenarios. A summary of the damage and remaining service life analyses is presented in Table 5. This table identifies the site under consideration, the results of the fatigue analysis for the three assumed shift factors, and the results of the rutting analysis.

Table 5 - Summary of Damage and Service Life Analysis

| Site | Fatigue Analysis | | | Rutting Analysis |
|--|------------------|--------|--------|------------------|
| | SF=18.4 | SF=10 | SF=4 | |
| US30 MP 425-426 | | | | |
| % Increase in Damage | 2.88% | 2.88% | Failed | 2.88% |
| % Reduction in Service Life | -2.80% | -2.80% | Failed | -2.80% |
| Reduction in design life for 5-yr period, years | -0.14 | -0.14 | Failed | -0.14 |
| Reduction in design life for 10-yr period, years | -0.28 | -0.28 | Failed | -0.28 |
| Reduction in design life for 20-yr period, years | -0.56 | -0.56 | Failed | -0.56 |
| US93 MP 59-60 | | | | |
| % Increase in Damage | 9.76% | 9.76% | 9.76% | 9.76% |
| % Reduction in Service Life | -8.895% | -8.89% | -8.89% | -8.89% |
| Reduction in design life for 5-yr period, years | -0.44 | -0.44 | -0.44 | -0.44 |
| Reduction in design life for 10-yr period, years | -0.89 | -0.89 | -0.89 | -0.89 |
| Reduction in design life for 20-yr period, years | -1.78 | -1.78 | -1.78 | -1.78 |

The results summarized in Table 5 reveal that the pavement conditions at both sites are very good, and that the pavements will sustain the expected traffic for both scenarios, when shift factors of 18.4 and 10 are considered. When a smaller shift factor (SF=4) was considered, the pavement section failed for both scenarios for the 20-year analysis period.

We note that whatever shift factor is considered, the relative increase in damage or reduction in service life remains unchanged. That is true because the “relative” not the “absolute” damage is calculated. That is also true when SF=4, but the damage ratio calculations indicate that the Georgetown (US30) pavement segment failed in the analysis periods.

We also note that the analysis considers only fatigue and rutting as being load-associated distresses. These pavements may still fail under other modes independent of the two traffic scenarios considered, such as surface disintegration due to weathering.

The important issue here is the difference in the impacts between the baseline and the heavy-truck scenarios. The results in Table 5 show that there was an increase in damage of about 2.88% at the US30 site, while the increase in damage was about 9.76% at the US93 site. The increase in damage was directly proportional to the increase in total ESALs operating on the pavement over the analysis period. The increase in damage leads to a proportional reduction in service life.

Figure 1 illustrates the relative increase in damage and the relative reduction in service life for the two pavement segments. In general, for the US30 pavement section, an increase in damage of about 2.88% was associated with a reduction in life of about 2.8%. For the pavement at US93, the 9.76% increase in damage was associated with reduction in life of about 8.89%.

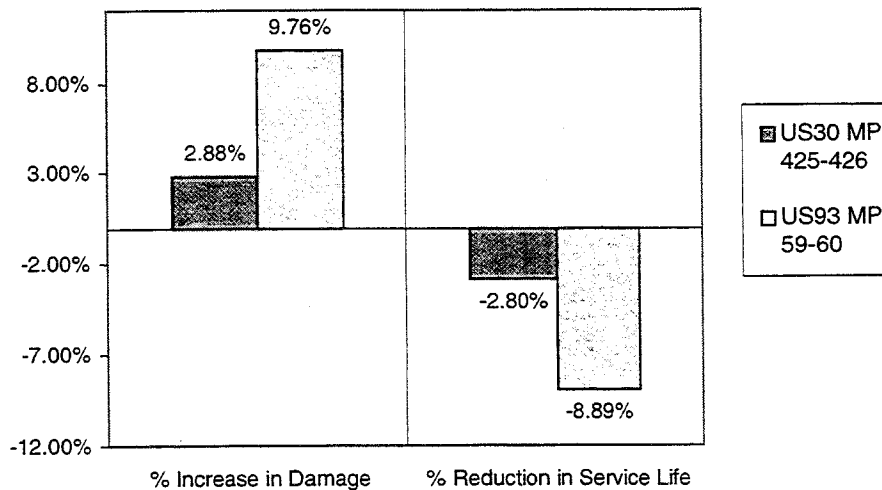


Figure 1 - Effects of Heavy-Truck Scenario on Pavement Damage and Service Life

When we consider the life predicted by the models for both scenarios, we find that the pavement survived the expected traffic. However, this is attributed to the relatively good condition of the pavements, and it depended on the shift factor considered.

To present the impacts of the heavy truck scenario in terms of reduced pavement life, we selected an arbitrary design life and compared the remaining service lives. Thus, we considered

three design periods, 5, 10 and 20-years. Applying the relative reduction in service life to these periods, we get the expected reduction in pavement service life in years. This is presented in Figure 2. For the 20-yr period, the expected reduction in service life of the pavement at the US30 site is about 0.56 years. For the pavement at the US93 site, the expected life is reduced by about 1.78 years.

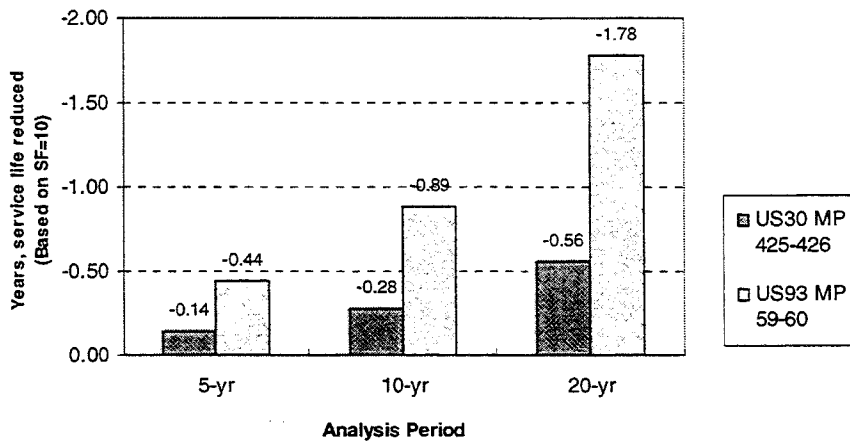


Figure 2 - Reduction in Service Life Over Varied Design Periods

Pavement Analysis Summary and Conclusions

In summary, the increased damaged is attributed to two main factors: the increased weight of trucks, which leads to an increase in the total ESALs; and the pavement structure capacity. If the pavement is in good condition, as is the case with these two sites, there will be minimal increased damage due to the increased truck weights. But, if the pavement structure is relatively weak, the increase in damage, or reduction in service life, will be greater.

By contrast, the “Turner Proposal”² suggests that higher weight trucks can reduce pavement damage. However, the “Turner Proposal” reduces the allowable loads on single axles, tandems and multiple axle configurations, while increasing the GVW. The pilot project legislation does not reduce the allowable loads on single axles, tandems or combinations. As a result, in the pilot project, the pavement damage increases rather than decreases.

Based on the assumed future “heavy-truck” scenario, the increase in pavement damage was determined to be 3% for the US30 site and 10% for the US93 site. Note that the increase in damage is equal to the increase in total accumulated ESALs over the analysis period. The service life will be reduced by about 3% at the US30 site and 9% at the US93 site. Over a 20-yr period, this will cause a reduction in service life of about 0.56 years for the US30 site, and 1.8 years for the US93 site.

It is important to emphasize that these results are based on:

- a) the assumed future traffic scenario, and
- b) the two selected pavement segments.

A final conclusion may not be drawn at this point, for several reasons: the number of permits issued is quite small, we included Montana's truck traffic data in our projection of future traffic, the modeling of traffic predictions is very limited, and the number of pavement sections analyzed is small. The important conclusion is this: if there will be an increase in total accumulated ESALs, then there will be a proportional increase in pavement damage and there will be an associated increase in maintenance and rehabilitation cost.

It is highly recommended that the truck traffic continue to be monitored closely by WIM at the two sites, as well as at other sites along the pilot routes. The WIM data should be re-evaluated, to determine whether there will be a real increase in total accumulated ESALs.

² TRB Special Report 227, *New Trucks for Greater Productivity and Less Road Wear, an Evaluation of the Turner Proposal*, National Research Council, Washington, D.C.

BRIDGE ANALYSIS

Bridges Analyzed

The pilot routes traverse 79 bridges. None of the bridges on the pilot route are load posted. They are all considered adequate for the current loads, using the current rating criteria. However, several of the bridges are older, and their load ratings are barely adequate for carrying the truck weights that were allowed before the pilot project. Those bridges with the lowest load ratings are most likely to be inadequate, so we selected them for the study. The heavier trucks used in our bridge rating analysis have more axles and a longer wheelbase than the AASHTO Type 3-3 and Type 3S2 trucks normally used for rating bridges. A bridge must be relatively long (greater than 95 feet) for the entire 129,000 lb. rating truck to be on the bridge simultaneously. Therefore, we also selected longer span bridges for analysis. The selection includes bridges of steel, reinforced concrete and prestressed concrete, representing the materials used in the majority of bridges in Idaho.

Based on these considerations, we have analyzed the following bridges:

| Bridge | Master Key | Span | Type |
|----------------|------------|------|------------------------|
| Low Line Canal | 15220 | 75' | WF Girder, simple span |
| Hansen Bridge | 14520 | 258' | Steel Girder, 3-span |
| UPRR; Topaz OP | 13705 | 379' | Steel truss |
| Salmon Creek | 17565 | 50' | RC T-beam simple span |
| "L" Canal | 13040 | 41' | RC T-beam simple span |
| N. Fork Teton | 12585 | 99' | Prestress 1-span |
| Deer Crossing | 13725 | 75' | Prestress 1-span |

Analysis Method – Inventory/Operating vs. LRFD

A variety of measures are possible when describing the performance of the bridge. Currently, ITD uses standard AASHTO bridge rating procedures to determine the adequacy of the bridges under both the new and old truck weight regimes. This approach has several drawbacks. The standard AASHTO approach provides both an inventory rating, for day-to-day truck traffic, and an operating rating for occasional permitted overweight trucks. Unfortunately, AASHTO provides no instructions regarding how often a truck must travel over a bridge before it is considered an inventory load rather than an operating load.

This study uses the AASHTO *Guide Specification for Strength Evaluation of Existing Steel and Concrete Bridges*, (1989) to rate the bridges. This procedure is based on Load and Resistance Factor Design (LRFD) concepts. This approach applies statistically derived factors to adjust the loads and structures' resistance to the loads, to account for the likelihood of various combinations of load and resistance occurring. The LRFD approach quantifies the effects of the frequency of the truck loading, and provides a single rating level for each bridge. In the future, ITD plans to rate all bridges using the LRFD-based approach.

The numerical values for the LRFD-based ratings are similar to the inventory/operating ratings; in most cases they fall between the inventory and operating levels. The result is similar to other national and state studies that have simply selected an arbitrary rating value somewhere between the inventory and operating ratings. For example, a DOT study³ increases the inventory rating by 15% to determine its final rating.

Rating Criteria

The bridge's rating is based on several performance criteria, including bending strength and shear strength of the girders, bending and shear strength of the deck, and for steel bridges fatigue of the girders, connections, stiffeners and other details. Serviceability criteria such as deflections and cracking were briefly considered for steel girders, but their rating factors were not as low as the strength rating factors and they are not included in this report. Only superstructure members such as girders and decks are included in the analyses. Substructure elements such as abutments or piers are not considered.

The rating is reported as a single number expressing the ratio of the capacity of the member over the demand imposed by the load. A rating greater than one indicates the bridge has the capacity to carry the loads indicated, less than one indicates that the bridge should be posted or replaced. Code-based ratings determine the capacity of the bridge through the duration of an assumed service life (typically 50 years), but they do not directly calculate the remaining service life of the bridge.

A bending strength rating is determined for each girder as the designated truck traverses the bridge. The reported bending strength rating is the lowest rating of any of the girders. Similar procedures determine the shear strength rating of the girders and the bending strength of the deck.

Loads

This study uses the standard AASHTO rating trucks as modified by ITD. These are designated:

| Vehicle | Axles | Length | GVW |
|----------------|--------------|---------------|------------|
| Type 3 | 3 | 19 ft | 54,000 lb |
| Type 3S2 | 5 | 41 ft | 84,000 lb |
| Type 3-3 | 6 | 54 ft | 90,000 lb |

³ DOT 1997. *U.S. DOT Comprehensive TS&W Study*.

As suggested by ITD, a fourth truck having a GVW of 129,000 lb was used to determine the bridge rating for the higher weight trucks. This truck has ten axles and is 95 ft long. If the number of axles on a truck is increased to more than ten, it is possible to carry 129,000 lbs GVW on trucks less than 95 ft long. However, it is difficult to steer a vehicle with a large number of closely spaced axles, making these configurations impractical.

The load factors are a function of the enforcement of load limits and the level of truck traffic. Under the annual permit system for non-reducible loads, it is very difficult to control the number of overweight trucks on the Idaho's highways. Therefore, the enforcement of overload restrictions is considered "poor" for all bridges according to the AASHTO *Guide Specification*.

The truck traffic is determined from the average daily truck traffic (ADTT) reported by the weigh-in-motion site nearest each bridge, and the ADTT from the inspection report.

An impact factor is also included in the loads for some members. This factor depends on the condition of the deck and the approaches. These values are determined from the inspection reports.

Strength

The strength of the girder, deck and other members to resist the loads is a function of the condition of the member as well as the quality of the inspection and maintenance procedures. The condition of the members is determined from the inspection reports and is indicated on the attached spreadsheets. Routine inspection is considered "careful", and routine maintenance is considered "intermittent" in accordance with AASHTO's *Guide Specification*.

Results

The bridge ratings are summarized in Table 6. The summary lists the type of bridge or portion of bridge under consideration, the rating factor for each type of truck that was applied to the bridge and the change in rating factor between the baseline scenario and the heavy-weight truck scenario.

Table 6 - Bridge Ratings

| Bridge | Master Key | Limit State | Rating Factor | | | | Change in Rating Factor |
|----------------------------|------------|---------------------|---------------|----------------|----------------|-------------------|-------------------------|
| | | | Type 3 truck | Type 3S2 truck | Type 3-3 truck | 129,000 lb. truck | |
| Hansen | 14520 | 100' Girder Bending | 2.37 | 1.91 | 1.75 | 1.77 | 1% |
| Multi-span Steel | | 258 Girder Bending | 3.69 | 2.63 | 2.43 | 1.96 | -19% |
| 100' to 258' spans | | Girder Shear | 2.43 | 1.66 | 1.55 | 1.34 | -14% |
| Low Line Canal | 15220 | Girder Bending | 1.49 | 1.32 | 1.20 | 1.31 | 9% |
| Single-span steel | | Deck Bending | 1.25 | 1.27 | 1.48 | 1.53 | 22% |
| 75' span | | | | | | | |
| Deer Crossing | 13725 | Girder Bending | 2.67 | 2.37 | 2.16 | 2.35 | 9% |
| 1-span prestressed | | Girder Shear | 2.54 | 2.60 | 2.36 | 2.57 | 9% |
| 75' span | | Girder Cracking | 2.92 | 1.36 | 1.24 | 1.27 | 2% |
| N. Fork Teton River | 12585 | Girder Bending | 1.58 | 1.28 | 1.17 | 1.19 | 2% |
| 1-span prestressed | | Girder Shear | 1.80 | 1.37 | 1.28 | 1.34 | 5% |
| 75' span | | Girder Cracking | 1.69 | 1.36 | 1.24 | 1.27 | 2% |
| | | Deck Bending | 1.47 | 1.71 | 1.71 | 1.76 | 20% |
| Salmon Creek | 17565 | Girder Bending | 1.18 | 1.30 | 1.17 | 1.21 | 8% |
| 1-span reinf. Concr. | | Girder Shear | 1.07 | 1.00 | 0.93 | 1.01 | 9% |
| 51' span | | | | | | | |
| "L" Canal | 13040 | Girder Bending | 1.58 | 1.76 | 1.77 | 1.76 | 11% |
| 1-span reinf. Concr. | | Girder Shear | 0.83 | 0.90 | 0.84 | 0.88 | 6% |
| 41' span | | | | | | | |
| UPRR & Canal; | 13705 | Girder Bending | 2.74 | 3.08 | 2.84 | 2.86 | 4% |
| Topaz Overpass | | Girder Shear | 2.20 | 2.25 | 2.02 | 2.16 | 7% |
| Multi-span steel truss | | Truss Force | 1.72 | 1.21 | 1.13 | 1.01 | -11% |
| 180' main span | | | | | | | |

The change in rating factor in the last column compares the "worst" rating factor for the existing trucks to the rating factor for the 129,000 lb truck. The positive changes indicate that the 129,000 lb truck has higher rating factors, in most cases. In other words, most bridges carry the 129,000 lb rating truck more readily than shorter-length AASHTO rating trucks. This is a result of the longer length and lower axle loads of the heavier rating truck. The 129,000 lb rating truck is 95 feet long. Bridges spanning less than 95 feet will not carry the entire truck at one time. As a result, only part of the truck, and thus part of the load, is on the bridge at any one time.

The shorter length of the Type 3-3 truck may allow the entire truck to be on the span. This concentrates more of the load toward the center and increases the bending load in that portion of the bridge, resulting in lower rating factors. For example, the 100-foot approach span on the multi-span Hansen Bridge has a higher rating factor for the 129,000 lb. truck than for the

Type 3-3. On the other hand, the 258-foot center span has a lower rating factor for the 129,000 lb truck than for the Type 3-3, because the longer span carries the entire 129,000 lb truck at one time. This is also true for the truss portion of the UPRR & Canal; Topaz Overpass.

Bridge Analysis Summary and Conclusions

Given the projected volume of truck traffic, the introduction of higher-weight trucks on these pilot routes does not immediately affect the bridges on these routes. None of the bridges were load posted before the pilot project, and they will not have to be load posted with the higher-weight trucks.

However, the bridge ratings and postings depend on the configuration of the trucks and the volume of truck traffic assumed in the scenarios. For example, under the pilot study regulations, it is possible to run a vehicle at, say, 121,000 GVW with a shorter wheelbase than is required for the 129,000 GVW vehicles. For some bridge span lengths, these shorter trucks might have a greater impact on bridges than the longer trucks.

In addition, bridge ratings will change if the volume of higher-weight truck traffic is significantly higher than projected in this study. It is possible that expansion of the pilot project routes would substantially increase the higher-weight truck traffic. Therefore, it is important to continue to monitor the pilot project trip logs to determine if the trucks are operating with configurations or volumes significantly different from those assumed in this study.

TRAFFIC OPERATIONS AND SAFETY

Introduction

While pavement wear and bridge deterioration are critical aspects of any discussion on increased truck size and weight limits, impacts on traffic operations and safety are also important considerations. Economic factors need to be balanced with the efficiency and safety of Idaho roads.

Literature Survey

For the purposes of this limited study, NIATT conducted a literature survey to identify information currently available on the effects of GVW and truck configuration on highway traffic operations and safety. The studies reviewed were:

- DOT 1998. *TS&W Impact Analysis Areas*. U.S. DOT Comprehensive TS&W Study.
- DOT 1997. *U.S. DOT Comprehensive TS&W Study*.
- TRB 1990. Special Report 225. *Truck Weight Limits, Issues and Options*.
- Battelle Team 1995. *Phase I: Synthesis for DOT Comprehensive TS&W Study. Traffic Operations and Truck Size and Weight Regulations*.
- Fancher, P.S., Campbell, K.L. 1995. *Phase I: Working Papers 1&2 for DOT Comprehensive TS&W Study. Vehicle Characteristics Affecting Safety*.
- FHWA 1995. *Summary Report for Phase I: Synthesis of TS&W Studies and Issues*.
- Montana Department of Transportation 1995. *A Study of Large Trucks*.
- FHWA 1999. *OMCHS Analysis Brief: Longer Combination Vehicles Involved in Fatal Crashes, 1991-1996*.

It must be stated at the outset that the studies summarized and cited here are based on the federal weight limits of 80,000 lbs. GVW. There are no studies to date quantifying the operations and safety impacts of 105,500 to 129,000 GVW trucks. Care must be taken in drawing conclusions from this information, since there may be impacts that cannot be accounted for, due to the limited data.

In addition, weight regulations cannot be evaluated in a vacuum. Previous national studies all agree that trucks are designed to provide certain performance characteristics based on configuration and GVW. The studies indicate that simply increasing the weight of a truck without making other changes, such as installing a more powerful engine or improved brakes, may result in a poorer crash record.

There is very little conclusive data correlating truck size, weight and configuration with data about highway crashes, such as the type, frequency and casualty rates. Nonetheless, some trends are identifiable. For example, many studies have noted that there is a higher crash risk for truck travel on rural roads (i.e. undivided, high speed, two lane roads) than on 4-lane, divided interstate

highways. According to ITD's Office of Highway Safety, in 1995, 64.4% of all truck collisions occurred on rural roadways, and 93.1% of the fatal heavy truck collisions occurred on rural roadways.⁴

One additional factor to be considered in these discussions is public perception. In its 1997 study for the DOT, the FHWA held a series of focus groups to research the perceptions and concerns of the auto driving public and over-the road truck drivers to mixed auto and truck traffic. They reported that the public perception of increased weight limits is uniformly negative. The vast majority of participants (both passenger car drivers and truck drivers) said they preferred the status quo on Federal TS&W standards, and a return to greater restrictions if any changes were actually made.⁵

The studies recognize that many factors influence traffic operations and highway safety. Some of these are:

- driver performance
- road design and condition
- traffic congestion
- weather
- vehicle performance
- truck GVW and truck configuration.

It is not within the scope of this survey to examine every one of these factors. The survey will instead focus on truck GVW and truck configuration. There is a complex interrelationship between GVW and truck configuration and a truck's performance relating to safety and traffic operations. For simplicity's sake, we have examined two truck characteristics which are most directly or indirectly influenced by truck GVW and truck configuration. These are the truck's handling and stability properties and traffic operations characteristics.

Handling and Stability Properties

The handling and stability properties of trucks that are affected by changes in GVW and configuration include:

- rollover threshold
- rearward amplification
- braking
- steering sensitivity
- low speed and high speed offtracking.

⁴ ITD *Statewide Transportation Improvement Program*, Draft July 1997, p. 109.

⁵ 1997 U.S. DOT *Comprehensive TS&W Study* p. v-8-11

Rollover Threshold

Rollover threshold is the amount of sideward acceleration that a truck can experience during a turn, without rolling over. Vehicles with low rollover thresholds tend to roll over on freeway exit ramps, when the driver makes a sudden steering correction, such as to avoid an obstacle, or when they run off the road. According to the DOT study, rollovers account for 8% to 12% of all combination-unit truck crashes, but are involved in approximately 60% of crashes fatal to heavy truck occupants. The principal determinant of rollover threshold is the center of gravity. Rollovers can be reduced by making vehicles more roll stable. Going from 5 to 6 axles in a 53-ft. van semitrailer combination would improve roll stability by 5%. However, loading more payload onto a given vehicle will in many cases worsen its rollover propensity. For a given freight commodity, decreasing the maximum GVW from 80,000 pounds to 73,280 pounds, the former Federal limit, would improve static roll stability by more than 6%." ⁶

Rearward Amplification

Rearward amplification is a concern for vehicles with more than one articulation point, such as double and triple combinations. It occurs when the driver makes a sudden steering movement, such as changing lanes rapidly or avoiding an obstacle. The rear trailer may make a whiplike response, and can possibly roll over. This phenomenon can be reduced by increasing trailer lengths, and reducing articulation points. The DOT study reports that increasing trailer lengths in a B-train double from 28 feet to 33 feet reduces its rearward amplification by 10%.⁷ According to the TRB study, when all other things are equal, rearward amplification of multiple-trailer combinations increases with increased GVW. And, for existing five-axle doubles, substantial increases in GVW without lengthening of the trailers can lead to increased rearward amplification.⁸

On the other hand, the DOT study notes that instances of these occurrences are rare, primarily because these vehicles (doubles and triples) accumulate less than 5% of total truck mileage, and are typically operated in comparatively benign operating environments (i.e. freeways). The number of incidents could be expected to increase, however, if larger numbers of these vehicles were used, particularly in denser traffic that gives rise to more frequent traffic conflicts.⁹

Braking

According to the DOT study, previous studies indicate that brake system performance plays a contributing role in approximately one-third of all medium/heavy truck crashes. In addition, adding more load to a given vehicle, without adding axles and brakes, decreases stopping performance.¹⁰ The TRB report found that changes in truck weight of 10 to 20 percent are not likely to affect practical stopping-distance capabilities of trucks. However, more substantial

⁶ 1997 U.S. DOT. *Comprehensive TS&W Study* p. v-18

⁷ 1997 U.S. DOT. *Comprehensive TS&W Study* p. v-19

⁸ Transportation Research Board *Truck Weight Limits Issues and Options*, 1990, p. 110.

⁹ 1997 U.S. DOT. *Comprehensive TS&W Study* p. v-20.

¹⁰ 1997 U.S. DOT. *Comprehensive TS&W Study* p. 19.

weight increases would lead to demand for higher brake torque capacity, which may lead to poorer stopping-distance capabilities.¹¹

The legislation authorizing the pilot project addressed this concern by requiring that the pilot project vehicles have brakes on all axles. Since existing trucks do not have to have brakes on all axles, the higher weight vehicles should have increased braking capacity

Steering Sensitivity

The TRB report notes that steering sensitivity of both existing tractor-semitrailers and five-axle doubles decreases slightly with increased GVW.¹² The study also implies that substantial increases in GVW of existing trucks may increase their fatal single-vehicle crash rates.

Low Speed and High Speed Offtracking

Low speed offtracking occurs when a combination-unit vehicle makes a low speed tight turn, such as at an intersection. In this case, the wheels of the rear trailer axle track inside of the path of the tractor wheels. High speed offtracking occurs when a combination-unit vehicle makes a high speed sweeping turn, such as at some freeway interchanges. The rear trailer axle wheels may track outside the tractor wheels. In general, GVW has little or no effect on offtracking. The literature does not provide any data on the relationship between offtracking and accident rates.

Traffic Operations Characteristics

GVW and configuration can affect the way that a truck interacts with other vehicles in the highway environment. Operating characteristics that can be affected are:

- speed on upgrades
- downhill operations
- intersection operations
- passing distances
- GVW can also impact the effectiveness of longitudinal barriers, such as bridge rails, guardrails and median barriers.

Speed on Upgrades

Trucks generally lose more speed on long uphill grades than passenger cars. Long lines of vehicles may form behind slow-moving trucks on upgrades, and drivers of other vehicles may be encouraged to attempt passing maneuvers under unsafe conditions. This situation can be

¹¹ Transportation Research Board *Truck Weight Limits Issues and Options*, 1990. P. 112.

¹² Transportation Research Board *Truck Weight Limits Issues and Options*, 1990, p. 112.

exacerbated on two-lane roads in hilly or mountainous terrain, where passing opportunities are limited.

The DOT study reports that, when speed differentials between vehicles in flowing traffic streams exceed 20 mph, crash risks increase significantly. Crash involvement may be from 15 to 16 times more likely at a speed differential of 20 mph.¹³ The TRB report indicates that the rates of rear-end crashes increased sharply when speed differentials exceeded 20 mph.¹⁴

Speed on upgrades is significantly affected by drive train to gear ratio, as well as truck weight to horsepower ratio. However, the literature suggests that setting truck speed requirements might be more effective than stating specific acceleration requirements. In its model regulations for longer combination vehicles (LCV's), the Western Highway Institute recommends that LCV's should have the ability to maintain a speed of 20 mph under normal operating conditions on any grade over which the combination is to be operated.

The FHWA study suggests that an alternative approach might be to specify minimum operating speeds in relation to the speed limit. For example, regulations might require that trucks on grades be capable of operating within 20 mph of the speed limit. Exceptions could be made for roads with special hill-climbing lanes.¹⁵

Downhill Operations

If drivers do not properly downshift at the top of long steep hills, they can be forced to rely too heavily on their brakes. This can lead to overheated brakes or total brake failure, and a potential runaway accident. The Fancher et al. report states that if trucks are allowed to carry heavier loads, there is a need to increase the thermal capacity of the brakes and/or restrict the vehicle to very slow speeds on downgrades. Since low speeds may represent a traffic hazard as well as a loss in productivity, greater thermal capacity is the preferred solution for heavier vehicles.¹⁶ The TRB report states that if all other factors are held constant, the probabilities of runaway crashes on downhill runs will increase as truck gross weights increase.¹⁷

Intersection Operations

Both GVW and truck configuration impact how effectively trucks can negotiate intersections. When a heavier truck enters the traffic stream on a two lane road from an unsignalized intersection, it could take longer to accelerate up to the posted speed limit. If sight distances at

¹³ 1997 U.S. DOT *Comprehensive TS&W Study* p. v-23.

¹⁴ Transportation Research Board *Truck Weight Limits Issues and Options*, 1990, p. 116.

¹⁵ Battelle Team 1995. *Phase I: Synthesis for DOT Comprehensive TS&W Study. Traffic Operations and Truck Size and Weight Regulations*. P. 3.

¹⁶ Fancher, P.S., Campbell, K.L. 1995. *Phase I: Working Papers 1&2 for DOT Comprehensive TS&W Study. Vehicle Characteristics Affecting Safety*. P. 13.

¹⁷ TRB 1990. Special Report 225. *Truck Weight Limits, Issues and Options*.

the intersection were not long enough, approaching vehicles might have to slow down abruptly. This could cause crashes or disrupt traffic flows.

According to the DOT report, longer vehicles crossing unsignalized intersections from a stopped position on a minor road could increase, by up to 10 percent, sight distances required by traffic on the major road being traversed. The degree to which larger or heavier vehicles perform worse in this regard, compared to smaller trucks, depends on their comparative acceleration performance characteristics. If equipped with appropriate powertrains that ensure adequate acceleration performance, or if routes were screened for suitability, concern about this issue would be minimized, regardless of the size or configuration of the vehicle.¹⁸

Longitudinal Barriers

Longitudinal barriers restrain and redirect vehicles on impact. They include bridge rails, guardrails and median barriers. According to the TRB report, most barriers are designed for passenger vehicles, are already inadequate for existing trucks, and will be more so as truck gross weights increase.

Field Crash Data

We examined field crash data from the states of Idaho and Montana, with statistics on the number of accidents, injuries and fatalities in the two states, for singles, doubles and triple trucks. It is important to note that these statistics do not reflect a specific truck weight. Since no accident data are available specifically for higher weight trucks, we included data on triple trailers, extrapolating that since triples are larger (longer or heavier or both), their crash record would reflect similarly on Idaho's heavier trucks.

Idaho Data

Crash data for Idaho highways from 1990 through 1998 is presented in Tables 7 and 8, and Figure 3. Figure 3 shows the total crash rate per million vehicle miles of travel for single trailer trucks, double trailer trucks, and triple trailer trucks. While the number of data points is relatively small¹⁹, the crash rates for triple trailers is less than for single or double trailers.

Further, the fatal crashes per million miles of travel, presented in Table 8, show that the rates are again lower for triple trailer trucks, for these more serious crashes.

¹⁸ DOT 1997. *U.S. DOT Comprehensive TS&W Study*. p.v-24.

¹⁹ The number of triple trailer crashes ranges from 6 in 1990 to 16 in 1998.

Table 7. Crashes per million miles

| Total Crashes (Number per million miles) | | | |
|---|----------------------|----------------------|----------------------|
| Year | Single Trucks | Double Trucks | Triple Trucks |
| 1990 | 0.909 | 0.962 | 0.276 |
| 1991 | 0.684 | 0.750 | 0.161 |
| 1992 | 0.065 | 0.761 | 0.093 |
| 1993 | 0.740 | 1.159 | 0.160 |
| 1994 | 0.565 | 0.994 | 0.283 |
| 1995 | 0.489 | 0.824 | 0.346 |
| 1996 | 0.620 | 0.910 | 0.210 |
| 1997 | 0.644 | 1.071 | 0.199 |
| 1998 | 0.644 | 0.946 | 0.601 |

Table 8. Fatal crashes per million miles

| Fatal Accidents (Number per million miles) | | | |
|---|----------------------|----------------------|----------------------|
| Year | Single Trucks | Double Trucks | Triple Trucks |
| 1990 | 0.019 | 0.008 | 0.000 |
| 1991 | 0.016 | 0.023 | 0.000 |
| 1992 | 0.023 | 0.023 | 0.000 |
| 1993 | 0.006 | 0.006 | 0.000 |
| 1994 | 0.183 | 0.027 | 0.028 |
| 1995 | 0.126 | 0.033 | 0.000 |
| 1996 | 0.020 | 0.020 | 0.000 |
| 1997 | 0.012 | 0.030 | 0.000 |
| 1998 | 0.007 | 0.019 | 0.000 |

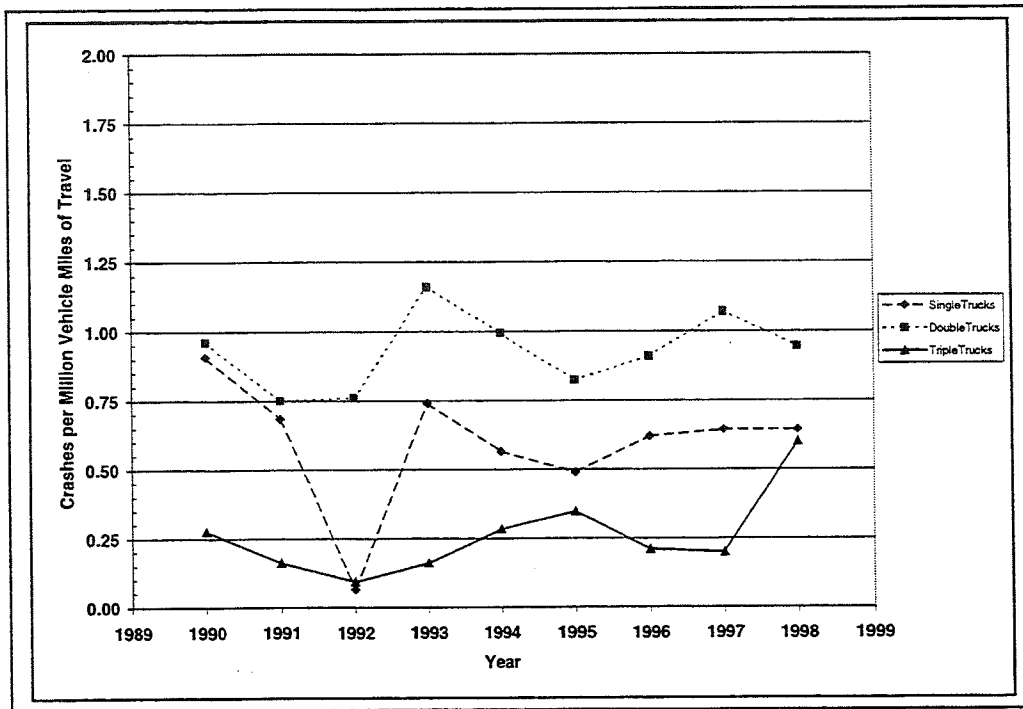


Figure 3. Crash rate per million miles of travel

A t-test was conducted to determine if these differences are statistically significant. The results of the t-test are given in Table 9. This analysis indicates that the crash rates as measured in accidents per million miles of travel are significantly less for triple trailers than for either single or double trailers during the period 1990 through 1998.

Table 9. t-test results

| Test | t statistic | t critical | Conclusion |
|--|-------------|------------|---|
| Single trailer trucks vs triple trailer trucks | 3.67 | 2.14 | The difference in the mean crash rates per million miles of travel between single trailer trucks (.595) and triple trailer trucks (.259) is statistically significant and is not due to chance. |
| Double trailer trucks vs triple trailer trucks | 9.94 | 2.12 | The difference in the mean crash rates per million miles of travel between double trailer trucks (.931) and triple trailer trucks (.259) is statistically significant and is not due to chance. |

These field measurements indicate that, despite the larger potential for crashes as indicated in the earlier discussion, factors such as advanced training and more experienced drivers result in an actual crash rate that is lower for triple trailers than for single or double trailer trucks.

Montana Data

We examined a report by the Montana Department of Transportation, which compiled accident data for large truck traffic on Montana's Interstate and primary systems. Montana's statistics indicate that there is no seeming increase in accident frequency in triple trailer operations.

The report notes that, "Based on traffic exposure and other accident data, there is no indication that there is a higher frequency of large truck accidents than for all vehicles traversing the interstate . . . (and the) primary system."²⁰

LCVs and Fatal Crashes Report

We also examined a recent report on longer combination vehicles (LCVs)²¹ and fatal crashes nationwide, prepared jointly by the Center for National Truck Statistics, University of Michigan Transportation Research Center and the Office of Data Analysis and Information Systems, OMCHS, Federal Highway Administration. The report is inconclusive, stating:

"Based on the data presented in this brief, no conclusions can be made on the relative safety of LCVs compared to other truck combinations. First, data on mileage driven mentioned above are based strictly on trailer number and length, while the definition of LCV used in this study is based partly on weight. Second, since travel by LCVs is rare, it is difficult to calculate the precise number of miles driven. Similarly, LCV fatal crashes are so infrequent that the number varies greatly from year to year. For example, LCV crashes dropped from 46 in 1992 to 31 in 1993 (down 33 percent), then rose to 43 in 1994 (up 39 percent). Based on the existing data, LCVs do not appear to be considerably more or less safe than other combination trucks. A more definitive conclusion could be reached only after further collection of data and additional analysis."²²

²⁰ *A Study of Large Trucks*. Montana Department of Transportation, Engineering Division, Preconstruction Bureau, Safety Management Section, August 1995.

²¹ For the purpose of this study, the researchers defined an LCV as a truck that meets one or more of the following criteria: a truck-tractor with at least two trailers, at least one of which is 29 feet long or longer; a truck-tractor with at least two trailers and a gross combination weight (GCW) greater than 80,000 lbs.; or a truck-tractor with three trailers.

²² *Longer Combination Vehicles Involved in Fatal Crashes, 1991-1996*. FHWA Office of Motor Carrier and Highway Safety, Analysis Brief, September 1999.

Traffic Operations & Safety Summary and Conclusions

Literature Survey

While data quantifying the effects of heavier trucks on traffic operations and safety are limited, several conclusions can be drawn from the national studies cited on p. 26:

1. Heavier trucks may decrease safety on Idaho's two-lane rural highways, due to higher incidences of:
 - Truck rollovers, due to higher center of gravity and increased rearward amplification.
 - Crashes, due to decreased stopping performance.
 - Crashes, due to trucks losing even more speed on uphill grades, and motorists attempting unsafe passing maneuvers.
 - Runaway trucks on downhill grades, due to full or partial brake failure.
 - Intersection-related crashes, due to inadequate sight distances.
2. However, some of this potential safety decrease could be moderated by:
 - Requiring changes in truck design that result in lower center of gravity, improved braking systems, and increased engine horsepower.
 - Addressing the need for increased passing distances, by providing additional truck passing lanes.
 - In addition, regulators could implement performance-based requirements such as setting minimum speeds on uphill grades.
 - Finally, some changes to intersection geometry, particularly to improve sight distance, may help to moderate the effects of heavier trucks.
3. All agree that brakes on every axle should mitigate the higher weights' adverse impacts on braking. The Idaho Legislature has recognized the need for improved braking systems, and the pilot project legislation requires brakes on all axles for the higher weight trucks.

Field Crash Data

Actual experience with heavier weight trucks is extremely limited. We simply do not have enough data on heavier truck configurations to draw firm conclusions. There are no studies to date quantifying the operations and safety impacts of 105,500 to 129,000 GVW trucks. However, if the experience with triple trailers in Idaho and Montana is an indicator, then the crash potential may not increase on primary routes such as Idaho's pilot project route.

As stated earlier in this report, economic factors need to be balanced with the efficiency and safety of Idaho roads. However, as the FHWA report of September 1999 states, "Based on the data presented in this brief, no conclusions can be made on the relative safety of LCVs compared

to other truck combinations. . . . A more definitive conclusion could be reached only after further collection of data and additional analysis.”²³

²³ *Longer Combination Vehicles Involved in Fatal Crashes, 1991-1996*. FHWA Office of Motor Carrier and Highway Safety, Analysis Brief, September 1999.

GENERAL CONCLUSIONS

As discussed in the introduction, this study is intended as a preliminary survey of the impacts of higher weight trucks on the two pilot routes in Idaho. It is based on a comparison between a traffic scenario with no higher weight trucks and only one traffic scenario that includes higher weight trucks. It is also based on a limited selection of pavement and bridges on the pilot route, and the analyses are somewhat limited in depth. The results are, therefore, intended to identify problems that may result from this pilot project and to identify areas that need further study.

Given the traffic scenario, truck configurations and pavement conditions considered in this study, we conclude the following:

- Both pavement segments survive the expected traffic. However, the remaining service life of the two pavement segments will be shortened by 3% (0.56 years) at the US30 site and 10% (1.8 years) at the US93 site, due to increases in the truck effects predicted by the assumed future traffic scenario.
- The bridges analyzed in this study are capable of carrying the higher weight trucks predicted by the study scenarios. In most cases the rating factor increased by 5 to 15% with some increasing as much as 20% indicating an increased ability to carry these trucks. However longer span bridges experienced a decrease in rating factor of 11 to 19%. If the majority of higher weight trucks eventually run at weights less than 129,000 lbs. GVW and do not require longer axle trains, the effect on shorter-span bridges will be more severe because the load is concentrated toward the center of the bridge span. This could result in the posting of some bridges.
- Heavier trucks may decrease safety on Idaho's two-lane rural highways, due to higher incidences of truck rollovers, crashes, runaway trucks on downhill grades, and intersection-related crashes. However, some of this safety decrease could be moderated by lowering the center of gravity, improving braking systems, increasing engine horsepower on higher weight trucks, increasing passing distances, setting minimum speeds on uphill grades, and changing intersection geometry. The Idaho Legislature has recognized the need for improved braking systems, and the pilot project legislation requires brakes on all axles for the higher weight trucks.
- If the scope of the pilot project is significantly changed, favoring a more substantial transfer of freight from other modes to higher-weight trucks, the damage to bridges and pavements will increase because heavier trucks will be making more trips.

Since the results of this study depend on the assumed traffic scenarios, it would be profitable to invest further efforts in the following:

- Continuing to monitor the pilot project trip logs to verify that the truck traffic and the vehicle configurations are consistent with those assumed in this study.
- Continuing to monitor the accident rate and safety performance of higher-weight trucks.
- Making more refined predictions of future traffic and analyzing the pavement and bridges for a range of scenarios.
- Analyzing a broader selection of pavement segments and bridges.
- Developing more detailed analyses of the bridges to determine the changes in fatigue service life attributable to heavier weight trucks.
- Estimating the costs and benefits to the State of Idaho resulting from increased truck weights.

Allowing higher weight trucks on our nation's roads has been a subject of debate for many years. Economic forces, combined with political change, may accelerate the acceptance of this concept. However, questions still remain regarding their effect on the transportation infrastructure. Given the value of the public's investment in that infrastructure, we feel that continued monitoring of pavement, bridges, and traffic safety is a critical element of this process.

References

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Appendix A

Table A1. Results of Pavement Analysis for Site US 30 at MP 425-426

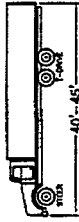
| Table A1. Results of Pavement Analysis for Site US 30 at MP 425-426 | | | | | | | | |
|---|---|--|-----------------|------------------------|---|--|---|--|
| Traffic Loads | | ESALs/year | Growth Rate, r% | Analysis Period, Years | Growth Factor, GF | Total ESALs over the analysis period | | |
| Baseline Scenario | | 546,907 | 1.0% | 20 | 22.01900399 | 12,042,357 | | |
| Heavy-Truck Scenario | | 562,643 | 1.0% | 20 | 22.01900399 | 12,388,835 | | |
| Pavement Material and Structure Properties | | | | | | | | |
| Seasonal Factors for Layer Moduli | | Number of Months | Avg. Temp, F | E2 factor | E3 factor | Multi-Layer Elastic Stress-Strain Analysis. | | |
| Summer | | 3.5 | 62 | 1.00 | 1.00 | AC Layer, h1=6 in. Granular Base, h2=12 in. | Tensile Strain at Bottom of AC Layer per Season | Compressive Strain at Top of Subgrade per Season |
| Fall | | 3.0 | 34 | 1.00 | 1.00 | | | |
| Winter | | 4.0 | 31 | 1.00 | 11.20 | | | |
| Spring | | 1.5 | 55 | 0.65 | 0.43 | | | |
| Moduli Values for each season | | | E1, psi | E2, psi | E3, psi | Season | | |
| Summer (Normal for E2 and E3) | | | 1,414,000 | 120,000 | 5,500 | Summer | 5.942E-05 | 2.028E-04 |
| Normal (Normal for E2 and E3) | | | 2,000,000 | 120,000 | 5,500 | Fall | 5.041E-05 | 1.836E-04 |
| Winter (Normal for E2) | | | 2,000,000 | 120,000 | 61,600 | Winter | 4.175E-05 | 7.055E-05 |
| Spring | | | 1,500,000 | 78,000 | 2,365 | Spring | 7.407E-05 | 3.022E-04 |
| Damage Analysis | | | | | | | | |
| Fatigue and Rutting Performance Models | | Fatigue Model Parameters | | | | | Rutting Model Parameters | |
| Factors for the Asphalt Institute (AI) Fatigue and Rutting Models | | f1 for SF=18.4 | f1 for SF=10 | f1 for SF=4 | f2 | f3 | f4 | f5 |
| | | 0.0796 | 0.0432 | 0.01728 | -3.291 | -0.854 | 1.37E-09 | -4.477 |
| Factors for the Shell Fatigue and Rutting Models | | f1 for Shell model has one value | | | -5.671 | -2.363 | 1.05E-07 | -4.000 |
| Allowable Fatigue and Rutting Service Lives | Maximum Allowed Number of Repetitions for Each Season | Based on Asphalt Institute Models | | | | Base on Shell Models | | |
| | | N, Fatigue for different Shift Factors | | | N, Rutting (no change in Shift Factors) | N, Fatigue (no change in Shift Factors) | N, Rutting (no change in Shift Factors) | |
| | | SF=18.4 | SF=10 | SF=4 | | | | |
| | | Summer | 36,009,487 | 19,542,837 | 7,817,135 | 46,600,378 | 185,441,347 | 62,075,110 |
| | | Fall | 46,009,869 | 24,970,180 | 9,988,072 | 72,740,231 | 207,675,135 | 92,405,664 |
| | | Winter | 85,556,493 | 46,432,670 | 18,573,068 | 5,265,159,129 | 604,802,802 | 4,238,393,029 |
| Spring | 16,578,231 | 8,997,231 | 3,598,892 | 7,813,657 | 46,221,623 | 12,589,586 | | |
| Service Life Calculations, Baseline Scenario | | Damage Based on Asphalt Institute Models | | | | | Damage Based on Shell Models | |
| Load Repetitions over Analysis period, 18-kip ESALs | | 12,042,357 | Fatigue Damage | | | Rutting Damage | Fatigue Damage | Rutting Damage |
| Per Season | N repetitions | SF=18.4 | SF=10 | SF=4 | | | | |
| Summer | 3,512,354 | 0.0975 | 0.1797 | 0.4493 | 0.0754 | 0.0189 | 0.0566 | |
| Fall | 3,010,589 | 0.0654 | 0.1206 | 0.3014 | 0.0414 | 0.0145 | 0.0326 | |
| Winter | 4,014,119 | 0.0469 | 0.0865 | 0.2161 | 0.0008 | 0.0066 | 0.0009 | |
| Spring | 1,505,295 | 0.0908 | 0.1673 | 0.4183 | 0.1926 | 0.0326 | 0.1196 | |
| Total Damage at the end of the Analysis Period | | 0.3007 | 0.5541 | 1.3851 | 0.3102 | 0.0726 | 0.2097 | |
| Remaining Service Life, Years | | 66.5 | 36.1 | 14.4 | 64.5 | 275.3 | 95.4 | |
| Service Life Calculations, Heavy Truck Scenario | | Damage Based on Asphalt Institute Models | | | | | Damage Based on Shell Models | |
| Load Repetitions over Analysis period, 18-kip ESALs | | 12,388,835 | Fatigue Damage | | | Rutting Damage | Fatigue Damage | Rutting Damage |
| Per Season | N repetitions | SF=18.4 | SF=10 | SF=4 | | | | |
| Summer | 3,613,410 | 0.1003 | 0.1849 | 0.4622 | 0.0775 | 0.0195 | 0.0582 | |
| Fall | 3,097,209 | 0.0673 | 0.1240 | 0.3101 | 0.0426 | 0.0149 | 0.0335 | |
| Winter | 4,129,612 | 0.0483 | 0.0889 | 0.2223 | 0.0008 | 0.0068 | 0.0010 | |
| Spring | 1,548,604 | 0.0934 | 0.1721 | 0.4303 | 0.1982 | 0.0335 | 0.1230 | |
| Total Damage at the end of the Analysis Period | | 0.3093 | 0.5700 | 1.4250 | 0.3191 | 0.0747 | 0.2157 | |
| Remaining Service Life, Years | | 64.7 | 35.1 | 14.0 | 62.7 | 267.6 | 92.7 | |
| Assessment of Heavy Trucks Impact on Pavement Serviceability | | % Increase in Damage | 2.88% | 2.88% | Failed | 2.88% | 2.88% | 2.88% |
| | | % Reduction in Service Life | -2.80% | -2.80% | Failed | -2.80% | -2.80% | -2.80% |
| Reduction in Design Life, years Based on Analysis period of: | | 5-yr | -0.14 | -0.14 | Failed | -0.14 | -0.14 | -0.14 |
| | | 10-yr | -0.28 | -0.28 | Failed | -0.28 | -0.28 | -0.28 |
| | | 20-yr | -0.56 | -0.56 | Failed | -0.56 | -0.56 | -0.56 |

Table A2. Results of Pavement Analysis for US 93 at MP 59-60

| Table A2. Results of Pavement Analysis for US 93 at MP 59-60 | | | | | | | | | |
|---|---|--|-----------------|------------------------|---|--|---|--|----------------|
| Traffic Loads | | ESALs/year | Growth Rate, r% | Analysis Period, Years | Growth Factor, GF | Total ESALs over the analysis period | | | |
| Baseline Scenario | | 160,411 | 1.0% | 20 | 22.01900399 | 3,532,089 | | | |
| Heavy-Truck Scenario | | 176,071 | 1.0% | 20 | 22.01900399 | 3,876,900 | | | |
| Pavement Material and Structure Properties | | | | | | | | | |
| Seasonal Factors for Layer Moduli | | Number of Months | Avg. Temp, F | E2 factor | E3 factor | Multi-Layer Elastic Stress-Strain Analysis. | | | |
| Summer | | 3.5 | 62 | 1.00 | 1.00 | AC Layer, h1=6 in. Granular Base, h2=12 in. | Tensile Strain at Bottom of AC Layer per Season | Compressive Strain at Top of Subgrade per Season | |
| Fall | | 3.0 | 34 | 1.00 | 1.00 | | | | |
| Winter | | 4.0 | 31 | 1.00 | 11.20 | | | | |
| Spring | | 1.5 | 55 | 0.65 | 0.43 | | | | |
| Moduli Values for each season | | | E1, psi | E2, psi | E3, psi | Season | | | |
| Summer (Normal for E2 and E3) | | | 323,000 | 121,000 | 6,500 | Summer | 9.243E-05 | 2.658E-04 | |
| Normal (Normal for E2 and E3) | | | 1,300,000 | 121,000 | 6,500 | Fall | 6.086E-05 | 1.969E-04 | |
| Winter (Normal for E2) | | | 1,400,000 | 121,000 | 72,800 | Winter | 5.031E-05 | 7.101E-05 | |
| Spring | | | 600,000 | 78,650 | 2,795 | Spring | 1.094E-04 | 3.700E-04 | |
| Damage Analysis | | | | | | | | | |
| Fatigue and Rutting Performance Models | | Fatigue Model Parameters | | | | | Rutting Model Parameters | | |
| Factors for the Asphalt Institute (AI) Fatigue and Rutting Models | | f1 for SF=18.4 | f1 for SF=10 | f1 for SF=4 | f2 | f3 | f4 | f5 | |
| | | 0.0796 | 0.0432 | 0.01728 | -3.291 | -0.854 | 1.37E-09 | -4.477 | |
| Factors for the Shell Fatigue and Rutting Models | | f1 for Shell model has one value | | | -5.671 | -2.363 | 1.05E-07 | -4.000 | |
| Allowable Fatigue and Rutting Service Lives | Maximum Allowed Number of Repetitions for Each Season | Based on Asphalt Institute Models | | | | Base on Shell Models | | | |
| | | N, Fatigue for different Shift Factors | | | N, Rutting (no change in Shift Factors) | N, Fatigue (no change in Shift Factors) | N, Rutting (no change in Shift Factors) | | |
| | | SF=18.4 | SF=10 | SF=4 | | | | | |
| | | Summer | 29,686,820 | 16,111,440 | 6,444,576 | 13,880,337 | 495,815,106 | 21,036,302 | |
| | | Fall | 35,757,653 | 19,406,163 | 7,762,465 | 53,185,663 | 197,467,648 | 69,856,438 | |
| | | Winter | 62,802,274 | 34,083,646 | 13,633,458 | 5,114,170,388 | 487,874,804 | 4,129,631,011 | |
| Spring | 10,045,369 | 5,451,758 | 2,180,703 | 3,157,138 | 44,121,669 | 5,602,507 | | | |
| Service Life Calculations, | | Damage Based on Asphalt Institute Models | | | | Damage Based on Shell | | | |
| Load Repetitions over Analysis period, 18-kip ESALs | | 3,532,089 | | | Fatigue Damage | | Rutting Damage | Fatigue Damage | Rutting Damage |
| Per Season | | N repetitions | SF=18.4 | SF=10 | SF=4 | | | | |
| Summer | | 1,030,193 | 0.0347 | 0.0639 | 0.1599 | 0.0742 | 0.0021 | 0.0490 | |
| Fall | | 883,022 | 0.0247 | 0.0455 | 0.1138 | 0.0166 | 0.0045 | 0.0126 | |
| Winter | | 1,177,363 | 0.0187 | 0.0345 | 0.0864 | 0.0002 | 0.0024 | 0.0003 | |
| Spring | | 441,511 | 0.0440 | 0.0810 | 0.2025 | 0.1398 | 0.0100 | 0.0788 | |
| Total Damage at the end of the Analysis Period | | | 0.1221 | 0.2250 | 0.5624 | 0.2309 | 0.0190 | 0.1407 | |
| Remaining Service Life, Years | | | 163.8 | 88.9 | 35.6 | 86.6 | 1,054.3 | 142.1 | |
| Service Life Calculations, Heavy Truck Scenario | | Damage Based on Asphalt Institute Models | | | | Damage Based on Shell Models | | | |
| Load Repetitions over Analysis period, 18-kip ESALs | | 3,876,900 | | | Fatigue Damage | | Rutting Damage | Fatigue Damage | Rutting Damage |
| Per Season | | N repetitions | SF=18.4 | SF=10 | SF=4 | | | | |
| Summer | | 1,130,763 | 0.0381 | 0.0702 | 0.1755 | 0.0815 | 0.0023 | 0.0538 | |
| Fall | | 969,225 | 0.0271 | 0.0499 | 0.1249 | 0.0182 | 0.0049 | 0.0139 | |
| Winter | | 1,292,300 | 0.0206 | 0.0379 | 0.0948 | 0.0003 | 0.0026 | 0.0003 | |
| Spring | | 484,613 | 0.0482 | 0.0889 | 0.2222 | 0.1535 | 0.0110 | 0.0865 | |
| Total Damage at the end of the Analysis Period | | | 0.1340 | 0.2469 | 0.6173 | 0.2534 | 0.0208 | 0.1544 | |
| Remaining Service Life, Years | | | 149.2 | 81.0 | 32.4 | 78.9 | 960.6 | 129.5 | |
| Remaining Service Life at the end of the analysis | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Assessment of Heavy Trucks Impact on Pavement Serviceability | | % Increase in Damage | 9.76% | 9.76% | 9.76% | 9.76% | 9.76% | 9.76% | |
| | | % Reduction in Service Life | -8.89% | -8.89% | -8.89% | -8.89% | -8.89% | -8.89% | |
| Reduction in Design Life, years | | 5-yr | -0.44 | -0.44 | -0.44 | -0.44 | -0.44 | -0.44 | |
| Based on Analysis period of: | | 10-yr | -0.89 | -0.89 | -0.89 | -0.89 | -0.89 | -0.89 | |
| | | 20-yr | -1.78 | -1.78 | -1.78 | -1.78 | -1.78 | -1.78 | |

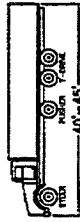
Appendix B

STRAIGHT TRUCKS SPECIAL PRODUCTS



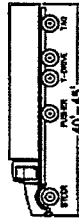
| AXLE LOADINGS | POUNDS PER INCH OF TIRE WIDTH |
|---------------|-------------------------------|
| STEER | 13,200 LBS |
| T-DRIVE | 37,800 LBS |
| T-DRIVE | 430 |

| | |
|---------|------------|
| GVW | 61,000 LBS |
| TARE | 26,000 LBS |
| PAYLOAD | 35,000 LBS |
| TRIPS | 770 |



| AXLE LOADINGS | POUNDS PER INCH OF TIRE WIDTH |
|---------------|-------------------------------|
| STEER | 13,200 LBS |
| PUSHER | 13,200 LBS |
| T-DRIVE | 37,800 LBS |
| T-DRIVE | 430 |

| | |
|---------|------------|
| GVW | 64,200 LBS |
| TARE | 28,500 LBS |
| PAYLOAD | 35,700 LBS |
| TRIPS | 531 |



| AXLE LOADINGS | POUNDS PER INCH OF TIRE WIDTH |
|---------------|-------------------------------|
| STEER | 13,200 LBS |
| PUSHER | 13,200 LBS |
| T-DRIVE | 37,800 LBS |
| T-DRIVE | 430 |
| T-DRIVE | 600 |

| | |
|---------|------------|
| GVW | 77,400 LBS |
| TARE | 28,000 LBS |
| PAYLOAD | 49,400 LBS |
| TRIPS | 405 |

TRACTOR SEMI-TRAILER



| AXLE LOADINGS | POUNDS PER INCH OF TIRE WIDTH |
|---------------|-------------------------------|
| STEER | 12,000 LBS |
| T-DRIVE | 34,000 LBS |
| T-DRIVE | 386 |

| | |
|---------|------------|
| GVW | 60,000 LBS |
| TARE | 30,000 LBS |
| PAYLOAD | 30,000 LBS |
| TRIPS | 400 |



| AXLE LOADINGS | POUNDS PER INCH OF TIRE WIDTH |
|---------------|-------------------------------|
| STEER | 11,000 LBS |
| PUSHER | 9,000 LBS |
| T-DRIVE | 34,000 LBS |
| T-DRIVE | 318 |

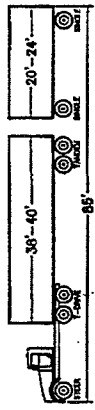
| | |
|---------|------------|
| GVW | 66,000 LBS |
| TARE | 32,000 LBS |
| PAYLOAD | 34,000 LBS |
| TRIPS | 313 |



| AXLE LOADINGS | POUNDS PER INCH OF TIRE WIDTH |
|---------------|-------------------------------|
| STEER | 12,000 LBS |
| T-DRIVE | 34,000 LBS |
| QUAD | 50,000 LBS |
| QUAD | 284 |

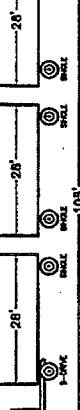
| | |
|---------|------------|
| GVW | 98,000 LBS |
| TARE | 32,000 LBS |
| PAYLOAD | 66,000 LBS |
| TRIPS | 313 |

LONGER COMBINATION VEHICLES (LCV)



| AXLE LOADINGS | POUNDS PER INCH OF TIRE WIDTH |
|---------------|-------------------------------|
| STEER | 10,500 LBS |
| T-DRIVE | 32,000 LBS |
| T-DRIVE | 364 |
| T-DRIVE | 364 |
| T-DRIVE | 352 |
| T-DRIVE | 352 |

| | |
|---------|-------------|
| GVW | 105,500 LBS |
| TARE | 34,000 LBS |
| PAYLOAD | 71,500 LBS |
| TRIPS | 274 |



| AXLE LOADINGS | POUNDS PER INCH OF TIRE WIDTH |
|---------------|-------------------------------|
| STEER | 10,500 LBS |
| S-DRIVE | 19,000 LBS |
| S-DRIVE | 409 |
| S-DRIVE | 352 |
| S-DRIVE | 352 |
| S-DRIVE | 352 |
| S-DRIVE | 352 |

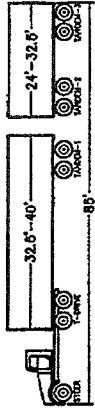
| | |
|---------|-------------|
| GVW | 105,500 LBS |
| TARE | 37,000 LBS |
| PAYLOAD | 68,500 LBS |
| TRIPS | 292 |



| AXLE LOADINGS | POUNDS PER INCH OF TIRE WIDTH |
|---------------|-------------------------------|
| STEER | 10,000 LBS |
| T-DRIVE | 28,500 LBS |
| T-DRIVE | 324 |
| T-DRIVE | 287 |
| T-DRIVE | 455 |
| T-DRIVE | 287 |

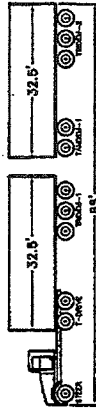
| | |
|---------|-------------|
| GVW | 105,500 LBS |
| TARE | 40,000 LBS |
| PAYLOAD | 65,500 LBS |
| TRIPS | 305 |

NEW COMBINATIONS POSSIBLE WITH EXTENDED FORMULA B



| AXLE LOADINGS | POUNDS PER INCH OF TIRE WIDTH |
|---------------|-------------------------------|
| STEER | 10,000 LBS |
| T-DRIVE | 28,500 LBS |
| T-DRIVE | 335 |
| T-DRIVE | 285 |
| T-DRIVE | 285 |
| T-DRIVE | 285 |

| | |
|---------|-------------|
| GVW | 117,500 LBS |
| TARE | 38,000 LBS |
| PAYLOAD | 79,500 LBS |
| TRIPS | 252 |



| AXLE LOADINGS | POUNDS PER INCH OF TIRE WIDTH |
|---------------|-------------------------------|
| STEER | 10,000 LBS |
| T-DRIVE | 29,500 LBS |
| T-DRIVE | 335 |
| T-DRIVE | 239 |
| T-DRIVE | 285 |
| T-DRIVE | 239 |

| | |
|---------|-------------|
| GVW | 128,500 LBS |
| TARE | 41,000 LBS |
| PAYLOAD | 87,500 LBS |
| TRIPS | 229 |

TRIPS

NUMBER OF TRIPS REQUIRED TO
TRANSPORT 10,000 TONS OF PAYLOAD.

POUND PER INCH OF TIRE WIDTH -
BASED ON 11" TIRE WIDTH.

STEER AXLES -
PUSHER AXLES -
TAG AXLES -

ALL
OTHER
AXLES

DUAL TRES, 4 PER AXLE

AXLE, TIRE AND EFFICIENCY COMPARISONS

