

**Impact of Increased International Trade (NAFTA)
on Washington Highways Part II:
Highway Impact by Corridor**

EWITS Research Report Number 25
November, 1998

by

Ken Eriksen
United States Department of Agriculture
Agricultural Marketing Service
Washington, DC

and

Kenneth L. Casavant, EWITS Project Director
Washington State University
Department of Agricultural Economics
101 Hulbert Hall
Pullman, WA 99164-6210

EWITS Research Reports: Background and Purpose

This report is the twenty-fifth in a series of Research Reports prepared from the Eastern Washington Intermodal Transportation Study (EWITS). The reports prepared as a part of this study provide information on the multimodal network necessary for the efficient movement of both freight and people into the next century.

EWITS is a six-year study funded jointly by the Federal government and the Washington State Department of Transportation as a part of the Intermodal Surface Transportation Efficiency Act of 1991. Dr. Ken Casavant of Washington State University is Director of the study. A state-level Steering Committee provides overall direction pertaining to the design and implementation of the project. The Steering Committee includes Jerry Lenzi, Chair, Regional Administrator (WSDOT, Eastern Region); Richard Larson (WSDOT, South Central Region); Don Senn (WSDOT, North Central Region); Charles Howard (WSDOT, Planning Manager), and Eric Berger, Executive Director, County Road Administration Board. Pat Patterson represents the Washington State Transportation Commission on the Steering Committee. An Advisory Committee with representation from a broad range of transportation interest groups also provides guidance to the study. The following are key goals and objectives for the Eastern Washington Intermodal Transportation Study:

- *Facilitate existing regional and state-wide transportation planning efforts.*
- *Forecast future freight and passenger transportation service needs for eastern Washington.*
- *Identify gaps in eastern Washington's current transportation infrastructure.*
- *Pinpoint transportation system improvement options critical to economic competitiveness and mobility within eastern Washington.*

For additional information about the Eastern Washington Intermodal Transportation Study or this Research Report, please contact Ken Casavant at the following address:

Ken Casavant, Project Director
Department of Agricultural Economics
Washington State University
Pullman, WA 99164-6210
(509) 335-1608

DISCLAIMER

The contents of this report reflect the views of the author, who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

EWITS PREVIOUS REPORTS NOW AVAILABLE

1. Gillis, William R. and Kenneth L. Casavant. "Linking Transportation System Improvements to New Business Development in Eastern Washington." EWITS Research Report Number 1. February 1994.
2. Gillis, William R. and Kenneth L. Casavant. "Lessons from Eastern Washington: State Route Mainstreets, Bypass Routes and Economic Development in Small Towns." EWITS Research Report Number 2. February 1994.
3. Gillis, William R. and Kenneth L. Casavant. "Washington State Freight Truck Origin and Destination Study: Methods, Procedures, and Data Dictionary." EWITS Research Report Number 3. December 1994.
4. Gillis, William R. and Kenneth L. Casavant. "Major Generators of Traffic on U.S. 395 North of Spokane: Including Freight Trucks and Passenger Vehicles Crossing the International Border." EWITS Research Report Number 4. January 1995.
5. Newkirk, Jonathan, Ken Eriksen, and Kenneth L. Casavant. "Transportation Characteristics of Wheat and Barley Shipments on Haul Roads To and From Elevators in Eastern Washington." EWITS Research Report Number 5. March 1995.
6. Jessup, Eric and Kenneth L. Casavant. "A Quantitative Estimate of Eastern Washington Annual Haul Road Needs for Wheat and Barley Movement." EWITS Research Report Number 6. March 1995.
7. Gillis, William R., Emily Gruss Gillis, and Kenneth L. Casavant. "Transportation Needs of Eastern Washington Fruit, Vegetable and Hay Industries." EWITS Research Report Number 7. March 1995.
8. Casavant, Kenneth L. and William R. Gillis. "Importance of U.S. 395 Corridor For Local and Regional Commerce in South Central Washington." EWITS Research Report Number 8. April 1995.

9. Gillis, William R., Eric L. Jessup, and Kenneth L. Casavant. "Movement of Freight on Washington's Highways: A Statewide Origin and Destination Study." EWITS Report Number 9, November 1995.
10. Chase, Robert A. and Kenneth L. Casavant. "Eastern Washington Transport-Oriented Input-Output Study: Technical Report." EWITS Research Report Number 10. March 1996.
11. Chase, Robert A. Kenneth L. Casavant. "The Economic Contribution of Transport Industries to Eastern Washington." EWITS Report Number 11. April 1996.
12. Lee, Nancy S. and Kenneth L. Casavant. "Waterborne Commerce On the Columbia-Snake System." EWITS Report Number 12. October 1996.
13. Alderson, Lynn C., Eric Jessup, and Kenneth L. Casavant. "Transportation Characteristics and Needs of Forest Products Industries Using Eastern Washington Highways: Part 1: Economic Structure of the Industry." EWITS Research Report #13. November 1996.
14. Eriksen, Ken and Kenneth L. Casavant. "Impact of North American Free Trade Agreement (NAFTA) on Washington Highways - Part 1: Commodity and Corridor Projections" EWITS Research Report Number 14. January 1997.
15. Alderson, Lynn C. and Kenneth L. Casavant. "Transportation Characteristics and Needs of Forest Products Industries Using Eastern Highways: Part 2 Movement of Raw Logs." EWITS Research Report Number 15. May 1997.
16. Alderson, Lynn C. and Kenneth L. Casavant. "Transportation Characteristics and Needs of Forest Products Industries Using Eastern Highways: Part 3 Shipment from Mills." EWITS Research Report Number 16. May 1997.
17. Alderson, Lynn C. and Kenneth L. Casavant. "Transportation Characteristics and Needs of Forest Products Industries Using Eastern Highways: Part 4 Commercial Shipments." EWITS Research Report Number 17. February 1997.
18. Jessup, Eric L., John Ellis, and Kenneth L. Casavant. "A GIS Commodity Flow Model for Transportation Policy Analysis: A Case Study of the Impacts of a Snake River Drawdown." EWITS Research Report Number 18. May 1997.
19. Lee, Nancy S. and Kenneth L. Casavant. "Rail Traffic in Washington: A Commodity and Origin-Destination Analysis 1990 to 1995." EWITS Research Report Number 19. December 1997.

20. Edwards, Richard, Eric L. Jessup, and Kenneth L. Casavant. "Eastern Washington On-Farm and Commercial Grain Storage." EWITS Research Report Number 20. January 1998.
21. Painter, Kathleen M. and Kenneth L. Casavant. "Washington State Freight Truck Origin and Destination Study: [County Series]." EWITS Research Report Number 21. January 1998.
22. Alderson, Lynn C. and R. Douglas Scott II. "Transportation Characteristics and Needs of Forest Products Industries Using Eastern Washington Highways Part 5: Road Usage and Characteristic." EWITS Research Report Number 22. April 1998.
23. Lee, Nancy S. and Kenneth L. Casavant. "Impacts of a Snake River Drawdown on Energy Consumption and Environmental Emissions in Transporting Eastern Washington Wheat and Barley." EWITS Research Report Number 23. March 1998.
24. Jessup, Eric L. and Kenneth L. Casavant. "Impacts of a Snake River Drawdown on Transportation of Grains in Eastern Washington: Competitive and Rail Car Constraints." EWITS Research Report Number 24. May, 1998. IN REVIEW PROCESS.

EWITS Previous Working Paper Series Now Available

1. Lee, Nancy and Ken Casavant. "Grain Receipts at Columbia River Grain Terminals." EWITS Working Paper #1, March 1996.
2. Lenzi, Jerry, Eric Jessup, and Ken Casavant. "Prospective Estimates for Road Impacts in Eastern Washington from a Drawdown of the Lower Snake River." EWITS Working Paper #2, March 1996.
3. Ellis, John, Eric Jessup, and Ken Casavant. "Modeling Changes in Grain Transportation Flows in Response to Proposed Snake River Drawdowns: A Case Study for Eastern Washington." EWITS Working Paper #3, March, 1996.
4. Painter, Kate and Ken Casavant. "A Comparison of Canadian Versus all Truck Movements In Washington State With A Special Emphasis On Grain Truck Movements." EWITS Working Paper #4, March 1996.
5. Jessup, Eric L. and John Ellis, and Kenneth L. Casavant. "Estimating the Value of Rail Car Accessibility for Grain Shipments: A GIS Approach." EWITS Working Paper #5, April 1996.
6. Painter, Kathleen M. and Kenneth L. Casavant. "Truck Movement Characteristics on Selected Truck Routes in Washington State." EWITS Working Paper #6, August 1996.
7. Lee, Nancy S. and Kenneth L. Casavant. "Grain Receipts at Columbia River Grain Terminals, 1980-81 to 1995-96." EWITS Working Paper #7. January 1997.
8. Jessup, Eric L. and Kenneth L. Casavant. "Economic Evaluation of Grain Shipment Alternatives: A Case Study of the Coulee City and Palouse River Railroad." EWITS Working Paper #8. March 1997.
9. Casavant, Kenneth L. and Nancy S. Lee. "Grain Receipts at Columbia River Grain Terminals: 1980-81 to 1996-97." EWITS Working Paper #9. January 1998.
10. Lenzi, Jerry C. "Preliminary Observations of Mobility Issues, Concerns, and Efforts in Europe and the United States." EWITS Working Paper #10. October, 1998.

Table of Contents

Introduction	4
North American Free Trade Agreement	4
Objectives	5
Study Procedure	5
Measuring Highway Damage	6
Damage Functions	9
Ton Miles and Damage by Corridor	13
Method of Analysis	13
Corridor Ton Mile Analysis	15
Interstate 5 Corridor	16
U.S. 97 Corridor	17
U.S. 395 Corridor	19
Interstate 90 Corridor	21
Highway Damage Estimates	23
Interstate 5	25
U.S. 97	26
U.S. 395	26
Summary	27
References	29
Appendix A: Modeling Framework, Projection Procedure Model, Ton Miles and Damage by Highway Segment	30

List of Tables

Table 1	Summary of Previous Studies on Highway Damage Coefficients.....	14
Table 2	Ton Mile Estimates, by Movement Type, in Washington, 1994 and 2005	15
Table 3	Washington NAFTA Corridor Ton Miles, 1994 and 2005.....	16
Table 4	Ton Mile Estimates, by Movement Type, in the I-5 Corridor, 1994 and 2005.....	17
Table 5	Ton Mile Estimates of the Nine Commodity Groups, Percent by Movement Type in the I-5 Corridor, 1994 and 2005.....	18
Table 6	Interstate 5 Ton Miles, 1994 and 2005	18
Table 7	Ton Mile Estimates, by Movement Type, in the U.S. 97 Corridor, 1994 and 2005.....	19
Table 8	Ton Mile Estimates of the Nine Commodity Groups, Percent by Movement Type in the U.S. 97 Corridor, 1994 and 2005	20
Table 9	U.S. 97 Ton Miles, 1994 and 2005	20
Table 10	Ton Mile Estimates, by Movement Type, in the U.S. 395 Corridor, 1994 and 2005.....	22
Table 11	Ton Mile Estimates of the Nine Commodity Groups, Percent by Movement Type in the U.S. 395 Corridor, 1994 and 2005	22
Table 12	U.S. 395 Ton Miles, 1994 and 2005	23
Table 13	Washington NAFTA Ton Miles on the Interstate 90 Corridor, 1994 and 2005.....	23
Table 14	Ton Mile Estimates of the Nine Commodity Groups, Percent by Movement Type in the I-90 Corridor, 1994 and 2005.....	24
Table 15	Total State Impacts, 1994 and 2005.....	25
Table 16	Interstate 5 Impacts, 1994 and 2005	26
Table 17	U.S. 97 Impacts, 1994 and 2005	26
Table 18	U.S. 395 Impacts, 1994 and 2005	26

List of Tables cont.

Table A1a	Ton Miles and Impacts of Northbound Movements (U.S. Exports) to Canada Using Interstate 5, by Highway Segment, 1994 and 2005.....	34
Table A1b	Ton Miles and Impacts of Southbound Movements (U.S. Imports) from Canada Using Interstate 5, by Highway Segment, 1994 and 2005.....	34
Table A2a	Ton Miles and Impacts of Northbound Movements (U.S. Exports) to Canada Using U.S. 97, by Highway Segment, 1994 and 2005.....	36
Table A2b	Ton Miles and Impacts of Southbound Movements (U.S. Imports) from Canada Using U.S. 97, by Highway Segment, 1994 and 2005.....	36
Table A3a	Ton Miles and Impacts of Northbound Movements (U.S. Exports) to Canada Using U.S. 395, by Highway Segment, 1994 and 2005.....	38
Table A3b	Ton Miles and Impacts of Southbound Movements (U.S. Imports) from Canada Using U.S. 395, by Highway Segment, 1994 and 2005.....	38

List of Figures

Figure 1	Major Highway Corridors that Support the Transportation of NAFTA Commodities on Washington Highways.....	4
Figure 2	Washington Highway Corridor Damage Procedure Model	7
Figure 3	Highway Damage and Vehicle Axle Weight.....	8
Figure 4	Weight and Pavement Life.....	10
Figure A.1	Data Management, Analysis, and Modeling Framework.....	31
Figure A.2	NAFTA Projections Procedure.....	32
Figure A.3	Interstate 5 Highway Segments Used to Support NAFTA Commodities....	33
Figure A.4	U.S. 97 Highway Segments Used to Support NAFTA Commodities.....	35
Figure A.5	U.S. 395 Highway Segments Used to Support NAFTA Commodities.....	37

Executive Summary

Washington State provides critical gateways and corridors for North American trade between Canada and the United States. In 1992, Western U.S.-Canada commercial truck traffic made up more than 832,000 or 53.0 percent of the 1.6 million cross-border trips at Washington-British Columbia Ports of Entry. Canadian commodities represent 28.6 percent of the 90.1 million tons of commodities on Washington highways; in 1994, over 1.8 million truck trips transported nearly 25.8 million tons of Canadian commodities valued at approximately \$33.3 billion. By 2005, NAFTA commodity trade is projected to increase by about one-third to 33.7 million tons on Washington highways. Four corridors, identified by the major highway on which Canadian commodities are transported—including all highways and roads within the corridors, make up the infrastructure on which that trade moves and includes three north-south: Interstate 5; U.S. 97; and U.S. 395, and one east-west: Interstate 90.

On January 1, 1994, Canada, Mexico and the United States enacted the North American Free Trade Agreement (NAFTA), creating the world's largest free trade agreement encompassing more than 376 million consumers and \$7 trillion in gross domestic product. The purposes of NAFTA are to create a free trade environment where producers, processors and transportation firms move goods safely, timely and cost effectively in a continuous flow, without complications or delays, from a packing house or processing plant directly to the buyer. Under NAFTA, Washington's transportation system will become more important for North American trade, in particular, between the U.S. and Canada.

The overall purpose of this study was to analyze the impacts of NAFTA on Washington's transportation infrastructure by specifically evaluating highway infrastructure investment requirements to sustain industry capacity in trade flows. The specific objectives were to 1) Determine impacted highways and assess needed transportation investment to support NAFTA trade on Washington corridors; and 2) Assess implications that arise from changes in NAFTA trade for Washington corridors.

For Canada and the U.S., the NAFTA is an extension of the Canada-United States Free Trade Agreement (CUSTA), which was enacted on January 1, 1989. The CUSTA's goals were to reduce and remove trade barriers, in particular tariffs, by 1999, to increase trade between Canada and the United States. The CUSTA was subsumed into, and superseded by the NAFTA. The NAFTA expands the CUSTA objectives by adding protection for intellectual property rights, ensuring land transportation market access, increasing investment opportunities and upholding environmental standards and agreements, while promoting sustainable development.

NAFTA truck ton-miles on Washington highways were approximately 10.4 billion in 1994. Nearly 69 percent of those ton-miles were transit movements and 18 percent and 13 percent were Washington origin and destination movements to and from Canada, respectively. By 2005, truck ton-miles are projected to increase 29 percent to 13.4 billion. Transit movements will be about 68 percent of the ton-miles, with destination

movements having an increased share of the ton-miles at 13 percent, just over one-half of one percent greater than in 1994.

Ton-miles by corridor vary significantly. In 1994, more than 75 percent of the ton-miles were concentrated in the I-5 corridor, while 15 percent and 9 percent were U.S. 97 and U.S. 395 respectively. By 2005, the share of ton miles in the I-5 corridor are expected to decrease below 75 percent, while U.S. 97 and U.S. 395 will increase respectively to 16 percent and 10 percent of the ton mile shares on Washington highways. Ton-miles in the U.S. 395 corridor will increase more, 34 percent over the period, than the I-5 and U.S. 97 corridors. I-5 and U.S. 97 will increase 28 percent and 31 percent respectively. However, total statewide ton-miles will increase 29 percent; less than the U.S. 97 and U.S. 395 corridors, but greater than the I-5 corridor. The commodity composition of ton-miles does vary by corridor, causing this differing need for road investment by corridor.

Damage on Washington highways associated with this increased trade requires attention. In 1994, highway maintenance requirements for the Interstate 5, U.S. 97, and U.S. 395 highways specifically, to sustain highway usage associated with NAFTA trade, totaled \$9.1 million. Northbound movements caused 45 percent of the damage while southbound movements made up 55 percent. By 2005, highway requirements are expected to increase 148 percent to \$22.6 million with northbound movements causing 49 percent of the damage and southbound movements 51 percent. Damage coefficients generated by the WSDOT-PMS, averaged \$0.011 per ton-mile where northbound movements averaged \$0.012 and southbound averaged \$0.009 per ton-mile for the three highways.

Total investment requirements of all three highways are significant. Highway damage occurs through five factors, which would mean that highways are designed and constructed to meet certain minimum requirements of those factors. As such, each highway has unique characteristics and special circumstances that generate varying damage coefficients. The next section evaluates projected impacts of NAFTA trade on each highway-by-highway segment.

Ton-miles on the three highways are expected to nearly triple by 2005 to 8.9 billion ton-miles. Northbound movements will about triple to 6.2 billion ton miles while southbound movements will more than double to 2.7 billion ton miles. The Interstate 5 highway supports 88 percent of the ton-miles among the three highways, yet it requires 61 percent of the increased highway investment needs. The U.S. 97 and U.S. 395 highways would require 22 percent and 17 percent, of the highway needs respectively, to sustain NAFTA shipments on Washington highways. Northbound movements make up 70 percent of the ton-miles while southbound movements would demand 51 percent of the investment requirements. The U.S. 97 highway pavement conditions, reflected by a higher damage coefficient, are worse than Interstate 5 and U.S. 395. Its highway damage coefficient (both northbound and southbound movements) of \$0.0121 per ton-mile is about seven times greater than Interstate 5's and half as much greater than U.S. 395's, and is about 1.1 times greater than its southbound coefficient.

Damage per ton-mile for southbound movements is expected to be \$0.0042 per ton-mile, which is about 2.5 times greater than northbound movement estimates. The higher southbound damage coefficient is attributed to the heavier trucks traveling southbound, where the average southbound truck weight, 37.8 tons (39.6 tons on the U.S. 395 highway), is heavier than the northbound movement average weight of 34.1 tons.

Specific attention must be committed to transit movements since they make up the bulk of the ton miles and are heavier loads being transported greater distances on Washington highways. Washington's infrastructure supports NAFTA trade, yet the associated benefits received for that trade may not necessarily be in proportion to the costs associated with transportation characteristics on that trade on Washington highways. A mechanism to internalize the benefits and costs within the state is needed.

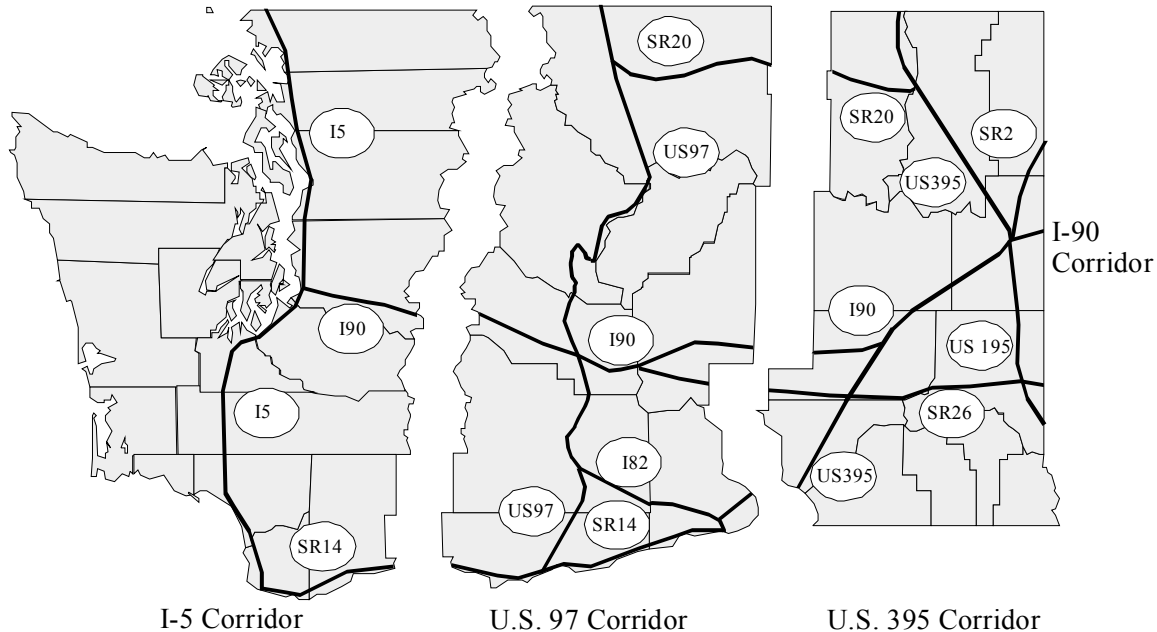
NAFTA trade is certain to increase on Washington's highways. If infrastructure investment is not adequate to sustain Washington's highways at serviceable levels, trade flows will be impeded and the associated highway damage of that trade will increase substantially as highway deterioration is accelerated. The incidence of NAFTA trade varies by corridor. Thus, highway impacts vary by corridor. However, the present serviceable levels of highways among the corridors may vary and serviceable levels of highways within corridors may vary. As such, attention to highways in the corridors with low serviceable ratings should be given priority; otherwise changes in NAFTA trade may significantly deteriorate those highways over the next seven years.

Introduction

Washington State provides critical gateways and corridors for North American trade between Canada and the United States. In 1992, Western U.S.-Canada commercial truck traffic made up more than 832,000 or 53.0 percent of the 1.6 million cross-border trips at Washington-British Columbia Ports of Entry (Federal Highway Administration, FHWA). Canadian commodities represent 28.6 percent of the 90.1 million tons of commodities on Washington highways; in 1994, over 1.8 million truck trips transported nearly 25.8 million tons of Canadian commodities valued at approximately \$33.3 billion (Eastern Washington Intermodal Transportation Study, 1994). Four corridors, identified by the major highway on which Canadian commodities are transported—including all highways and roads within the corridors, include three north-south: Interstate 5; U.S. 97; and U.S. 395, and one east-west: Interstate 90, as shown in Figure 1.

North American Free Trade Agreement

Figure 1: Major Highway Corridors that Support the Transportation of NAFTA Commodities on Washington Highways



On January 1, 1994, Canada, Mexico and the United States enacted the North American Free Trade Agreement (NAFTA), creating the world's largest free trade agreement encompassing more than 376 million consumers and \$7 trillion in gross domestic product (World Bank). The purposes of NAFTA are to create a free trade environment where producers, processors and transportation firms move goods safely, timely and cost effectively in a continuous flow, without complications or delays, from a packing house or processing plant directly to the buyer. For Canada and the U.S., the NAFTA is an extension of the Canada-United States Free Trade Agreement (CUSTA), which was enacted on January 1, 1989. The CUSTA's goals were to reduce and remove trade barriers, in particular tariffs, by 1999, to increase trade between Canada and the United States. The CUSTA was subsumed into, and superseded by the NAFTA. The NAFTA expands the

CUSTA objectives by adding protection for intellectual property rights, ensuring land transportation market access, increasing investment opportunities and upholding environmental standards and agreements, while promoting sustainable development (Schaeffer and Wahl).

A free trade agreement between countries is an attempt to let international markets perform on a level playing field. Under a free trade agreement, barriers that inhibit trade and keep out competition are removed. Commonly used trade barriers between countries are tariffs and non-tariff barriers (quotas, sanitary and phytosanitary requirements, licenses, etc.) on imported goods. As free trade agreements are enacted and implemented, the type and flow of trade changes as firms pursue new markets and manufacturing and logistics strategies under cost competitive advantages. Trade flows are dependent upon the transportation sector to transport commodities from manufacturer, processor and producer to consumer. However, problems can exist when transportation options and corridors are inadequate to support increased trade volumes, or price signals do not reflect all costs, which then impedes the movement of products and decreases the economic returns to production and/or the utility of the consumer. This issue is the underlying theme of this study.

Objectives

The overall purpose of the study is to analyze the impacts of NAFTA on Washington's transportation infrastructure. In Part I: "Commodity and Corridor Projections," (EWITS Research Report #14) the specific North American, in particular U.S.-Canada, commodity flows into, out of, and through Washington were identified and forecasts of those trade flows were made. Mexican commodity volumes in Washington State are insignificant relative to U.S.-Canadian commodity volumes at this time, thus Mexico is not a part of this study. In this Part II of the study, highway infrastructure investment requirements to sustain industry capacity in trade flows are evaluated. The theory of highway deterioration and the associated highway damage coefficients are reviewed, followed by an evaluation and projection of ton miles and the cost of highway damage associated with NAFTA trade flows on Washington's major highways that support NAFTA trade. The specific objectives of Part II were to:

1. Determine impacted highways and assess needed transportation investment to support NAFTA trade on Washington corridors; and
2. Assess implications that arise from changes in NAFTA trade for Washington corridors.

Study Procedure

This report uses results from Part I as the foundation to formulate highway investment requirements to support NAFTA trade on Washington's transportation infrastructure. In Part I, the major commodities transported (both import and export) over Washington's highways were identified, expanded to represent all commodity movements transported by corridor, and projected to 2005. The procedure used to forecast commodity movements was shown in Figures 1 and 2 in Part I (shown in appendix as Figures A1 and A2). In order to evaluate highway investment requirements, Figure 2 of Part I was extended by incorporating the Washington State Department of Transportation Performance Monitoring System (WSDOT-PMS), as shown in Figure 2 of this report. The WSDOT-PMS was used to evaluate investment requirements to support NAFTA trade by specific highways in the major trade corridors identified in Figure 1. The next section reviews the process of measuring highway damage.

Measuring Highway Damage

In order to ascertain the impact of increased traffic on highway infrastructure, a review of highway design and performance is useful. Five major elements affect the performance of highways. These include the underlying soil (the subgrade), the pavement structure, traffic loads (weight), traffic volume, and the environment. The relationship of the elements affecting highway performance is expressed in equation (1) (Tolliver).

$$(1) \quad PL = f(N, C, SSN, STR)$$

where:

PL	=	Pavement life
N	=	Cumulative passes of a given axle type and load
C	=	Climatic zone or regional factor
SSN	=	Soil support number or index
STR	=	Strength of the highway section (some function of D or SN, TH1, and/or TH2)

where:

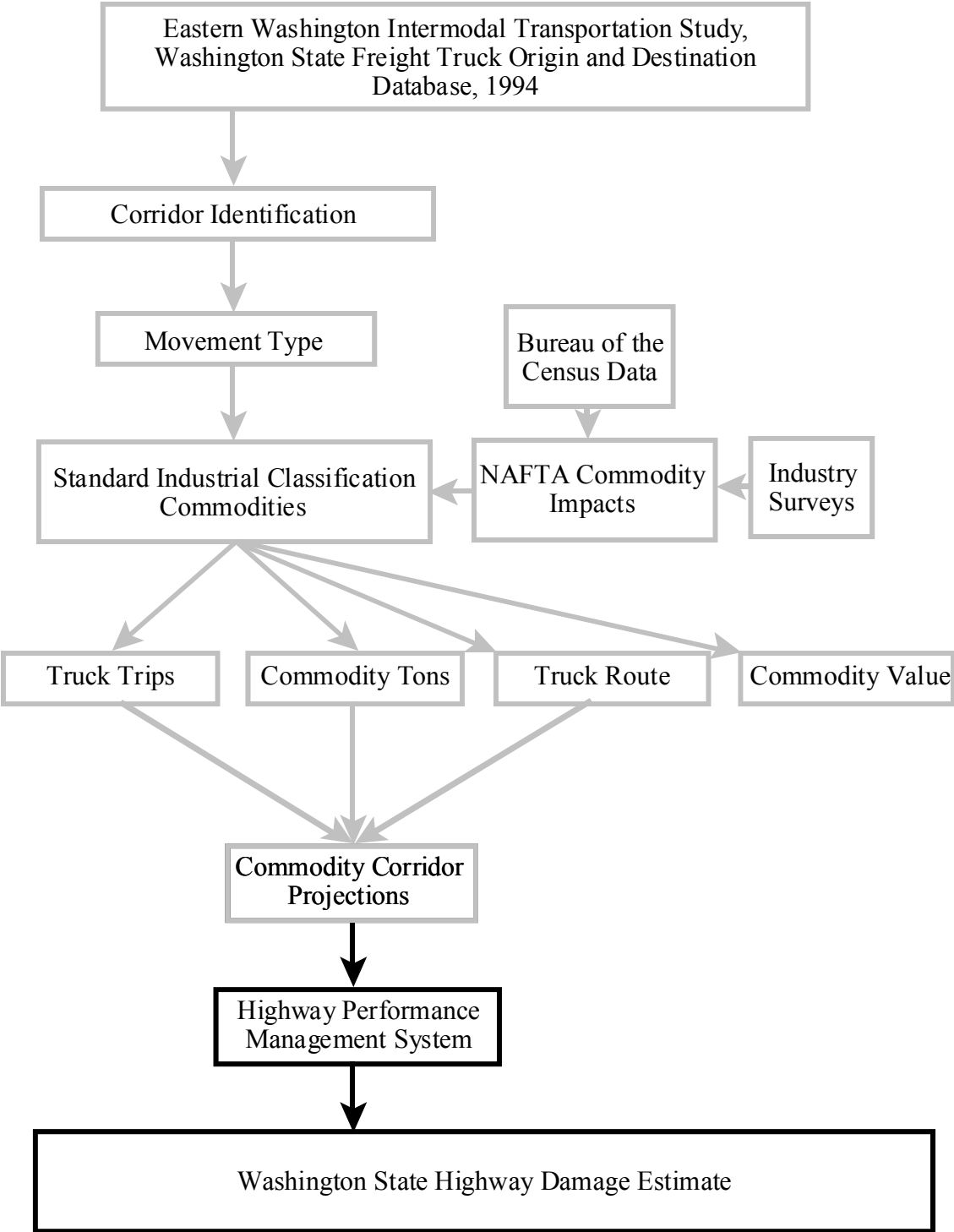
D	=	Slab thickness (Portland Cement Concrete Pavements)
SN	=	Structural number (flexible or asphaltic concrete pavements)
TH1	=	Thickness of asphaltic concrete layers
TH2	=	Thickness of the aggregate base.

Pavements are generally divided into two types: flexible and rigid. Flexible pavement (SN in Equation (1)) often consists of an asphalt concrete pavement (ACP), built on a base and resting on a compacted subgrade or the natural soil foundation. Rigid pavements are composed of a Portland Cement Concrete Pavement (PCCP) slab (D in Equation (1)) placed on a subgrade or subbase. The essential difference between the two is the manner in which they distribute the load over the subgrade. With asphalt layers, the force of a load passes through the asphalt directly below the load. Concrete or rigid pavement functions more like a board or plank, spreading the force over a larger area. Rigid pavements generally withstand repetitive loading better than flexible pavements and normally have a longer life cycle between necessary repairs (Casavant and Lenzi). Highways in this study are a combination of flexible and rigid highways but are mainly flexible.

The speed of pavement deterioration is affected by the number and type of loadings and the environment, principally the moisture and freeze-thaw cycle which create internal stress that limit a pavement's life. As the environment causes pavement deterioration, this process can be accelerated by heavy traffic (Casavant and Lenzi).

The life of a pavement is directly affected by the pavement design relative to traffic volumes and loads. It is not just the maximum size of a load that is critical, but the number of loads applied to the pavement that is important. Loads are evaluated using the common measures of Kips (1,000 pounds) and ESALs. ESALs are equivalent single-axle loads rated at 18,000 pounds such that all loads, both single and tandem (dual) axles, are expressed in the number of ESALs that will pass over a pavement during its design life cycle (Casavant and Lenzi).

Figure 2: Washington Highway Corridor Damage Procedure Model



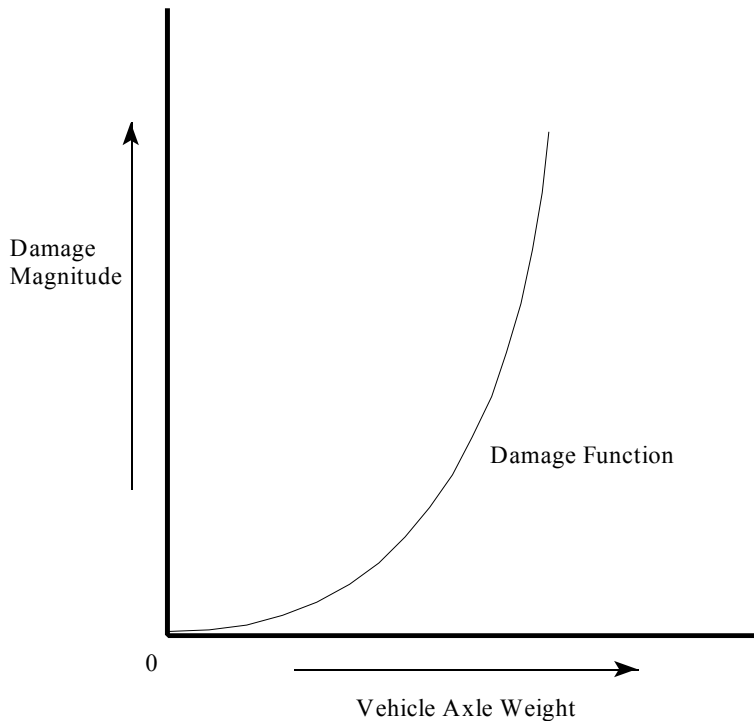
The force inflicted on a pavement depends on gross vehicle weight, per axle weight and the distance between axles. The general relationship between vehicle axle weight and damage is shown in Figure 3. Damage increases in a greater proportion than the increase in weight; thus overloaded or heavier trucks create extra impact on highways, especially on highways not designed for those loads. This general relationship between axle weight and damage magnitude can be expressed by Equation (2) (Tolliver):

$$(2) \quad g = \left(\frac{N}{\tau} \right)^\beta$$

where:

- g = an index (between 0.0 and 1.0) of damage or deterioration
- N = the number of passes of axle groups at a specified weight and configuration (e.g. the 18,000-pound single axle)
- τ = the number of axle passes at which the section reaches failure
- β = rate of deterioration.

Figure 3: Highway Damage and Vehicle Axle Weight



Source: Casavant, Kenneth L. and J. C. Lenzi. Procedure for Predicting and Estimating the Impact of Rail Line Abandonments on Washington Roads. Washington State Department of Transportation, Olympia, 1989.

When N equals zero, according to Equation 1, there is no deterioration and g equals zero. As N increases, the rate of highway deterioration increases, thus increasing g, highway damage. When g equals one, highway damage is at a maximum and the maximum N, ESALs, have passed over the highway section.

Damage Functions

In the previous section, highway damage and deterioration were evaluated. This section looks at quantifying the cost of that highway damage and deterioration through the use of a highway damage function. The overall impact of increased weight and traffic volume on pavement life is shown in Figure 4. The area between the curves reflects the increased maintenance and reconstruction costs necessary to achieve the desired road life. This impact is generated by the increased incidence of ESALs and environmental effects on highways in Washington trade corridors (Casavant and Lenzi).

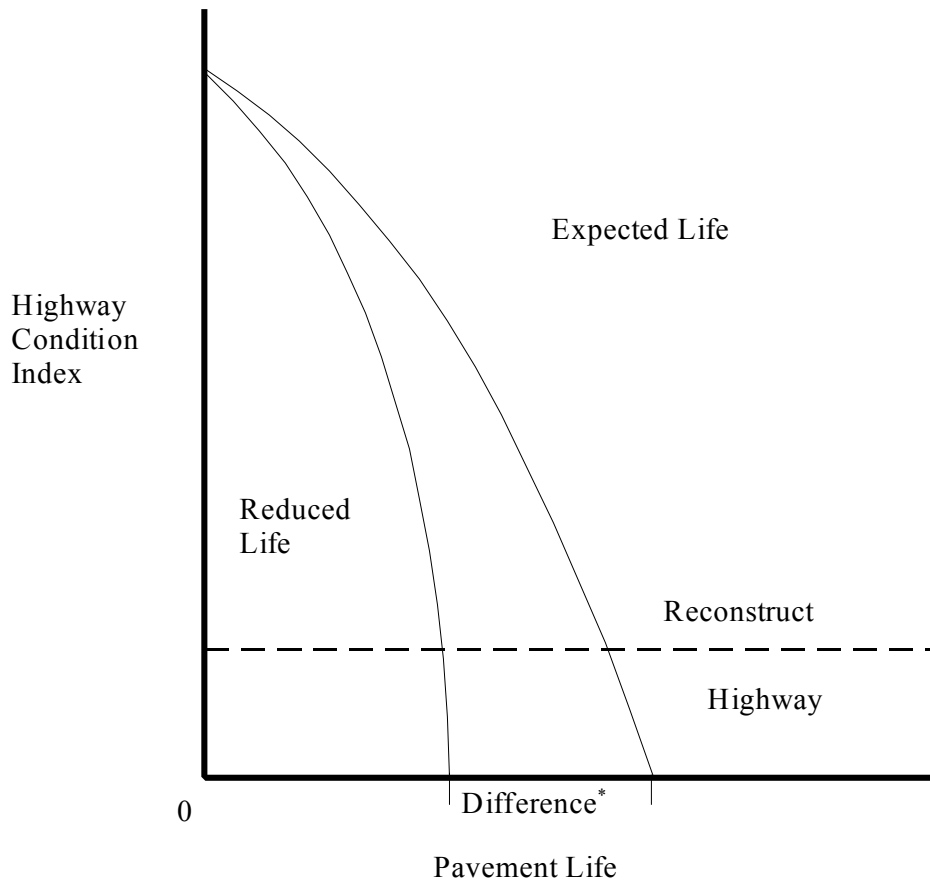
Two economic cost methods have been identified for highway damage cost analysis: marginal cost (MC) and incremental cost (IC). Each cost might be short run or long run in nature (Tolliver). The cycle between replacement periods, the capacity of a highway section to absorb ESALs, is the short run period (the area between the curves in Figure 4). At the end of a short run period, a highway section is either replaced to its original condition or to a higher standard. The long run cycle of a highway is the entire time of existence from initial construction to abandonment (Tolliver).

Marginal cost impact analysis reflects the additional consumption of highway capacity from the addition of one more ESAL to a highway section. Incremental costs encompass relatively large traffic increases as opposed to a single ESAL analysis. For instance, a free trade agreement might cause a shift in commodity trade between countries, thus impacting the flow of goods on highways. Such an example would constitute an incremental class of traffic (Tolliver). In that instance, highway planners must account for a sizeable flow of traffic rather than a single vehicle as a result of a free trade agreement.

Short run marginal cost (SRMC) contains three factors: the ESAL life of a highway section, the replacement cost incurred at the beginning of the cycle and the current condition of the highway section. Pavement serviceability declines or the magnitude of damage increases in a nonlinear function of vehicle axle weight (Figure 3). The SRMC is the derivative of the pavement serviceability rating with respect to axle passes (Tolliver).

$$(3) \quad SRMC = \frac{\partial PSR}{\partial N}$$

Figure 4: Weight and Pavement Life



*Equates to increased or earlier repair/reconstruction that must be done sooner than normal life cycle design.

Source: Casavant, Kenneth L, and J. C. Lenzi. Procedure for Predicting and Estimating the Impact of Rail Line Abandonments on Washington Roads. Washington State Department of Transportation, Olympia, 1989.

where:

PSR = Pavement serviceability rating¹
 N = Cumulative passes of a given axle type and load.

¹An index ranging from 0.0 to 5.0. A PSR of 5.0 denotes a newly built or reconstructed highway. A PSR from 4.0 to 4.9 denotes a highway section in very good condition. A PSR in the 3.0 to 3.9 range is considered good. A PSR from 2.0 to 2.9 is considered fair, while a PSR from 1.0 to 1.9 is considered poor. A PSR below 1.0 denotes a poor highway section. Historically, state DOT's have resurfaced or rebuilt major highways when the PSR reaches a level of 2.5. The trigger PSR has historically been 2.0 for other classes of highways (Tolliver).

The long run marginal cost (LRMC) does not consider the present serviceability of a highway section. LRMC evaluates the need to increase pavement strength as one more ESAL passes over the highway section. The net result would be an additional pavement layer to maintain the service life of the highway. However, one additional ESAL does not necessitate an additional layer of pavement. It is the accumulation of ESALs over time that necessitates the additional layer.

LRMC only considers pavement thickness, not current serviceability. Thus, LRMC is a derivative of pavement thickness with respect to ESALs.

$$(4) \quad \text{LRMC} = \frac{\partial \text{TH1}}{\partial \text{ESAL}}$$

where:

TH1 = Thickness of asphaltic concrete layers
 ESAL = Equivalent single axle load.

The South Dakota Department of Transportation's Planning Division developed a function, which quantifies specific impacts by corridor and highway, as follows (Casavant and Lenzi):

$$(5) \quad (M_o - M_n)_H = (T)(V)(L) \times [0.00251331]$$

where:

$(M_o - M_n)_H$ = Increased annual highway maintenance cost (\$)
 M_o = Original miles
 M_n = New miles
 H = Section of highway
 T = Number of one-way truck trips per year transporting commodities (in this study, NAFTA traffic)
 V = Average gross vehicle weight per trip (tons).
 L = Length of haul (miles)

Multiplying T, V and L equals ton-miles. The 0.00251331 is the associated damage function, dollars per ton-mile, to keep South Dakota highways serviceable. This approach, however, looks only at increased highway maintenance cost and does not include reconstruction costs (Casavant and Lenzi).

Estimates of highway damage vary quite widely by state and within a state. The variability among states and within the State of Washington is due to differences in road condition, load types, the environment and the type of road being impacted. But it is a predictable, useful range for sensitivity analysis, as presented in this section. This study looks at short run incremental costs associated with NAFTA commodity flows in and through Washington.

According to Tolliver, the California Department of Transportation (1990) estimated incremental maintenance costs to be approximately 11.3 cents per ton-mile. Casavant and Lenzi estimated incremental pavement costs in four case studies to range from 2 cents per ton-mile to 9 cents per ton-mile, with a mean value of 7.5 cents per ton-mile. Bitzan, Honeyman, Tolliver and Casavant estimated that highway damage resulting from rail line abandonment of four line segments in Washington State ranged from 1.9 cents to 10.8 cents per ton-mile with an average value of 6.8 cents per ton-mile. The result of Tolliver's Nebraska study determined incremental pavement costs to be 2.5 cents per ton-mile. Jessup estimated state highway damage to be \$0.01 per ton-mile, interstate to be \$0.002 per ton-mile and for county roads \$0.04 per ton-mile in 1998. The 1995 highway damage coefficients for Washington highways were estimated to range between \$0.019 and \$0.108 per ton-mile (Bitzan et al.). The available studies, which have evaluated damage coefficients, are summarized in Table 1.

In another example, Tolliver estimated unit costs per ton-mile by simulating impacts on three classes of rural highways over a typical design period of 20 years. Results of the simulations provided a range of impacts with respect to changes in structural design. The cost per ton-mile varied \$9.21 per ton-mile from 2.8 cents per ton-mile for a structural design of 3.2 (requiring only resurfacing) to \$9.24 per ton-mile for a structural design of 1.5 (at this level, reconstruction is required). Thus, as the highway serviceability rating declines, highway damage per ton-mile increases in a greater proportion. The next section discusses ton-miles and damage by corridor and highway.

Ton Miles and Damage by Corridor

Commodities on Washington highways totaled 90.1 million tons in 1994 (Gillis, Jessup and Casavant) and NAFTA (U.S. and Canada) commodity movements were 29 percent of those tons (EWITS, 1994). Those NAFTA shipments were transported by more than 1.8 million truck trips, hauling nearly 25.8 million tons. By 2005, NAFTA commodity trade is projected to increase by about one-third to 33.7 million tons on Washington highways (Part I analysis). The next section describes the method of analysis used to evaluate ton-mile estimates, which is used to determine highway investment requirements.

Method of Analysis

Corridor investment requirements reported in this section are annual dollar estimates, based on current and projected NAFTA commodity volumes in Washington, to maintain highways at current levels. To determine highway investment requirements, each truck shipment route was identified and distance in miles measured, by corridor and entire shipment route, while in Washington. The miles were multiplied by commodity tons being transported, including the weight of the truck (assumed to weigh 12 tons), to arrive at a ton-mile estimate for commodities transported on Washington highways. The resulting dollar values (unadjusted for inflation for 2005) in the highway damage section represent the estimated highway damage associated with this trade on Washington highways, and, therefore, investment needed to maintain highway serviceability for those commodities. Ton-miles and highway damage by individual highways and their corresponding highway segments reflect results using the WSDOT-PMS. It is important to note that results generated by the WSDOT-PMS do not necessarily reflect each highway completely. For instance, some sections of each highway do not have adequate information to fully estimate damage from the WSDOT-PMS. As such, highway damage reflects only those segments for which complete information is available.

Ton-miles are reported by two groups of movement types: Washington origin, Washington destination or Washington transit (the truck and its cargo neither originated in nor were destined for Washington) movements; or southbound or northbound movements. The origin, destination and transit movement group facilitates an understanding of how much ton-miles are attributed to those movement types in this group. Grouping movements by southbound and northbound divides transit ton-miles into north- or southbound movements and are then aggregated into the corresponding origin ton-miles, which are northbound ton-miles, or destination ton-miles, which are southbound movements. This is important since each highway being analyzed within each corridor, will be accomplished on the lane of travel, northbound or southbound. The construction characteristics of each lane, of each highway, depend on the conditions on which each lane is constructed. As such, a more accurate measurement of NAFTA's impact can be measured.

Table 1--Summary of Previous Studies on Highway Damage Coefficients

Study	Highway Type	Description of Study	Date of Study	Damage Coefficient (\$/Ton Mile)
Casavant and Lenzi	State	Four rail line abandonments in Washington State	1989	0.01 to 0.06
	County			Average 0.05 0.02 to 0.09 Average 0.075
Casavant and Tolliver Bitzan et al.	State and County	Rail line abandonment	1996	0.02
	State and County	Mott to Mandon, North Dakota rail line abandonment		0.02
	Collector and Arterial	Four rail line abandonments in Eastern Washington (Grant, Lincoln, Spokane and Whitman counties)		1996
Tolliver	State and County	Nebraska rail line sale	1996	0.04
	PSR 3.2	Simulations	1995	0.08
	PSR 2.5			0.11
	PSR 2.0			Average 0.039
	PSR 1.5			0.07
Jessup	State and County	California	1990	0.03
	State	Nebraska	1995	0.07
	State	Simulations of origin and destination movements	1998	0.14
	Interstate			9.24
	County			0.11
				0.03
				0.01
				0.002
				0.04

Corridor Ton Mile Analysis

NAFTA truck ton-miles on Washington highways were approximately 10.4 billion in 1994. Nearly 69 percent of those ton-miles were transit movements and 18 percent and 13 percent were Washington origin and destination movements to and from Canada respectively (Table 2). One hundred-twenty six commodity groups at the 3-digit Standardized Industrial Classification (SIC) level were identified in Part I, and were originally selected from the 2-digit SIC level. Those 2-digit SICs made-up nearly two-thirds of U.S.-Canadian commodity tons on Washington highways. Nine commodity groups made up 42 percent of the tons from the 2-digit SIC groups while the remaining 117 commodity groups at the 3-digit SIC level made up 58 percent of the tons transported on Washington highways. The nine commodities include: agricultural chemicals; canned and preserved fruits, vegetables, and seafoods; converted paper and paperboard; fresh fruit; fresh vegetables; industrial inorganic chemicals; lumber; meat—fresh, chilled and frozen; and miscellaneous food preparations. Transit movements were nearly 78 percent of the ton-miles for the nine commodities of interest, with destination movements at 12 percent and origin movements 10 percent (Table 2). From Part I, commodity origin tons were greater than destination tons.

Table 2--Ton Mile Estimates, by Movement Type, in Washington, 1994 and 2005

Item	Origin		Destination		Transit		Total Ton Miles (millions)
	Ton Miles (millions)	%	Ton Miles (millions)	%	Ton Miles (millions)	%	
1994							
9 Commodities	460.6	10.5	525.4	12.0	3,391.5	77.5	4,377.5
Other	1,467.6	24.5	801.4	13.4	3,728.2	62.2	5,997.2
Total	1,928.2	18.6	1,326.8	12.8	7,119.7	68.6	10,374.6
2005							
9 Commodities	583.1	10.4	753.5	13.5	4,245.1	76.1	5,581.7
Other	1,915.3	24.5	1,045.9	13.4	4,865.5	62.2	7,826.7
Total	2,498.4	18.6	1,799.4	13.4	9,110.6	67.9	13,408.4

By 2005, truck ton-miles are projected (using export and import commodity flow data between 1989-95 to project growth) to increase 29 percent to 13.4 billion. The other 117 commodities will increase nearly 31 percent while the nine commodities will increase 28 percent. Transit movements will be about 68 percent of the ton-miles, with destination movements having an increased share of the ton-miles at 13 percent, just over one-half of one percent greater than in 1994 (Table 2).

Ton-miles by corridor vary significantly. In 1994, more than 75 percent of the ton-miles were concentrated in the I-5 corridor, while 15 percent and 9 percent were U.S. 97 and U.S. 395 respectively. By 2005, the share of ton miles in the I-5 corridor are expected to decrease below 75 percent, while U.S. 97 and U.S. 395 will increase respectively to 16 percent and 10 percent of the ton mile shares on Washington highways (Table 3). Ton-miles in the U.S. 395 corridor will increase more, 34 percent over the period, than

the I-5 and U.S. 97 corridors. I-5 and U.S. 97 will increase 28 percent and 31 percent respectively (Table 3). However, total statewide ton-miles will increase 29 percent; less than the U.S. 97 and U.S. 395 corridors, but greater than the I-5 corridor. The commodity composition of ton-miles does vary by corridor, causing this differing need for road investment by corridor.

Table 3--Washington NAFTA Corridor Ton Miles, 1994 and 2005

Corridor	1994		2005		% Change 1994 to 2005
	Ton Miles (millions)	%	Ton Miles (millions)	%	
Interstate 5	7,807.0	75.3	10,016.7	74.7	28.3
U.S. 97	1,594.4	15.4	2,091.4	15.6	31.2
U.S. 395	973.2	9.3	1,300.3	9.7	33.6
State Total	10,374.6	100.0	13,408.4	100.0	29.2

Interstate 5 Corridor

Commodity tons in the I-5 corridor were 10.4 million tons in 1994 and are estimated to increase 28 percent by 2005. In 1994, ton-miles in the corridor were 7.8 billion. Transit movements made up 70 percent of the ton-miles while Washington origin and destination movements were 18 percent and 12 percent respectively. The nine commodity groups were nearly 43 percent of the ton-miles, with 81 percent of those movements transit, 10 percent origin and 9 percent destination movements. The other 117 commodities made up 57 percent of the ton-miles, with 62 percent of those ton-miles transit movements, 24 percent origin and 14 percent destination (Table 4).

The fresh vegetables and lumber commodity groups generated more than two-thirds of the ton-miles in the I-5 corridor for 1994 and will represent nearly 62 percent by 2005. By including fresh fruits, the total increases to 72 percent, by 2005 (Table 5). In 1994, origin movements of the nine commodities were concentrated in four groups; fresh vegetables, fresh fruit, lumber, and converted paper products, with 65 percent of the origin ton-miles. By 2005, nearly 90 percent of the origin ton miles are expected to be concentrated in six groups; fresh vegetables, fresh fruit, canned and preserved fruits, vegetables and seafoods, miscellaneous foods, converted paper products and industrial chemicals. Lumber, miscellaneous food products and industrial chemicals will make up 81 percent of the destination ton-miles by 2005. Lumber will make up greater than 70 percent of the transit southbound ton-miles and fresh vegetables will make up greater than 60 percent of the northbound transit ton-miles (Table 5). By 2005, lumber will increase to approximately 71 percent of the transit southbound ton-miles and fresh vegetables will increase to greater than 64 percent of the northbound transit ton-miles (Table 5).

By 2005, ton-miles in the I-5 corridor will increase 28 percent to 10 billion. The share of ton-miles in the corridor by movement type will change slightly. Transit movements will decrease to 69 percent while origin and destination movements will increase to 18

percent and 13 percent respectively. The destination movements will increase greater than both transit and origin movements but ton-miles will remain less than transit and origin. Fresh vegetables, canned and preserved fruits, vegetables and seafoods, miscellaneous foods, industrial chemicals and agricultural chemicals will cause destination movements to increase in Washington. However, by 2005, destination ton-miles among the nine commodity groups will be greater than origin movements (Table 4).

Interstate 5 is the major highway in the I-5 corridor. In 1994 ton miles on I-5 totaled 3.1 billion, where 68 percent was northbound movements and 32 percent southbound. By 2005, ton-miles will exceed 7.8 billion, an increase of 151 percent, with northbound movements representing 57 percent of the ton-miles and southbound 43 percent. Ton-mile estimates for I-5 are shown in Table 6.

U.S. 97 Corridor

From 1994 to 2005, commodity tons in the U.S. 97 corridor are estimated to increase 33 percent from 3 million tons to 4 million tons. Ton-miles in the corridor were nearly 1.6 billion in 1994. Ton-miles by movement type are predominately transit, 58 percent, while Washington origin movements had 25 percent and destination 17 percent. Destination ton-mile movements among the nine commodity groups were greater than origin movements (Table 7). Yet commodity tons by origin movements were greater than destination movements as shown in Part I. The difference reveals that destination movements are transported greater distances (miles) than origin movements on Washington highways.

Table 4--Ton Mile Estimates, by Movement Type, in the I-5 Corridor, 1994 and 2005

Item	Origin		Destination		Transit		Total Ton Miles (millions)
	Ton Miles (millions)	%	Ton Miles (millions)	%	Ton Miles (millions)	%	
1994							
9 Commodities	339.4	10.1	297.2	8.9	2,711.3	81.0	3,347.9
Other	1,050.7	23.6	618.3	13.9	2,790.1	62.6	4,459.2
Total	1,390.1	17.8	915.5	11.7	5,501.4	70.5	7,807.0
2005							
9 Commodities	431.0	10.3	442.3	10.5	3,323.9	79.2	4,197.2
Other	1,371.2	23.6	806.9	13.9	3,641.3	62.6	5,819.5
Total	1,802.2	18.0	1,249.2	12.5	6,965.3	69.5	10,016.7

Table 5--Ton Mile Estimates of the Nine Commodity Groups, Percent by Movement Type in the I-5 Corridor, 1994 and 2005

Commodity	Origin		Destination		Transit Southbound		Transit Northbound		Total	
	1994	2005	1994	2005	1994	2005	1994	2005	1994	2005
Fresh Vegetables	15.3	15.0	1.7	2.6	1.2	2.1	60.8	64.6	34.6	34.6
Fruits	23.5	25.2	0.0	0.0	0.7	0.7	13.0	15.1	9.5	10.3
Meat: Fresh, Chilled and Frozen	5.5	6.1	3.0	2.1	1.6	1.2	0.7	0.8	1.6	1.6
Canned and Preserved Fruits, Vegetables and Seafoods	9.5	15.6	2.2	4.0	2.9	5.8	4.3	7.6	4.3	7.5
Misc. Foods	7.8	13.6	11.9	19.2	4.4	7.9	2.2	4.2	4.2	7.8
Lumber	13.2	1.5	57.2	52.1	70.7	70.9	12.5	1.6	32.4	27.3
Converted Paper	12.8	10.4	9.6	4.9	16.9	9.6	5.3	4.7	9.6	6.7
Industrial Chemicals	9.1	10.1	12.1	12.2	1.2	1.3	0.7	0.8	2.7	3.1
Agricultural Chemicals	3.3	2.5	2.4	2.9	0.3	0.4	0.7	0.6	1.0	1.0
Total (millions ton miles)	340,096	430,440	297,570	442,411	915	1,235	1,795,812	2,089,114	3,348,906	4,196,970

Table 6--Interstate 5 Ton Miles, 1994 and 2005

Characteristic	Northbound	Southbound	Total
Ton miles, 1994	2,137,181,068	1,002,506,578	3,139,687,646
Ton miles, 2005	5,801,005,335	2,019,068,137	7,820,073,472
Average truck weight	32.9	36.3	34.6

By 2005, ton-miles are estimated to increase greater than 31 percent to 2.1 billion. The share of ton-miles by movement type will not change significantly between 1994 and 2005. However, transit ton-miles of the nine commodity groups will increase 62 percent between 1994 and 2005. Ton-miles among the nine commodity groups will increase 32 percent to 784 million ton miles, and ton-miles for the other 117 commodities will increase 31 percent between 1994 and 2005 (Table 7).

Fresh vegetables, fresh fruit, and canned and preserved fruits, vegetables and seafoods make up nearly 73 percent of the origin ton miles in 1994 and will make up 81 percent by 2005. Four groups; meat products, lumber, converted paper, and industrial chemicals made up almost 90 percent of the destination ton miles in 1994 and by 2005 will make up nearly 85 percent. Southbound transit ton-miles were concentrated in lumber movements, 71 percent in 1994 and will be 68 percent in 2005. Northbound transit ton miles had three groups; fresh vegetables, canned and preserved fruits, vegetables and seafoods, and converted paper making up 67 percent of the ton miles and by 2005 those commodities are estimated to make up 72 percent of the ton miles (Table 8).

The major highway in the U.S. 97 corridor is U.S. 97. In 1994, ton-miles on it totaled more than 155 million with 39 percent northbound and 61 percent southbound. By 2005, ton-miles will increase 166 percent to 412 million, where 44 percent will be northbound movements and 56 percent from southbound movements. Ton-mile estimates for U.S. 97 are shown in Table 9.

U.S. 395 Corridor

Commodity tons in the U.S. 395 corridor were 2.3 million tons in 1994 and are projected to increase 37 percent to 3.2 million tons by 2005. Ton-miles in the corridor were 973 million with 71 percent transit movements, 15 percent Washington origin and 14 percent Washington destination movements (Table 10). The nine commodity groups were about 45 percent, with transit movements 74 percent of the ton-miles, destination movement's 22 percent and origin movements 4 percent for those commodities. Movements among the other commodities were 68 percent transit while origin movements were nearly 24 percent and destination 8 percent.

Table 7--Ton Mile Estimates, by Movement Type, in the U.S. 97 Corridor, 1994 and 2005

Item	Origin		Destination		Transit		Total Ton Miles (millions)
	Ton Miles (millions)	%	Ton Miles (millions)	%	Ton Miles (millions)	%	
1994							
9 Commodities	101.4	17.1	133.8	22.6	357.7	60.3	593.0
Other	288.7	28.8	140.8	14.1	571.8	57.1	1,001.4
Total	390.1	24.5	274.6	17.2	929.6	58.3	1,594.4
2005							
9 Commodities	126.8	16.2	173.2	22.1	484.5	61.8	784.5
Other	376.8	28.8	183.8	14.1	746.3	57.1	1,306.9
Total	503.6	24.1	357.1	17.1	1,230.8	58.8	2,091.4

Table 8--Ton Mile Estimates of the Nine Commodity Groups, Percent by Movement Type in the U.S. 97 Corridor, 1994 and 2005

Commodity	Origin		Destination		Transit Southbound		Transit Northbound		Total	
	1994	2005	1994	2005	1994	2005	1994	2005	1994	2005
Fresh Vegetables	39.9	39.4	2.1	3.6	3.2	5.1	44.5	44.0	18.8	18.8
Fruits	22.8	24.7	3.0	3.2	6.8	6.4	7.3	7.9	8.8	9.0
Meat: Fresh, Chilled and Frozen	2.5	2.7	18.8	15.2	4.9	3.6	7.5	8.3	8.2	7.0
Canned and Preserved Fruits, Vegetables and Seafoods	10.2	17.0	1.4	3.0	0.0	0.0	11.3	18.7	4.7	7.5
Misc. Foods	1.6	2.9	0.0	0.0	5.9	9.9	3.4	6.0	3.2	5.7
Lumber	9.4	1.1	46.4	48.8	71.3	67.9	9.0	1.1	40.6	38.2
Converted Paper	6.6	5.4	13.4	8.0	4.2	2.3	11.5	9.4	8.4	5.6
Industrial Chemicals	4.0	4.5	11.0	12.9	0.6	0.6	1.1	1.2	3.6	4.0
Agricultural Chemicals	3.0	2.3	3.8	5.4	3.3	4.3	4.5	3.5	3.7	4.0
Total (millions ton miles)	100,971	126,513	134,000	172,659	219,849	312,239	137,562	172,282	592,381	783,692

Table 9--U.S. 97 Ton Miles, 1994 and 2005

Characteristic	Northbound	Southbound	Total	
Ton miles, 1994		61,372,358	94,374,091	155,746,449
Ton miles, 2005		179,909,720	232,451,571	412,361,291
Average truck weight		34.1	37.5	35.8

By 2005, ton-miles in the corridor are estimated to increase 34 percent with the nine commodity groups increasing the most at 37 percent and the other commodities at 31 percent. Origin ton-miles among the nine commodities will have a lower share by 2005, while the share of destination movements will increase to 23 percent and transit movements decrease to 73 percent (Table 10).

Fresh vegetables, fresh fruit, and canned and preserved fruits, vegetables, and seafoods made up 78 percent of the origin ton miles in 1994 and, by 2005, will make up 84 percent of the origin ton miles (Table 11). Destination ton-miles in 1994 had four groups; meats, lumber, industrial chemicals, and agricultural chemicals that made up 88 percent of the ton-miles and, by 2005 will make up 88.4 percent of the ton-miles. In 1994, southbound transit ton-miles were concentrated in lumber and agricultural chemicals with 67 percent of the ton-miles and, by 2005, 70 percent. Northbound transit ton miles were made up predominately by fresh vegetables, and canned and preserved fruits, vegetables and seafoods with nearly 69 percent of the ton miles and, by 2005, almost 76 percent of the ton miles will be from fresh vegetables, fresh fruit, and lumber (Table 11).

The major highway in the U.S. 395 corridor is U.S. 395. In 1994, ton-miles on the highway were 250 million tons, where northbound movements made up 38 percent of the ton-miles while southbound movements were 62 percent. By 2005, ton-miles will increase 183 percent to 708 million. Northbound movements will be 36 percent of the ton-miles and southbound 64 percent. Ton-mile estimates for U.S. 395 are shown in Table 12.

Interstate 90 Corridor

The Interstate 90 corridor is important for the movement of NAFTA commodities by providing inter- and intra-corridor access. In 1994, 2.5 million tons of commodities were transported on I-90 and, by 2005, commodity tons will exceed 3.7 million tons.

Ton-miles on I-90 were nearly 1.2 billion in 1994. By 2005, ton-miles will increase 32 percent to 1.5 billion. In 1994, 53 percent of the ton-miles were from the nine commodity groups. By 2005, those nine commodity groups will make up 53.3 percent of the ton-miles on I-90. The nine commodity groups will increase the most at 34 percent to 809.3 million ton miles while the other 117 commodities will increase 31 percent to 708.3 ton miles (Table 13).

Origin ton miles of the nine commodities in 1994 were largely made up of three groups; fresh vegetables, and fresh fruits and canned and preserved fruits, vegetables and seafoods, with 70 percent of the origin ton miles. By 2005, those three groups will increase to 77 percent of the ton-miles. Four groups; meat, lumber, converted paper and industrial chemicals, made up 87 percent of the destination ton miles and, by 2005, nearly 80 percent. Southbound transit movements were concentrated to two groups, miscellaneous food products and lumber, with 73 percent of the ton-miles and, by 2005, they will be 76 percent of the ton-miles. Northbound transit ton-miles were distributed among 5 groups making up nearly 88 percent of the ton-miles in 1994 and 83 percent in 2005 (Table 14).

Table 10--Ton Mile Estimates, by Movement Type, in the U.S. 395 Corridor, 1994 and 2005

Item	Origin		Destination		Transit		Total Ton Miles (millions)
	Ton Miles (millions)	%	Ton Miles (millions)	%	Ton Miles (millions)	%	
1994							
9 Commodities	19.7	4.5	94.4	21.6	322.5	73.9	436.6
Other	128.2	23.9	42.3	7.9	366.2	68.2	536.6
Total	147.9	15.2	136.6	14.0	688.7	70.8	973.2
2005							
9 Commodities	25.4	4.2	138.0	23.0	436.6	72.8	600.0
Other	167.3	23.9	55.1	7.9	477.9	68.2	700.3
Total	192.6	14.8	193.2	14.9	914.5	70.3	1,300.3

Table 11--Ton Mile Estimates of the Nine Commodity Groups, Percent by Movement Type in the U.S. 395 Corridor, 1994 and 2005

Commodity	Origin		Destination		Transit Southbound		Transit Northbound		Total	
	1994	2005	1994	2005	1994	2005	1994	2005	1994	2005
Fresh Vegetables	56.0	54.4	1.9	3.0	4.3	6.9	49.4	49.2	17.2	17.3
Fruits	12.2	13.0	3.0	2.8	0.9	0.9	8.4	9.2	3.7	3.7
Meat: Fresh, Chilled and Frozen	0.0	0.0	17.0	12.0	8.5	6.2	6.9	7.8	9.5	7.7
Canned and Preserved Fruits, Vegetables and Seafoods	9.9	16.2	1.9	3.4	0.0	0.0	10.4	17.5	3.4	5.3
Misc. Foods	1.4	2.5	0.0	0.0	2.1	3.6	2.2	4.0	1.7	2.8
Lumber	5.9	0.7	26.5	24.5	53.3	51.2	9.5	1.1	34.6	31.8
Converted Paper	6.4	5.2	5.2	2.7	9.5	5.1	7.4	6.1	7.9	4.8
Industrial Chemicals	5.9	6.4	17.6	18.1	7.2	7.7	1.9	2.2	8.1	8.8
Agricultural Chemicals	2.3	1.8	26.9	33.4	14.1	18.3	3.9	3.0	13.8	17.7
Total (millions ton miles)	20,007	54,504	94,709	138,666	215,807	304,355	106,896	132,743	437,419	601,268

Table 12--U.S. 395 Ton Miles, 1994 and 2005

Characteristic	Northbound	Southbound	Total
Ton miles, 1994	95,314,358	155,199,194	250,513,552
Ton miles, 2005	258,021,375	450,630,757	708,652,132
Average truck weight	31.1	39.6	35.4

Table 13--Washington NAFTA Ton Miles on the Interstate 90 Corridor, 1994 and 2005

Commodities	1994		2005		% Change 1994 to 2005
	Ton Miles (millions)	%	Ton Miles (millions)	%	
9 Commodities	603.1	52.6	809.3	53.3	34.2
Other	542.7	47.4	708.3	46.7	30.5
Total	1,145.8	100.0	1,517.6	100.0	32.4

Highway Damage Estimates

Damage on Washington highways associated with this increased trade is presented in this section. Given that highway damage coefficients vary by highway, the WSDOT-PMS was used to estimate highway damages associated with the growth in NAFTA trade using Washington's three major highways (Interstate 5, U.S. 97 and U.S. 395). Each highway was divided into segments over which NAFTA trade travels. For instance, I-5 and U.S. 97 were divided into ten segments, and U.S. 395 five segments (see Appendix A, Figures A3-A5). Dividing highways into segments provides better analysis of the accumulative effect of trade on a specific segment rather than generalizing over the entire length of the highway.

Ton-miles and damage by highway segment for each highway are shown in Appendix A, Tables A1-A3. The volume of total tons (truck weight plus payload) and number of truck trips using each segment were forecasted. The WSDOT-PMS was used to evaluate those tons and trips to determine highway damage in the form of a damage coefficient. The resulting damage coefficient assumed:

- a 5-axle semi-trailer configuration (one single and two tandem axles)
- a weighted average structural number (SN, pavement condition and existing truck traffic on each highway) obtained from WSDOT-PMS
- a terminal pavement serviceability rating of 2.0– a level usually requiring reconstruction
- an 11 year design period
- a nine percent growth in truck trips.

The life cycle ESALs were estimated using SN and the WSDOT-PMS damage function. Environmental decay impacts were then subtracted from the life cycle ESALs.

Table 14--Ton Mile Estimates of the Nine Commodity Groups, Percent by Movement Type in the I-90 Corridor, 1994 and 2005

Commodity	Origin		Destination		Transit Southbound		Transit Northbound		Total	
	1994	2005	1994	2005	1994	2005	1994	2005	1994	2005
Fresh Vegetables	47.7	47.4	2.7	4.6	4.3	6.8	35.0	33.3	19.6	19.6
Fruits	11.7	12.8	0.0	0.0	0.2	0.2	6.2	6.5	3.8	3.8
Meat: Fresh, Chilled and Frozen	4.6	5.2	21.8	16.9	8.6	6.2	11.3	12.1	11.9	10.2
Canned and Preserved Fruits, Vegetables and Seafoods	10.1	16.8	2.0	4.1	0.0	0.0	16.4	26.3	6.5	10.3
Misc. Foods	2.2	4.0	0.0	0.0	10.1	16.8	4.7	8.1	4.8	8.3
Lumber	8.9	1.1	41.9	42.4	63.0	59.3	10.8	1.2	34.6	31.0
Converted Paper	9.2	7.6	10.2	5.8	8.8	4.7	14.4	11.3	10.6	7.1
Industrial Chemicals	2.1	2.3	13.1	14.8	1.3	1.3	0.7	0.7	4.2	4.7
Agricultural Chemicals	3.6	2.8	8.4	11.4	3.8	4.8	0.6	0.5	4.1	5.0
Total (millions ton miles)	109,173	135,668	152,056	203,218	188,254	270,945	153,651	199,487	603,133	809,318

The incremental damage was evaluated by multiplying 1994 trips times 2.37 ESALs per truck to get 1994 ESALs related to the commodities. Cost (unadjusted for inflation) is based on the additional depth, pro-rated from the cost per lane-mile (\$85,000 at 0.15 feet depth ACP, for a 12 foot lane). The additional design depth is the amount of highway material required to support the incremental growth in truck trips and tons. Damage coefficients are evaluated on a per ton-mile basis for Washington State and U.S. highways. The damage coefficients are then multiplied by the estimated ton-miles to determine investment requirements to maintain the major highway in each corridor.

In 1994, highway maintenance requirements for Interstate 5, U.S. 97, and U.S. 395, to sustain highway usage associated with trade, totaled \$9.1 million. Northbound movements caused 45 percent of the damage while southbound movements made up 55 percent. By 2005, highway requirements are expected to increase 148 percent to \$22.6 million with northbound movements causing 49 percent of the damage and southbound movements 51 percent (Table 15). The damage coefficients generated by the WSDOT-PMS averaged \$0.011 per ton mile where northbound movements averaged \$0.012 and southbound averaged \$0.009 per ton mile for the three highways.

Total investment requirements of all three highways are significant. As mentioned earlier, highway damage occurs through five factors, which would mean that highways are designed and constructed to meet certain minimum requirements of those factors. As such, each highway has unique characteristics and special circumstances that generate varying damage coefficients. The next section evaluates projected impacts of NAFTA trade on each highway-by-highway segment.

Table 15--Total State Damage, 1994 and 2005

Characteristic	Northbound (\$)	Southbound (\$)	State Total (\$)
Cost, 1994	4,047,032	5,040,012	9,087,044
Cost, 2005	11,125,683	11,475,156	22,600,839
Cost per ton mile	0.0120	0.0098	0.0109

Interstate 5

While it was shown that I-5 supports nearly 89 percent of total ton miles on Washington highways (Table 4), consumption use of the highway was 64 percent of the state total in 1994 at \$5.8 million and its share will fall to 61 percent of the damage while overall damage will increase to \$13.7 million by 2005, a 136 percent increase. Damage between northbound and southbound movements was even in 1994 at \$2.9 million. However, by 2005, northbound damage will increase 165 percent to \$7.7 million, while southbound damage will increase 103 percent to \$5.9 million. The greater share of northbound damage will occur as ton-miles increase more in the northbound movements than southbound. The damage coefficient for northbound movements was estimated at \$0.001 per ton-mile and southbound movements at \$0.002 per ton-mile (Table 16). Damage by individual highway segment is shown in Appendix A, Table A1. Damage is greatest near the U.S.-Canada border areas, segments A, B, and C, and segment I— a gathering area for traffic near the Washington-Oregon border and the longest segment used in the analysis of I-5, as shown in Figure A1.

Table 16--Interstate 5 Damage, 1994 and 2005

Characteristic	Northbound (\$)	Southbound (\$)	State Total (\$)
Cost, 1994	2,854,972	2,940,975	5,795,947
Cost, 2005	7,749,323	5,923,182	13,672,505
Cost per ton mile	0.0013	0.0025	0.0019

U.S. 97

Highway consumption on U.S. 97 totaled \$1.9 million in 1994. By 2005, damage will increase 163 percent to \$5 million. Northbound movements made up 35 percent of the damage in 1994 while southbound movements made up 65 percent. In 2005, northbound movements will increase 193 percent to \$2 million and southbound damage will exceed \$3 million. Incremental costs per ton-mile are about 1.2 times greater on southbound lanes at \$0.022 per ton-mile than northbound lanes. The damage coefficient for the entire U.S. 97 highway averaged \$0.02 per ton-mile (Table 17). Impact by individual highway segment is shown in Appendix A, Table A2.

Table 17--U.S. 97 Damage, 1994 and 2005

Characteristic	Northbound (\$)	Southbound (\$)	State Total (\$)
Cost, 1994	665,752	1,232,104	1,897,856
Cost, 2005	1,951,615	3,034,779	4,986,394
Cost per ton mile	0.0185	0.0223	0.0204

U.S. 395

Highway consumption on U.S. 395 was 6 percent of the three highways in 1994 at \$1.4 million. In 2005, highway damage is expected to increase 186 percent to \$4 million. Southbound lanes will suffer the most damage. In 1994, southbound damage was 62 percent of total U.S. 395 damage at \$867,000, and in 2005, southbound lanes will incur 64 percent of the damage at \$2.5 million. Northbound lanes had costs of \$526,000 in 1994 and will increase 166 percent to \$1.4 million by 2005. However, highway damage coefficients between the northbound and southbound lanes vary significantly. The northbound coefficient, \$0.016 per ton-mile, is about 3.2 times greater than the southbound coefficient of \$0.005 (Table 18). The significant difference between northbound and southbound damage estimates is attributed to greater ton-miles, heavier trucks and about twice as much additional design depth required (feet of road surface to maintain status quo) on the southbound lanes, by 2005. Damage by individual highway segment is shown in Appendix A, Table A3.

Table 18--U.S. 395 Damage, 1994 and 2005

Characteristic	Northbound (\$)	Southbound (\$)	State Total (\$)
Cost, 1994	526,308	866,933	1,393,241
Cost, 2005	1,424,745	2,517,195	3,941,940
Cost per ton mile	0.0163	0.0045	0.0104

Summary

NAFTA trade will continue to increase its presence in Washington's corridors with ton-miles increasing 30 percent by 2005. Transit movements of that trade will make up more than two-thirds of the ton-miles while the I-5 corridor will support three-quarters of the ton-miles. Investment requirements of the State of Washington to sustain the transportation of NAFTA commodities on Washington highways are expected to more than double to \$23 million by 2005.

The purpose of this study was to analyze NAFTA impacts on Washington's transportation infrastructure and the industry's need for sustainable capacity of the infrastructure to achieve the goals of free trade. The specific objectives of this study were to determine the impacted highways and the needed transportation investment to support NAFTA trade in each corridor, and assess the implications that arise from changes in NAFTA trade for Washington's corridors. Specific attention was given to NAFTA, U.S.-Canada, commodity flows on Washington highways. In this study three corridors, I-5, U.S. 97, and U.S. 395, were used to evaluate the effects of NAFTA. Highway damage was conducted on the corresponding major highway in each corridor.

The corridor analysis used evaluated the total sum of commodity movements, expressed as ton-miles, on all highways the commodities were transported on while in the corridor. Movements of commodities were identified as Washington origin, Washington destination, or Washington transit (the commodity transported neither originated nor was destined from or to locations within Washington). These movements help policy-makers determine how many ton-miles are generated within Washington (origin and destination movements) or how much is generated by non-Washington locations.

The three highways, Interstate 5, U.S. 97, and U.S. 395 form the core infrastructure within each corridor, respectively, on which NAFTA trade is transported. These highways provide an adequate basis to quantify the impacts of NAFTA, through the use of a highway damage coefficient in order to provide the magnitude of investment needed to sustain the infrastructure for free trade. Movements by highway were identified as northbound (exports to Canada) and southbound (imports from Canada). These movement types are important when estimating damage from increased trade. While it would appear that ton miles could be summed for each highway in total without respect for direction of travel, the reality is that measuring damage by direction accounts for the varying highway design and construction characteristics of each highway direction and reflects the movement demand using Washington highways, for instance, the demand of imports for sustained transportation services which is identified as southbound movements in this study. In the corridor analysis the origin and destination movements could easily be identified as northbound and southbound movements, respectively. Transit movements on the other hand, include both northbound and southbound movements.

Variation among highway damage coefficients occurs since environmental effects and highway volume differ by highway and highway segment. Damage was reported using results from the subsequent report to this study, "Impact of North American Free Trade (NAFTA) on Washington Highways, Part I: Commodity and Corridor Projections" (Eriksen and Casavant), EWITS database (EWITS, 1994), and WSDOT-PMS on the volume of NAFTA trade using Washington's major highways.

Ton-miles on the three highways are expected to nearly triple by 2005 to 8.9 billion ton-miles. Northbound movements will about triple to 6.2 ton billion miles while southbound movements will more than double to 2.7 billion ton miles. The Interstate 5 highway supports 88 percent of the ton-miles among the three highways, yet it requires 61 percent of the increased highway investment needs. The U.S. 97 and U.S. 395 highways would require 22 percent and 17 percent, of the highway needs respectively, to sustain NAFTA shipments on Washington highways. Northbound movements make up 70 percent of the ton-miles while southbound movements would demand 51 percent of the investment requirements. The U.S. 97 highway pavement conditions, reflected by a higher damage coefficient, are worse than Interstate 5 and U.S. 395. Its highway damage coefficient (both northbound and southbound movements) of \$0.0121 per ton-mile is about seven times greater than Interstate 5's and half as much greater than U.S. 395's, and is about 1.1 times greater than its southbound coefficient.

Damage per ton-mile for southbound movements is expected to be \$0.0042 per ton-mile, which is about 2.5 times greater than northbound movement estimates. The higher southbound damage coefficient is attributed to the heavier trucks traveling southbound, where the average southbound truck weight, 37.8 tons (39.6 tons on the U.S. 395 highway) is heavier than the northbound movement average weight of 34.1 tons.

Specific attention must be committed to transit movements since they make up the bulk of the ton miles and are heavier loads being transported greater distances on Washington highways. Washington's infrastructure supports NAFTA trade, yet the associated benefits received for that trade may not necessarily be in proportion to the costs associated with transportation characteristics on that trade on Washington highways. A means to internalize the benefits and costs within the state is needed.

NAFTA trade is certain to increase on Washington's highways. If infrastructure investment is not adequate to sustain Washington's highways at serviceable levels, trade flows will be impeded and the associated highway damage of that trade will increase substantially as highway deterioration is accelerated. The incidence of NAFTA trade varies by corridor. Thus, highway impacts vary by corridor. However, the present serviceable levels of highways among corridors may vary and serviceable levels of highways within corridors may vary. As such, attention to highways in the corridors with low serviceable ratings should be given priority; otherwise changes in NAFTA trade may significantly deteriorate those highways over the next seven years.

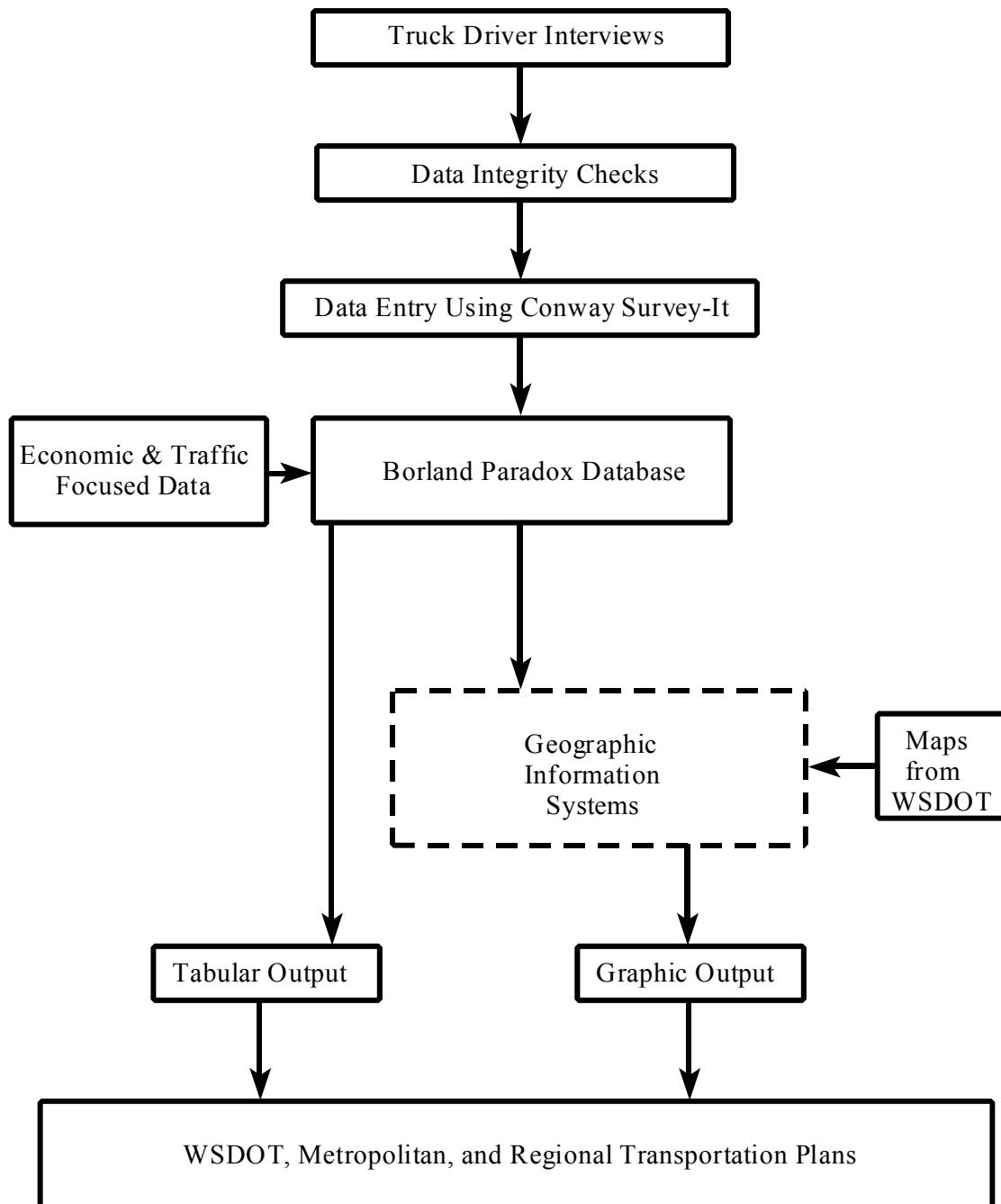
References

- Bitzan, John, Joel Honeyman, Denver Tolliver, and Ken Casavant. The Impact of Rail Restructuring on Rural and Agricultural America, Case Studies of Rail Abandonment. Upper Great Plains Transportation Institute, North Dakota State University, Fargo, 1996.
- Casavant, Kenneth L. and J. C. Lenzi. Procedure for Predicting and Estimating the Impact of Rail Line Abandonments on Washington Roads. Washington State Department of Transportation, Olympia, November 1989.
- Eastern Washington Intermodal Transportation Study. Washington State Freight Truck Origin and Destination Database. Washington State University, Department of Agricultural Economics, Pullman, 1994.
- Eriksen, Ken A. and Kenneth L. Casavant. Impact of North American Free Trade Agreement (NAFTA) on Washington Highways Part I: Commodity and Corridor Projections. Eastern Washington Intermodal Transportation Study Report #14, Washington State University, Department of Agricultural Economics, Pullman, January 1997.
- Federal Highway Administration. U.S. Department of Transportation. Descriptive Report of Cross-Border Traffic and Transportation in the Western U.S.-Canada Region. Washington D.C.: U.S. Department of Commerce National Technical Information Service, September 1993.
- Gillis, William R. and Kenneth L. Casavant. Washington State Freight Truck Origin and Destination Study: Methods, Procedures, and Data Dictionary. Eastern Washington Intermodal Transportation Study Report #3. Washington State University, Department of Agricultural Economics, Pullman, December 1994.
- Gillis, William R., Eric L. Jessup and Kenneth L. Casavant. Movement of Freight on Washington's Highways: A Statewide Origin and Destination Study. Eastern Washington Intermodal Transportation Study Report #9. Washington State University, Department of Agricultural Economics, Pullman, November 1995.
- Jessup, Eric L. Transportation Optimization Marketing for Commodity Flow, Private Shipper Costs, and Highway Infrastructure Impact Analysis. Ph.D. Dissertation, Washington State University, Pullman WA, May, 1998.
- Schaeffer, Cathy J. and Thomas I. Wahl. The North American Free Trade Agreement: Effects on Washington State Agriculture. Information Series Report #67, IMPACT Center, Washington State University, Pullman, June 1993.
- Tolliver, Denver. Highway Impact Assessment. Westport, Connecticut: Quorum Books, 1994.
- U.S. Department of Commerce, U.S. Bureau of the Census. Cross-border data. Washington D.C., March 1996.
- World Bank. The International Bank for Reconstruction and Development. World Tables. Washington D.C., 1995.

Appendix A

Modeling Framework, Projection Procedure Model,
Ton Miles and Damage by Highway Segment

Figure A.1: Data Management, Analysis and Modeling Framework



Source: Gillis, William R. and Kenneth L. Casavant. Washington State Freight Truck Origin and Destination Study: Methods, Procedures, and Data Dictionary. Eastern Washington Intermodal Transportation Study Report #3. Washington State University, Department of Agricultural Economics, Pullman, December 1994

Figure A.2: NAFTA Projections Procedure Model

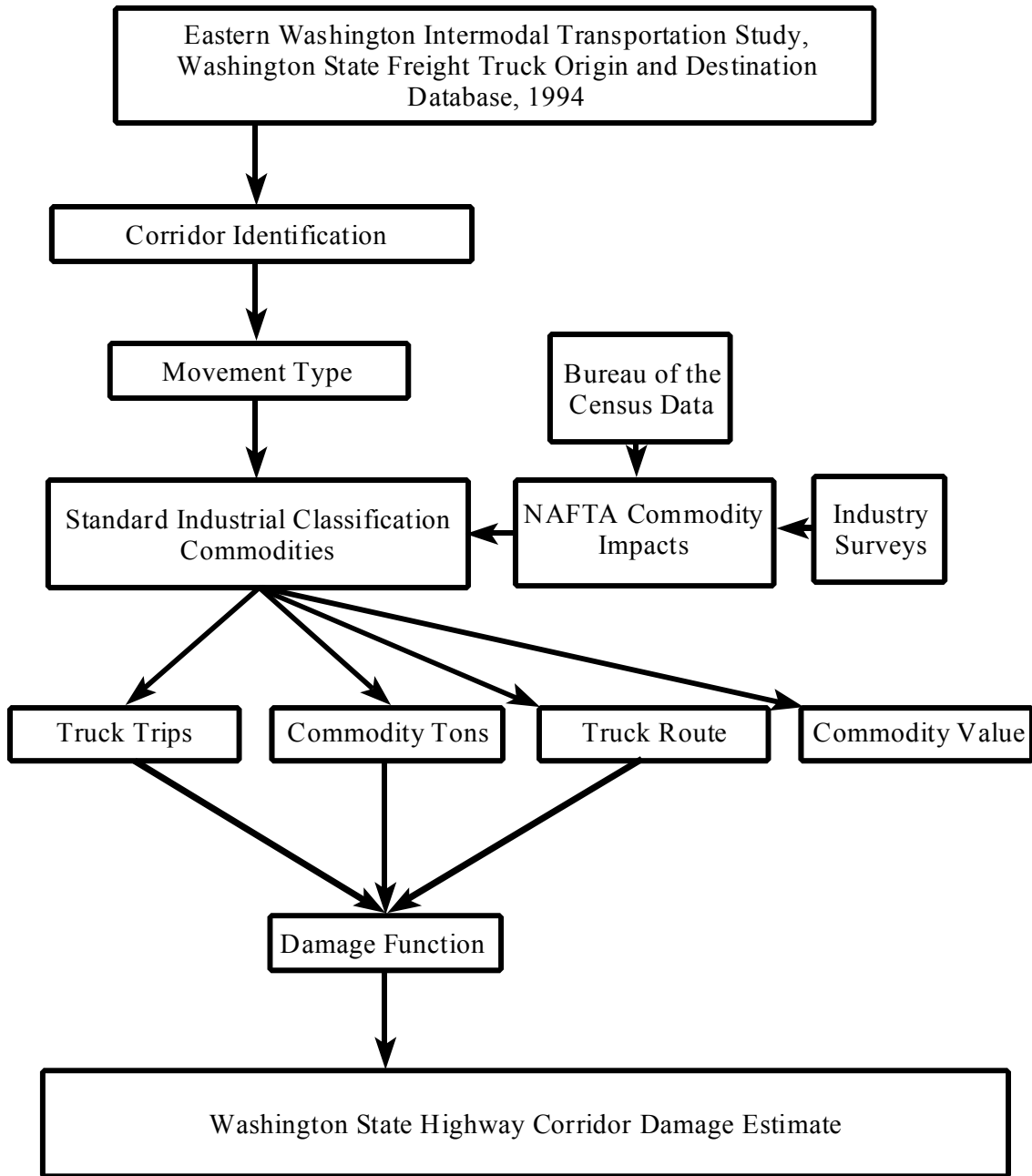
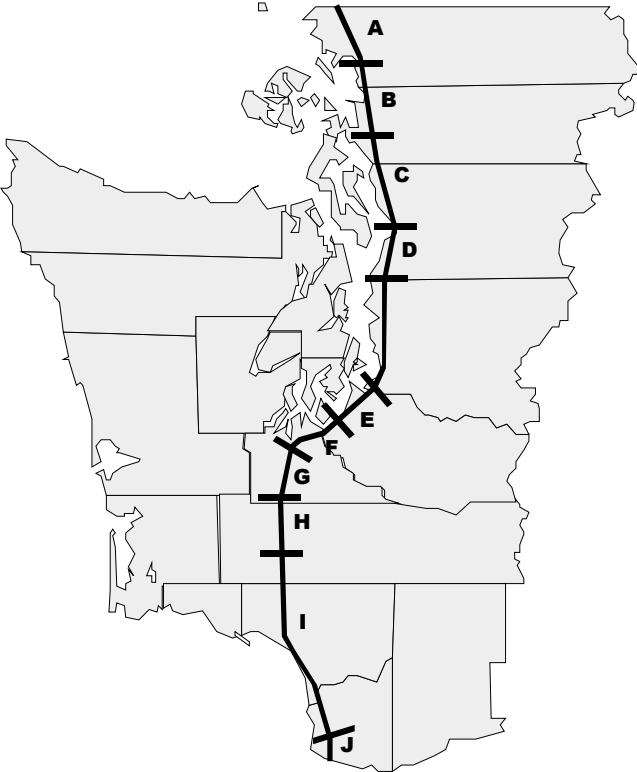


Figure A.3: Interstate 5 Highway Segments Used to Support NAFTA Commodities



Interstate 5

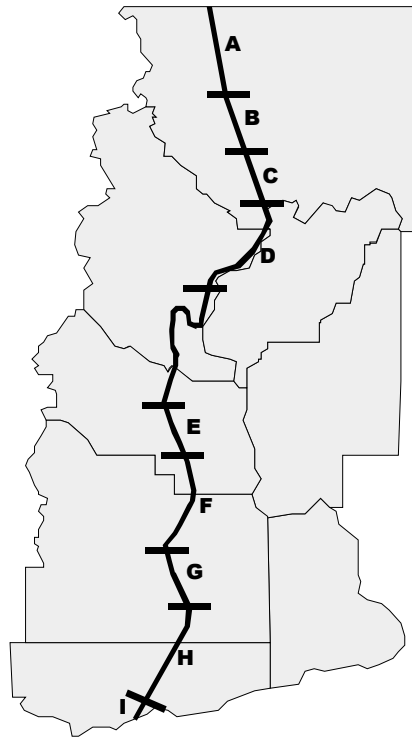
Table A.1a--Ton Miles and Damage of Northbound Movements (U.S. Exports) to Canada Using Interstate 5, by Highway Segment, 1994 and 2005

Segment	Ton Miles 1994	Ton Miles 2005	Cost per Ton Mile (\$)	Damage 1994 (\$)	Damage 2005 (\$)
A	217,800,530	591,181,559	0.0017	370,261	1,005,009
B	252,551,635	685,507,374	0.0016	404,083	1,096,812
C	367,268,327	996,885,830	0.0017	624,356	1,694,706
D	109,694,955	297,747,826	0.0011	120,664	327,523
E	54,331,611	147,473,683	0.0011	59,765	162,221
F	260,883,422	708,122,558	0.0011	286,972	778,935
G	134,481,196	365,025,757	0.0010	134,481	365,026
H	167,722,794	455,254,277	0.0011	184,495	500,780
I	505,440,592	1,371,930,349	0.0011	555,985	1,509,123
J	67,006,007	181,876,123	0.0017	113,910	309,189
Total	2,137,181,068	5,801,005,335	0.0013	2,854,972	7,749,323

Table A.1b--Ton Miles and Damage of Southbound Movements (U.S. Imports) from Canada Using Interstate 5, by Highway Segment, 1994 and 2005

Segment	Ton Miles 1994	Ton Miles 2005	Cost per Ton Mile (\$)	Damage 1994 (\$)	Damage 2005 (\$)
A	116,918,780	235,476,743	0.0017	198,762	400,310
B	135,573,725	273,048,172	0.0032	433,836	873,754
C	197,650,905	398,072,845	0.0028	553,423	1,114,604
D	59,026,368	118,880,276	0.0023	135,761	273,425
E	25,333,447	51,022,066	0.0023	58,267	117,351
F	118,811,646	239,289,012	0.0019	225,742	454,649
G	56,261,074	113,310,919	0.0015	84,392	169,966
H	66,651,379	134,237,200	0.0012	79,982	161,085
I	200,857,091	404,530,167	0.0055	1,104,714	2,224,916
J	25,422,162	51,200,738	0.0026	66,098	133,122
Total	1,002,506,578	2,019,068,137	0.0025	2,940,975	5,923,182

Figure A.4: U.S. 97 Highway Segments Used to Support NAFTA Commodities



U.S. 97

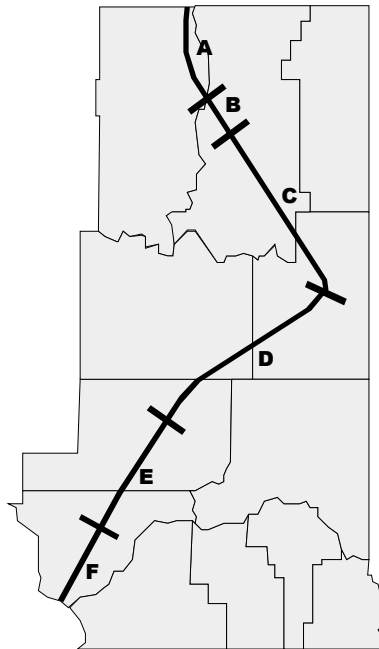
Table A.2a--Ton Miles and Damage of Northbound Movements (U.S. Exports) to Canada Using Interstate 5, by Highway Segment, 1994 and 2005

Segment	Ton Miles 1994	Ton Miles 2005	Cost per Ton Mile (\$)	Damage 1994 (\$)	Damage 2005 (\$)
A	1,989,078	5,830,874	0.0175	34,809	102,040
B	2,912,104	8,536,673	0.0215	62,610	183,538
C	3,276,117	9,603,758	0.0172	56,349	165,185
D	5,996,662	17,578,887	0.0058	34,781	101,958
E	896,556	2,608,205	0.0470	42,138	123,526
F	21,570,901	63,233,919	0.0072	155,310	455,284
G	4,623,089	13,552,332	0.0100	46,231	135,523
H	19,351,940	56,729,155	0.0117	226,418	663,731
I	755,913	2,215,917	0.0094	7,106	20,830
Total	61,372,358	179,909,720	0.0185	665,752	1,951,615

Table A.2b--Ton Miles and Damage of Southbound Movements (U.S. Imports) from Canada Using Interstate 5, by Highway Segment, 1994 and 2005

Segment	Ton Miles 1994	Ton Miles 2005	Cost per Ton Mile (\$)	Damage 1994 (\$)	Damage 2005 (\$)
A	16,434,752	40,480,219	0.0093	152,843	376,466
B	16,793,130	41,362,936	0.0094	157,855	388,812
C	16,983,438	41,831,682	0.0088	149,454	368,119
D	22,034,765	54,273,539	0.0087	191,702	472,180
E	3,999,427	9,850,935	0.0167	66,790	164,511
F	12,423,595	30,600,391	0.0230	285,743	703,809
G	1,354,111	3,335,292	0.0376	50,915	125,407
H	4,231,639	10,422,894	0.0402	170,112	419,000
I	119,234	293,684	0.0561	6,689	16,476
Total	94,374,091	232,451,571	0.0223	1,232,104	3,034,779

Figure A.5: U.S. 395 Highway Segments Used to Support NAFTA Commodities



U.S. 395

Table A.3a--Ton Miles and Damage of Northbound Movements (U.S. Exports) to Canada Using U.S. 395, by Highway Segment, 1994 and 2005

Segment	Ton Miles 1994	Ton Miles 2005	Cost per Ton Mile (\$)	Damage 1994 (\$)	Damage 2005 (\$)
B	1,163,724	3,150,266	0.0209	24,322	65,841
C	8,483,546	22,965,441	0.0157	133,192	360,557
D	29,983,288	81,166,461	0.0123	368,794	998,347
Total	95,314,358	258,021,375	0.0163	526,308	1,424,745

Table A.3b--Ton Miles and Damage of Southbound Movements (U.S. Imports) from Canada Using U.S. 395, by Highway Segment, 1994 and 2005

Segment	Ton Miles 1994	Ton Miles 2005	Cost per Ton Mile (\$)	Damage 1994 (\$)	Damage 2005 (\$)
A	17,246,279	50,075,672	0.0017	29,319	85,129
B	5,541,864	16,091,154	0.0069	38,239	111,029
C	40,400,185	117,304,514	0.0049	197,961	574,792
D	40,983,401	118,997,917	0.0081	331,966	963,883
E	26,335,641	76,467,213	0.0092	242,288	703,498
F	24,691,824	71,694,287	0.0011	27,161	78,864
Total	155,199,194	450,630,757	0.0045	866,933	2,517,195