Port-to-Port Transportation Corridor Earthquake Vulnerability

This study was accomplished as part of
Project Impact - A Partnership between King and Pierce Counties, "Creating Disaster Resistant Communities"

USGS
science for a changing world

Washington State
Department of Transportation

Western States
Seismic Policy
Council

US Department
of Transportation

Pierce County

King County

EQE International

Note – this report is intended to be used with the project web site: www.rspa.dot.gov/oet, then select Special projects. The web site contains all the project result maps and graphics, none of which are included herein. However, this report contains all of the economic impact findings, none of which are not included on the web site. Alternatively, some of the project maps and graphics are contained in a 16-page color brochure entitled "Port to Port Transportation Corridor Vulnerability Mitigation".

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Executive Summary

In the late 1990's,the Federal Emergency Management Agency (FEMA) initiated a nationwide program called Project Impact. The impetus for this effort was to promote public and private partnerships which would focus on pre-disaster mitigation to reduce the cost and impact of recurring natural disasters. Both King and Pierce Counties were separately awarded individual agency grants to promote disaster resistant communities in their jurisdictions.

King and Pierce Counties agreed to work together beginning in 1998 on pre-disaster mitigation. This was done for two reasons: 1) Disasters do not recognize artificial jurisdictional boundaries; and 2) it was the Counties' intent to engage regional businesses in partnering in mitigation activities. Subsequently the Counties formed a legal partnership via an interlocal agreement for the purposes of collectively addressing pre-disaster mitigation.

In the Fall of 1998 King and Pierce Project Impact jointly hosted a meeting with approximately over 40 community representatives from the public and private sectors to solicit their input on what hazards should be addressed, and which mitigation activities would be of value to our region. The greatest interest from the group was in investigating the seismic vulnerabilities of our transportation network within the Central Puget Sound Region. Transportation was seen as being vital to our economy, impacting every facet of our individual, business and community well-being.

A significant amount of time was spent in a scoping exercise, in determining what segment of our transportation network could be examined based upon time and resources available. After much discussion and consultation with the partnering organizations iThe Counties determined to use the south-north I-5 corridor running from the Port of Tacoma to the Port of Seattle. The study area includes the main transportation routes of I-5, and Highways 99 and 167 and one short east-west segment of I-405. No major bridge structures or other routes were included because of the lack of resources to perform an accurate and in-depth study.

Coordination meetings were held with partners on a routine basis with additional meetings conducted between consulting technical agencies and personnel. Significant contributions to the study came from:

- United States Geological Survey (USGS)-who provided earthquake scenarios and projected ground motions based upon the three major sources of earthquakes in the region.

- Washington State Department of Natural Resources (DNR) who provided soil analysis, including liquefaction information for the segment of the transportation network being studied.

- Washington State Department of Transportation (WSDOT) provided construction data on the individual bridges that make up the road network.

- ABS Consulting (formerly EQE International) pulled the above pieces together and provided the analysis to estimate individual bridge and route performance under six separate earthquake scenarios.

- University of Washington Geography Department provided an economic impact assessment of transportation system outages to businesses and the community at large

- Both King and Pierce Counties performed separate contingency planning scenarios to determine the impact of a studied route being made unavailable and how that would effect local arterials, and how detours might be managed to alleviate the expected traffic jams.

Findings from the study are detailed within this document. In the worst case scenario of a Seattle Fault (a shallow earthquake) up to 40 bridges lying between the Port of Tacoma and the Port of Seattle have a significant risk of failing. Both deep earthquakes, of the type of the Nisqually Earthquake, and a subduction event do not have the same levels of risk, but there are lower percentages of bridges at risk within the study area. For a complete presentation on bridge performance, should go to http://www.rspa.dot.gov/oet/ and click on "Special Studies."

The economic impact studied only one earthquake scenario which was a deep earthquake centered under the City of SeaTac. This therefore should not be considered a worst case scenario. However, the projected economic impact is severe. The earthquake's transportation related effects could mean

- reduced business revenues of $3 billion;
- loss of 39,000 jobs costing over $1 billion in income,
- and tax losses to local government of $72 million.

Trucking firms, port related businesses, "just-in-time" manufacturers and retailers depending on customer access to stores could be hard hit. Small businesses without financial reserves could face bankruptcy. Furthermore, these estimates of economic loss are based only on the study area, and not the entire region.

The contingency planning efforts by both counties revealed significant challenges in redirecting up to 200,000 cars per day (I-5) onto surface streets. Simultaneous route outages could bring traffic to a standstill, with few arterial substitutes to carry daily traffic. Earthquake damage to multiple bridges would disable entire routes for up to three to six months. One of the major benefits of this multi-jurisdictional contingency planning was that it brought together transportation planners for the first time to address these types of issues.

This study is only a beginning. Expansion of this work is needed to give a complete picture of the seismic risks our region faces when we experience an earthquake. It is vital to the economic well-being of Washington State that the study be expanded to do the entire I-5 corridor from Olympia to Everett and include I-90, Highway 520, and all of

I-405 in the study. Additional funding to accomplish this work is currently not programmed.

King and Pierce County Emergency Management agencies are grateful to all our partners for their participation in conducting this study of our transportation system's seismic vulnerability. We have learned from one another and forged new public and private bonds that are being expanded upon in numerous areas of intergovernmental and public-private cooperation and coordination. Together we will continue to seek new ways to build disaster resistant communities right here in the Puget Sound Region.

1. Introduction

1.1. Economic Importance

Washington is the most trade-dependent state in the country, where one in four jobs rely on international trade. The airplane, software, financial, forest product, and biomedical industries are all key to the region's economic success. Two and a half million people (40% of the State population) reside along the north-south corridor supporting these industries. One hundred billion dollars in goods moves through the ports of Seattle and Tacoma annually. Much of the cargo, 60 percent, moves through the region to inland domestic markets. The Puget Sound region accounts for seven percent of the nation's international trade, but is home to only one percent of the population. In the highly competitive import-export shipping business, disruption of service from a disaster could deal a terrible blow to the Puget Sound economy, shifting business to foreign and domestic West Coast ports.

In this region, the I-5 corridor is funneled by the Cascade Mountains to the east, and the Puget Sound to the west, so there is minimal transportation "redundancy" in the event one of the major routes is damaged in an earthquake. The I-5 corridor moves about 200,000 vehicles per day north south between Tacoma and Seattle, where most of region's businesses are located. Parallel routes, including SR-167 and SR-99, have a total capacity about half that of I-5, and are already jammed. Boeing (the nation's largest exporter) is dependent on moving airplane components along the corridor, as part of their manufacturing process. All employers depend on the corridor to get people to work to ship and receive goods, and for access of customers.

1.2. Project Impact

In 1998, Washington's King and Pierce counties combined their Project Impact funding to address regional issues. When they convened a group of public and private sector citizens and asked them to identify their greatest concern following a disaster, the overriding consensus was transportation. Not only is transportation critical to provide emergency response but it provides the lifeblood to maintain the long-term economic vitality of the region. And transportation systems in the Pacific Northwest are already at maximum capacity.

With that direction the counties developed a project to evaluate the post-earthquake reliability of a key section of the regional transportation system, and if it were not operational, to estimate the regional economic impact. Consulting with their partners, the Counties defined the study area as the "Port to Port" Corridor connecting the nation's fifth and sixth busiest container ports: Seattle and Tacoma. Ultimately, the counties are planning to use the project results to help spur development and implementation of effective mitigation strategies.

Additionally, this project can serve as a model for similar vulnerability studies of other critical transportation corridors.

1.3. Project Objectives

Based on the background presented above, the project team established the following five project objectives:

1. Engage business and government participation.
2. Evaluate post-earthquake transportation system survivability.
3. Develop an emergency response and recovery plan.
4. Estimate the economic impact of transportation system outage.
5. Promote mitigation of high-risk bridges on critical lifeline corridors.

These were used to formulate the project approach, and as guidance throughout the project.

1.4. National Marine Transportation System

One of the driving forces behind the project was dependence on the ports. On November 13, 1998, U.S. Congress directed the Secretary of Transportation to "…establish a task force to assess the adequacy of the Nation's marine transportation system (including ports, waterways, harbor approach channels, and their intermodal connections) to operate in a safe, efficient, secure, and environmentally sound manner." The Task Force was to consider the capability of the nation's marine transportation system, the adequacy of the depth of channels and harbors, and the cost to the Federal government of accommodating projected increases in foreign and domestic traffic over the next 20 years.

The findings of the Task Force were published in September 1999 as "An Assessment of the U.S. Marine Transportation System" [www.dot.gov/mts/report/]. The Executive Summary notes, "As the world's leading maritime and trading nation, the United States relies on an efficient and effective MTS to maintain its role as a global power. The MTS provides American businesses with competitive access to suppliers and markets in an increasingly global economy."

This statement confirms the view of the King-Pierce Project Impact's Port to Port Transportation Corridor Seismic Vulnerability study team's thesis that our port's transportation corridors are, indeed, a critical component of a local, regional and national transportation system critical to our nation's economy and national security.

1.5. Project Approach

The project carried out a four-step evaluation process to estimate the earthquake risk associated with the transportation corridor.

1. Hazard assessment - quantifying hazards, including ground motions and liquefaction
2. Loss estimation - evaluating individual bridge vulnerability/reliability, route reliability, and recovery time.
3. Economic analysis - estimating the regional economic impact if the corridor is disrupted.
4. Contingency planning – developing plans to detour around key collapsed bridges.

HAZUS was used as the platform to integrate the hazards and individual reliabilities. HAZUS 99 (the version that was current when this study was performed) is an earthquake loss estimation software developed and funded by FEMA to help communities to prepare, plan, and build stronger and safer communities. Documentation for HAZUS can be found as a link on this projects web site. Among many HAZUS 99 uses are analysis of disaster-related damages; identification of vulnerable areas; assessment of vulnerability of housing, essential facilities and lifelines; estimation of potential losses; and aid in development of response and recovery plans.

The HAZUS 99 earthquake loss estimation methodology for highway transportation systems, and in particular for highway bridges is described herein.

Highway transportation systems generally consist of roadways, bridges, and tunnels. Road damage occurs due to surface fault ruptures or extreme soil failure. Bridge damage can occur due to extreme ground shaking and or site soil failure. Loss of bridge function usually results in significant disruption to the transportation network, and thus is a key component to reliability of these lifelines. The project focuses on the lost estimation methodology utilized in HAZUS 99 for bridges.

The reliability of individual bridge structures was estimated based on the local earthquake hazards, the bridge structural design characteristics, and performance of similar structures in previous earthquakes. Most of the bridges along the I-5 corridor were constructed before the mid-1970s, when more rigorous seismic design codes were initiated.

The reliability of the transportation corridor "system" was estimated by combining the reliabilities of the individual bridge structures. The reliability of each bridge in a linear system such as I-5 has a dramatic impact on the overall route reliability. In the Puget Sound region, there are limited redundant routes compared to the grid, or network of highways that were available in Los Angeles following the Northridge Earthquake.

The potential regional economic impact was estimated considering the likely bridge/highway segment outage time, associated increased travel times, and the resulting impact on a cross section of the region's employers.

Contingency planning was developed by stakeholders with interests in each county including the counties (public works and sheriffs), cities, the WSDOT, and the State Police.

1.6. Project Partners

One of the key aspects of Project Impact is the participation of project partners. King and Pierce Counties Project Impact partners included a significant list of active participants from both the private and public sector as shown below.

Private

ABS Consulting (formerly EQE)
American Red Cross
Bank of America
Boeing Employees Credit Union (BECU)
Boeing
Burlington Northern Santa Fe Railroad (BNSF)
Frank Russell Company
Gordon Trucking
KOMOABC4
Microsoft
Olympic Pipe Line (now BP AMOCO)
Tacoma-Pierce County Chamber of Commerce
Western States Seismic Policy Council (WSSPC)

Public

Federal Emergency Management Agency (FEMA)
King County
Pierce County
Port of Seattle
Port of Tacoma
Sound Transit
University of Washington (UW)
U.S. Department of Transportation (USDOT)
U.S. Geological Survey (USGS)
Washington Military Department, Emergency Management Division (EMD)
Washington Department of Community, Trade and Economic Department (WSDCTED)
Washington State Department Natural Resources (DNR)
Washington State Department of Transportation (WSDOT)

1.7. Report Organization and Work Products

This report is divided into nine sections as follows:

1. Introduction – this section.
2. Hazard Assessment – the US Geological Survey (USGS) provided the earthquake scenario ground motions, the Washington State Department of

Natural Resources (DNR) provided liquefaction and soils mapping, and ABS Consulting (formerly EQE) evaluated site amplification.

3. Engineering Analysis – the Washington State Department of Transportation provided the bridge data and provided guidance on use of that data. ABS Consulting conducted the engineering analysis with the use of HAZUS to assist in data analysis.

4. Economic Analysis – Dr. Stephanie Chang and Dr. William Beyers, both of the University of Washington, performed the economic analysis.

5. Contingency Planning – King and Pierce Counties emergency management, public works, and sheriffs, and the Washington State Police developed contingency plans based on the outage scenarios.

This report should be used in conjunction with two other documents:

1. Port-to-Port Transportation Corridor Vulnerability Mitigation Brochure, a 16 page color document showing many maps and graphics used in developing the project.

2. Port to Port Transportation Corridor Vulnerability [www.rspa.dot.gov/oet/ (click on "special studies")]. – a web site that shows a comprehensive set of maps and graphics developed during the project.

2. Hazard Assessment

2.1. Introduction

A hazard assessment was performed for six earthquake scenarios. Ground motion assumptions were developed, site amplification estimates applied, and liquefaction susceptibility mapping prepared.

Ground motions were develop outside HAZUS due to the limitations of HAZUS generated scenarios. HAZUS does not allow site amplification of user supplied ground motions within the program, so “amplified” ground motions were input into HAZUS.

The scenario ground motion approach was selected rather than using probabilistic ground motions. The premise of probabilistic ground motions is that they will not be exceeded over the associated return period. This may result in overestimating the impact as several different earthquakes may contribute to those ground motions. Ground motions for scenario were used to better approximate what may occur for a single event.

Further information on the input hazard information for HAZUS can be found in Chapter 4 of the HAZUS Technical Manual, Potential Earth Science Hazards (PESH). Refer to the project web site for a link to the HAZUS web site.

2.2. Pacific Northwest Earthquakes

The Puget Sound is vulnerable to earthquakes from three sources each represented in the scenarios under evaluation. The USGS provided ground motions for six earthquake scenarios.

The scenarios are based on the same ground-motion prediction relations used in the 1996 national seismic hazard maps. The scenario maps are for a NEHRP B-C boundary site with an average shear-wave velocity in the top 30m of 760 m/sec. All magnitudes cited are moment magnitudes. The scenario maps were produced for median values of the peak horizontal ground acceleration and 0.3 and 1.0 sec spectral accelerations (5% of critical damping). The following is a description of each scenario.

Crustal Earthquakes: Seattle, Tacoma, South Whidbey Island faults have been identified, each of which are capable of producing ground motions comparable to the Northridge and the Great Hanshin (Kobe, Japan) earthquakes. Paleoseismic evidence identified by the USGS, a Project Impact partner, recorded an event in approximately 900 AD that caused a vertical offset of 22 feet across Puget Sound. The scenarios modeled included:

- Seattle Fault M6.5: The fault strikes east-west and has a length of 20 km and a downdip width of 12 km. The fault dips to the south at 20 degrees. The shallowest (northern) edge of the fault is at a depth of 7 km. For all crustal fault scenarios, we used the ground motions averaged from the relations of Boore et al. (1997), Sadigh et al. (1997), and Campbell (1997).

- Seattle Fault M7.0: The fault strikes east-west with a length of 40 km and downdip width of 19 km. The fault dips 45 degrees to south, with its shallowest (northern) edge at 3 km depth.

- Tacoma Fault, M6.7: This fault is poorly known and its trace is highly uncertain. The length of the fault is 32 km, with a 12 km downdip width. The assumed fault had a 3 km minimum depth and dips to the north at 45 degrees.

Cascadia Subduction Zone earthquake – an earthquake with an estimated magnitude of 9 occurred along the Pacific coast 300 years ago, and produced “minutes” of shaking. The scenario modeled was:

- Cascadia M9.0: We used the plate interface geometry of Fluck et al. (1997) for the rupture zone of this fault. The eastern edge of the rupture zone was taken to be the base of the elastic zone from their model. We used the Youngs et al. (1997) attenuation relations for interface earthquakes.

Deep (Benioff Zone) earthquakes have guided the development of building codes. Six magnitude 6+ earthquakes have occurred over the last century, including the magnitude 6.8 Nisqually Earthquake on February 28, 2001. The two scenarios modeled were:

- Benioff zone M6.5: We used the hypocenter of the 1965 earthquake: latitude 47.4 N longitude 122.3 W, depth of 59 km. We applied the Youngs et al. (1997) attenuation for intraslab earthquakes.
- Benioff zone M7.1: We used the same hypocenter as the 1965 earthquake.

The contribution from each of these is being considered in evaluation of the earthquake risk. This new understanding of our regional seismicity is pushing earthquake hazard levels in the central Puget Sound, approaching those in Los Angeles and San Francisco.

2.3. Site Amplification

Site amplification for peak ground acceleration and 1-second spectral acceleration were taken as developed in NEHRP, and applied in HAZUS. The amplification values were renormalized to better represent the their original basis.

2.3.1. Soils Map

The soils map used as a basis for the site amplification was provided by the Washington State Department of Natural Resources.

2.3.2. Peak Ground Acceleration

The “original” site amplification values shown in Table 2.1 are based on a site amplification of 1 for site class B that has a mean shear wave velocity of 1130 m/sec. The attenuation relationships used to estimate ground motion are from: Boore and

Joyner, Sadigh, and Campbell (weighted equally). The shear wave velocities used in their attenuation relationships are 760, 620, and 420 m/sec, respectively. The geometric mean of the 3 is 580 m/sec, close the mean shear wave velocity of site class C (560 m/sec). Therefore the values were renormalized, by dividing the original amplification by the site class C amplification factor for the particular ground motion range. The results are shown in Table 2.1.

The scenario peak ground accelerations were amplified by these values and used as input to HAZUS for calculation of liquefaction probability.

Table 2.1

SITE AMPLIFICATION FOR PEAK GROUND ACCELERATION

Spectral Acceleration	S_s<= 0.25	S_s= 0.50	S_s= 0.75	S_s= 1.00	S_s= 1.25
Site Class\PGA	PGA<= 0.10	PGA=.20	PGA=.30	PGA=.40	PGA=.50
Original Amplification Values					
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	
Modified Amplification Values for Port to Port project					
A	0.7	0.7	0.7	0.8	0.8
B	0.8	0.8	0.9	1.0	1.0
C	1.0	1.0	1.0	1.0	1.0
D	1.3	1.2	1.1	1.1	1.0
E	2.1	1.4	1.1	0.9	
Note: PGA capped at 45% g in site class E soils					

2.3.3. 1 Second Spectral Acceleration

The original site amplification values are based on a site amplification of 1 for site class B that has a mean shear wave velocity of 1130 m/sec. The attenuation relationships used to estimate ground motion are from: Boore and Joyner and Sadigh (weighted equally). The shear wave velocities used in their attenuation relationships are 760 and

620 m/sec, respectively. The geometric mean of the 2 is 686 m/sec, approximately 0.75 of the way between 1130 m/sec (site class B) and 560 m/sec (site class C mean shear wave velocity). The amplification values were renormalized by dividing the original amplification value by the (site class C amplification factor to the 0.75 power) X (site amplification factor for site Class B to the 0.25 power [which is 1] for the particular ground motion range. For example. for Ss<= 0.1 site class E, the new site amplification factor = 3.5/(1.7^0.75 * 1.0^0.25) = 2.4. The results are shown in Table 2.2.

The scenario 1 second spectral accelerations were amplified by these values and used as input to HAZUS for calculation of bridge reliability.

Table 2.2

SITE AMPLIFICATION FOR 1 SECOND SPECTRAL ACCELERATIONS

Spectral Acceleration/Site Class	S_s<= 0.1	S_s= 0.2	S_s= 0.3	S_s= 0.4	S_s>= 0.5
Original Amplification Values					
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	
Modified Amplification Values for Port to Port project					
A	0.5	0.6	0.6	0.6	0.7
B	0.7	0.7	0.7	0.8	0.8
C	1.1	1.1	1.1	1.1	1.1
D	1.6	1.4	1.3	1.2	1.2
E	2.4	2.2	2.1	1.9	

2.4. Generation of Liquefaction Hazard Maps for HAZUS

The Washington State Department of Natural Resources provided liquefaction mapping. Liquefaction and lateral spread can have a dramatic impact on bridge foundations and highways segments. The Puget Sound region has a higher potential for liquefaction than many other areas, because of high water tables in river valleys with young geologic deposits, such as in the Kent and Duwamish river valleys. Liquefaction can result in loss of bearing, and lateral movement (spread) can occur, measured in meters.

HAZUS uses liquefaction susceptibility map data in determining a conditional liquefaction probability used in subsequent damage-state calculations. The program translates a relative liquefaction susceptibility (ranging from very high to none) into a conditional liquefaction probability using a simplified version of a relationship presented by Liao and others (1988). The conditional probabilities are adjusted for earthquake magnitude (duration) effects and variation in the depth to groundwater. These probabilities are then used to calculate the expected permanent ground displacement both from lateral spreading and settlement. The permanent ground displacements then modify direct damage estimates.

Liquefaction susceptibility mapping at a scale of 1:24,000 was available for the entire study area. Sources of these map data are summarized in Table 2.3, including reference citations. The individual maps were merged into a single GIS map coverage (originally ArcInfo and converted into MapInfo), and liquefaction susceptibility ratings were assigned to correspond to the HAZUS rating system. The relation between HAZUS liquefaction susceptibility and ground settlement amplitude (Table 3.15, HAZUS Technical Manual (1997), Volume I) was used in making these assignments. Table 2.4 summarizes the HAZUS liquefaction susceptibility with the geologic deposits delineated on the available liquefaction mapping.

Table 2.3

LIQUEFACTION MAPPING DATA SOURCES

Geographic Area	*Map Data Sources*
Seattle urban area	Grant and others (1998)
Greater Eastside (Bellevue-Redmond)	Palmer and others (2001, in press)
Kent Valley (Renton-Auburn-Sumner)	Palmer and others (1994) – northern Kent Valley Palmer and others (1995) – southern Kent Valley Palmer (1995) – Sumner area
Tacoma urban area – Puyallup Valley	Shannon and Wilson, Inc. (1993), Palmer and others (in preparation)

Table 2.4

CORRELATION OF GEOLOGIC DEPOSITS AND HAZUS LIQUEFACTION SUSCEPTIBILITY

Geologic Deposit	HAZUS Liquefaction Susceptibility
Artificial fill	Very high (major fills) or high (minor fills)
Abandoned or avulsed channels in the Kent Valley and Sumner areas	Very high
Holocene alluvium in the Puyallup River valley	Very high
Holocene alluvium in the Kent Valley and minor drainages	High
Holocene landslide and mass wasting deposits	Moderate
Holocene beach deposits	Moderate
Vashon sandy recessional outwash and lake deposits	Moderate
All other Pleistocene deposits	Very low
Bedrock	None

3. Engineering Analysis

The engineering methodology is described in this section. Refer to the associated project web site for the results (www.rspa.dot.gov/oet then click on special studies).

3.1. HAZUS Highway Bridge Damage Functions

3.1.1. General Model

Earthquake damage can be estimated for various transportation components based on anticipated ground accelerations and ground deformation. The required data to estimate bridge damage includes:

- Geographical location
- Longitude and latitude
- Bridge classification (structure type)
- Site spectral accelerations at 0.3 seconds and 1.0 seconds and permanent-ground deformation (PGD)
- Peak-ground acceleration (for PGD-related calculations)

HAZUS 99 (refer to the project web site for links to the HAZUS 99 reference documents) classifies bridges into 28 categories based on the following structural characteristics:

- Seismic design
- Number of spans
- Structure type and material

- Pier type
- Abutment type
- Span continuity

General bridges with good seismic design features can accommodate relatively higher seismic input and allowable drift limits. The general fragility curves for each of the 28 bridge classes can be further refined in HAZUS 99 using bridge specific data such as: bridge length/span length/number of spans, bridge width, and skew. The effects of these parameters for several bridge types were investigated using sensitivity spreadsheet analyses.

3.1.2. Definitions of Damage States

HAZUS 99 defines five bridge damage states that are related to the damage ratio (i.e. the repair-to-replacement cost) for evaluation of direct economic loss. The basic damage states are: none (DS1), slight or minor (DS2), moderate (DS3), extensive (DS4), and complete (DS5). These represent the following types of damage (descriptions modified by WSDOT, but consistent with HAZUS):

- Slight damage (DS2) - minor cracking or spalling to concrete bridge elements. Bridge remains structurally sound.
- Moderate damage (DS3) – Any column experiencing moderate cracks but remaining structurally sound, moderate superstructure displacement (< 2 inches), any damaged connections, bearing failure or moderate (< 6 inches) settlement of approach. Requires temporary repair and/or capacity or functionality reduction.
- Extensive damage (DS4) – Any columns degrading without collapse – shear failure (column structurally unsafe), significant permanent displacement at connectors or major settlement (6 inches or greater) of an approach, or differential structural alignment.

- Complete damage (DS5) – Any column collapsing or span losing all bearing support that may lead to imminent span collapse, tilting of structure due to foundation failure.

3.1.3. Damage Algorithms for Bridges

The HAZUS 28 primary bridge classes are defined for the above damage states as a function of ground motion and ground displacement. These are median damage functions with a dispersion of 0.4 for ground shaking and 0.2 for ground failure. The assumptions in the development of these damage algorithms were reviewed and verified for applicability in this project. Discussion of this verification procedure is presented in the subsequent section. The verification focused on the most vulnerable bridge types that generally consist of simple-span bridge structures lacking modern seismic design features. A typical plot of a family of highway bridge fragility curves as the function of spectral acceleration is presented in Figure 3.1. For ground deformation, HAZUS considers incipient unseating and collapse as the possible types of damage due to ground failure. Initial damage to bearings, which correspond to slight damage from ground failure, is not considered.

Restrainers do not have a significant effect on the shape of the fragility curve for ground motion but will modify the expected performance of bridges when subjected to liquefaction/lateral spread.

For this project, damage states 4 and 5 were of primary interest since they result in loss of functionality. Figure 3.1 shows probabilities that a given bridge structure will not be extensively damaged, i.e., damage state will be less than DS4 (extensive damage) or DS5 (complete damage).

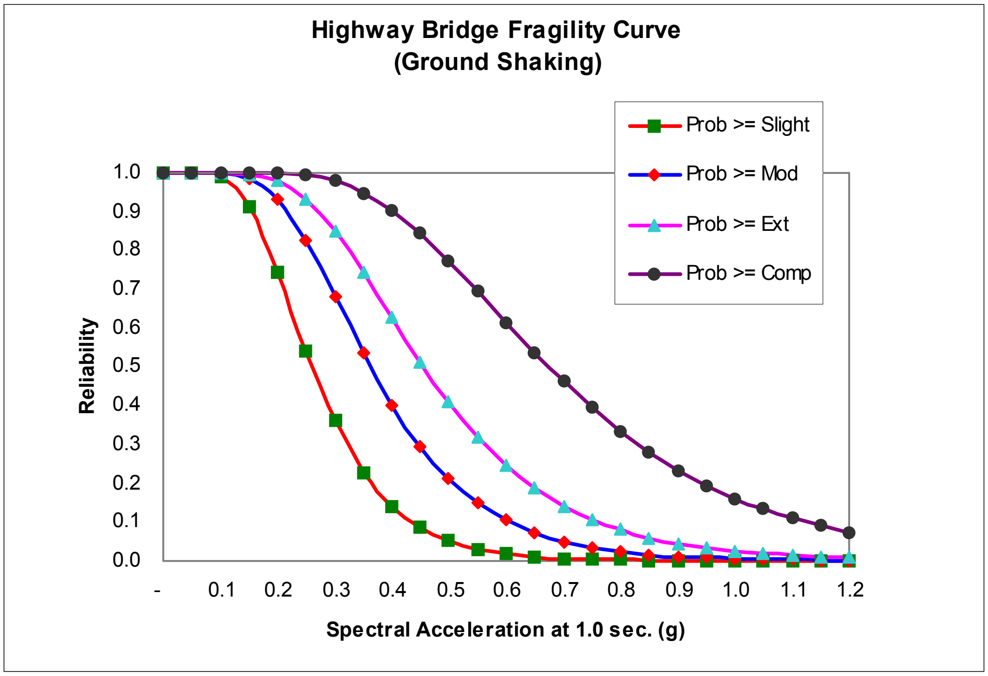

Figure 3.1

HIGHWAY BRIDGE FRAGILITY - PRESTRESSED CONCRETE BRIDGE MULTI-COLUMN BENT, SIMPLE SUPPORT

3.2. Bridge Damage Function Evaluation

3.2.1. Evaluation Considerations

The important questions to ask when applying HAZUS-based bridge vulnerability functions to Project Impact port-to-port corridor study are the following:

1. Is the bridge data currently in HAZUS database accurate relative to bridge location, physical characteristics, and key descriptors important for seismic performance?

2. Do damage functions, particularly for the most vulnerable bridges, accurately reflect Washington State bridge stock and design practice?

3. What modifications need to be made to appropriately model corridor bridges and assess the vulnerability of the lifeline network?

The following paragraphs describe our approach to bridge data verification and analysis of the assumptions in the current HAZUS bridge model relative to Washington State bridge design and construction practice. Recommendations are made for modeling modifications for bridges “driving” lifeline segment reliability results.

3.2.2. Bridge Inventory Verification

It is important that the database used for HAZUS analysis has accurate information relative to bridge locations, bridge type and classification, span length, and construction date. In addition, it is important to update that information by examining Washington State Department of Transportation's (WSDOT) bridge database and seismic upgrade database. This verification process had several components.

First, the existing HAZUS geographic database for the port-to-port corridor was examined to see whether bridges are accurately located. Second, the HAZUS database and WSDOT bridge database fields were mapped against each other to verify consistency of the key descriptors such as bridge type, bridge length, span length, number of spans, construction date, etc. Bridges with data discrepancies were discussed with WSDOT staff to establish an accurate input data for those structures. Furthermore, new structures, retrofitted bridges, and bridges with unique seismic features were also discussed to appropriately classify these within the available 28 HAZUS bridge classes. Specific issues addressed included:

- 11 bridges that were originally unclassified were classified.
- Bridge database was updated for retrofits.
- Bridge classifications were modified by date of construction in accordance with WSDOT discussions or use of seismic design standards.

- Use of large diameter columns in Washington than in California – minimum 3' diameter, majority 4' diameter, most using 1% steel. Ultimate shear capacity 2 times what is required. Shear failure not addressed until 1970's.

- Starting in 1960, WSDOT designed bridges for 0.10 g lateral force. Before then, 0.03 g was used in Eastern Washington and 0.05 g in Western Washington.

- Starting in 1972 – as a result of San Fernando event – WSDOT design criteria included increased confinement (significant code change).

- "Current" AASHTO seismic design requirements were published in 1983, and generally adopted in 1990. However, WSDOT began using these provisions in 1982.

- Liquefaction considerations were incorporated into the design in mid-1980's.

3.2.3. Preliminary Bridge Screening

Once the input database was verified, it was appropriate to examine, on a preliminary basis, the resulting database content for bridge type, bridge function (i.e., ramp, overcrossing, or main line bridge), and by route. The purpose of this screening was to determine the common bridge types within a segment, or route, and to observe which bridge classes appeared on a preliminary basis to be most vulnerable, thus potentially controlling the reliability of a given segment. The results of this screening is presented in Table 3.1. The table presents bridge count within each category, the percentage for all bridges, the bridge's lateral load capacity (in percent of 1 second spectral acceleration), and its capacity to accommodate lateral displacement caused by liquefaction/lateral spreading.

Table 3.1

SUMMARY OF BRIDGE CLASSES AND ASSOCIATED CAPACITIES

Bridge Class	Number/ Percent of Total		Lateral Capacity (g)	PGD Capacity (in)	Bridge Type
HWB10	76	36%	1.05	3.9	Continuous Concrete
HWB17	68	32%	0.44	3.9	Multi-Col. Bent, Simple Support-P/T Concrete
HWB23	23	11%	1.05	3.9	Continuous - Prestressed Concrete
HWB22	12	6%	1.05	3.9	Continuous - Prestressed Concrete
HWB11	11	5%	1.05	23.6	Continuous Concrete
HWB3	9	4%	1.1	3.9	Single Span
HWB4	4	2%	1.1	3.9	Single Span
HWB12	4	2%	0.44	3.9	Multi-Col. Bent, Simple Support- Steel
HWB15	3	1%	0.76	3.9	Continuous Steel
Other	4	2%	varies		
Total	214				

Based on the tabulated data the m*ost vulnerable bridge types in the inventory are single-span or simple support multi-span bridges. A relatively high percentage of these bridges is located along Routes 5 and 167, and many are mainline structures. Consequently, it is appropriate to focus on the vulnerability assumptions for simple-span bridges. The following paragraphs discuss this topic.

3.2.4. Screening of Vulnerable Bridges

A significant number of corridor bridges consist of simple-span structures. Traditionally these types of bridges consist of single or multiple spans placed in a series. The span supports are alternately fixed and free to allow for thermal movements. As demonstrated in recent earthquakes, these types of structures suffer from the lack of redundancy and ductility.

Simple-span bridge collapses observed in recent earthquakes in California, Japan, and Central and South America, can be attributed to unseating of spans and inadequate reinforcement in the supporting piers and columns. Causes of collapses were due to severe ground shaking, ground rupture, or excessive ground movement (liquefaction or landsliding.) Many simple-span Washington State bridges were built in the 1960s and may exhibit similar concerns. In summary, damage to bridges built prior to the early 1970's was due to:

1. Low seismic design forces
2. Higher than expected deflection
3. Inadequately located hinge locations

Since for simple-span bridges the critical elements are unseating of span and/or pier column failure, bridge vulnerability curves in HAZUS for these bridges are based on shear capacity of the critical pier and additional capacity provided by the deck arching action. For simple-span bridges there are three subclasses of bridges based on seismic detailing incorporated in the design:

1. Seismic design. Modern ATC-6 and 1980s AASHTO seismic design provisions.
2. California design prior to 1975. This is a lesser quality bridge predating AASHTO 1973 seismic design provisions.
3. Non-California Pre-1990. This is the most vulnerable category assumed to be lacking the fundamental bridge seismic design detailing.

3.2.4.1. Age of Construction

Based on our discussions with WSDOT Bridge and Structures engineers, it is apparent that WSDOT has closely followed California DOT (Caltrans) seismic design practice.

Consequently, for this project it is appropriate to modify the use of these three curves as follows:

1. "Seismic design" category will be applied to all Washington State bridges built during or after 1982. WSDOT adopted ATC-6 provisions at that time.
2. The second category, originally intended to correspond to pre-1975 construction in California, will be applied to WSDOT bridges built between 1973 and 1982 according to AASHTO 1973 provisions.
3. The third category, intended for those bridges which lacked key seismic features or were designed to very low seismic forces, will be applied to WSDOT bridges built in Washington state prior to 1973.

A family of these vulnerability curves is shown in Figure 3.2. The plots indicate reliability (onset of extensive damage) along the vertical axis as a function of spectral acceleration. Various damage states for pre-1973 WSDOT bridges is shown in Figure 3.1.

3.2.4.2. Drift Limitations

The loss of function or failure of a simply supported bridge can occur either due to loss of span or pier column failure. Based on our calculations, it appears that the span seat width typically used in WSDOT bridges appears sufficient to prevent unseating prior to column failure. Consequently, it appears that drift limits and permanent ground displacements used in HAZUS appear appropriate.

The vulnerability curves for permanent ground displacement are calculated as a function of column height times 0.025. This corresponds to extensive damage in columns with low ductility (confinement).

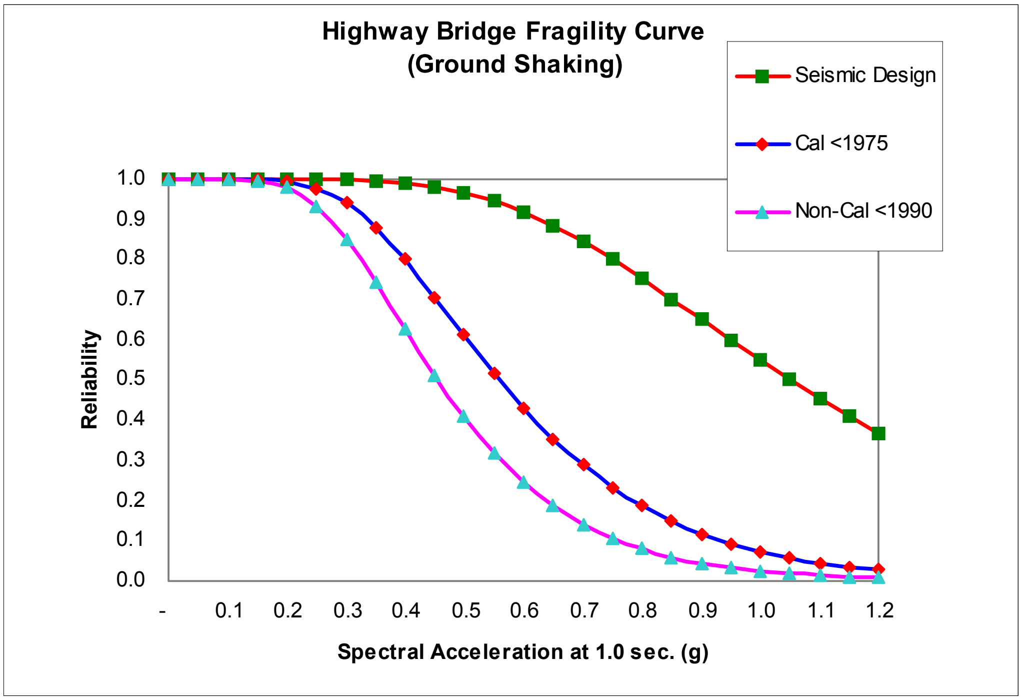

Figure 3.2

HIGHWAY BRIDGE FRAGILITY – PRESTRESSED CONCRETE BRIDGE MULTI-COLUMN BENT, SIMPLE SUPPORT

3.2.5. *Simple-Span Bridge Analyses and Results*

Given that simple-span bridges tend to dominate the results and overall lifeline segment vulnerability, it is appropriate to examine specific bridges of this type and verify that the bridge configuration and design assumptions are consistent with HAZUS approach. In addition, some of these structures originally built in the 1960s and 1970s were widened. The effect of bridge widening in seismic response is of interest.

A nonlinear static pushover analysis for typical transverse bridge bents for selected bridges along State Route 167 was performed. This was of interest since column behavior governs WSDOT bridge response for simple span bridges. A pushover analysis is used to determine the load-deformation behavior of a structure prior to failure. Failure is defined as that point at which the structure becomes unstable resulting in collapse. The analysis was performed using a two-dimensional finite element model of a transverse bridge bent. The lateral force can be related to the spectral acceleration, and further normalized to spectral acceleration at one-second period to compare with existing HAZUS bridge fragility models.

Five WSDOT bridges originally built between 1966 and 1972 were analyzed to determine load-deformation behavior and spectral acceleration characteristics (see Table 3.2). The following sections provide a brief description of each bridge.

Table 3.2

SUMMARY OF PUSHOVER ANALYSES

Bridge	Δ (in)	Period (sec)	S_a (g)	S_a norm (g)
Railroad	3.7	1.00	0.38	0.38
212th Street	2.8	0.83	0.42	0.35
Meeker (West)	2.2	0.66	0.52	0.34
Meeker (East)	3.5	0.79	0.57	0.45
277th Street	3.5	0.91	0.43	0.39

3.2.5.1. 212th Street Bridge

The 212th Street bridge is a four-span 1972 vintage State Route 167 mainline structure. The original structure has three bridge bents with 105-foot deck spans. Columns are approximately 18 feet tall and spaced 18 feet apart. In 1991 the existing structure was widened. Extension of the existing cap beam and addition of a circular column was performed at each bent. Concrete-filled steel piles support the columns. Bent-frame member data is summarized below:

212th Street Bridge Bent Member Data

Member	Dimensions	Longitudinal Steel	Steel Ties
Original Capbeam	48” x 48” Square	18 #11 Grade 40 ksi	#5 at 5”o.c.
Widened Capbeam	48” x 48” Square	18 #8 Grade 40 ksi	#4 at 4”o.c.
Original Columns	36” Dia	12 #11 Grade 40 ksi	#4 at 12”o.c.
Widened Column	36” Dia	18 #10 Grade 40 ksi	#4 at 3”o.c.

3.2.5.2. 277th Street Bridge

The 277th Street bridge is a three-span 1966 vintage structure along State Route 167. The original structure has two bridge bents with 70 feet of deck span tributary to each bent. The original columns are approximately 18 feet tall and spaced 25 feet apart. In 1994 the existing cap beam lengthened 16 feet, with a circular column added 16’ from the nearest existing column. Cast-in-place concrete piles underlay the column footings.

277th Street Bridge Bent Member Data

Member	Dimensions	Longitudinal Steel	Steel Ties
Original Capbeam	48” x 48” Square	18 #11 Grade 40 ksi	#5 at 5”o.c.
Widened Capbeam	48” x 48” Square	18 #8 Grade 40 ksi	#4 at 4”o.c.
Original Columns	36” Dia	12 #11 Grade 40 ksi	#4 at 12”o.c.
Widened Column	36” Dia	18 #10 Grade 40 ksi	#4 at 3”o.c.

3.2.5.3. Meeker Bridge East and West

The 1966-vintage East Meeker Street bridges include two bents with a tributary deck span of 55 feet to each bent. The original bents had three columns, each approximately 16 feet tall and spaced on average 18 feet apart. In 1994 each bridge bents cap beam was ltngthened by 16 feet with an additional circular column located 16 feet away from an existing column. Timber piles underlay the column footings.

Meeker Street Bridge Bent Member Data

Member	**Dimensions**	**Longitudinal Steel**	**Steel Ties**
Original Capbeam	48” x 39” Rect.	20 #10 Grade 40 ksi	#5 at 5”o.c.
Widened Capbeam	48” x 39” Rect.	18 #9 Grade 60 ksi	#5 at 10”o.c.
Original Columns	36” Dia	12 #11 Grade 40 ksi	#4 at 12”o.c.
Widened Column	36” Dia	18 #10 Grade 40 ksi	#4 at 3”o.c.

3.2.5.4. Railroad Bridge

The 1966-vintage Railroad Bridge has two bridge bents with tributary deck spans of 113 feet. The original bents have three columns approximately 30 feet tall and spaced 18 feet apart. The existing cap beams were lengthened on one side of the existing bridge with an additional column 18 feet away from existing columns. Concrete piles underlay the column footings.

Railroad Bridge Bent Member Data

Member	Dimensions	Longitudinal Steel	Steel Ties
Original Capbeam	42” x 36” Rect.	16 #11 Grade 40 ksi	#6 at 18”o.c.
Widened Capbeam	48” x 36” Rect.	16 #9 Grade 60 ksi	#5 at 7”o.c.
Original Columns	36” Dia	14 #11 Grade 40 ksi	#4 at 12”o.c.
Widened Column	36” Dia	12 #8 Grade 60 ksi	#5 at 3”o.c.

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3.2.6. Bridge Modeling

“Pushover” analyses were performed on the typical transverse bents for the above bridges. The purpose of the analysis was to validate that the WSDOT bridges were representative of the assumed fragility curves. A simplified diagram of a bent model is shown in Figure 3.3.

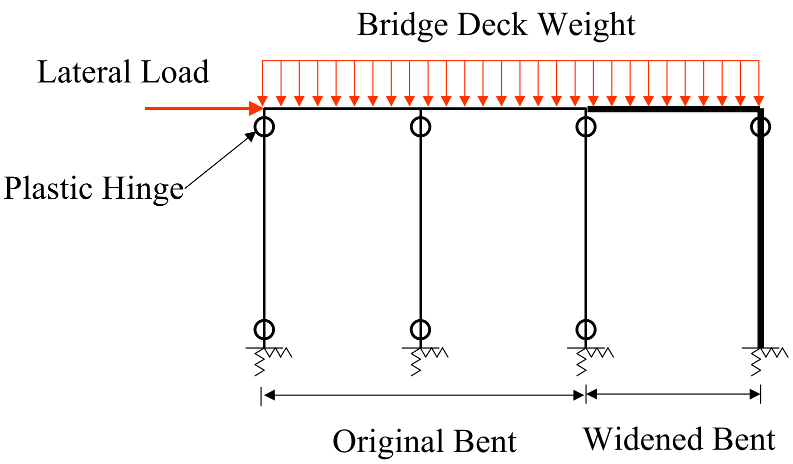

Figure 3-3

Typical Bridge Bent Model

Pushover analysis included the following assumptions:

- Model transverse bridge bent
- Use cracked concrete section properties
- Include "widened" section properties
- Include gravity "deck" loads
- Model soil stiffness (linear springs)
- Failure of bridge bent controlled by column plastic moment capacity (Mp) - verified

Pushover analysis procedure includes:

- Increase lateral load until Mp is developed at column.
- Determine bent stiffness based on load and deflection prior to failure.
- Calculate spectral acceleration (Sa) at failure given bent stiffness and the weight of the structure.
- Compare to HAZUS bridge fragility curves for non-ductile detailing (pre-1973 WSDOT bridges).

The maximum calculated displacements for sample bridges range from 2.2" to 3.7" (this is just prior to the last hinge forming), as summarized in Table 3.2. At this displacement level, a bridge is extensively damaged, but has not yet failed. The corresponding HAZUS value is 3.9", which is in reasonable agreement. The "failure" displacement of HAZUS is 13.9" – i.e., the bridge can probably accommodate additional displacement after the full hinge mechanism is formed. This corresponds to some reduced moment capacity (i.e. non-zero moment strength) in the columns, after the hinges have formed.

To determine the effect of the bridge widening a separate analysis was performed neglecting the additional columns and cap beam extension or assuming the new columns and cap beam were built similar to the original structure. The results are similar to those reported in Table 3.2.

3.2.7. *Earthquake Duration Effects in Bridge Vulnerability*

It is important to consider long-duration earthquakes, such as those originating on the Cascadia Subduction zone, and their effects on bridge performance. Long-duration effects apply at 0.23 g lateral force representing the median value for onset of cracking in bridge columns.

Bridge vulnerabilities are based on:

- 90% probability of failure is at 0.40 g
- 90% probability of cracking is at 0.28 g

Thus, if a bridge responds in the “plastic” range (above 0.28 g), in a a long duration event, then it could degrade and fail. Therefore, the vulnerability of bridges under these conditions is reduced by a factor of 1.4 (0.4 g/0.28 g).

3.3. Highway Segment Reliability and Recovery

Highway segment reliabilities immediately following the earthquake were calculated by multiplying together the reliabilities of individual bridges in the segment. The results on shown on the project web site. Bridge reliabilities are combined using this approach immediately after the earthquake because the probabilities of failure of each bridge are not influenced by restoration management decisions. The reliability of highway segments after restoration is based on the restoration of the individual bridge that HAZUS estimates has the longest restoration time.

Restoration time will be influenced by the availability of resources. The general approach assumes that for “low” damage category earthquakes, there will be adequate resources to pursue restoration of all bridges immediately following the earthquake. For “moderate” and “large” damage category earthquakes (refer to Table 3.3), it is assumed that bridge restoration will be delayed for lower priority bridges.

Table 3.3

REGIONAL BRIDGE DAMAGE ESTIMATES (EXTENSIVE OF COMPLETE DAMAGE)

Earthquake Scenario	Project Area Bridges Damaged	Regional Impact Multiplier	Regional Bridges Damaged	Damage Category	Additional Soft Soil/ Lique-faction	Additional area affected by shaking
Benioff M6.5	6	1	6	Low	No	Limited
Benioff M7.1	13	1.25	16	Low	No	Limited
Tacoma M6.7	23	1.5	35	Moderate	Nisqually	I-5 south to Olympia, SR-16 (competent soils), I-705, SR-509, SR-410, SR-18.
Seattle M6.5	28	1.5	42	Moderate	Limited	I-5, I-405 and SR-99 north to Snohomish County Line (-). I-90, SR-520, SR-522.
Seattle M7.0	40	2	80	High	Limited	I-5, I-405 and SR-99 north to Snohomish County Line (+). I-90, SR-520, SR-522
Cascadia Subduction M9.0	29	3	87	High	Significant	Entire state west of the Cascades. All alluvial valleys along I-5 corridor. All state routes west of I-5.

The HAZUS restoration curve shows that on the “average” bridge will be about 67 percent restored within 3 months. It is assumed that many of the resources that would be used in the initial stages of bridge restoration would be freed up after 3 months, and could be applied to other bridges. For high damage category earthquakes, bridges are divided into 3 priorities for restoration, with delays for starting restoration of 3 and 6 months respectively for 2nd and 3rd priority highway segment bridges.

In order to establish the bridge damage categories in Table 3.3, bridge damage results are used to estimate the total number of bridges across the state that will have at least extensive damage. This done by multiplying the average probability of being in the damage state times the total number of bridges. This approach is applied to main line bridges, as those are the bridges required to resume near full traffic volumes. The estimated number of bridges with at least extensive damage is shown in Table 3.3 for each earthquake scenario.

The study area only encompasses a portion of the interstate bridge system that would likely be impacted by an earthquake. The WSDOT would be responsible for restoration of all state owned bridges. Therefore an order of magnitude estimate is provided of the total number of interstate bridges that would be damaged as shown in Table 3.3. This estimate takes into account the location, type, and expected distribution of ground motions of each earthquake, and the location of bridges in areas with significant site amplification and liquefaction susceptibility. In general, the study area (this project) encompasses the largest liquefiable areas in the region. To the north, the next large liquefiable area is the Snohomish River valley/delta just north of Everett. To the south, the next significant liquefiable are is the Nisqually River valley/delta. Each earthquake scenario affects bridges differently. Those affects are described in Table 3.3. The result is the total number of bridges with at least extensive damage for the entire region, as shown in Table 3.3.

The six earthquake scenarios are subdivided into 3 groups for low, moderate, and high levels of earthquake bridge damage, based on the total number of bridges with at least extensive damage. High levels of damage are expected for the Cascadia Subduction M9.0 earthquake and the Seattle M7.0 earthquake. Moderate levels of damage are expected for the Seattle M6.5 and the Tacoma M6.7 events. Low levels of damage are expected for the Benioff earthquakes. For the high level of damage category, it is assumed that bridges will be restored in 3 priorities: 1) I-5, 2) SR-167 north of SR-18 to I-405, and SR-518, and 3) all other highways. For moderate levels of damage, 2 priorities are identified: 1) I-5, and 2) all others. For low levels of damage, it is assumed that restoration will start on all bridges at the same time.

4. Economic Analysis

4.1. Overview

This portion of the study aimed to gain insights into how highway transportation disruption in the Project Impact earthquake scenarios would impact local businesses and the regional economy.[1] Our approach consisted of two steps. First, we interviewed local businesses to learn about potential impacts and developed case studies from these interviews. Second, we ran a model of the regional economy to estimate overall effects based, in part, on what we learned from the interviews. We anticipate that the case studies will encourage local businesses to think systematically about the role of transportation in their operations, their own potential losses in an earthquake, and the importance of the region's investing in seismic strengthening of the highway system. We anticipate that the regional economic impact estimates will help inform decision-makers who can influence investment in earthquake mitigation and preparedness. Due to the limited scope of the pilot study, our results represent preliminary findings only.

The interviews sought an in-depth understanding of how businesses might be impacted by the highway disruption scenarios. Section 4.2 below describes the earthquake scenario information we presented to the businesses. We conducted 21 in-person interviews with local business owners and managers from February through May, 2001. Interviews typically lasted one to one and a half hours. In designing the study, we were guided by previous research, particularly studies of business impacts in the 1994 Northridge and 1995 Great Hanshin (Kobe, Japan) earthquakes. In addition to the potential magnitude of business losses, we were interested in finding out what are the main factors influencing loss, how impacts might differ between types of businesses, and

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[1] We would like to express our appreciation to all those who assisted us in this study, including Washington State Department of Transportation, Washington State Emergency Management Division, and businesses that we interviewed. To protect confidentiality, we do not name these businesses (exceptions are noted in the text).

what firms have been doing to prepare themselves for disasters. We also inquired into the firms' experiences in the February 28, 2001, Nisqually earthquake. We supplemented the in-person interviews with telephone interviews to 5 additional businesses, primarily to gather information on the impacts of the Nisqually event.

Interviewees were selected non-randomly with the intent of covering a cross-section of the regional economy. The 21 businesses interviewed in person included 3 manufacturing firms, 3 transportation service companies, 6 retail and wholesale trade concerns, 6 in finance and insurance, and 3 transportation and communications infrastructure providers. (The 5 telephone interviews were conducted with transportation firms and infrastructure agencies.) Half are major employers while 4 of the 21 are small businesses. Some had invested heavily in disaster mitigation and preparedness; others had given it no thought at all. All but 5 had their sole or main regional facility in the Port-to-Port transportation corridor.

Section 4.3 below summarizes findings from the interviews in aggregate statistical terms as well as through a series of descriptive case studies. Several caveats are warranted. First, with one exception, we developed composite case studies in order to protect confidentiality. These composite case studies depict "typical" businesses rather than specific firms and capture what we consider to be the essence of business vulnerability. The exception consists of infrastructure service providers where disguising their identity would have rendered the case study meaningless; these providers agreed to be identified individually. Second, the scope of the pilot study limited our efforts to a small, non-random sample. The statistical results therefore pertain to the sample of businesses we interviewed and cannot be directly extrapolated to the entire population of regional businesses. We suspect, for example, that the large employers we interviewed constitute a biased sample of businesses that are unusually well-prepared for disasters. Similarly, it is difficult to delineate a "typical" business from a small sample. A third caveat pertains to the lack of major disaster experience by businesses in the region, even including the Nisqually event, where transportation disruptions were mainly confined to short-term air transport problems. The extent to which our interviewees fully anticipated what would actually happen in a major disaster is unknown. Finally, the scope of the pilot study limited the discussion to the Port-to-Port highway corridor, considering only highway damage and then only to a small portion of the regional transportation network. This pilot study therefore lays the groundwork for a full study that could involve conducting a scientific survey of businesses, considering transportation impacts in the context of other earthquake effects, estimating travel time effects using a traffic model, and including disruption to the entire regional transportation system.

The Washington State Input-Output Model was used to estimate the impacts of the M7.1 Benioff Zone earthquake. The model is driven by final demands; it has at its heart a system of multipliers that translate changes in final demands into changes in sales or output. The model also tracks labor income and the level of employment associated with output in each industry included in the model. For the purposes of this analysis a 28-sector version of the model was utilized. In undertaking the impact analyses reported in section 4.4, we modified the structure of this model, to take into account types of impacts identified by people we interviewed. In effect, an earthquake of the type hypothesized would alter the structure of production, which means that the multiplier structure would be affected. In particular we developed a model in which it was possible to adjust truck transport costs (both own-account and purchased) and labor costs. We developed from the detailed Washington input-output model a highway construction cost vector, which we used to model the impacts of rebuilding the damaged highway system. We also developed a flexible system for modeling these various parameters, which allowed sector-specific levels of impact. The simulations undertaken here were based on the state structure of production, as no data are available that define the composition of industrial output in the study region in terms of the sectors included in the input-output model. The impacts that were estimated should be regarded as indicative of the levels of impact that would occur due to an event of the type modeled. More precise estimates of impact would require the development of sector-specific output measures for the region under study; resources were not available in this pilot study to make such measures.

4.2. Highway Outage Scenarios and Estimated Travel Times

Each business interview focused on two of the earthquake scenarios described earlier in this report: (1) the M 7.1 Benioff Zone earthquake, and (2) either the M 6.5 Seattle Fault or the M 6.7 Tacoma Fault earthquake, depending on the business' location in the study area. We conducted a pre-test interview to determine how to effectively communicate the highway outage scenarios to businesses. This indicated that the scenarios should be presented in deterministic, rather than probabilistic, terms, should distinguish between short- and medium-term timeframes, and should include estimates of associated travel time increases.

We therefore developed map scenarios for use in the interviews in which highway segments are coded either open, closed, or partial capacity (red, green, or yellow). These deterministic scenarios were based on Monte Carlo simulation using the probabilistic bridge damage results. Specifically, random numbers were generated for each bridge and compared with its damage probability to simulate either an open or closed state. If one or more bridge were closed on a highway segment, the entire segment was considered to be closed. If bridge closure affected traffic in only one direction, partial capacity was indicated. Businesses were asked to consider the Benioff Zone event at 72 hours after the earthquake and at 1 month afterwards. It was assumed that in the 1 month scenario, detours and lane re-striping would be implemented for partial capacity segments, and travel times would be somewhat improved. Additional questions pertained to the Seattle/Tacoma Fault event at 1 month after the earthquake.

In consultation with representatives of Washington State Department of Transportation, very rough travel times were estimated for use in the interviews. The Port-to-Port corridor was divided into four north-south portions, which, under normal rush hour conditions, typically each take about 15 minutes to traverse. Depending on which particular highway route segments were open or closed, these travel times were increased judgmentally for the various earthquake scenarios. For example, in the Benioff Zone event at 1 month, it was estimated that the normal 1-hour travel time between Seattle and Tacoma would be lengthened to 4.5 hours. These travel time estimates were indicated on the scenario maps used in the interviews. In practice, businesses required only approximate travel time impact information to help them visualize the scenarios.

4.3. Business Interviews and Results

The interview questions focused on obtaining several types of information. We gathered background data on the business itself; for example, number of employees, facility locations, scope of business, etc. We also inquired generally into modes of business resiliency. That is, we were interested in the kinds of options available to particular business types to “work around” disaster situations. Such options as flexible scheduling of employee work, operating overtime, and sending work to other company locations are more applicable to some types of businesses than to others. We asked about the Nisqually earthquake and other recent, non-earthquake experiences of business interruption.

We then spent a good share of time on the first scenario, the M 7.1 Benioff Zone event at 72 hours after the earthquake. Key questions pertained to the degree of disruptiveness of highway outage for various business functions including employees’ ability to get to work, ability to receive supplies and ship products, and customers’ ability to reach the business location. We inquired as to which highway-dependent business functions were most critical for the operations of the business. We also asked about anticipated revenue losses and cost increases associated with the scenario.

The final portion of the interviews concerned determining the range of revenue and cost impacts that might occur. Businesses were asked to consider whether the situation would be better or worse after one month, and why. They were asked about likely revenue and cost impacts in the Seattle or Tacoma Fault event, this time considering not only highway damage but building and other types of damage that would be likely to occur. For this purpose, we used a regional loss estimate for the Seattle Fault event that the Washington State Emergency Management Division had developed for us using

FEMA's HAZUS software tool. Findings are presented below in two parts: in aggregate statistical form, and in a series of case studies for various sectors of the economy.

4.3.1. *Aggregate Findings*

Table 4.1 reports on the expected disruptiveness of highway outage to business functions in the Benioff Zone event at 72 hours. The vast majority of businesses would find the situation "disruptive" or "very disruptive" to employees' ability to get to work. Of the businesses with major facilities in the Port-to-Port corridor, 44 percent would find the situation very disruptive to employee commuting. Many businesses, however, anticipated that other business functions such ability to make shipments or customer access would be even more impacted. In terms of overall business functionality, 76 percent of the interviews considered that the scenario would be "very disruptive".

Table 4.1

OVERALL BUSINESS DISRUPTION, M 7.1 BENIOFF EVENT AT 72 HOURS

Business function(1)	**Not at all disruptive**	**Not very disruptive**	**Disruptive**	**Very disruptive**	**TOTAL**(3)
Employees' ability to get to work --All businesses (N=21)	0 %	19 %	48 %	33 %	100 %
--Businesses within study area (N=16)	0 %	13 %	44 %	44 %	100 %
Overall functionality(2) (N=21)	0 %	5 %	19 %	76 %	100 %

Notes: (1) N=sample size; (2) maximum disruptiveness to any major business function; (3) figures may not add due to rounding error.

Table 4.2 summarizes findings on revenue loss in this scenario event. The interviewees' open-ended responses have been paraphrased into four loss categories for ease of presentation. The table shows that revenue losses vary widely across the sample of businesses. Roughly half the respondents anticipated no or little revenue loss, while the other half estimated anywhere from 20 to 75 percent drops in revenue. This variation is in fact correlated with business sector, an insight that is brought out in the case studies below.

Table 4.2

REVENUE LOSS, M 7.1 BENIOFF EVENT AT 72 HOURS

Revenue loss responses	**Percent of businesses** (N=17)
“None”	18 %
“Little” (e.g., fees)	35 %
“20~30% loss”	29 %
“50~75% loss”	18 %
TOTAL	100 %

Table 4.3 summarizes responses concerning how costs might increase as the business responded to the emergency. Again, open-ended responses have been paraphrased into three general categories. In contrast to the revenue impact question, a majority of businesses reported that there would be some form of significant cost increase. Almost all of these cited labor cost increases associated with having to work overtime to deal with transportation disruptions. Others anticipated raises in transport fees charged by trucking firms. In a number of the interviews, respondents suggested that while production levels could be maintained, this would be achieved at a potentially significant cost.

Table 4.3

COST INCREASES, M 7.1 BENIOFF EVENT AT 72 HOURS

Cost increase responses	**Percent of businesses** (N=16)
"None"	19 %
"Little"	25 %
"Significant"(1)	56 %
TOTAL	100 %

Note: (1) E.g., overtime pay, decreased labor productivity, increased freight costs, relocation expenses.

Businesses were also asked about impacts in other scenarios. When asked if the Benioff event scenario were to continue for 1 month, whether the business situation would improve or worsen, 50 percent (N=20) said it would worsen. Frequently cited explanations included continued emergency response costs and weakened demand. Some 20 percent said the situation would improve because people would adjust their behavior. The remainder gave ambiguous responses. Regarding the "bounding event", or the Seattle/Tacoma Fault event, respondents generally indicated that the situation would be much worse than in the Benioff event scenario, many citing greater revenue losses and virtually all indicating significant response costs due to own-facility damage, customer impacts, and other causes in addition to severe highway disruption. Businesses were asked whether they anticipated any long-term business losses in such an event, and 63 percent of respondents (N=16) indicated that they did.

Some general observations can be made from these aggregate findings. First, there is substantial variability across businesses in terms of how and how much highway disruption would impact business operations. Second, this variability confirmed many findings from the literature on disaster impacts, including the significance of business sector, size, access to resources, market, and competitive situation. In addition, the findings suggest that businesses are likely to suffer greater cost impacts than revenue losses from the highway disruption.

4.3.2. Case Studies

This section presents several case studies of potential business impact in the earthquake scenarios described above. The case studies represent “typical” firms in the industry. While based on interviews with actual companies, they do not depict any specific firms.

4.3.2.1. Infrastructure Service Providers

Background

Urban infrastructure services are critical to the vitality of a region’s economy. Without them, businesses would be unable to operate. In addition to highways, infrastructure includes other transport modes and utility systems that support the activities of households, businesses, and government – systems that, themselves, rely on the viability of the highway network. This section considers how highway damage might impact these other infrastructure services and, in turn, cause substantial economic losses to ripple through the economy.

Infrastructure service disruption was one of the most important sources of business interruption loss in the Nisqually earthquake. Examples include temporary closure of SeaTac Airport and King County International Airport (Boeing Field), localized power outage, and loss of phone service due to congestion from excessive call volumes. Indeed, in most of our interviews, business owners and managers cited loss of phone service as a main reason – sometimes the only reason – for business interruption in the disaster.

Our case studies here consider the Ports of Seattle and Tacoma, respectively, and Qwest, a major telephone service provider. We focus on how highway damage might impact the operations of these infrastructure providers and, in turn, cause losses to businesses that they serve.

Port of Seattle

The vast majority of import and export goods are transported via seaports. Ports act as transportation hubs, a convergence zone for trucks, railroad cars, and ocean vessels. More than $32 billion of foreign trade goods made their way through the Port of Seattle in 2000, much of it originating from or destined for markets east of the Rocky Mountains. The Port of Seattle also owns and operates SeaTac International Airport, which served 28.4 million passengers in 2000. It has been estimated that maritime and air transportation activities at the Port of Seattle generate 83,700 direct jobs in the region in cargo handling, trucking, airlines, and the like.

While the Port of Seattle’s expected costs and revenue losses from an earthquake will depend on the particular event, a few generalizations can be made. Four factors are critical to operations: 1) the efficient functioning of the highway system; 2) efficient functioning of the railway network; 3) availability of electric power, and 4) functioning of piers and cranes. Only the last factor can be directly influenced by port mitigation activities.

Highway damage in the M 7.1 Benioff Zone earthquake scenario would be very disruptive to the port’s ability to receive and distribute cargo. When the Alaskan Way Viaduct was closed for safety inspections after the Nisqually earthquake, port managers observed that road congestion made it very difficult to get truck freight moved to and from the port. The Benioff Zone scenario would also severely hamper port employees’ ability to get to work.

Highway damage in the scenario earthquake would also impede port customers’ ability to use the port efficiently. A number of warehousing customers in the Kent Valley would have difficulty reaching their storage facilities on East Marginal Way and at the port itself. Moreover, since freight is moved from ship to rail via truck at the Port of Seattle, impeded access to the rail yards would have ramifications for shippers’ ability to move cargo to the mid-west and eastern U.S. by rail.

One sector that could be hard hit is the Alaskan fishing industry. The fleet docks at the Port of Seattle's Fisherman's Terminal near Ballard, as well as other facilities, then transports fish to cold storage and processing facilities throughout the Seattle metropolitan region. A large share of fish processing, for example, takes place in the Kent Valley. Depending on the season, major highway damage could be very problematic for this industry.

The extent of economic disruption to the Port of Seattle from highway damage would depend largely on the duration of outage. If regional highways were to be severely impaired for a month, for example, shipping companies would certainly divert freight to other seaports. For example, some lines that routinely call at Seattle and Vancouver, British Columbia, could drop Seattle from their itinerary, at least temporarily.

In the M 7.1 Benioff Zone scenario, the Port of Seattle estimates that it may lose $2.5 million in revenue per month of severe highway damage. As a general rule of thumb, extra expenses related to dealing with the disaster might cost an additional 60 percent of that amount. For example, to counter-act highway congestion and delays, the Port of Seattle may have to extend current 12-hour operations to 24-hour service, thereby incurring substantial overtime labor costs. These costs would probably be borne largely by the port's customers and local trucking companies.

In a catastrophic disaster such as a M 6.5 Seattle Fault earthquake, losses would be even more severe. Because 80 percent of the cargo moving through the port is discretionary – meaning that it does not have to transit through Seattle – the Port of Seattle is very vulnerable to diversion of this business to its competitors. It could suffer as much as a 75 percent reduction in traffic due to the regional highway situation. Damage at the port itself might reduce capacity by 50 percent. Large numbers of customers could be lost to Vancouver, BC, and the major southern California ports. It is likely that, as with the Port of Kobe after the 1995 earthquake, it would be difficult for the Port of Seattle to recover from such a disaster.

Port of Tacoma

Like the Port of Seattle, the Port of Tacoma is a major container port and economic engine in the region. In 2000, $19.8 billion in imports and exports flowed through the Port of Tacoma. It has been estimated that over 10,000 direct jobs and 22,000 total jobs in Pierce County are related to port activity. All of the ports along the West Coast compete heavily with each other. In a major earthquake, both the Port of Tacoma and the Port of Seattle are likely to be similarly impacted and to lose customers to competitors outside the region. The displacement of cargo would likely result in substantial congestion at these other ports, as excess capacity is insufficient to absorb the combined volumes from Seattle and Tacoma. This would hamper commerce throughout a broad sector of the U.S.

Highway damage as estimated for the M 7.1 Benioff Zone earthquake scenario would be very disruptive to truck access to the Port of Tacoma. About 30 percent of cargo at the port uses truck transport. Half of this may be lost in such a disaster, amounting to a 15 percent loss of traffic due to highway problems, even if no damage were suffered to the port's own facilities or to railroad connections. Railroad failures would cause even more disruption than highway damage.

The port would probably try to compensate for traffic congestion by increasing hours of operation. This could increase labor costs by as much as 50 percent. The scenario would also be disruptive to employees' ability to get to work and the port's ability to receive needed supplies, such as crane parts.

In addition to regional impacts, disruptions at the Port of Tacoma would quickly cause problems to the economy of the state of Alaska. Some 70 percent of northbound cargo to Alaska passes through the Port of Tacoma, including much of the food and beverages consumed there. A large portion is handled through warehousing in the Seattle-Tacoma corridor.

Cargo would undoubtedly be shifted to competing West Coast ports in the U.S. and Canada. In the 1989 Loma Prieta earthquake that struck the San Francisco Bay Area, the Port of Tacoma apparently benefited from such cargo diversion from the Port of Oakland.

One of the port's steamship line customers confirmed that if port and regional transportation disruptions were to last a week or more, the company would divert cargo to other ports. If the Port of Seattle were also experiencing problems, the company would look first to Vancouver, BC, then to Portland and Oakland. About half of the company's cargo through the Port of Tacoma uses regional trucking.

In a catastrophic disaster such as a M 6.7 Tacoma Fault earthquake, the situation would be compounded by damage at the port itself. Revenue losses of $20 million (one-third of current annual revenues) are possible. As with the Port of Seattle, some 70 percent of Tacoma's cargo is bound for and originating from outside the Pacific Northwest. Since it does not need to transit through Tacoma, portions of the diverted cargo may not return. A catastrophic earthquake would likely lead to long-term loss of business at the port.

Highway disruption would also impede military readiness. In the event that military action is called for in the Pacific, plans are for Fort Lewis to move, wholesale, out of the Port of Tacoma. Highway system disruption would prevent a rapid deployment.

Qwest

Qwest is the major provider of local telephone service in the region. As an infrastructure provider, it has invested in disaster preparedness and mitigation activities; for example, Qwest maintains emergency operation centers supporting each state that it serves. In addition, if customer-care centers and business office functions in Seattle become inoperable, customer calls can be automatically rerouted to Portland or other cities where Qwest customer support groups are located. In a truly catastrophic disaster, the company has an option of shifting business office functions to Portland while damage is being repaired in the Seattle area.

Qwest's main concern in an earthquake would be to ensure adequate service on the telephone network. Electric power failures, for example, are a major concern. While highway disruption would have little direct impact on phone service, it could impede the company's ability to make rapid damage assessments and repairs to the telecommunications network. The M 7.1 Benioff Zone scenario would be disruptive to repair capabilities. To get around congestion problems, Qwest would probably set up temporary garages near repair sites and have workers stay at the site, if necessary. Such activities would entail additional costs.

4.3.2.2 Transportation Industry

Background

Any disruption to the regional highway system would cause immediate and direct losses to firms in the transportation industry. Highway damage would not only disrupt the business of goods movement, it would also cause losses to other economic sectors that depend on these goods being transported regionally, nationally, and globally.

The Nisqually earthquake caused temporary closures and reduced capacity at SeaTac airport, Boeing Field, the Alaskan Way Viaduct and other transportation infrastructure. While short, this disruption led to significant dislocations in the transportation industry. For example, one air cargo carrier using Boeing Field estimated that it incurred over $600,000 in extra expenses from having to work around the 2-week closure of the airport, despite suffering virtually no damage to its own facilities.

Trucking is particularly vulnerable to highway damage in earthquakes because profit margins are very low in this industry, fixed costs are high, and the vast majority of firms are small with low financial reserves. Indeed, as demonstrated recently when fuel prices soared, a single bad quarter can put a trucking firm out of business.

According to the 1999 Washington State Data Book, there are 78,000 jobs in the transportation, communications, and utilities sector in King and Pierce Counties. In this profile, we focus on two important types of businesses involved in goods transportation: trucking companies and air cargo shipping firms.

Case A: Trucking Company

Company A is a Renton-based trucking firm that has been in business for over 40 years. With 150 office employees and 400 drivers, it is considered a large firm in this industry. *Company A* hauls industrial and consumer products such as paper, clothing, and beverages within a service area spanning the Pacific Northwest and California.

The highway damage estimated for the M 7.1 Benioff Zone earthquake scenario would be devastating to *Company A*'s ability to conduct business. Trucking in the Puget Sound would be crippled by congestion and the company would be unable to bring cargo into the region.

Because of weight restrictions on roads and through certain cities, *Company A* would have difficulty diverting its trucks off the main highways even in an emergency. For the most parts, trucks would have to sit in traffic. Local drivers are paid by the hour, so this would translate directly into productivity and profit losses for the company.

Revenues would be immediately impacted because perhaps one quarter of the fleet would be inoperable. This translates into a daily loss of some $85,000 in revenue loss per day. In an industry characterized by very slim profit margins, loss of even one day's worth of revenue could potentially wipe out profits for the month.

Any losses that *Company A* suffers from a major earthquake would have repercussions for its customers. Some of the cargo feeds into just-in-time production processes that would shut down if the goods did not arrive on time. More generally, for a disruption lasting more than a few days, the company would probably impose an emergency surcharge to pass on unanticipated costs to its customers. For disruptions of a month or more, the company would need to resort to such actions to survive.

In the M 6.5 Seattle Fault scenario, the situation would be further complicated by the need for employees to take care of their home situations first. With fewer available drivers and legal limits on the number of hours per day that a driver can be on the road, *Company A* would have to walk away from any business that it couldn't handle. This could easily lose the company accounts, particularly from customers outside the disaster region. Even though it is currently in good financial health, in a prolonged highway disruption scenario, *Company A* would face prospects of failing altogether.

Case B: Air Shipping Company

Company B is a major shipping company that provides overnight package delivery service to businesses and consumers. While headquartered outside of Washington State, it maintains a major regional office in downtown Seattle that houses 1,000 employees as well as a critical mainframe computer. The company uses Boeing Field for all its deliveries going from or to the Pacific Northwest. An inbound package would be flown into Boeing Field and trucked to one of the 5 distribution stations to be sorted and delivered to its ultimate destination.

In an earthquake, *Company B* has identified three critical factors governing business impacts: performance of highways, airports, and the company's mainframe facility. Should access to the mainframe computer be compromised, the firm has contingency plans to activate a "hotsite" in Texas where a duplicate, temporary facility could be rapidly set up to take over information processing functions. This would require transporting over 1,000 backup tapes out of Seattle through a regional airport to the hotsite and would therefore also rely on the viability of the regional transportation system.

The old rule of thumb was that a shipping company must recover within 3 days in order to avoid noticeable losses in revenue. However, in today's world of online sales and dot.com business, losses now accrue in as little as 3~5 hours.

As a large business, *Company B* is able to respond flexibly to disasters to try to minimize business interruption losses. It has invested in a backup electric power generator at its Seattle office, a telecommuting program available to its key employees, and the capacity to automatically reroute incoming telephone calls to other call centers in Portland and elsewhere outside the region.

Nonetheless, highway disruption of the severity estimated for the M 7.1 Benioff Zone earthquake scenario would be very disruptive to *Company B*'s ability to deliver packages in a timely fashion. The company would probably have to suspend regional overnight delivery service, lose service fees, and incur substantial overtime labor costs. In the long run, it would lose customers, particularly in the arena of online businesses requiring next-day delivery, to any competitors that performed better during the crisis.

Disruptions to shipping firms like *Company B* would cause ripple effects throughout the Seattle regional economy. Many small manufacturers use these firms rather than maintaining their own fleet of trucks and planes. Businesses operating just-in-time production processes require immediate transportation functionality and would be quickly impacted.

4.3.2.2. Manufacturing Industry

Background

After transportation services, manufacturing may be the industry that is most reliant on the regional highway infrastructure. Manufacturing processes typically involve shipping raw materials and other inputs to a plant, usually by truck on interstate highways. Manufactured goods must then be similarly transported to distribution centers or directly to customers, generally outside the region.

For instance, the regional highway network plays an important role in the manufacture of commercial airplanes by the Boeing Company. In the Seattle metropolitan area, Boeing operates major commercial airplane and aerospace plants at Everett, Renton, Auburn, Kent, Frederickson, and Boeing Field. Parts for aircraft production, such as wing sub-assemblies, are continuously being moved by truck between these plants in a just-in-time production process.

Many manufacturing firms are large businesses that tend to have more resources for disaster preparedness, mitigation, response, and recovery than smaller businesses. Manufacturers interviewed for this study were confident of their ability to weather a major earthquake disaster, provided the production plants themselves survived. Highway damage alone would be challenging and possibly costly, but not insurmountable. The case study below illustrates how a "typical" manufacturing firm might be impacted by highway disruption in a disaster.

It should be noted, however, that dependence on the highway network varies tremendously from one manufacturing company to the next. The degree of dependence corresponds to three main factors: the nature of the product (e.g., its perishability), the nature of the production process (e.g., single- or multi-plant, origin of raw materials, production lead times), and the nature of the market for the product (e.g., competition).

Case C: Large Manufacturer

Company C is a world-renowned producer of gourmet chocolates and confectioneries. Over the last century, it has grown from a small, family-run business to a large corporation with a global market. It sells about half its products to specialty food distributors and the other half directly to consumers through its own chain of retail stores located throughout the country.

Company C maintains two main facilities in the region: a headquarters building in Bellevue and a manufacturing plant in the Kent Valley. Approximately 1,200 employees work at these two locations. The Bellevue facility houses marketing, payroll, and other important support functions.

The company has taken some actions to deal with the earthquake risk in the region. They are undergoing seismic retrofit of their headquarters building and have invested in some key nonstructural mitigation such as bolting down computer servers. They also have earthquake insurance for property damage and some business interruption. The insurance is subject to the standard 2 percent deductible, which comes to over $1 million. Plans to build a second plant on the East Coast will provide the added benefit of diversifying the location of production.

Regional highway disruption would principally impact *Company C* by hindering its ability to get materials and products in and out of the Kent Valley plant. The M 7.1 Benioff Zone earthquake scenario of highway damage would be disruptive – possibly very disruptive – to the functioning of the plant. Since the chocolates and confections are produced with about a one-month lead time, any short-term disruptions could be made up through working overtime. This would involve extra labor costs but ensure that to its customers, there would be no interruption in business.

The Benioff Zone scenario of highway damage would also be very disruptive to employees' ability to get to work. If necessary, the company would put up key employees in nearby hotels and incur other similar costs to work around the congestion situation.

If this kind of highway disruption were to last a month, it would probably cause revenue losses. Not all of the production losses could be made up through overtime work. The company would also have to delay introducing some new products to the market. The M 6.5 Seattle Fault scenario would be extremely disruptive to the company's ability to do business. The biggest impact would derive from the crippling of distribution capacity from the Kent Valley plant. Because *Company C* enjoys high brand name recognition and loyalty, and moreover does not face serious competition for its products, it is not especially worried about suffering long-term loss of business in such a scenario.

4.3.2.3. Retail Trade

Background

Generally speaking, retail trade businesses are less dependent on the highway network than firms in transportation services or manufacturing, for whom being able to move goods by truck is vital. Losses in retail would derive primarily from impeded passenger mobility in the region – if customers cannot reach the stores, they cannot buy from them. However, unlike trucks, automobiles can use local streets to bypass highway closures and congested areas.

While retailers are less dependent on highways, this does not mean they will fare better in the event of an earthquake. Transportation disruptions alone could potentially result in layoffs and lost revenue. Indeed, of the businesses interviewed for this study, retailers anticipated some of the highest revenue losses from highway disruption.

The Nisqually earthquake demonstrated how even local road damage can be very disruptive to retail trade businesses. Closure of the Fourth Avenue Bridge in Olympia reduced access to downtown from the west side. This reportedly cost some stores and restaurants sales losses of up to 25~70 percent. Several weeks after the earthquake, retailers in Seattle's earthquake-damaged Pioneer Square district were most concerned that the closure of Jackson Street was turning away potential customers.

It can be argued that one business' loss may be another's gain. If indeed consumers simply make their purchases elsewhere, then while specific local businesses and business districts may suffer, there would be no net loss from a regional standpoint. It should be kept in mind, however, that disasters can reduce overall consumption levels. If regional traffic congestion is severe and protracted after a disaster, consumers may very well reduce non-essential shopping trips. There may also be net out-migration of population.

Retail trade is highly vulnerable to losses in disasters for a variety of reasons. First, businesses tend to be small or medium-sized. They therefore lack the resources available to large businesses – resources to invest in mitigation and preparedness before a disaster, as well as to respond to and recover from the event once it happens. Second, retailers generally serve local markets that would be impacted in the same disaster. In exporting to other regions, manufacturers do not face the same potential loss of demand for their products. Additionally, some types of retail sales loss cannot be made up through overtime work.

Of course, some retailers such as franchises may have access to the resources of a national or multi-national corporation. They would be able to better weather the potential impacts of a disaster than small, single-location businesses. *Case D* below presents an example of a large retailer of this type.

Small businesses are perhaps the most vulnerable of all businesses to disaster. Because revenues are often low and debt relatively high, profit margins are thin. Competition for customers is often intense. Small businesses often cannot spare the time or resources to plan for disasters ahead of time. They often cannot afford earthquake insurance. In a disaster, they have generally have few options and little financial reserves to draw upon. Previous studies have found that many small business owners will attempt to finance disaster losses using personal credit card debt. *Case E* below depicts how a typical small retailer would be impacted in the scenario earthquakes.

Case D: Large Retailer

Company D is a well-known home electronics “superstore” located in south Seattle. Some 40,000 shoppers visit the store each week. Although operating under the name of a national chain, it is owned by two partners in a franchise-type arrangement with the parent company. The store employs 400 people, most of whom live close by. While *Company D* earns the vast majority of revenue from the sales floor, it has recently begun a home delivery service and maintains a small fleet of trucks this purpose. The store serves a market area extending from Mount Vernon to Portland. Most of its customers, however, live north of the store in the Seattle-Bellevue area.

Company D has not given much thought to disaster preparedness beyond setting up emergency evacuation plans. Fortunately, as a franchise, the store participates in the parent company's national insurance plan and can expect some financial and technical support from the parent company in the event of a disaster. Even the worst-case earthquake scenario is therefore unlikely to force *Company D* into bankruptcy.

However, the store could suffer severe short-term business losses if transportation systems were disrupted in a disaster. On a recent winter day when streets were paralyzed by heavy snow, the store managed to open but made only 25 percent of its usual daily sales. Experience has shown that up to two-thirds of lost sales may be made up later, as consumers simply defer making their purchases. The remaining third, being spontaneous shopping, is never recaptured. The actual magnitude of permanently lost sales would also depend upon the duration and extensiveness of the transportation disruption.

In the event of highway disruption, store managers would be most concerned about two things: first, the ability of customers to reach the store, and second, the ability to receive inventory shipments by truck. The M 7.1 Benioff Zone scenario would be very disruptive to both these critical functions.

Company D relies on trucks to bring in its entire inventory. Some of the stock is delivered from warehouses in California and elsewhere, mostly traveling from the south via Interstate 5. The remainder arrives by ship at the Port of Seattle from overseas manufacturers. These goods also need to be trucked to the store. *Company D* normally replaces stock sold in one weekend by the next weekend. It maintains about 3 weeks' worth of inventory in the store, so delays in restocking would quickly affect its bottom line.

Store managers anticipate substantial cost increases in the scenario earthquakes. The trucking companies used by the business, such as *Company A* (see above), would certainly pass on the costs of disaster-related expenses. In addition, *Company D* would probably incur extra advertising and promotional expenses. It would expand its home delivery service, possibly “eating” the extra cost rather than charging a fee for the service. It would have to pay overtime to its delivery truck drivers and office personnel, which could amount to as much as 10 to 20 percent of revenues. Even with the extra hours, the drivers might not be able to make as many trips as needed due to heavy congestion.

Revenues, moreover, would take an enormous hit. People would not be thinking about buying electronics in the aftermath of a disaster. In the first week of the M 7.1 Benioff Zone earthquake scenario, the store might suffer as much as a 75 percent loss of revenue. As people adjust their travel behavior, subsequent weeks might see this reduced to a 50 percent loss. If the situation did not improve much, layoffs might be necessary. Layoffs would have a multiplier effect on the regional economy, as the lost income would not be spent.

The M 6.5 Seattle Fault scenario would be even more devastating, since it would be a direct hit on *Company D*’s main customer base. After one month of disruption, revenue losses might still be as high as 70 percent.

Like other retailers, *Company D* is “very much at the mercy of the local economy.” The impact of an earthquake would depend largely upon how the market responded. There could be a silver lining to the disaster, as households would need to replace damaged home electronics. However, in the atmosphere of thrift that would likely prevail, this boon might not extend to the luxury product lines from which the store gains much of its profits.

Case E: Small Business

Company E is a small, independently owned women’s apparel store in South Center Mall. It has been in business for less than a year and employs 4 people, including the manager. The store takes in average revenues of $1,000 per day. As a new business still paying off a loan, *Company E* is struggling to stay on its feet and maintains no cash reserves. If all goes well, the owner would like to open up a second store in the future. *Company E*'s main competitors are the chain, brand-name apparel stores in the mall.

If regional highways were disrupted in an earthquake, customer access to the store would be very disrupted. This would be the manager's main concern. The store's ability to receive supplies would also be very disrupted, but this would be of lesser concern if there were fewer customers in the event. Since most of the employees live very close by, commuting difficulties would also be a lesser problem.

Highway disruption in the M 7.1 Benioff Zone scenario earthquake could cause revenue losses of some 50 percent in the short-term. If the situation continued for a month, people might adapt their travel patterns to deal with the traffic congestion, so the number of shoppers might recover somewhat. However, the business situation for *Company E* would deteriorate further. The store would not order any new stock, but instead just try to sell what was on the racks in order to stay in the black. Some employees might be laid off. *Company E* would be in serious financial trouble if the situation lasted for more than a few weeks.

4.3.2.4. Finance and Insurance

Background

Transportation disruption would cause less overall disruption to businesses in the finance and insurance industry, as compared with other sectors profiled in this report, but the impacts of a major disaster would still be serious.

Businesses in this industry are primarily dependent upon the highway network for employee commuting. All of those interviewed for this study – even those whose major facilities are located outside the Port-to-Port study corridor – affirmed that highway disruption in the M 7.1 Benioff Zone earthquake disaster would be "disruptive", if not "very disruptive", to employees' ability to get to work.

Insurance companies are unique in that the major portion of their losses would come from claims from policy-holders. Since they interact with their customers via telephone or electronically, transportation disruption alone would have few impacts other than on commuting. Highway congestion would cause inconveniences for field claims adjusters, though this would not necessarily delay paying out insurance claims. Being able to maintain acceptable levels of service would be important to avoid losing new customers and customers outside the disaster region, who may not be as understanding of the local disaster situation.

Banks, however, also rely on the highway network to transport checks and cash between facilities in the region. Checks need to be processed and returned to their originating bank, and access to the airports is important for this function. Delays in processing checks would result in loss of interest revenue that could add up to significant financial losses for a bank.

In the Nisqually earthquake, temporary closures of SeaTac Airport and Boeing Field caused some disruption in check processing functions at regional banks. The physical flow of paper had to be diverted to other airports, in some instances to Everett or Portland, from where they were trucked in at some delay. One institution diverted a small portion of its Seattle region check processing work to an out-of-state facility.

In the aftermath of a disaster, just when the public would be demanding cash for emergency purchases, banks may have difficulty stocking ATMs due to traffic conditions. Banks prefer to stock ATMs on a just-in-time basis. Machines typically get serviced about once a week, although some busier ones get restocked almost once a day.

Impaired customer access to banks could also be an issue. However, if customers could not reach their bank in person, conducting business by Internet or telephone could be a viable alternative.

Businesses in finance and insurance tend to be large firms that have engaged in some degree of disaster mitigation and preparedness. Parts of the industry are required by regulatory agencies to have business recovery plans. Firms often invest in backup electricity generators at critical sites, can automatically reroute customer calls to out-of-state locations, and subscribe to earthquake insurance.

Partial relocation is typically an option, though a costly one. Many have contracted with vendors for emergency work locations, including hotsites where data centers could be moved. Activating a hotsite and moving a data center there could cost up to $1 million. One company that was interviewed had suffered extensive damage to a leased building in the 1994 Northridge earthquake. They were able to quickly relocate the entire office to another facility in the L.A. region. Some businesses have contracts with hotels near the offices, where they could put employees up in an emergency.

Other responses are possible that would make a business more resilient to transportation disruption. Telecommuting and flexible scheduling of work hours are options for some employees, particularly in the insurance industry. Given the range of adjustments that would take place, businesses typically anticipate that losses would decrease over time, even if the highway network remained impaired.

Actual losses in finance and insurance – and indeed, in other services – will depend greatly on the overall impacts to the regional economy and the severity of losses suffered to the employment and customer base.

Case F: Banking Services

Company F is a banking firm with offices throughout the western and central U.S. It employs 900 people in King and Pierce counties, where facilities include branches and a regional headquarters building in Tacoma. The latter houses a call center, a data center with mainframe computers, a cash vault, and a check processing center. Incoming checks and outgoing cash letters need to be transported between the firm's main office facility and Boeing Field, SeaTac Airport, and the Federal Reserve clearinghouse in downtown Seattle.

Highway damage in the M 7.1 Benioff Zone scenario earthquake would be very disruptive, particularly for check processing. Delays could cost the firm several thousands of dollars a day in forgone interest. The bank could also face surcharges if it were unable to return checks back to a sending bank within a certain period of time. Employee commuting would be severely impacted, but people would learn to adjust their travel patterns. Up to one third of the employees would be able to get around transportation problems by working at other locations, at home, or on flexible work schedules.

If the dislocation were to last a month or more, *Company F* would start serving its western Washington banking out of its smaller Portland office. This would incur additional expenses for relocating employees and hauling checks and related paper.

In a catastrophic disaster such as a M 6.7 Tacoma Fault event, *Company F* would expect serious damage to its regional headquarters building, as well as widespread infrastructure failures. It would probably relocate its data center to its out-of-state hotsite for up to a month, at a cost of $400,000. Some employees would also be relocated to other offices. Overall losses and expenses could exceed a million dollars. However, the company does not expect to suffer any long-term loss of business once regional facilities and infrastructure are repaired.

4.4. Regional Economic Impact

In approaching the impacts of the M 7.1 Benioff Event we were guided by the results of the interviews, as described above. We assumed that there would be relatively severe impacts for the first 3 months, the time we assumed it would require the regain functionality in the highway network. However, we also assumed that after this time period there would still be impacts due to the ongoing reconstruction efforts, which we assumed would take one year to complete. We assumed that the cost of highway reconstruction would be $292 million, a figure based on analyses of the cost of replacing bridges in the Northridge earthquake. The impact of this reconstruction activity is described in Table 4.4, which indicates business activity in the regional economy would total $654 million, creating 8,247 jobs, yielding $214 million in labor income, and almost $15 million in tax revenues. We assumed that the funds for this reconstruction activity would come from outside the region, thereby not redistributing funds that would otherwise go towards other transportation projects.

Table 4.4

IMPACT OF $292 MILLION CONSTRUCTION EXPENDITURE

Output (Mils. $2000)	653.87
Manufacturing	82.54
Nonmanufacturing	571.32
Wholesale and Retail Trade	74.30
Services	88.92
Other	408.10
Employment	8,247
Manufacturing	476
Nonmanufacturing	7,771
Wholesale and Retail Trade	1,241
Services	1,888
Other	4,642
Labor Income (Mils. $2000)	214.09
Manufacturing	19.62
Nonmanufacturing	194.47
Wholesale and Retail Trade	30.28
Services	45.11
Other	119.08
Sales Taxes	11.38
B&O Taxes	3.58
Total Tax Revenue ($millions 2000)	14.96

In estimating the negative impact on business activity due to the M 7.1 Benioff Event earthquake itself, we took into consideration several factors that altered production relationships in the input-output model. These alterations to the direct requirements matrix were in turn used to calculate direct, indirect, and induced requirements matrix multipliers that embodied these explicit modeling considerations. We assumed that in the first 3 months, these effects would be more severe than in the 9 month time period in which the highway system would be reconstructed. We further assumed, as a first approximation, that travel times would increase by 100%. The truck component of the transportation services purchase coefficient was increased by this percentage in each industry. We assumed that prices would remain unchanged, and further assumed that these increased transport costs would be reflected in lower value added. Output losses were assumed to be 5% in manufacturing, 25% in transport and trade, and 5% in all other industries. We assumed cost increases for labor in manufacturing and transportation services of 25% to pay for overtime, and a 25% increase in fuel purchases by the transport services sector (we made this change in the direct requirements matrix coefficient). Table 4.5 describes the impacts associated with this scenario. Output losses would be almost $1.4 billion, with the annual equivalent of 19,000 lost jobs, over half a billion in-lost labor income, and over $35 million in lost tax revenue.

Table 4.5

3-MONTH IMPACT ESTIMATES

Output (Mils. $2000)	-$1,379.27
Manufacturing	-321.68
Nonmanufacturing	-1,057.59
Wholesale and Retail Trade	-362.10
Services	-275.33
Other	-420.17
Employment	-19,224
Manufacturing	-1,477
Nonmanufacturing	-17,747
Wholesale and Retail Trade	-6,048
Services	-5,091
Other	-6,608
Labor Income (Mils. $2000)	-$523.25
Manufacturing	-95.59
Nonmanufacturing	-427.66
Wholesale and Retail Trade	-140.16
Services	-141.05
Other	-146.46
Sales Taxes	-$27.82
B&O Taxes	-7.95
Total Tax Revenue ($millions 2000)	-35.77

It is recognized that within this 3 month time period there maybe more severe disruptions immediately following the earthquake.

In the ensuing nine months during which highway reconstruction occurs, it was assumed that there were still impacts on mobility and on costs of production due to recovery efforts. The coefficient structure of the model was changed (compared to the 3-month scenario), with impacts assumed to be half of those modeled in the 3-month scenario. Thus, output impacts are half of the 3 month impact levels, travel time increase is half of the 3 month scenario, labor cost increases are half of the 3 month scenarios, and fuel cost in transport sector is also increased by ½ of the 3 month scenario. The impact on the regional economy of this scenario is significant, with output losses of over $2 billion, the annual equivalent of 28 thousand lost jobs, $746 million in lost labor income, and $51 million in lost tax revenue.

Table 4.6

IMPACTS IN MONTHS 4-12

Output (Mils. $2000)	-$2,031.11
Manufacturing	-478.45
Nonmanufacturing	-1,552.66
Wholesale and Retail Trade	-534.30
Services	-404.12
Other	-614.25
Employment	-28,456
Manufacturing	-2,198
Nonmanufacturing	-26,257
Wholesale and Retail Trade	-8,925
Services	-7,450
Other	-9,883
Labor Income (Mils. $2000)	-$746.17
Manufacturing	-128.35
Nonmanufacturing	-617.82
Wholesale and Retail Trade	-206.63
Services	-207.15
Other	-204.04
Sales Taxes	-$39.67
B&O Taxes	-11.69
Total Tax Revenue ($millions 2000)	-51.35

The cumulative impacts of these scenarios are presented in Table 4.7, which are simply the values in Tables 4.5 and 4.6 added together. Here we can see that the cumulative impact on the regional economy would be a loss of $3.4 billion in output, over 47 thousand jobs, $1.3 billion in labor income, and $87 million in lost tax revenue.

Table 4.7

TOTAL PRODUCTION IMPACTS, ONE YEAR

Output (Mils. $2000)	-$3,410.38
Manufacturing	-800.13
Nonmanufacturing	-2,610.25
Wholesale and Retail Trade	-896.40
Services	-679.45
Other	-1,034.42
Employment	-47,680
Manufacturing	-3,675
Nonmanufacturing	-44,005
Wholesale and Retail Trade	-14,973
Services	-12,541
Other	-16,491
Labor Income (Mils. $2000)	-$1,269.42
Manufacturing	-223.94
Nonmanufacturing	-1,045.48
Wholesale and Retail Trade	-346.79
Services	-348.20
Other	-350.50
Sales Taxes	-$67.49
B&O Taxes	-19.64
Total Tax Revenue ($millions 2000)	-87.12

The combined impact of reconstruction and business curtailed by the earthquake are presented in Table 4.8. Clearly, the losses of output, employment, labor income and taxes significantly outweigh the stimulatory effects of reconstruction. In this simulation, there would be net decrease in output of $2.8 billion, which is about a 4% reduction in overall output compared to the baseline level of activity assumed in this modeling exercise. Slightly higher percentage impacts are estimated for losses in jobs, labor income, and taxes. Impacts are relatively higher in trade and transportation because of more severe assumptions made about the output impacts on these two sectors, compared to manufacturing and other industries included in the model.

Table 4.8

TOTAL IMPACTS

		% Change from Baseline
Output (Mils. $2000)	-$2756.51	-4.1%
Manufacturing	-717.59	-3.2%
Nonmanufacturing	-2038.93	-4.6%
Wholesale and Retail Trade	-822.10	-7.7%
Services	-590.53	-4.1%
Other	-626.32	-3.2%
Employment	-39,433	-4.7%
Manufacturing	-3,199	-3.2%
Nonmanufacturing	-36,233	-4.9%
Wholesale and Retail Trade	-13,732	-7.7%
Services	-10,653	-4.1%
Other	-11,849	-3.9%
Labor Income (Mils. $2000)	-1,055.33	-4.6%
Manufacturing	-204.32	-3.8%
Nonmanufacturing	-851.01	-4.9%
Wholesale and Retail Trade	-316.51	-7.5%
Services	-303.09	-4.1%
Other	-231.42	-4.0%
Sales Taxes	-56.11	-4.6%
B&O Taxes	-16.06	-4.7%
Total Tax Revenue ($millions 2000)	-72.16	-4.6%

The scenario reported here could be altered, with higher or lower percentage changes in production costs, and lost levels of output. This scenario should be considered indicative of the likely impacts. It is a relatively conservative scenario, essentially trying to isolate the economic impacts of damage to the highway network due to the hypothesized Benioff 7.1 event. If the region experienced an earthquake of this nature, there would be other economic impacts that have not been considered in this modeling effort. These include damages to households, (increased household travel costs were included in these simulations), damages other than to highways, and damages to businesses, government, and households in locations outside the corridor that was the focus of this study.

The modeling approach used here has assumed that prices for the output of industries impacted by the earthquake would not be altered. The cost structure for production was altered by changes in transport costs and labor costs as described above in the impact scenario, with increases in these costs resulting in decreases in value added other than labor income. In a linear model of this type aggregate multipliers are only marginally affected by these adjustments. In contrast, the assumptions about lost production translate directly into negative output, employment, income, and tax revenue effects. The magnitude, composition, and temporal distribution of these impacts could be more complexly specified than in the scenario developed here.

4.5. Economic Analysis Summary

The economic impact portion of this study investigated how the Project Impact earthquake scenarios of highway outage would impact local businesses, as well as the regional economy as a whole. The approach consisted of conducting a series of business interviews, developing case studies from these, and running a regional economic impact model to estimate total impacts. In-person interviews were conducted with 21 local businesses selected to represent a cross-section of the economy, from manufacturing to trade to financial services. A few critical infrastructure service providers were also interviewed. The businesses ranged from a 2-person family operation to major employers accounting for thousands of regional jobs. Important findings from the interviews include the following:

- The highway outage situation anticipated for the M 7.1 Benioff Zone earthquake scenario would be “very disruptive” for 76 percent of the businesses interviewed.
- Revenue losses in this scenario would be minimal for some types of firms but very great for others. Retail trade businesses appear to be particularly vulnerable, with respondents anticipating up to an immediate 75 percent loss of revenue.

- Even businesses that could avoid revenue losses would suffer significant cost increases. Many cited the need to pay for overtime labor as an important disaster-related expense.

- Certain sectors would be especially hard hit by the highway disruption. Examples include trucking and other transportation firms, sectors requiring access to the ports (e.g., warehousing, Alaskan fishing fleet), just-in-time manufacturers, and retailers dependent on customer access to the stores.

- Trucking firms would find the M 7.1 Benioff Zone scenario “devastating” and pass on cost increases to their customers. As a result, regional transportation costs will rise significantly.

- Many small businesses have low financial reserves and could face bankruptcy in the event of prolonged regional transportation disruption.

Insights such as these were incorporated into the regional economic impact modeling effort. This analysis made use of a modified version of the Washington State input-output model, customized to handle cost changes and output changes similar to those described above from our interviews. We explicitly considered increased transportation costs (purchased and own-account), as well as lost output, increased labor costs (related to overtime), as well as the costs of reconstructing the highway system. The stimulatory effect of spending for reconstruction is more than offset by the losses incurred by businesses due to the hypothesized earthquake. It is estimated that sales or output would decrease by $2.8 billion, or 4.1%, job reduction would be 39 thousand (a 4.7% decrease), labor income would decline by $1.1 billion (4.6%), and sales and B&O tax revenues would decline by $72 million (4.6%).

5. Contingency Planning

5.1. Introduction

The Puget Sound highway transportation system is currently at/or near capacity for most of the day. Accidents, major and minor repairs or maintenance or other unforeseen short-term closures can cause significant delays, often lasting for hours.

What would be the effect on the region to a longer-term major outage in the system do to a significant earthquake, and what could be put into place to quickly help address the problem?

5.2. Transportation Contingency Planning

Project Impact of King/Pierce Counties through the “Port to Port” Transportation Study decided to develop a pilot contingency planning program for two specific locations, one in each County. Working independently of one another, each County selected a location to work through the contingency planning process.

In King County the selected site was Interstate 5 and the junction of 405 near the Seattle/Tacoma Airport. The Pierce County location was the Puyallup River Bridge on Interstate 5 at the City of Tacoma and the City of Fife border. This site is near the Port of Tacoma.

In both cases Transportation Planners and Engineers, Public Works Officials, Law Enforcement, Emergency Management Response personnel , and representatives of the Ports of Seattle and Tacoma were brought together from the effected Cities, the County and the State to begin the discussion process. In addition a representative of the United States Department of Transportation monitored the effort in Pierce County.

5.3. Methodology

Historically, while their has been some cooperative efforts among jurisdictions to coordinate transportation issues, nothing like this contingency planning for a specific major transportation outage has ever been undertaken in either County.

The first question to answer was given this exact geographical site being affected, where do the vehicles go when this option is taken away? Transportation experts had to educate the other representatives on the new transportation computer modeling programs that provide estimates on the effects on the surrounding road infrastructure. Maps were then produced utilizing Geographic Information Systems (GIS) that showed the traffic alternatives and effects on the collateral road systems.

From that information the alternative routes were identified by responsible jurisdiction, analyzed for capacity and signaling capabilities, and placarding, route directional signage, and road barricade needs identified.

5.4. The Plan

The emergency response plan for failure at either site consists of the following element;

1. An emergency response team consisting of personnel from the Washington State Department of Transportation, Washington State Patrol, the Public Works/Transportation and Law Enforcement Departments from the affected Counties and Cities will operate from the County Emergency Operations Center and they will immediately activate the emergency plan.

2. Preplanned traffic signal changes, road direction signage, road blockades will be implemented as specified under the plan. In addition WSDOT will temporally restripe one-lane exit ramps on the Interstate that have suitable width, into two lane exit ramps.

3. The County’s Public Information Plan will be activated along with the Joint Information Center Plan to ensure that complete and adequate information is disseminated to the media and the public.
4. Damage assessment and time outage estimations will be quickly made to determine the possible closure length of time and to analyze if there needs to be a transition from immediate or temporary closure to a more permanent long-term situation. This may require additional detours or signage issues.

5.5. Conclusion

There have been many positive developments from the contingency planning initiative that has been undertaken in the “Port to Port” study area.

The first multi-jurisdictional transportation emergency response plan is being developed and exercised by agencies that historically have not worked together.

New public safety planning and working relationships have been formed between transportation officials and public safety personnel that did not previously exist. Identification of roles and responsibilities among the group, and the education of each other’s function and capabilities have been extremely valuable.

The new emergence of disaster transportation planning, and the economic impact that is possible from not doing such planning, has been a revelation to those involved in this process. Given the fragile state and capacity issues involving our road infrastructure system, it is clear that this kind of effort needs to be quickly expanded.

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