ESTIMATED ECONOMIC VALUE OF AN INVESTMENT PROGRAM TO MITIGATE IMPACTS OF A MAJOR SEISMIC EVENT USING THE OREGON STATEWIDE INTEGRATED MODEL

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Abstract: The Oregon Statewide Integrated Model was used to evaluate the potential for avoided economic impacts as a result of a major seismic event off the coast of Oregon. The analysis used three primary scenarios: reference scenario, major seismic event with seismically reinforced bridges and landslide mitigation, and a major seismic event without any seismic mitigation investment. The difference in economic production between the modeled scenarios was used to estimate the potential for avoiding economic losses by investing preemptively in seismic reinforcements on key corridors across the state. Results indicate avoided losses in state production activity are far greater than the cost of a large seismic retrofitting investment program, clearly demonstrating such a program represents a good investment choice for the State of Oregon.
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INTRODUCTION

May 2012 the Oregon Department of Transportation (ODOT) completed the Oregon Seismic Lifelines Route Identification Project (1). The purpose of the project was to facilitate the implementation of Policy 1E of the Oregon Highway Plan (2), which states: "It is the policy of the State of Oregon to provide a secure lifeline network of streets, highways and bridges to facilitate emergency services response and to support rapid economic recovery after a disaster." Specific highways and bridges were identified as a backbone network of connecting facilities supporting emergency response and recovery efforts. This backbone network was broken into three distinct priority tiers indicating the level of urgency assigned to restoring system functions.

February 2013 the Oregon Highways Seismic Options Report (3) recommended a strategy to mitigate seismic vulnerabilities of the state highway system. The strategy objective is to lessen highway damage and restore emergency services more quickly. The Oregon Statewide Integrated Model was used to evaluate the economic benefit of investing in a statewide seismic program. This paper presents the modeling analysis used to estimate potential avoided economic impacts of a seismic retrofitting investment program. Estimated benefits from a program such as this must be compared to the program cost before considering a financial commitment of this scale. The results of this analysis indicate this strategy provides an excellent return on investment for the state of Oregon. The magnitude of a large investment program such as this is currently beyond the resources of the state. However, this strategy can be used to establish a long range investment program implemented over time.

REAL WORLD EXPERIENCE

Major events, such as a 9.0 Cascadia subduction zone earthquake (4), significantly impact an economy beyond short term emergency management issues. Several recent case studies from Japan, Turkey and New Zealand reveal a predictable pattern of economic disruption (5-8). Generally speaking, the patterns are as follows:

- Very large proportion of small to medium sized firms fail the first few months after a major earthquake
- Firms attempt to adapt to post-event conditions to maintain business activity:
    - Maintain access to selling markets by choosing new routes and modes if necessary;
    - Maintain access to production inputs by using firms able to provide what is needed, if local firms are unavailable, shift to next best supplier;
    - Maintain access to workers;
    - Relocate firm if access to necessary resources are constrained for a period long enough to threaten the firm's position in the competitive market
    - Once a firm relocates, there is little incentive to return to the previous location. Small and medium firms supporting production activity are likely to relocate near the new location area as well.

Each industry has a unique mix of production activity, logistical needs, and market presence driving their business decisions. The long range impact of major damage to transportation infrastructure has the potential to significantly alter the industrial mix of an area. In turn, such changes will alter the characteristics of the economy, such as wages, population growth and land use.

METHODOLOGY

The purpose of this analysis is to provide high level estimates of avoidable economic impacts caused by damage to the transportation system from a major seismic event (a 9.0 Cascadia Subduction Zone Earthquake, where the fault breaks along the entire subduction zone – a worst case earthquake scenario). In the geological sense, this area is overdue for such an event (4). The chance of a 9.0 earthquake is 12% within the next 50 years. This analysis was prepared for the ODOT Bridge Engineering Section, which is evaluating risks and identifying strategies to mitigate seismic vulnerabilities of the state highway system. The scenario approach was designed to provide a general sense of the magnitude and direction of avoidable economic impacts to Oregon from damage occurring on the highway/street transportation system alone. Non-transportation losses were not accounted for in this analysis, though they would be considerable. Analysis related to loss of life, emergency services, and immediate mitigation requirements were evaluated in the Oregon Seismic Lifelines Route Identification Project (1).

The modeling analysis was conducted using the Oregon Statewide Integrated Model (SWIM). SWIM supports analysis needing to account for intricate connections and feedback amongst Oregon's economy, land use, and transportation systems within one dynamic modeling environment. The complexity and challenges associated with such interaction is addressed through integrated sub-models:

- Economic module: provides characteristics of the state economy, based on the forecast used for the state revenue forecast produced by the Department of Administrative Services (DAS);
- Population synthesizer: control totals consistent with official state population estimates, locates households, which provide labor to business production activity;
- Production location module: allocates business productions and transactions,
- Aggregate land development: simulates land availability,
- Person travel: activity-based model with short and long distance travel;
- Commercial travel: simulates transportation of goods, and
- Traffic assignment: assigns travel to the transportation network

Complete detailed documentation of the SWIM design is available online: http://www.oregon.gov/ODOT/TD/TP/pages/statewide.aspx . The model produces results each year for all modules. The model area includes the state of Oregon and 36 counties surrounding the state border in Washington to the north, Idaho to the east, Nevada and California to the south. Changes in spatial location of economic activity resulting in the transportation limitations were evaluated. Regional aggregation of modeling results provides reliable indication of the relative economic impacts of preparing the transportation infrastructure for a seismic event.

Only the roadway network was altered for the modeled scenarios. Corridors expected to experience damage from a major seismic event were represented as "failing." The points of failure were identified by the ODOT Bridge Engineering Section for high-use state-owned facilities. For lower use corridors and non-state owned facilities in the SWIM network, adjacent parallel routes within these corridors needed to be altered to maintain consistency in network coding. Therefore, the full network was reviewed and altered for consistency. Nearby facilities with similar proximity and characteristics of those identified to fail were represented to fail in the same manner.

Representing loss of commercial buildings or housing, damage to utilities, other damage or loss of life resulting from an earthquake was outside the scope and purposes of this analysis. The purpose of this analysis focused on determining the isolated impacts of the failure of the transportation system, not to create an estimate of the overall economic impact of a major seismic event. No changes were made to the regional forecast of economic activity by industry sector.

Analysis suggests the impacts of a major seismic event result in reduction of production activity for the western region of the state. This study evaluated four scenarios representing multiple stages of strengthening corridors to withstand the impacts of a seismic event. The effects of a seismic event after a three-stage pre-emptive program is implemented are compared to the effects of a worst-case scenario event with no seismic strengthening. The difference in the impact on production activity represented in the statewide model was used as a proxy for estimating the avoided economic losses to Gross State Product (GSP). The analysis focuses on the western portion of the state, defined as the area to the west of the Oregon Cascade Range. The ODOT Bridge Section provided a list of damaged bridges and landslide locations entered into SWIM.

Conducting seismic strengthening before the event occurs enables Oregon to avoid significant economic loss as measured by production activity alone. The losses avoided are larger than the cost of the repair programs, indicating a good return on the investment. Particularly at risk of impacts to production is the Oregon manufacturing sector, since this industry is export oriented and depends heavily on the transportation system to get goods to market and maintain access to the factors of production.

Illustrating this point, **TABLE 1** describes the manufacturing industry by firm size and employment. Given patterns observed in areas hit by major earthquakes in recent history, Oregon's manufacturing industry has the potential to lose a large proportion of firms and jobs in the first year, since small and medium firms are the most likely to fail shortly after a major event. This increases the likelihood of dependent firms relocating to areas unaffected by the earthquake. Repair and strengthening of the system before the seismic event will reduce the rate of firm failure, mitigating economic impacts in the short and long run.

TABLE 1. Manufacturing Sector, First Quarter 2011, Statewide Number of Firms by Size and Employment (in thousands)

% of State	NAICS 31-33 Manufacturing	1 to 19 workers	20 to 249 workers	250+ workers	TOTAL
5%	Establishments	4,062	1,108	98	5,268
	% of sector establishments	77	21	2	100
13%	Employment	21,086	70,561	76,604	168,251
	% of sector employment	13	42	46	100
	% of sector wages	6	29	65	100

Source: Oregon Employment Department

Economic impacts were measured by evaluating the model output values for industry production activity, employment and population. SWIM simulates reduced access to markets cause by disruptions to the transportation system, population relocation and business relocation in response to the reduction in accessibility. The model outcomes do not represent the full economic impacts from seismic event, which is intentional by design.

Caveats

Results presented here derive from hypothetical scenarios where only highways and adjacent local routes fail and all other infrastructure continue to operate as if no earthquake occurred. Given the analysis focuses only on transportation infrastructure and does not account for loss of commercial buildings or housing, damage to utilities, other damage, or loss of life, these estimates are likely lower than what

would actually occur when such a disruptive event occurs. More detailed analysis is required to itemize specific impact areas. This analysis provides results at a high level aimed at providing a general sense of the magnitude and direction of avoidable economic impacts. All consideration and use of the analysis results must reflect this context.

This analysis does not report itemized results for:

- loss of life and injuries,
- loss of worker productivity as an input to industrial production,
- savings from improved emergency service accessibility,
- shifts of resources to provision of basic needs/services,
- shifts of resources to re-construction from other industries,
- loss in productivity due to lost capital, floor space, equipment, utilities and commodity flows,
- damage to and failure of dams,
- loss of electricity, water, telephone (cell and land lines), natural gas, and fuel pipeline

It is important to note true complete isolation is not represented in the model run, SWIM will not run if the network is coded in this way. In order to represent conditions after a large event like this, existing segments that became impassible were assigned a new speed of 1 mph or a fixed travel time of up to a day to represent the difficulty of crossing the temporary alternatives likely developed for each section failure. This is a practical simulation approach for aggregate analysis designed to fulfill the purpose of the analysis.

Description of Scenario Alternatives Evaluated

The Bridge Engineering Section in coordination with Portland State University provided a list of bridges and highway sections that “fail” after a major seismic event. Bridge and landslide repairs and completion dates were provided by the ODOT Bridge Section for five years after the seismic event. The repair schedule and staging was based on the findings of the Oregon Lifelines report. The failures were coded onto the SWIM network in a manner representing the impact to traffic flows over the course of a year. The level of impacts varied depending on the location, such as a major landslide, bridges over water, bridges over land, and interchanges.

The model simulation includes eight years, beginning with the seismic event (year 0), five years of repair activities (years 1-5) and two years of continued economic activity (years 6-7) with a fully functioning highway system. All highway sections in the model were assumed to be open and operating as usual within five years. Thus, network characteristics modeled were the same for all scenarios for years 0, 6 and 7.

Reference Scenario: This is the baseline comparison scenario with current highway conditions, no earthquake or major shocks to the transportation network, and economic growth consistent with current forecasts for the state for eight years.

Major Seismic Event with no Pre-emptive Reinforcement: This scenario represents highway conditions after a 9.0 subduction zone earthquake occurs. This scenario serves as a hypothetical worst-case example representing the greatest level of highway damage. The scenario represents the list of state-owned bridges and sections of highway that “fail” and “repairs” them according to an estimated schedule provided by the Bridge Section.

Major Seismic Event with Pre-emptive Reinforcement: In order to produce a modeled scenario with consistent post-earthquake routing, multiple lower functional class state highways and non-state-owned roads were coded to "fail". Many of these bridges are off the state system, but included in the SWIM network. Thus, they were not specifically identified by the Bridge Section to fail. For example, OR 20 to the coast was identified to fail, but OR 34 an adjacent facility with a similar or likely more problematic alignment was not (because it is a lower function road). In order to represent consistent effects from a major earthquake, OR 34 was coded to fail as well. All the lower functional class roads and off-system roads were coded to be rebuilt within 5 years to remain consistent with the state facility assumptions.

The sections of highways affected by failures are illustrated in **FIGURE 1.** The roadway network is color coded to illustrate when corridors would be repaired and returned to pre-earthquake conditions. The time of completion ranges from 1 to 5 years. **FIGURE 2** provides further illustration of the duration of area isolation due to damaged roads and bridges. Areas coded with the lightest color regain access to the highway system within one year, where the darkest red areas remain effectively isolated for the full five year repair period. Isolation and damage due to loss of power, water, building collapses, fire and other causes are not included in **FIGURE 2** or this analysis. For this analysis, isolation means severely limited access to markets for the local economy, causing delay in economic recovery.

FIGURE 1. Failures and Repair Schedule: Major Seismic Event

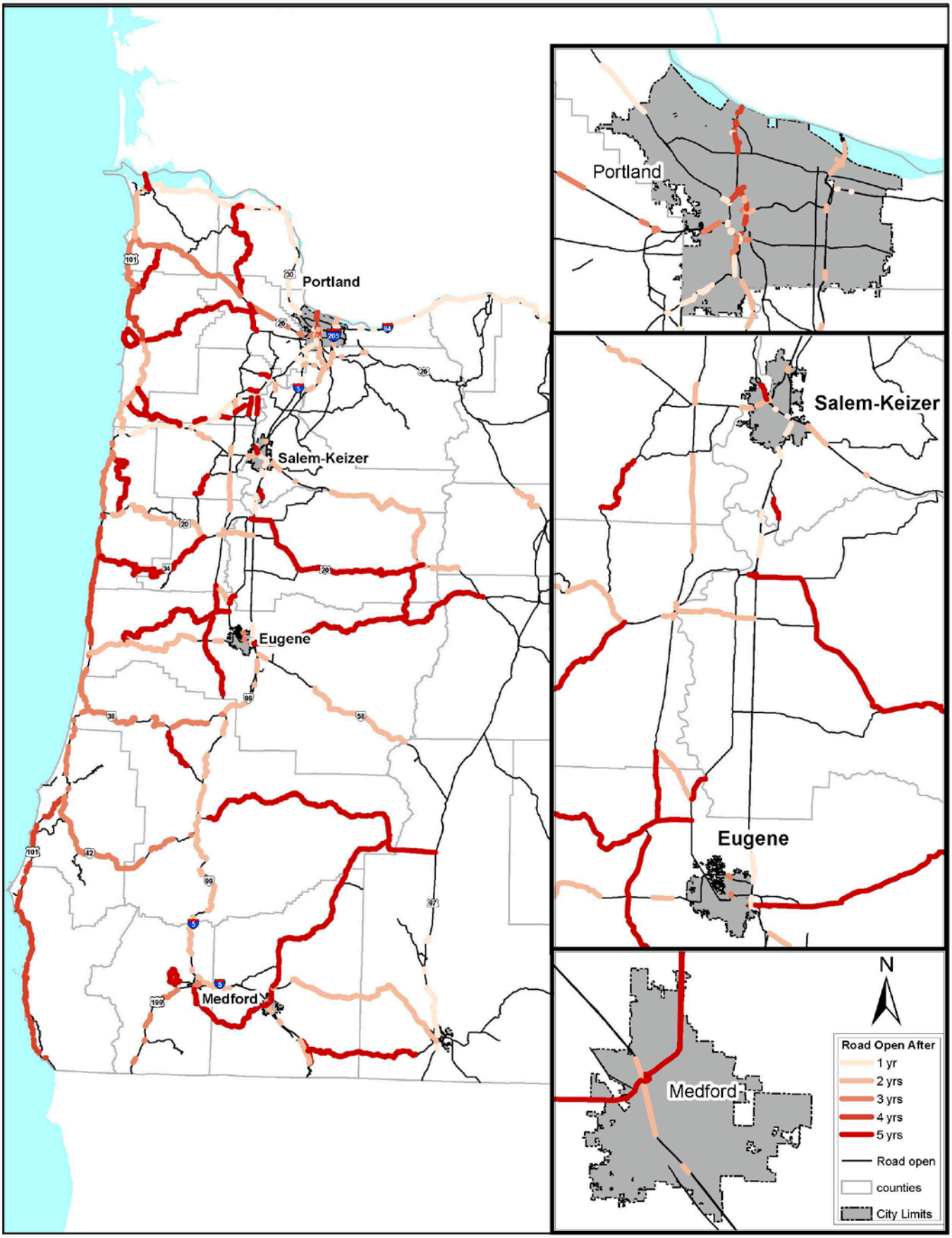
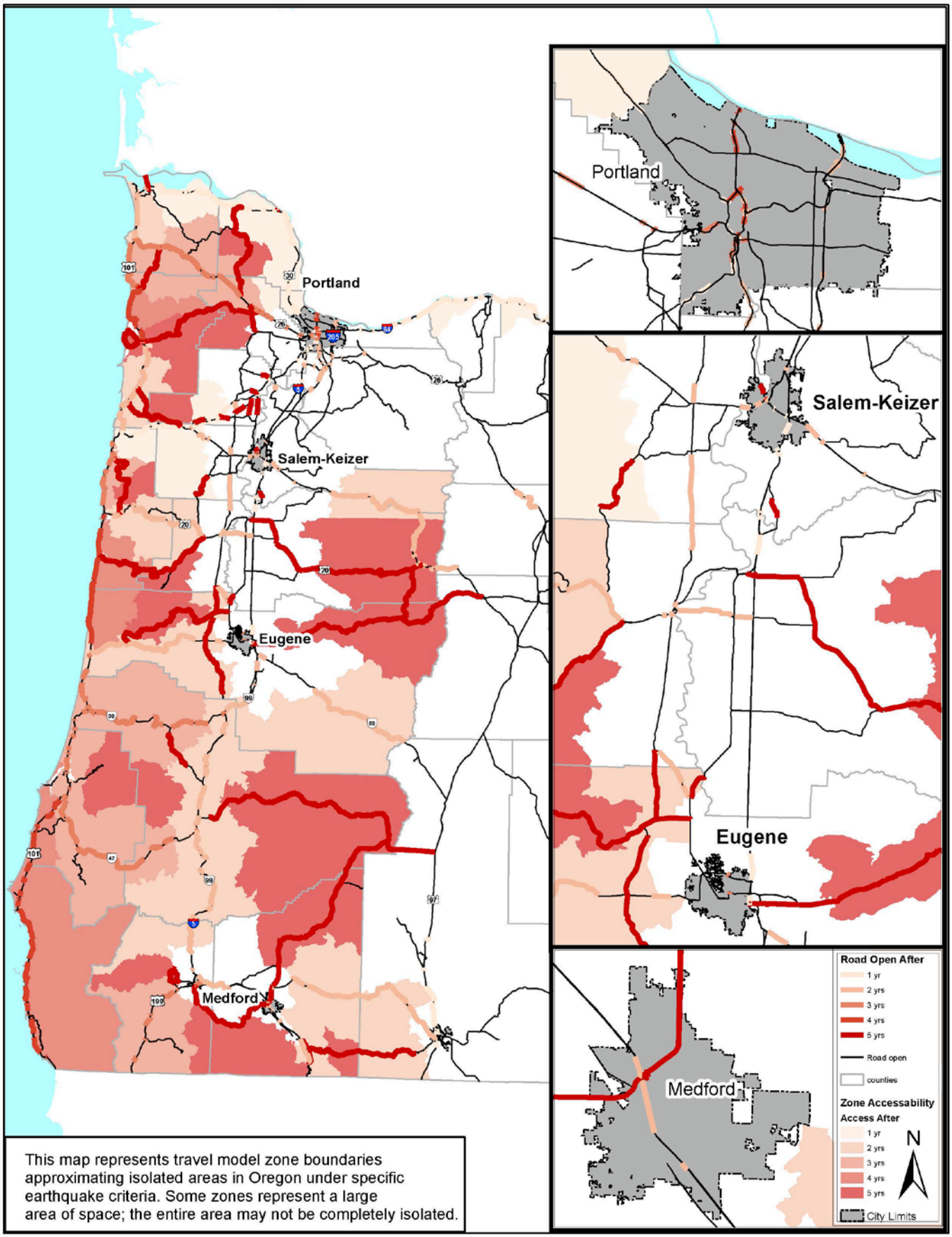


FIGURE 2. Isolated Zones and Repair Phasing: Major Seismic Event Scenarios



A seismic bridge retrofitting, rockfall and landslide stabilization program budget was provided for three separate stages. Scenarios were designed to capture the effects of the individual stages in order to gain a sense of the economic benefits associated with each stage.

Stage 1: This scenario represents conditions after a 9.0 subduction zone earthquake, given the completion of seismic fortification for corridors identified stage 1. **FIGURE 3** illustrates the repair completion schedule and isolation timelines for this scenario. This scenario is represented in SWIM in the same manner as the Major Seismic Event scenario; the only difference is the presence of reinforced bridges and landslide/rockfall mitigation through a seismic improvement program. This program enables Oregon to avoid major earthquake damage to several key corridors, allowing faster and larger scale access to emergency services and supplies necessary to rebuild, as well as accelerated repair damaged sections of the transportation system.

Stages 1 & 2 Scenario: This scenario represents investing at the Stage 1 level and adding Stage 2 improvements, as illustrated in **FIGURE 4.** This figure also reports the level of isolation by geographical location associated with this level of investment.

Full Seismic Program (Stages 1, 2, & 3): This scenario is the level of investment for all three stages of the program, as illustrated in **FIGURE 5.** This figure also reports the level of isolation by geographical location associated with the full seismic program.

FIGURE 3. Isolated Zones and Repair Phasing: Stage 1 Scenario

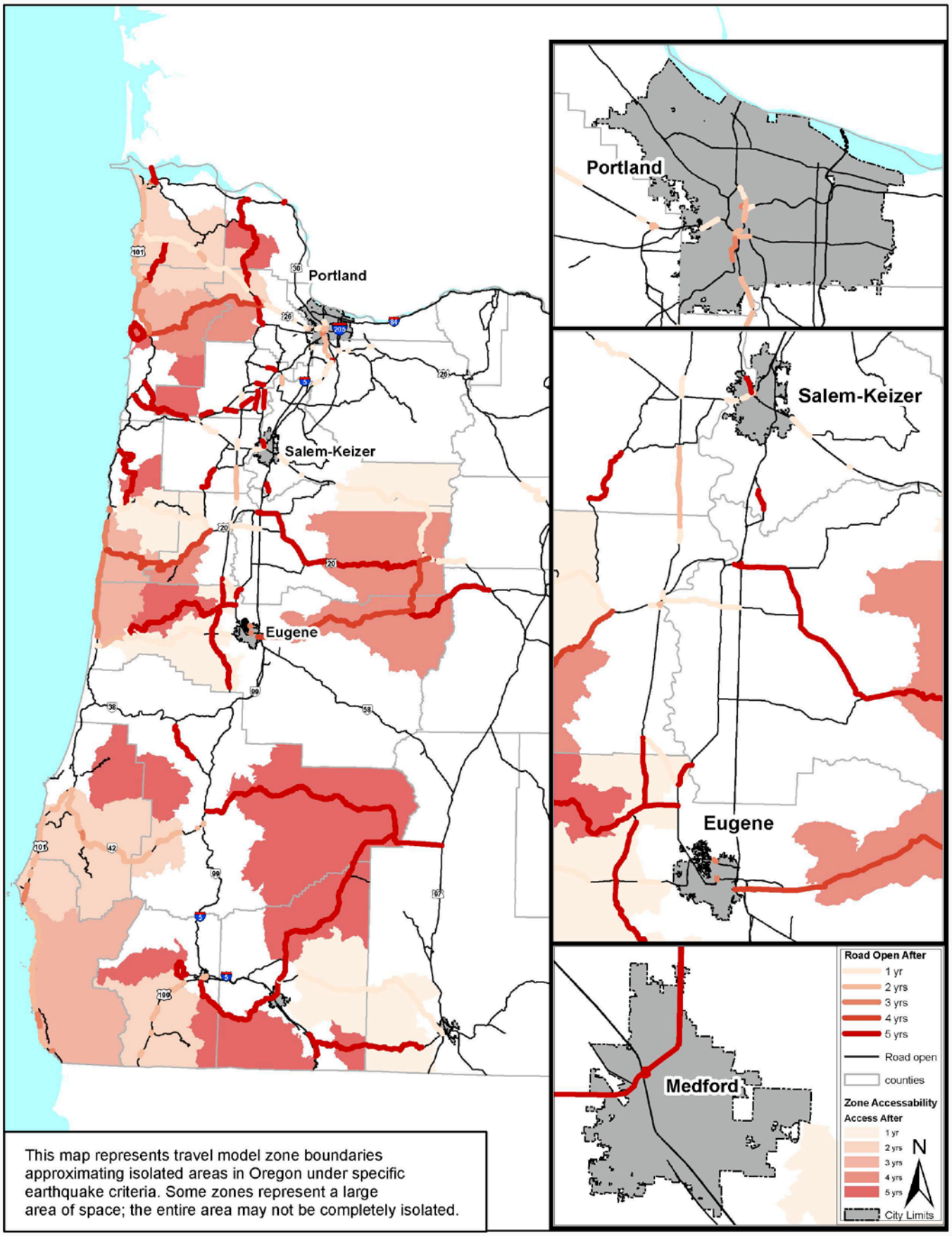


FIGURE 4. Isolated Zones and Repair Phasing: Stage 1 and 2 Scenario

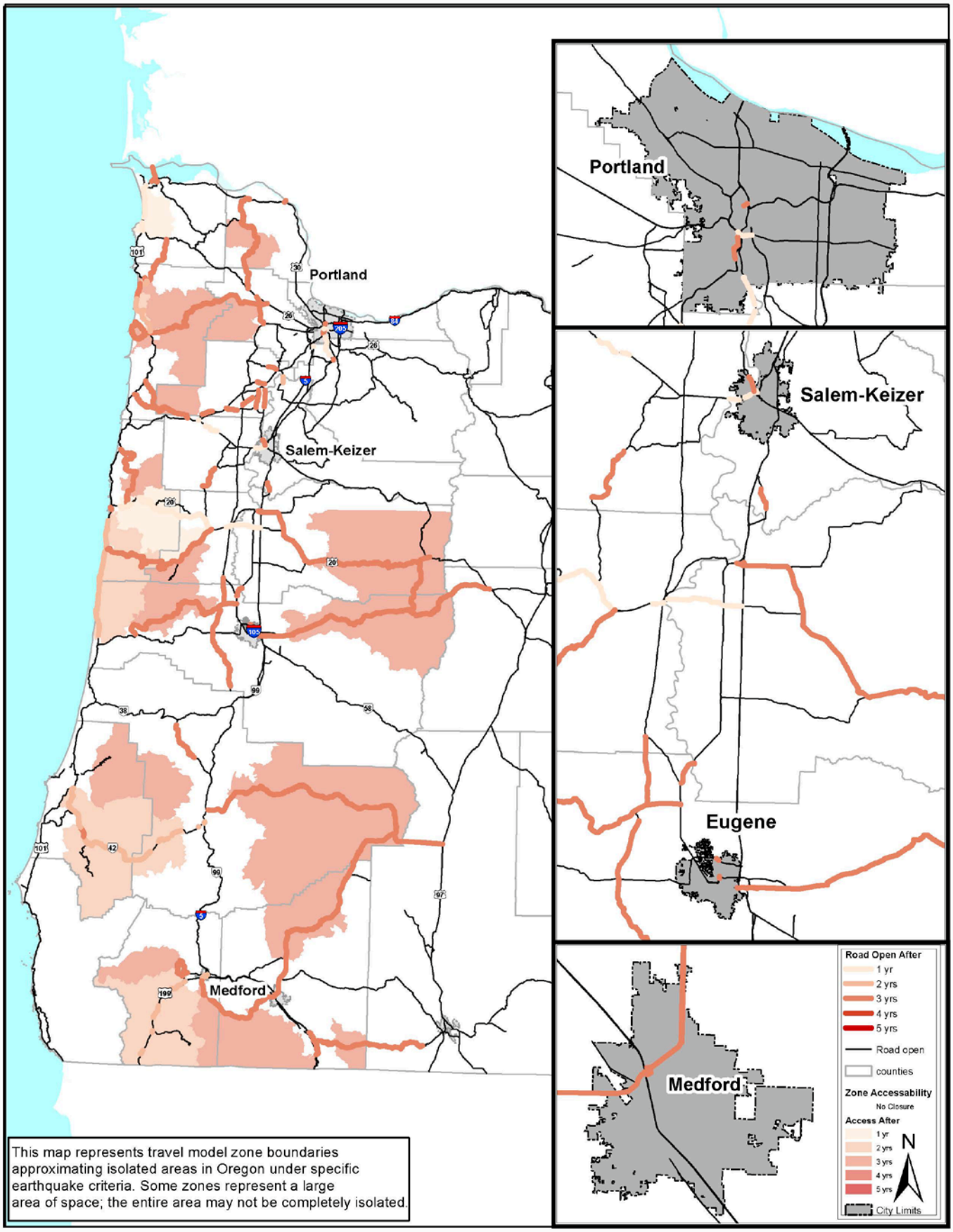
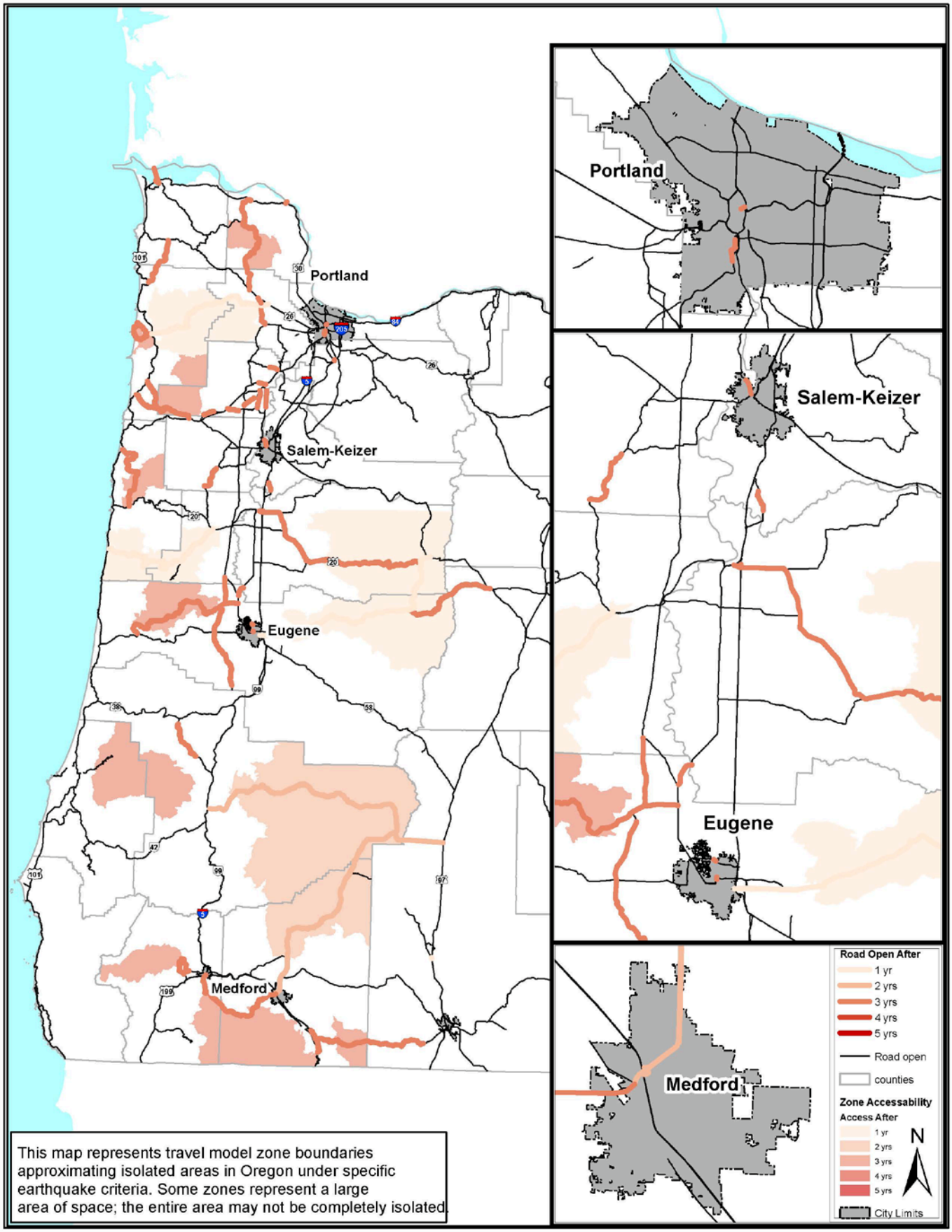


FIGURE 5. Isolated Zones and Repair Phasing: Full Seismic Program Scenario (Stages 1, 2, & 3)



FINDINGS

Western Oregon Impacts

Western Oregon would be significantly affected by a major seismic event. This region of the state generates over eighty percent of the statewide Gross State Product (GSP). In order to gain a general sense of the economic impacts avoided by strengthening of the highway system before the major event occurs, SWIM was used to produce estimates of the value of avoiding reductions to state production levels. This is an appropriate reporting approach because SWIM production activity outputs closely relate to GSP.

The US Bureau of Economic Analysis reported Oregon's 2011 Gross State Product (GSP) as $194,700 million. **TABLE 2** presents the western region share of GSP, including the shares for four sub-regions of the western part of the state using spatial results from SWIM. This information is used as the basis for forecasting the state GSP for this analysis. Assuming the Oregon economy has slow growth over the next ten years (1.5% annually) and the western region's share of GSP remains at 86%, GSP is estimated for the years modeled for this analysis and presented in **TABLE 3**. The modeled year of the earthquake is 2014. These are fairly conservative economic assumptions for growth that can be altered to represent more refined economic forecast for the state if desired. However, these estimates are sufficient in order to gain a general sense of the benefits associated with the seismic program relative to no preliminary seismic preparations.

TABLE 2. Regional Share of Oregon Gross State Product 2011 (millions)

State GSP 2011	$ 194,700
Coast Share (6%)	$ 11,700
Greater Portland Metro (46%)	$ 89,600
Mid-Willamette Valley (24%)	$ 46,730
Southern Valley (10%)	$ 19,500
Western Region share (86%)	$ 167,400

TABLE 3. Forecast Value of Production Activity for Western Region of Oregon (millions)

Year After Event	Estimated GSP	Western Share of GSP
1	$ 206,600	$ 177,700
2	$ 209,700	$ 180,400
3	$ 212,900	$ 183,100
4	$ 216,100	$ 185,800
5	$ 219,300	$ 188,600
6	$ 222,600	$ 191,500
7	$ 226,000	$ 194,300

Estimate based on 2011 GSP with annual growth of 1.5%. Western share of GSP remains 86% over time; figures are in 2011 dollars

TABLE 4 provides the modeled year-to-year reduction in production activity for the western region of the state for the four alternative scenarios compared side-by-side. Over the course of the modeled years, the greatest loss to production activity occurs under the Major Seismic Event scenario. The fully implemented three-tiered seismic improvement program significantly reduces these losses by millions of dollars.

TABLE 4. Estimated Reduction in Economic Activity Relative to Reference Scenario
(2011 dollars, millions)

	Scenario			
Year After Event	Seismic Event	Stage 1	Stage 1&2	Full Program
1	67,500	56,900	55,100	48,000
2	55,900	50,500	48,700	41,500
3	53,100	51,300	43,900	38,500
4	48,300	48,300	37,200	31,600
5	45,300	43,400	35,800	32,100
6	42,100	34,500	38,300	38,300
7	42,700	35,000	40,800	40,800
TOTAL	354,900	319,900	299,800	270,800

TABLE 5 presents the dollar value of the avoided GSP reduction by scenario for the first three full years of recovery followed by the last four years. The first three years of construction for the different stage scenarios provide more than half of the economic benefit over the course of the eight year recovery period modeled. This demonstrates how important a speedy recovery is to the economy of Oregon.

TABLE 5. Avoided Reduction in Production Activity by Scenario
(2011 dollars, millions)

	Scenario			
	Seismic Event	**Stage1**	**Stage 1&2**	**Full Program**
First Three Years Loss	176,500	158,700	147,700	128,000
Loss Avoided		**17,800**	**28,800**	**48,500**
Last Four Years Loss	178,400	161,200	152,100	142,800
Loss Avoided		**17,200**	**26,300**	**35,600**
TOTAL AVOIDED LOSS		**35,000**	**55,100**	**84,100**

Economic Impacts by Region

For this analysis, western Oregon was divided into several sub-regions. **FIGURE 6** illustrates the sub-regions used for this analysis:

- The Coast (split into five parts)
- The Metro Area (Portland)
- The Mid-Willamette Valley (MWV) including Salem, Corvallis and Eugene; and
- The Southern Valley area (SV) including the area south of Eugene and north of California, bordered by the Cascade and Coastal mountain ranges.

FIGURE 6. Areas of Analysis

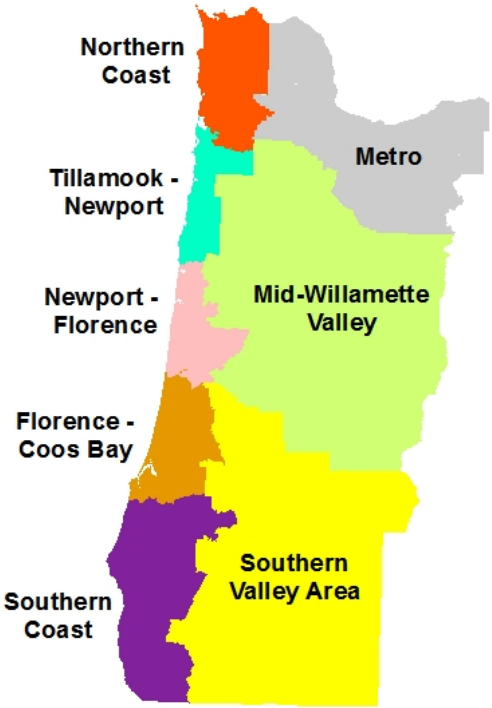


TABLE 6 provides a brief summary of the economic impacts on regional production activity for all four seismic scenarios relative to the reference scenario. The western region of Oregon generates about 86% of the total statewide production activity. The Coastal region represents 6% of statewide production activity, Portland Metro 46%, Mid-Willamette Valley 24% and the Southern Valley 10%.

TABLE 6. Percent Reduction in Economic Production With Respect to Reference Scenario

	Seismic Event			Stage 1			Stage 1&2			Full Program		
Region (percent share of state)	Yr 1	Yr 3	Yr 7	Yr 1	Yr 3	Yr 7	Yr 1	Yr 3	Yr 7	Yr 1	Yr 3	Yr 7
Coast Total (6)	63	49	11	53	38	10	49	30	11	34	24	11
Portland Metro (46)	32	25	28	28	26	21	26	24	26	25	21	26
Mid-Willamette Valley (24)	38	26	16	34	24	15	33	23	16	25	22	14
Southern Valley (10)	49	37	12	39	33	11	42	30	11	39	24	11
Western Total (86)	38	29	22	32	28	18	31	24	21	27	21	21

Oregon Coast

Under the Major Seismic Event scenario, the Oregon coast economy is significantly impacted, with production initially dropping over 60% and employment over 70%. Within a couple of years the economy continues to perform at a significantly lower level with 49% less production activity than forecast in the reference scenario and employment 63% lower. By the end of the seventh year after the seismic event, production activity recovers to a level 11% lower than the reference scenario and employment 10% lower.

Portland Metro

The Portland Metro economy is significantly impacted under the Major Seismic Event scenario, with production initially dropping by about 32% and employment about 24%. Within a couple of years the economy continues to perform at a significantly lower level with 25% less production activity than forecast in the reference scenario and employment 16% lower. By the end of the seventh year after the seismic event, production activity is 28% lower than forecast and employment 20% lower.

Mid-Willamette Valley

Under the Major Seismic Event scenario, the Mid-Willamette Valley is significantly impacted, with production initially dropping 38% and employment 32%. Within a couple of years the economy continues to perform at a significantly lower level with 26% less production activity than forecast in the reference scenario and employment 24% lower. By the beginning of the eighth year after the seismic event, production activity recovers to a level 16% lower than the reference scenario and employment 14% lower.

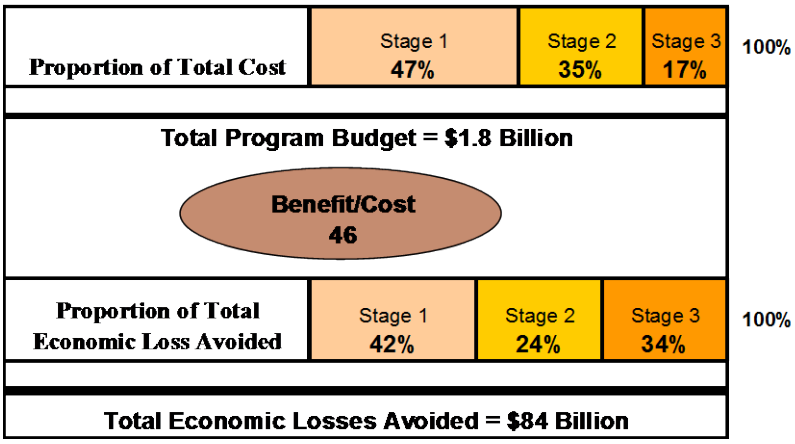
Southern Valley

Under the Major Seismic Scenario, the Southern Valley is significantly impacted, with production initially dropping 49% and employment 56%. Within a couple of years the economy continues to perform at a significantly lower level with 37% less production activity than forecast in the reference scenario and employment 50% lower. By the end of the seventh year after the seismic event, production activity and employment recover to a level 12% lower than the reference scenario.

CONCLUSION

A major seismic event will significantly impact the Oregon economy immediately after and in the longer run. Results of this analysis indicate strengthening corridors before a major seismic event will enable the state to avoid a significant amount of economic loss. This analysis evaluated four alternative scenarios in order to gain a sense of the potential loss in production activity we could expect due to the damage to the transportation system after a major seismic event. Four scenarios representing seismic preparation and repair demonstrate the value added (impacts avoided) to the Oregon economy. Significant economic losses in production activity can be avoided by preparing for a major earthquake ahead of time. With no preparation ahead of time, Oregon could lose up to $355 billion in gross state product in the 8 to 10 year period after the event. Proactive investment in bridge strengthening and landslide mitigation reduces this loss between 10% and 24% over the course of the eight years simulated for this analysis. **FIGURE 7** presents the estimated cost of the preventive seismic work alongside the economic benefits, as measured by avoided loss of state production activity. This results in a benefit-cost ratio of 46 for the full seismic program. Weighting this result with the 12% chance of a major event occurring within the next 50 years, the ratio is adjusted to 6.

FIGURE 7.


Proportion of Total Cost
Stage 1
47%
Stage 2
35%
Stage 3
17%
100%
Total Program Budget = $1.8 Billion
Benefit/Cost
46
Proportion of Total Economic Loss Avoided
Stage 1
42%
Stage 2
24%
Stage 3
34%
100%
Total Economic Losses Avoided = $84 Billion

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