Spatial Investigation of Mineral Transportation Characteristics in the State of Washington

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of Hayk Khachatryan find it satisfactory and recommended that it be accepted.

Chair

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Abstract

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The aggregates industry in Washington is a major provider of construction materials such as sand and gravel, crushed stone and, as such, plays vital role in the state's infrastructural development. Availability of aggregates in general can affect the support for regional economic development since one of the biggest consumers of the aggregates industry is the transportation industry. High quality aggregates are used for maintenance and repair of state highways to increase the durability of state highways, as well as for the development of new roads. With the growing traffic volume on state highways and increasing durability standards, the demand for construction aggregate continues to grow.

The main purpose of this study is to investigate the transportation and operational characteristics of Washington's mined products, using the data from the survey conducted for Washington State Department of Transportation (WSDOT). As a part of a six year comprehensive research and implementation project - Strategic Freight Transportation Analysis (SFTA), the study investigates needs of the mining industry as they pertain to Washington’s road networks. Data collected from this survey will help to inform both the location and type of need for road maintenance and improvements. To achieve that purpose, Geographic Information Systems (GIS) is used as an analytical tool to create desired maps and to analyze spatial relationship between mine locations and road system. Maps containing locations of mines were created based a GIS coverage file provided by Washington State Department of Natural Resources (DNR) Division of Geology and Earth Resources (DGER). County and highway system GIS files were obtained from the WSDOT GeoData Distribution Catalog.

Further, the survey data is used to study spatial correlation of Washington’s mines and road networks, as well as an attempt to measure mining industry’s “contribution” to Washington’s roads usage and potential deterioration. Many studies have examined the relationship between transportation cost and construction unit productivity, but there’s minimal information available pertaining to the relationship between payload weights, shipment distances and highway deterioration. Thus, as a first step in a series of forthcoming studies, the spatial relationships between aggregates shipments and hauling trucks’ payload weights are examined more closely.

Spatial non-stationarity of the data is possible whenever any process takes place over many different geographical locations. Therefore, the study employs a spatial error model with distance based weights matrix to address spatial autocorrelation, to capture the interaction between spatial units, and to predict the incremental change in payload weights resulting from increasing hauling distance. Results show a highly significant positive relationship between payload weights and increasing shipment distances.

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CHAPTER ONE

INTRODUCTION

The aggregates industry in Washington is a major provider of construction materials such as sand and gravel, crushed stone and, as such, plays vital role in the state's infrastructural development. Availability of aggregates in general can affect the support for regional economic development since one of the biggest consumers of the aggregates industry is the transportation industry. High quality aggregates are used for maintenance and repair of state highways to increase the durability, as well as for the development of new roads. Today, one mile of interstate highway construction consumes about 20,000 tons of aggregate per lane (Zettler, Rick)[1]. With the growing traffic volume on state highways and increasing durability standards, the demand for construction aggregate continues to grow.

As a part of a six year comprehensive research project, Strategic Freight Transportation Analysis (SFTA), this study investigates needs of the mining industry as they pertain to Washington's road networks. Data collected from this survey that was designed to investigate the transportation and operational characteristics of Washington's mined products will help to inform both the location and type of need for road maintenance and improvements. To achieve that purpose, Geographic Information Systems (GIS) is used as an analytical tool to create desired maps and to analyze spatial relationship between mine locations and road system. Maps containing locations of mines were created based a GIS coverage file provided by Washington

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[1] Note that 94% of the asphalt and 80% of concrete pavements consist of construction aggregate (National Stone, Sand and Gravel Association).

State Department of Natural Resources (DNR) Division of Geology and Earth Resources (DGER). County and highway system GIS files were obtained from the WSDOT GeoData Distribution Catalog.

Further, the survey data is used to investigate the spatial relationships between construction aggregate shipment and the trucks' payload weight as it pertains to highway deterioration in the State of Washington.

The Survey Objective

The main objective of the survey was to examine transportation characteristics of mining Washington's aggregates and to analyze spatial relationship between mine locations and road network. Because the transportation of mined products underlies the state's economy and regional operations, better understanding of the mining industry needs (as they pertain to the road network) is very useful. The majority of the first phase of the survey was accomplished in 2006. The second mailing of the survey, designed for non-responder companies, followed after about two weeks, in late January, 2006. The initial mailing of the survey resulted in a 20.4% response rate (mining sites), which increased to 47.2% at the end of the second mailing.

Mining Industry in Washington

The State of Washington is one of the top 10 aggregates producer states in the United States (Wallace P. Bolen, USGS Construction Sand and Gravel Statistics and Information, 2004). Its mineral industry produced an average of 42.2 million tons of construction sand and gravel and 13.7 million tons of crushed stone annually from 2001 to 2003 (Table 2.1.1).

Table 2.1.1 Nonfuel Raw Mineral Production in Washington[2] (Thousand metric tons and thousand dollars unless otherwise specified) [1, 2]

	2001		2002		2003[p]	
Mineral	Quantity	Value	Quantity	Value	Quantity	Value
Clays, common	89	258	89	169	89	169
Gemstones	N/A	25	N/A	29	N/A	29
Gold[3] (kilograms)	1,700	14,900	980	9,810	--	--
Sand and gravel, construction	41,400	220,000	43,200	223,000	42,000	218,000
Silver[3] (kilograms)	--	--	729	108	--	--
Stone, crushed	14,100	84,300	13,700	79,900	13,400	79,100
Combined values of cement (portland), diatomite, lime, magnesium metal(2001), olivine, peat, sand and gravel (industrial), and stone (dimension miscellaneous)	XX	178,000	XX	124,000	XX	133,000
Total	XX	498,000	XX	437,000	XX	430,000

[p] Preliminary. NA Not available. XX Not applicable. -- Zero.

[1] Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

[2] Data are rounded to no more than three significant digits; may not add to totals shown.

[3] Recoverable content of ores, etc.

The table was adopted from *The Mineral Industry of Washington 2003*, U.S. Geological Survey, USGS Minerals Yearbook 2003.

The two main sources of natural aggregates, construction sand and gravel and crushed stone, are the most extractable and most demanded natural resources (Wallace P. Bolen, USGS Construction Sand and Gravel Statistics and Information, 2004). Defined as Aggregates, those represent about 96 % of Washington's mined minerals volume (Transportation of Mining/Mineral Survey results). However, in order to develop more comprehensive information on the mining industry from this study, 12

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[2] Nonfuel indicates the difference from fuel minerals, which represent any materials/minerals that release energy as a result of changing or converting their chemical or physical structure – (coal, peat, etc.)

types of minerals were included: sand and gravel, rock or stone, coal, carbonate, clay, peat, metals, ash, diatomite, silica sand, soil and gold.

Below are definitions of aggregate types that are broadly discussed in this study.

- *Natural aggregates* can be defined as materials that are composed of rock fragments and are used in their natural condition except for such operations as crushing, sizing and washing.
- *Rocks* are solid, consolidated materials derived from the earth and usually have relatively small size.
- *Gravel* is a granular material mostly retained on the No. 4 (4.75 mm) sieve that is received from natural disintegration and abrasion of rock or processing of weakly bound conglomerates.
- *Crushed gravel* results from the artificial crushing of gravel or small cobblestones with substantially all fragments having at least one face resulting from fracture.
- *Crushed stone* results from the artificial crushing of rock, boulders, or large cobblestones, (all faces result from crushing operation).
- *Coarse aggregate* is composed of mainly gravel-size particles and predominantly retained on the No. 4 (4.75 mm) sieve.
- *Fine aggregate* mainly composed of sand-size particles (passing the 3/8 inch (9.5 mm) and No. 4 (4.75 mm) sieves).
- *Sand* is a granular material passing the 3/8 inch (9.5 mm) sieve, almost entirely passing the No. 4 (4.75 mm) sieve, and mainly retained on the No. 200 (75 μm) sieve that is received from natural disintegration and abrasion of rock or processing of completely friable sandstone.
- *Sand and gravel aggregate* is a mixture (or aggregation) of sand and gravel where gravel is accounted for 25% or more of the mixture (McLaughlin, et al. 1960).

The transportation industry proves to be the biggest consumer of Washington's aggregates industry based on volumes of sand and gravel and crushed stone sold or used in 2002 by major category, (Table 2.1.2). The use, consisting of end-use[3] categories such as road base and coverings, road stabilization (cement), fill, snow and ice control, railroad ballast, consumed a significant portion of aggregates industry's production (USGS Minerals Yearbook 2003, The Mineral Industry of Washington 2003). Shown in Tables 2.1.2 and 2.1.3 are volumes of various uses of aggregates by major category in 2002.

Table 2.1.2 Washington's construction sand and gravel sold or used in 2002, by major use category [a]

Use	Quantity (thousand metric tons)	Value (thousands)	Value (per ton)
Concrete aggregate (including concrete sand)	7,810	$53,000	$6.78
Concrete products (blocks, bricks, pipe, decorative, etc.)[b]	152	1,710	11.24
Asphaltic concrete aggregates and other bituminous mixtures	1,840	10,100	5.49
Road base and coverings	7,700	36,100	4.68
Fill	6,740	23,000	3.41
Snow and ice control	105	449	4.28
Railroad ballast	139	774	5.57
Other miscellaneous uses	220	1,340	6.09
Unspecified:[c]			
Reported	8,220	40,400	4.92
Estimated	10,000	56,000	5.47
Total or average	43,200	223,000	5.16

[a] Data are rounded to no more than three significant digits, except unit value; may not add to totals shown.
[b] Includes plaster and gunite sands.
[c] Reported and estimated production without a breakdown by end use.
The table was adopted from *The Mineral Industry of Washington 2003*, U.S. Geological Survey, Minerals Yearbook 2003.

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[3] End-use is defined as the use of mineral commodity in a particular industry sector.

Table 2.1.3 Washington's crushed stone sold or used by producers in 2002, by use category[1]

Use	Quantity (thousand metric tons)	Value (thousands)	Unit value
Construction:			
Coarse aggregate (+1 1/2 inch):			
Macadam	W[2]	W	$8.59
Riprap and jetty stone	64	$511	7.98
Filter stone	12	93	7.75
Other coarse aggregates	122	774	6.34
Total or average	198	1,380	6.96
Coarse aggregate, graded:			
Concrete aggregate, coarse	(2)	(2)	4.19
Bituminous aggregate, coarse	(2)	(2)	8.27
Bituminous surface treatment aggregate	(2)	(2)	4.24
Railroad ballast	48	276	5.75
Other graded coarse aggregates	25	126	5.04
Total or average	104	609	5.86
Fine aggregate (-3/8 inch):			
Stone sand, concrete	(2)	(2)	3.69
Screening, undesignated	(2)	(2)	5.15
Other fine aggregates	9	53	5.89
Total or average	82	413	5.04
Coarse and fine aggregate:			
Graded road base or subbase	641	2,780	4.33
Unpaved road surfacing	331	1,820	5.49
Terrazzo and exposed aggregate	W	W	9.92
Crusher run or fill or waste	102	444	4.37
Other coarse and fine aggregates	764	3,240	4.23
Total or average	1,840	8,270	4.50
Other construction materials	91	840	9.23
Agricultural	5	21	4.20
Chemical and metallurgical	69	847	12.28
Special	135	1,420	10.53
Other miscellaneous uses	(7)	(7)	6.50
Unspecified[3]	11,100	65,700	5.91
Grand total or average	13,700	79,900	5.82

W Withheld to avoid disclosing company proprietary data; included with "Other."

[1] Data are rounded to no more than three significant digits, except unit value; may not add to totals shown.

[2] Withheld to avoid disclosing company proprietary data; included in "Totals."

[3] Reported and estimated production without a breakdown by end use.

The table was adopted from *The Mineral Industry of Washington 2003*, U.S. Geological Survey, Minerals Yearbook 2003.

Residential and commercial construction industries are other consumers of the aggregates, given that 80% of concrete is construction aggregate. As an example, the average home construction requires about 400 tons of construction aggregates (National Stone, Sand and Gravel Association). Recently, the average level of annual aggregate consumption in the US reached 10 tons per person, which is 80 times of the volume consumed in early 1900s. Concurrently, increasing demand for extraction of aggregates results in growing pressures from environmental agencies and local communities (Zettler, Rick).

The Aggregates Industry in Washington study conducted by Pacific Lutheran University in 2000 found about 52% of aggregates and ready mix was used by the transportation industry. Projects were classified as road maintenance, street & runway construction and bridges. About twenty two percent was attributed to residential, 18.5% to commercial and offices, and 7.5% to public sectors' uses (B. Finnie, J. Peet 2003).

There were 2,807 surface mines in the state of Washington, 1,645 of which are currently terminated (Norman, D., Figure 2.1.1). Terminated status represents mines that were depleted and fully reclaimed. Active mines[4] can be further categorized as currently operational or non-operational. Non-operational represents mines that are not operating because of various obstacles such as high transportation costs or absence of construction projects in the economically feasible region, or mines that are kept as a reserve for further use.

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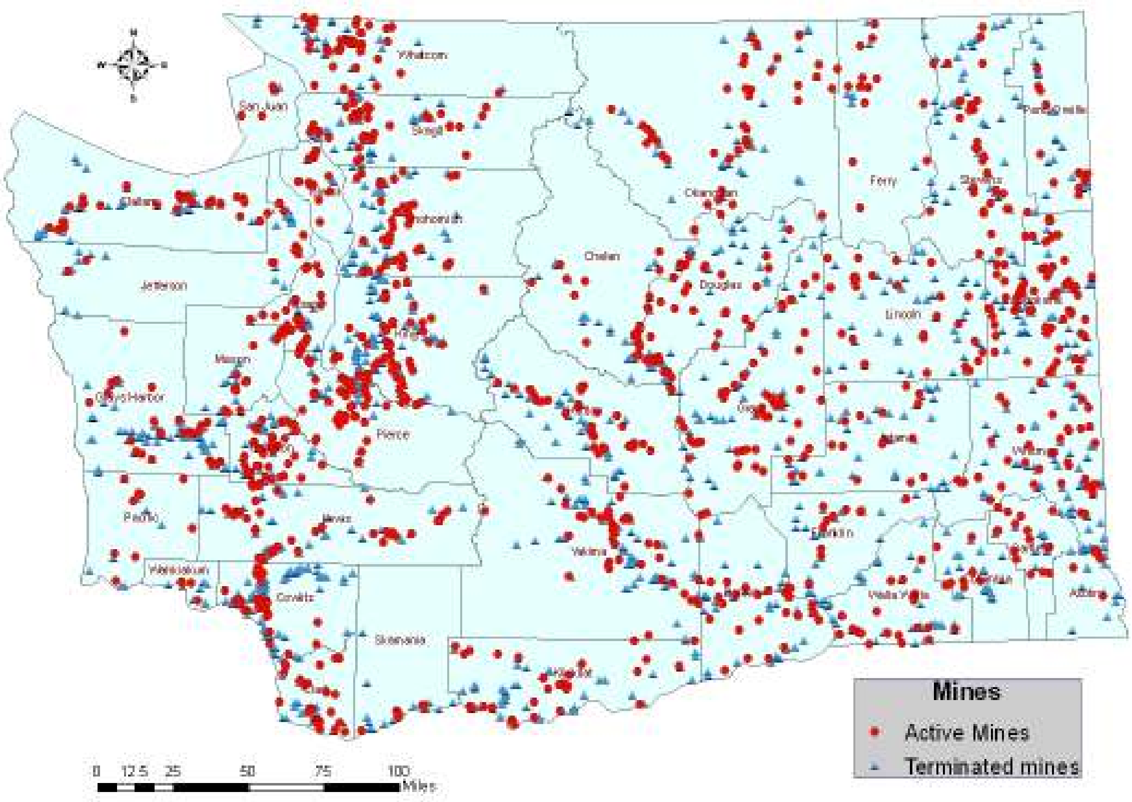
[4] Hereafter, "mines" refers to "surface mines."

Figure 2.1.1 State of Washington Active and Terminated Mines



Data Sources: Geographic site information was obtained from Washington Department of Natural Resources, Division of Geology and Earth Resources. County GIS files were downloaded from the WSDOT GeoData Distribution Catalog.

Mining Regulations

Reclamation permits for Washington's mines are issued by Department of Natural Resources (DNR), which has exclusive authority to endorse reclamation plans (DNR Division of Geology and Earth Resources (DGER)). As such, the DRN DGER carries responsibility for ensuring reclamation of the active (approximately1,200) permitted mines.

The main objective of reclamation at terminated mines is to reestablish the vegetative cover, soil stability, and water conditions at the site (Surface Mining Reclamation Program, DNR DGER). *The Surface Mining Reclamation Act* requires a reclamation permit for each mine in State of Washington that has the following three characteristics: results in 3 or more acres of mine-related disturbance, or has a high-wall that is higher than 30 feet and steeper than 45 degrees (Surface Mining Reclamation Program).

Each of the mining permit holders must have a quality reclamation plan, which is required to be periodically reviewed and updated (DNR DGER). Detailed reclamation plans that include contouring of land, placement of topsoil and reseeding with native vegetation/crops/trees, must be approved by government officials and local permitting groups before mining begins. As a result reclaimed mine sites are returned to productive uses such as recreational parks, golf courses or wildlife areas, which is sometimes better than their original conditions (National Mining Association).

All other mine-related activities are permitted by local governments or state and federal agencies. Particularly, local governments must officially approve the location and use of mine sites (Surface Mining Reclamation Program, RCW 78.44.091) before they receive a reclamation permit from the DNR.

Transportation of Minerals

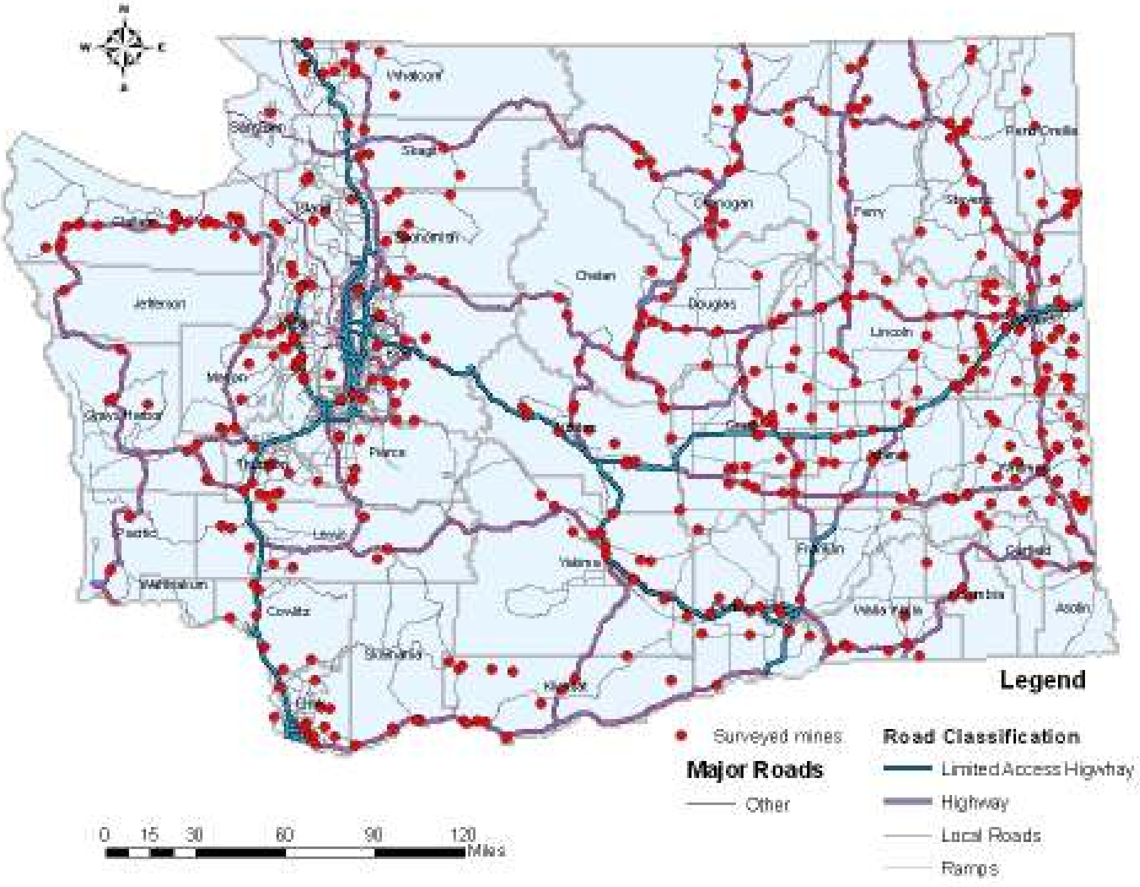
Aggregates industry is highly affected by transportation in terms of high cost of movement. More than 90% of transported mined commodities were hauled using trucks as a mode of transportation from mine pit to points of sale or processing plant, 3% used waterway and 1% used rail (Wallace P. Bolen, USGS Construction Sand and Gravel Statistics and Information, 2004, Table 1, Appendix A).

Looking generally, the location pattern of active mines in the study area seems reasonably dispersed. However, closer investigation of mine locations, road network and highly urbanized areas showed local clustering, emphasized in Figure 2.3.1. This is explained by high concentration of highway, home and office construction in urban areas.

The opening of a new mine site usually changes the pattern of transportation of aggregates in the region. If aggregate producers and construction sites are transportation cost minimizing, the new path of aggregates transportation from a new site will require less truck transport than the pattern of transportation used to haul from other mine sites (Berck, Peter, 2005).

Considering weight to value ratio, aggregates are inexpensive products, but adding the transportation costs may increase the unit price significantly for each additional hauling distance. The total cost of transportation and production may explain a high correlation between mine and construction sites locations.

Figure 2.3.1 Washington's active mines and road network



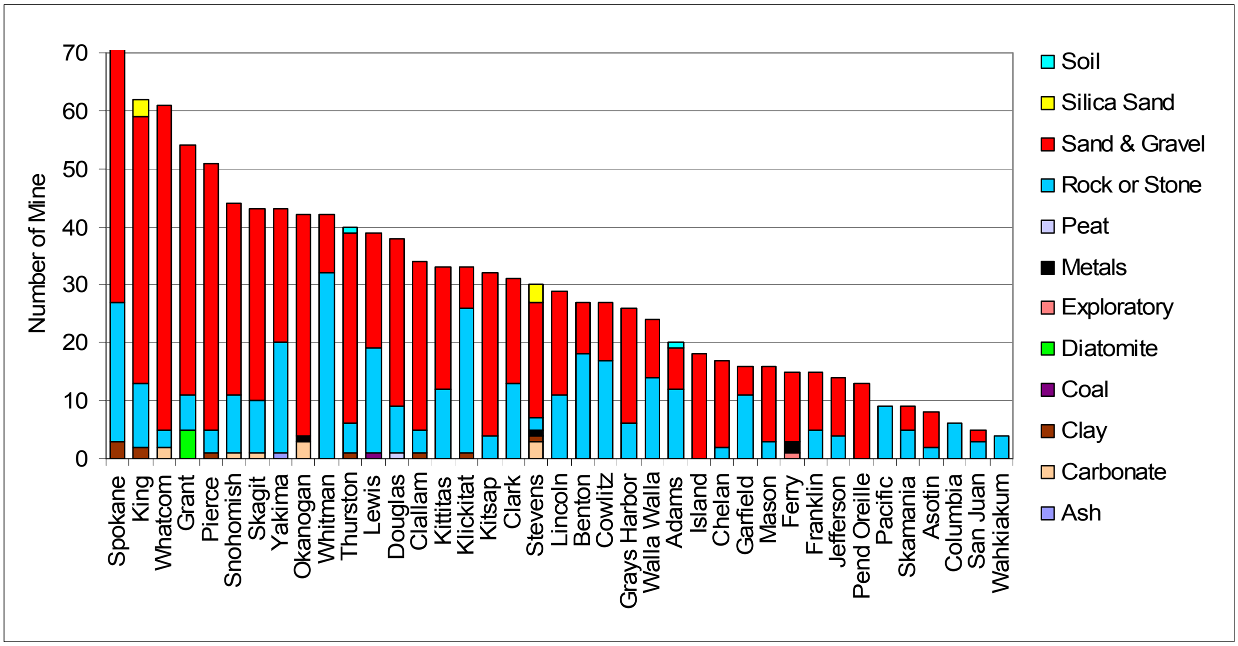
Data Sources: Geographic site information was obtained from Washington Department of Natural Resources, Division of Geology and Earth Resources. County and highway system GIS files were downloaded from the WSDOT GeoData Distribution Catalog.

CHAPTER TWO

THE SURVEY AND RESULTS

Mining companies were included in the survey based on the permit holder list provided by DNR DGER. The initial survey population was more than 500 companies that owned in total more than 1,100 mine sites. The number of mines on the initial list ranged from 4 to 72 mines per county, with an average of 29 mines per county. Descriptive/initial information about number of mines and types of commodities for surveyed mines classified as active is presented in Figure 3.1. Information sought via the survey questionnaire included mining site location, commodity type mined, annual tons of production, highway usage by specific mine, distance of shipment and transportation mode used, shipment destinations, factors influencing monthly shipments, seasonality of mine operations and mineral shipments, average payload weight of outbound truck shipments, number of axles of trucks, as well as information on daily and monthly operations. (For a full version of the questionnaire refer to Appendix E).

Figure 3.1 Total numbers of surveyed mines by type per county



Data Source: Donald T. McKay, Jr., et al, Directory of Washington Mines 2001, Department of Natural Resources, Division of Geology and Earth Resources.

Mines and Volumes of Production

Responses were received from 194 companies, 39% of the total number of companies. Those 194 companies provided information for 523 mines, which was 47.2% of the total number of mines in the state. As it was stated earlier active mines were divided into two categories; consequently, information was categorized into operational and non-operational mines. Out of the 523 mine sites 184 (or 35%) are non-operational, and remaining 339 (65%) are in operation (Figures 4.1.1 and 4.1.2).

Figure 4.1.1 Study responses: operational and non-operational mines

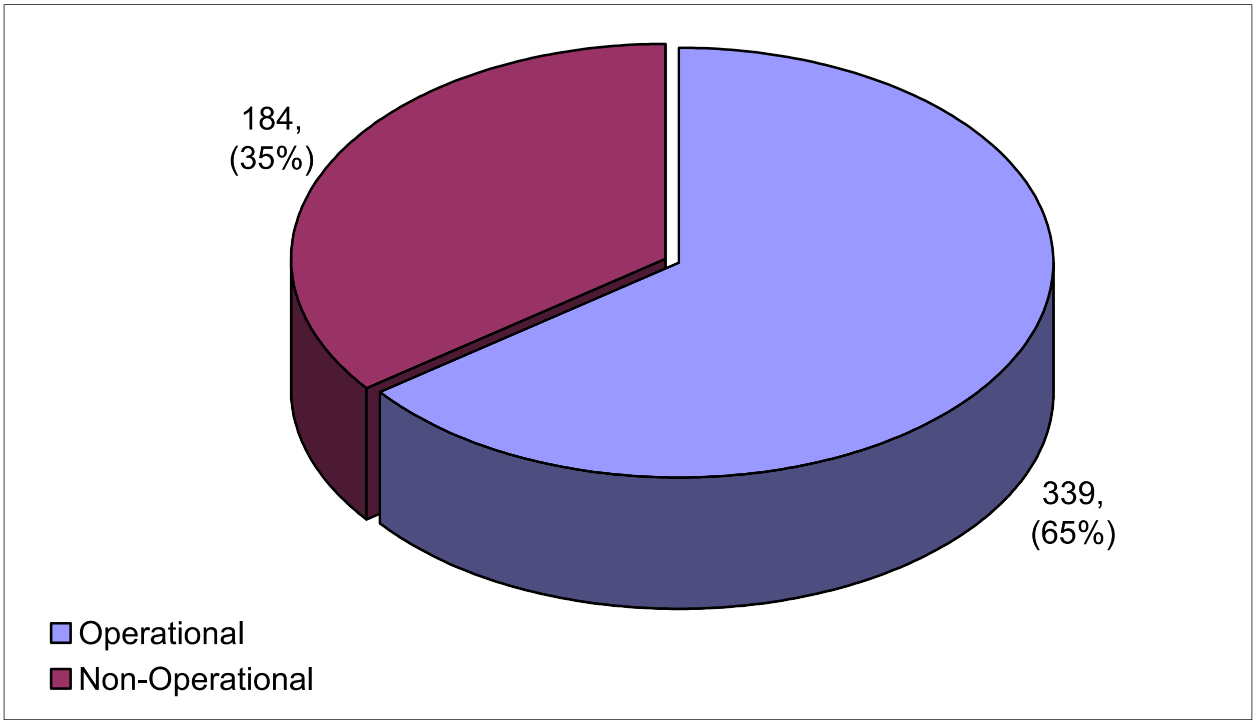
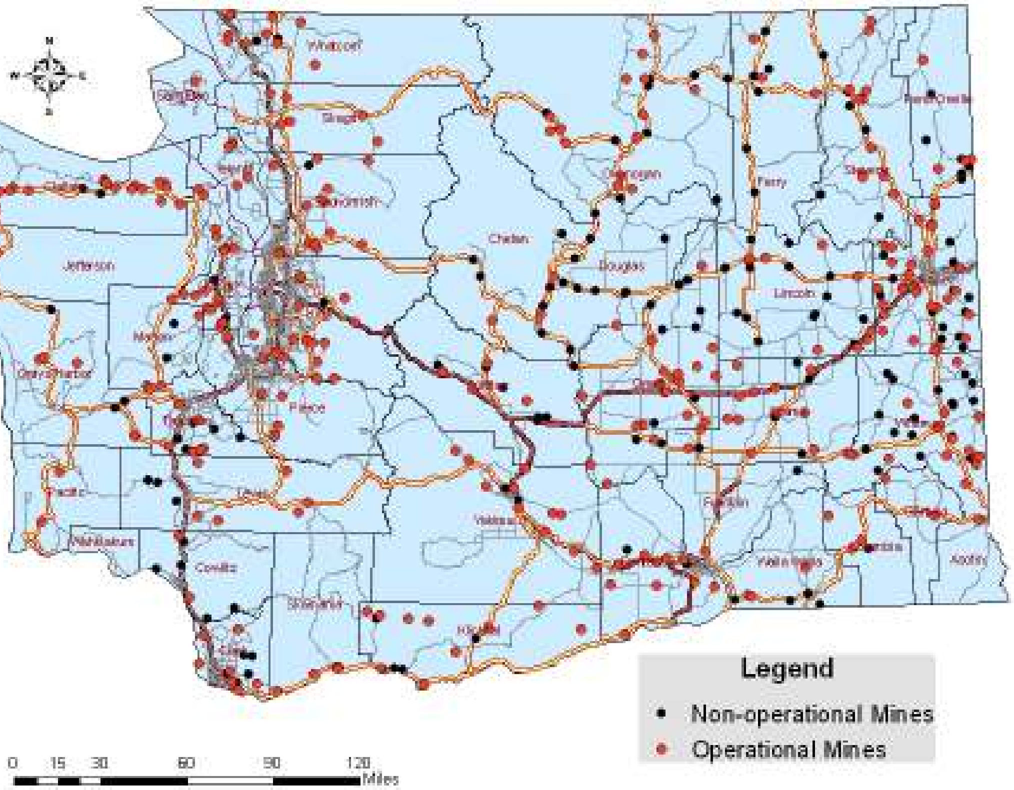


Figure 4.1.2 Study responses: operational and non-operational mines

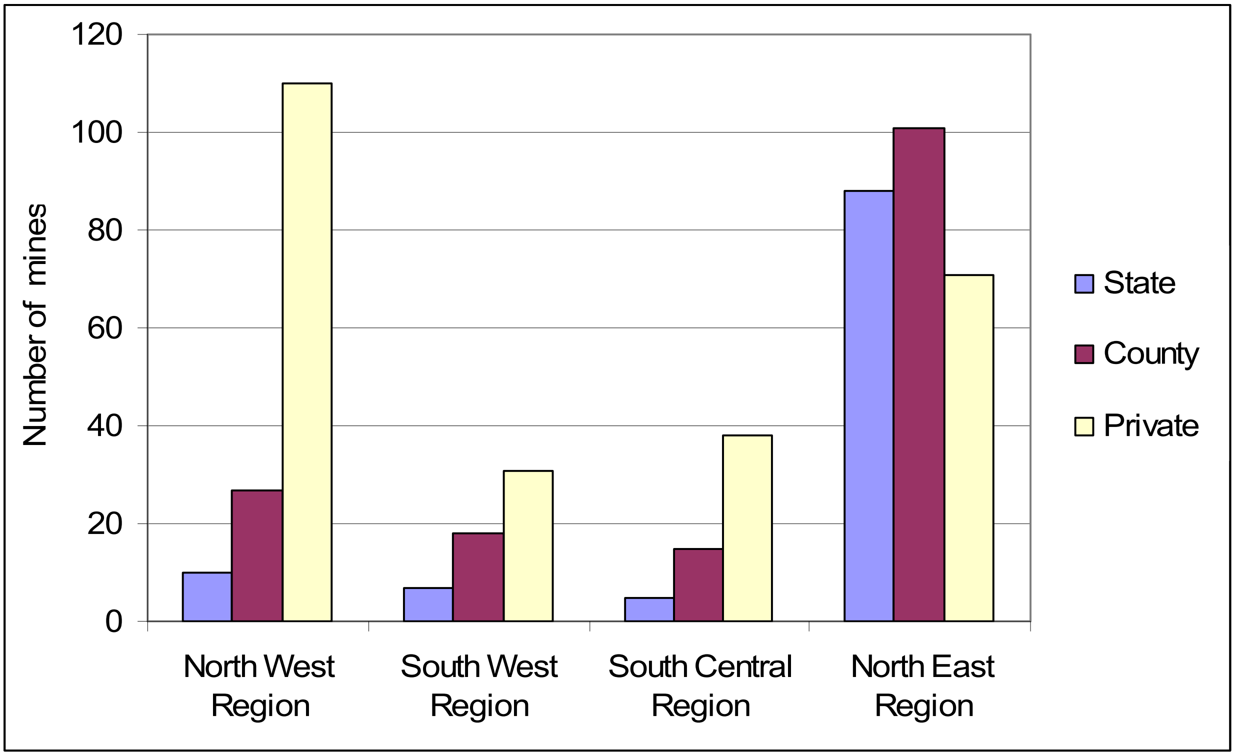


Data Sources: Geographic site information was obtained from Washington Department of Natural Resources, Division of Geology and Earth Resources. County and highway system GIS files were downloaded from the WSDOT GeoData Distribution Catalog.

The ownership of mines is divided into state, county and privately owned. Survey results showed that most of the mines in the State of Washington are owned by private firms (48%). WSDOT or DNR owned mines represent about 21% of study responses and the remaining (31%) are owned by local governments.

Spatial investigation of the ownership data exhibited variability across the state. The proportion of state owned mines (mostly located in the North East Region) varies from as low as 7% in the North West Region to 34% in the North East Region of the state. In contrast, privately owned mines are found more in the North West Region (75%), South Central Region (65.5%) and South West Region (55%). The proportion of mines owned by Counties ranges from 18% in the North West Region of the state to 39% in the North East (Figure 4.1.3 and Table 4.1.1).

Figure 4.1.3 Study responses: ownership of mines by category[5]



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[5] The geographic split is based on WSDOT Regions, such that DOT's Olympic and North West regions form North West region/part for this study, North Central and North East regions form North East part. South West and South East separations for the study coincide with the geographical boundaries of DOT's homonymous regions.
WSDOT Regions:
Southwest Region - Pacific, Lewis, Wahkiakum, Cowlitz, Clark, Skamania and Klickitat counties.
Olympic Region – Clallam, Jefferson, Grays Harbor, Mason, Thurston, Kitsap and Pierce counties.
Eastern Region – Pend Oreille, Ferry, Stevens, Lincoln, Spokane, Adams and Whitman counties.
Northwest region – San Juan, Island, Whatcom, Skagit, Snohomish and King counties.
North Central Region – Okanogan, Chelan, Douglas and Grant counties.
South Central Region – Kittitas, Yakima, Benton, Franklin, Walla Walla, and Columbia counties.

Table 4.1.1 Study responses: ownership of mines global vs. regional

	North West Region		South West Region		South Central Region		North East Region		Global Results	
	mines	%	mines	%	mines	%	mines	%	mines	%
State	10	7%	7	13%	6	8.6%	88	34%	111	21%
County	27	18%	18	32%	14	25.9%	101	39%	160	31%
Private	110	75%	32	55%	39	65.5%	71	27%	252	48%
Total	147		56		58		260		523	

Ten counties each produce annually more than 1million tons of minerals, 12 counties produce between 300,000 and 950,000 tons, and remaining counties produce less than 300,000 tons per year. The number of mines ranged from 2 to 48 mines (with the average of 15 mines) per county. As expected from the number of responses of total mine site responses (47.2%), these numbers closely represent about half of the statistics of the original listing (*min 4, max 72, and average 29*). A list of counties with total annual production across all types of minerals included in the survey is presented in table 4.1.2.

Table 4.1.2 Study responses: mines' annual production volumes by county

County	Tonnage	As % of total production	County	Tonnage	As % of total production
Lewis	5,260,000	16.1%	Skagit	425,000	1.3%
Pierce	3,010,000	9.4%	Pend Oreille	411,500	1.3%
Snohomish	2,865,711	8.9%	Clallam	383,480	1.2%
Spokane	2,130,000	6.6%	Whatcom	375,030	1.2%
Benton	1,640,000	5.1%	Klickitat	250,000	0.8%
Grant	1,582,750	4.9%	Chelan	213,000	0.7%
King	1,481,000	4.6%	Kittitas	208,500	0.6%
Mason	1,434,050	4.5%	Island	197,013	0.6%
Clark	1,425,200	4.4%	Grays Harbor	160,200	0.5%
Whitman	1,140,003	3.5%	San Juan	153,000	0.5%
Lincoln	1,020,000	3.2%	Columbia	140,000	0.4%
Thurston	950,100	3.0%	Asotin	105,000	0.3%
Stevens	933,152	2.9%	Skamania	105,000	0.3%
Kitsap	920,000	2.9%	Franklin	100,000	0.3%
Douglas	761,000	2.4%	Pacific	85,000	0.3%
Adams	650,000	2.0%	Cowlitz	70,100	0.2%
Ferry	567,550	1.8%	Walla Walla	66,000	0.2%
Yakima	479,673	1.5%	Jefferson	51,500	0.2%
Okanagan	453,300	1.4%	Garfield	25,000	0.1%
Total tons					32,227,812
Max					5,260,000
Min					25,000
Average					848,100

The top 10 county mineral producers by annual volume were: Lewis, Pierce, Snohomish, Spokane, Benton, Grant, King, Mason, Clark and Whitman, with the average of 2,196,871 tons (for top 10) each year. The top five counties produce 46% of the total volume. On average individual Washington counties produce 848,100 tons of minerals per year, ranging from 25,000 to 5,260,000 tons. Detailed information for each county's number of mines, types of minerals mined and annual production volumes can be found in Figures 4.1.4, 4.1.5 and Table 2, 3 (Appendix A).

Figure 4.1.4 Study responses: annual production volumes of mines by county

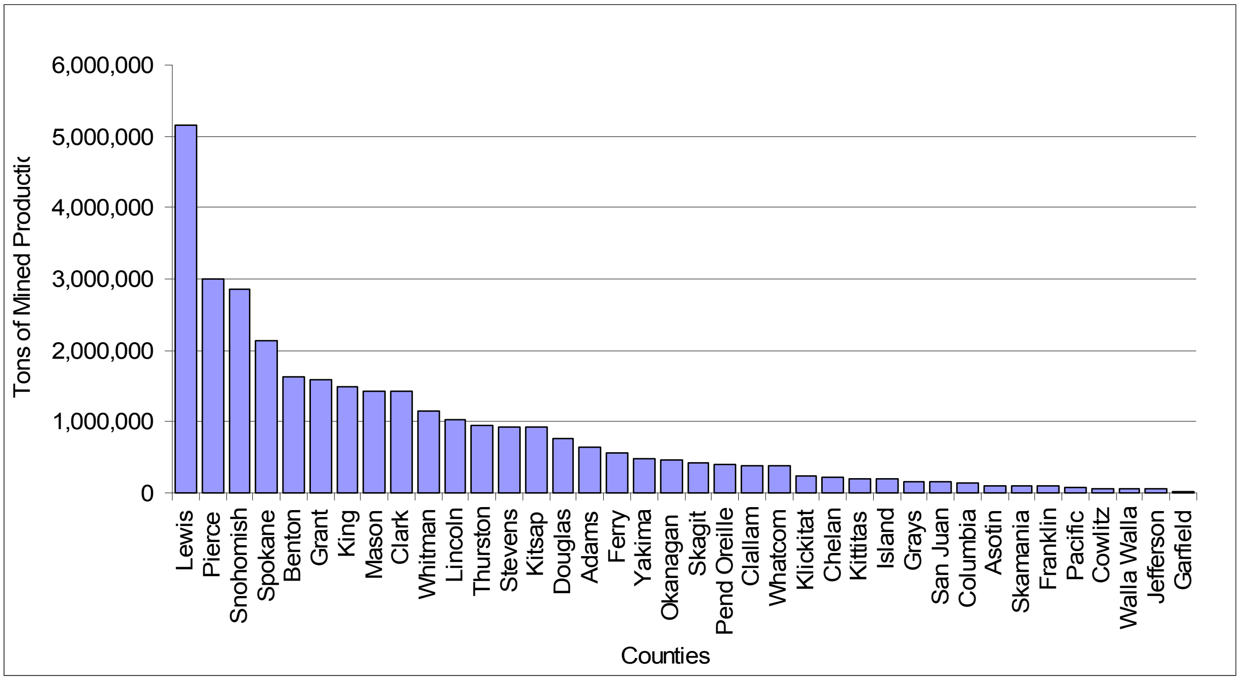
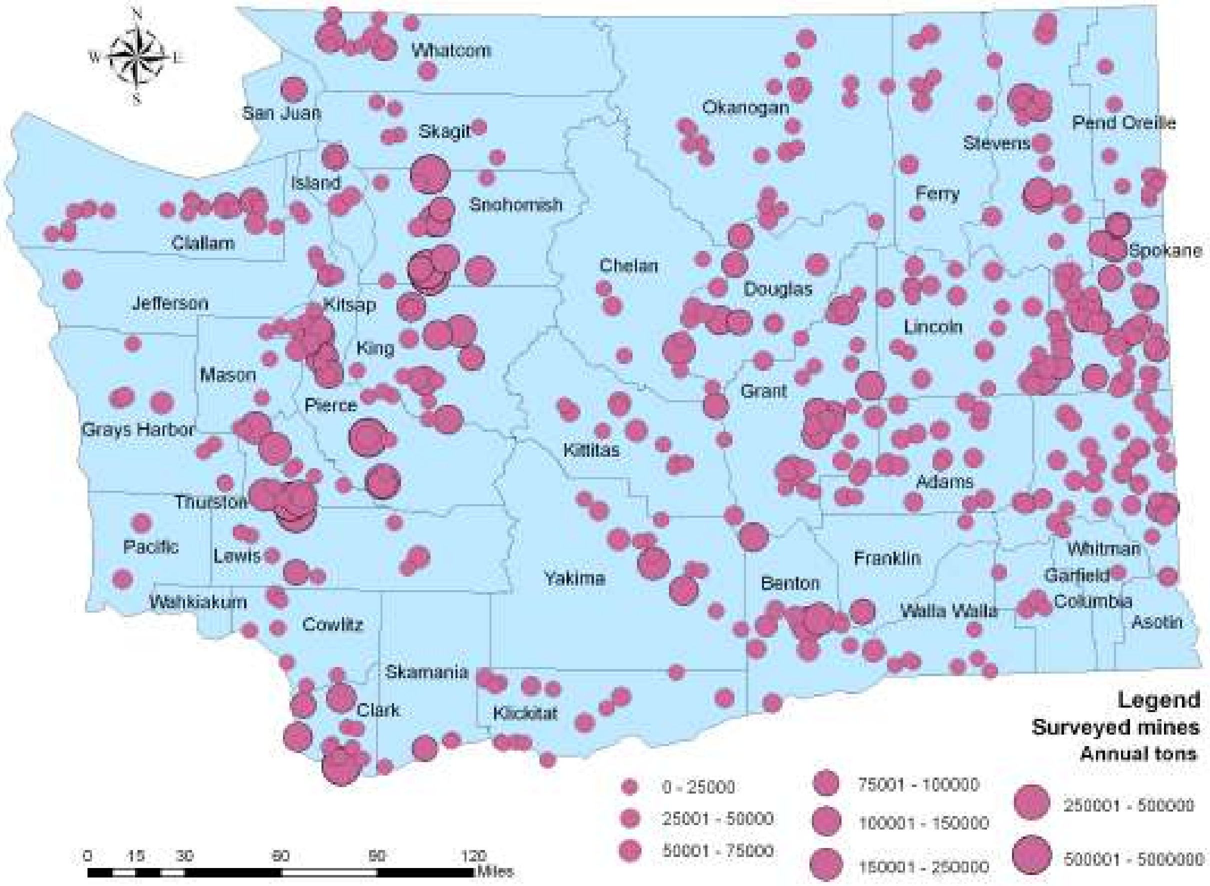


Figure 4.1.5 Study responses: mine sites by annual production volume



Data Sources: Geographic site information was obtained from Washington Department of Natural Resources, Division of Geology and Earth Resources. County and highway system GIS files were downloaded from the WSDOT GeoData Distribution Catalog.

The data were then examined separately among WSDOT Regions (table 4.1.2). WSDOT Southwest, Olympic, Northwest and Eastern regions each produce about the same level of North Central and South Central regions' production volumes combined. Regional production volumes can be useful for examining the highway or local roads usage by mineral hauling trucks in the region, given average hauling distances. However, on-site use of mined minerals has to be considered as well. Although the Southwest Region is listed with the highest annual production level, it is not considered to be the largest user of the highway or local road system, due to the coal mine located in that region, which has on-site use of about 5 million tons of annual production. To investigate this relationship further, maps for each of the WSDOT Regions were created using mine sites location information joined with annual production volumes and types of minerals mined (Appendix B).

In order to determine segments of highways used for hauling minerals, this information was linked with the average shipment distances and discussed more in the section 4.12 (“Shipment Distances by Volume and Road Network Used”). Further, to assess the overall effect by truck movements, the frequency of those highways used by the mines is discussed in the same section. For closer investigation of highway segments, maps were created at county level, each with corresponding highway usage frequency tables.

Table 4.1.3 Study responses: mines' annual production volumes by Washington State Department of Transportation regions

DOT region	Annual Production (Tons)	As % of total production
Southwest Region[6]	7,195,300	22.3%
Olympic Region	6,909,330	21.4%
Eastern Region	6,852,205	21.3%
Northwest Region	5,496,754	17.1%
North Central Region	3,010,050	9.3%
South Central Region	2,764,173	8.6%
Total	32,227,812	
Max	7,195,300	
Min	2,764,173	
Average	5,371,302	

Mines and Types of Commodities

Fifty nine percent of mined minerals is represented by the sand and gravel commodity, and 35.5%[7] is accounted for by rock or stone. The remaining 5.5% is divided among the rest of the types of mines (Figure 4.2.1 and 4.2.2).

The high percentage of this most extractable and demanded natural resources is explained by its multipurpose and diverse use. Accounting for 94% of the asphalt and 80% of concrete pavements, construction aggregates are used for highway, residential

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[6] WSDOT **Southwest Region** includes Pacific, Lewis, Wahkiakum, Cowlitz, Clark, Skamania and Klickitat counties. **Olympic Region** – Clallam, Jefferson, Grays Harbor, Mason, Thurston, Kitsap and Pierce counties, **Eastern Region** – Pend Oreille, Ferry, Stevens, Lincoln, Spokane, Adams and Whitman counties, **Northwest region** – San Juan, Island, Whatcom, Skagit, Snohomish and King counties, **North Central Region** – Okanogan, Chelan, Douglas and Grant counties, **South Central Region** – Kittitas, Yakima, Benton, Franklin, Walla Walla, Columbia.

[7] According to National Stone, Sand and Gravel Association about two-thirds of the non-fuel minerals mined each year in the U.S. are aggregates.

or commercial constructions, as well as for public works (hospitals, airports, water treatment plants, schools, etc.).

Figure 4.2.1 Study responses: number of mines by type

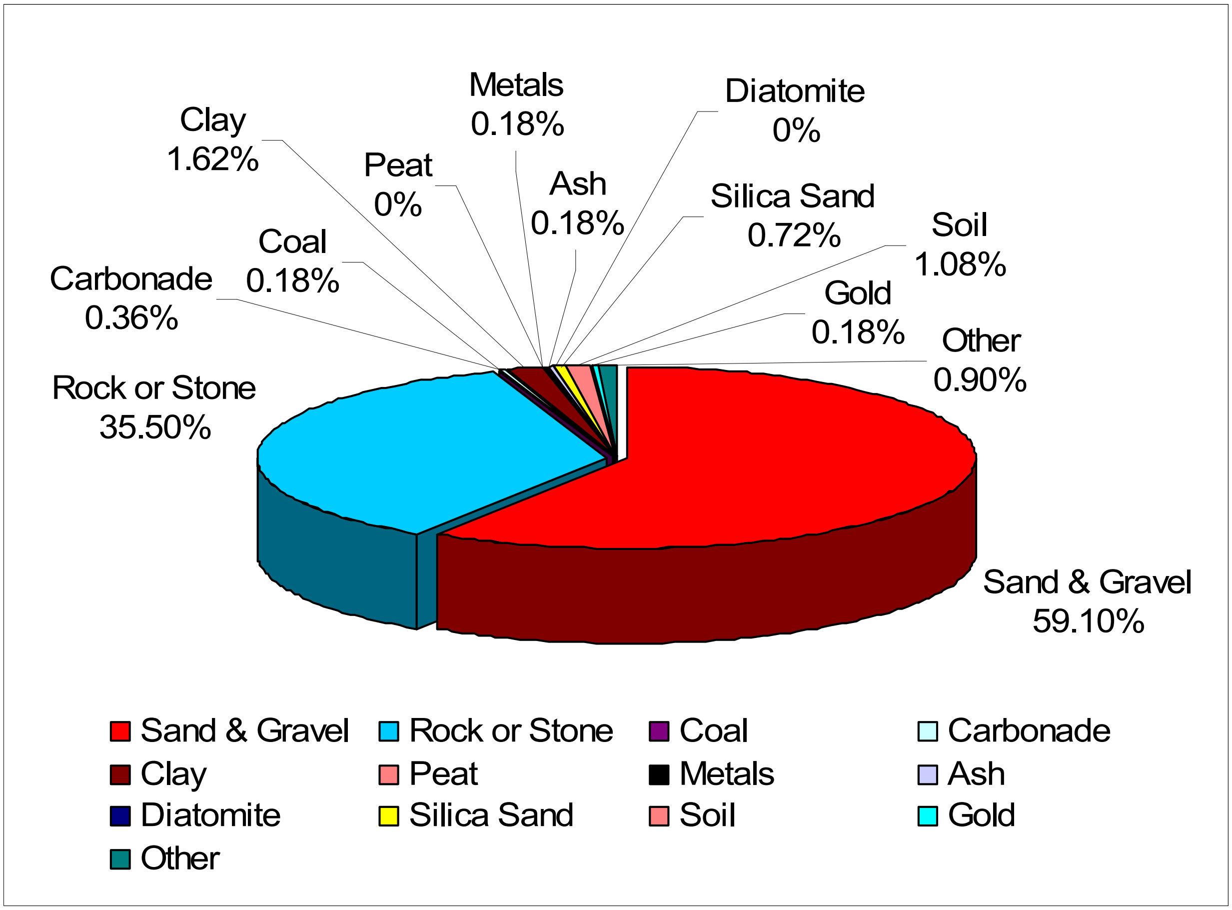
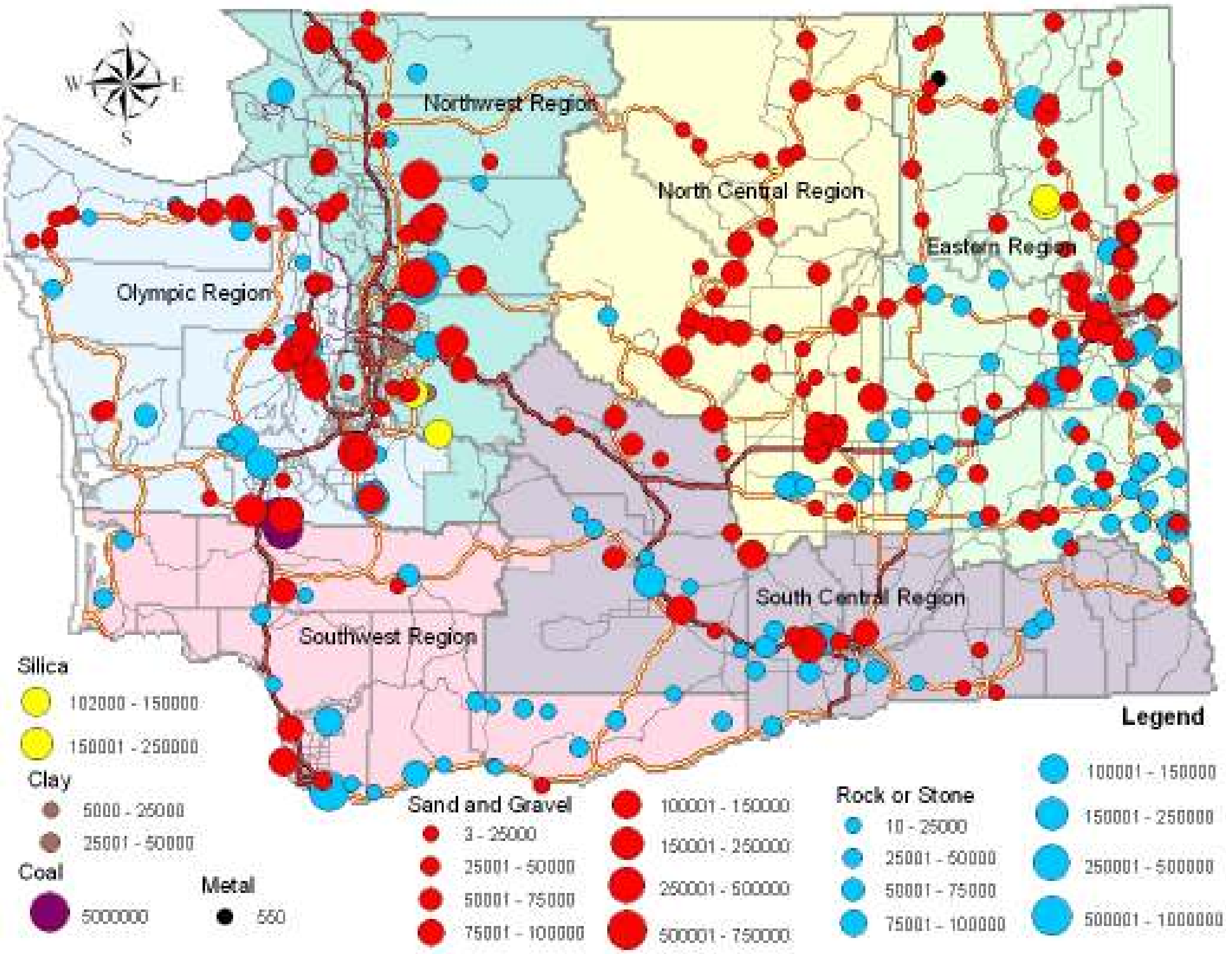


Figure 4.2.2 Survey responses: mines by type and production volume in relation to Washington State Department of Transportation regions



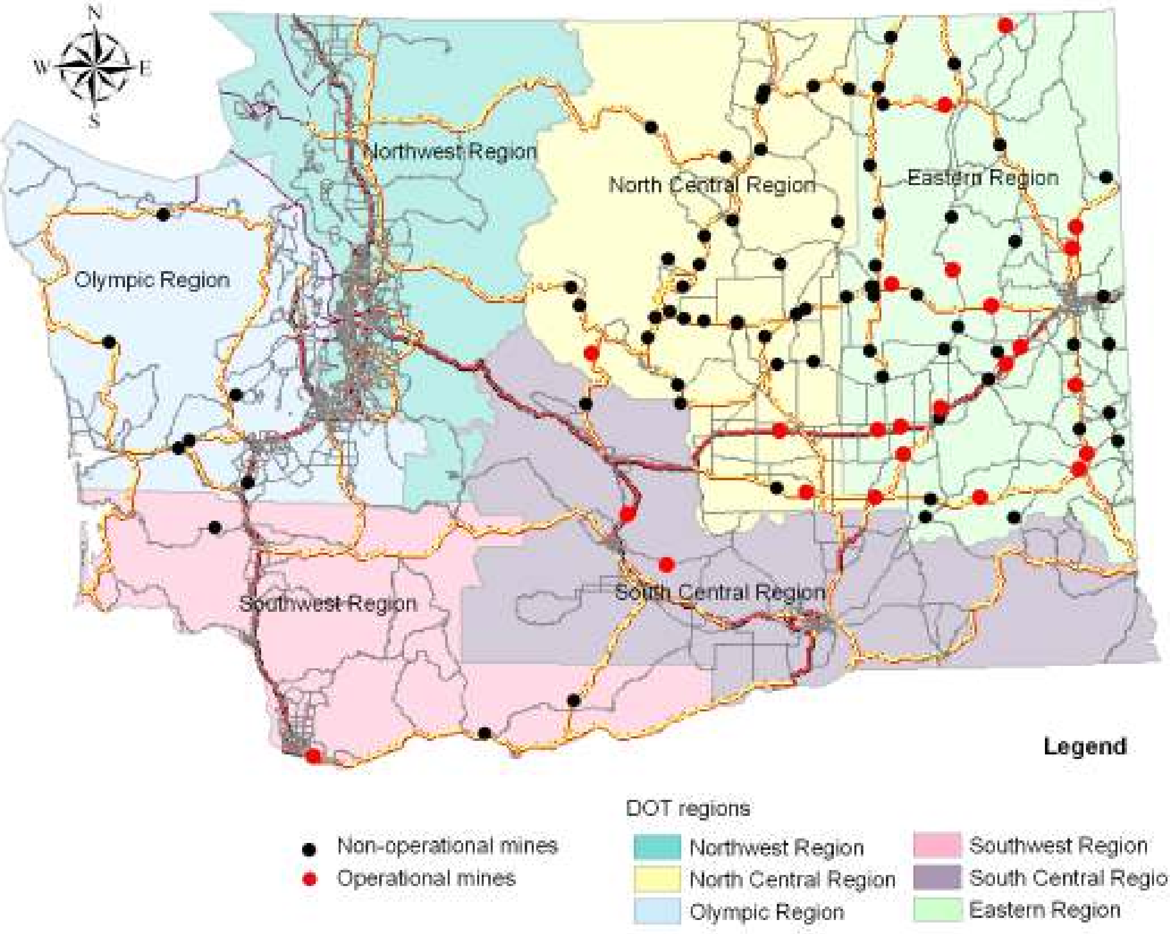
Data Sources: Geographic site information was obtained from Washington Department of Natural Resources, Division of Geology and Earth Resources. County and highway system GIS files were downloaded from the WSDOT GeoData Distribution Catalog.

Washington State Department of Transportation owned mines

More than 10% of Washington's active mines are permitted to the WSDOT. Sixty-nine percent of these mines produce sand and gravel and the remaining (31%) mines are rock or stone. However, a number of the WSDOT owned mines have not been used for many years. According to the survey responses, a large proportion of mines listed for the WSDOT South Central Region has not been used for the last 13-45 years. As an alternative or reserve resource, those mines can be utilized in the future for the WSDOT highway construction and improvement projects, especially by the construction contractors who do not have their own supply of aggregate. Only about 26% of State owned permitted mines are currently in operation. Figures 4.2.3 and 4.2.4 show locations of the WSDOT owned operational (26%) and non-operational (74%) mines, as well as types of minerals and production volumes for each mine. Geographic distribution of operational mines suggests a high degree of availability of construction sand and gravel or crushed stone in the WSDOT Eastern Region.

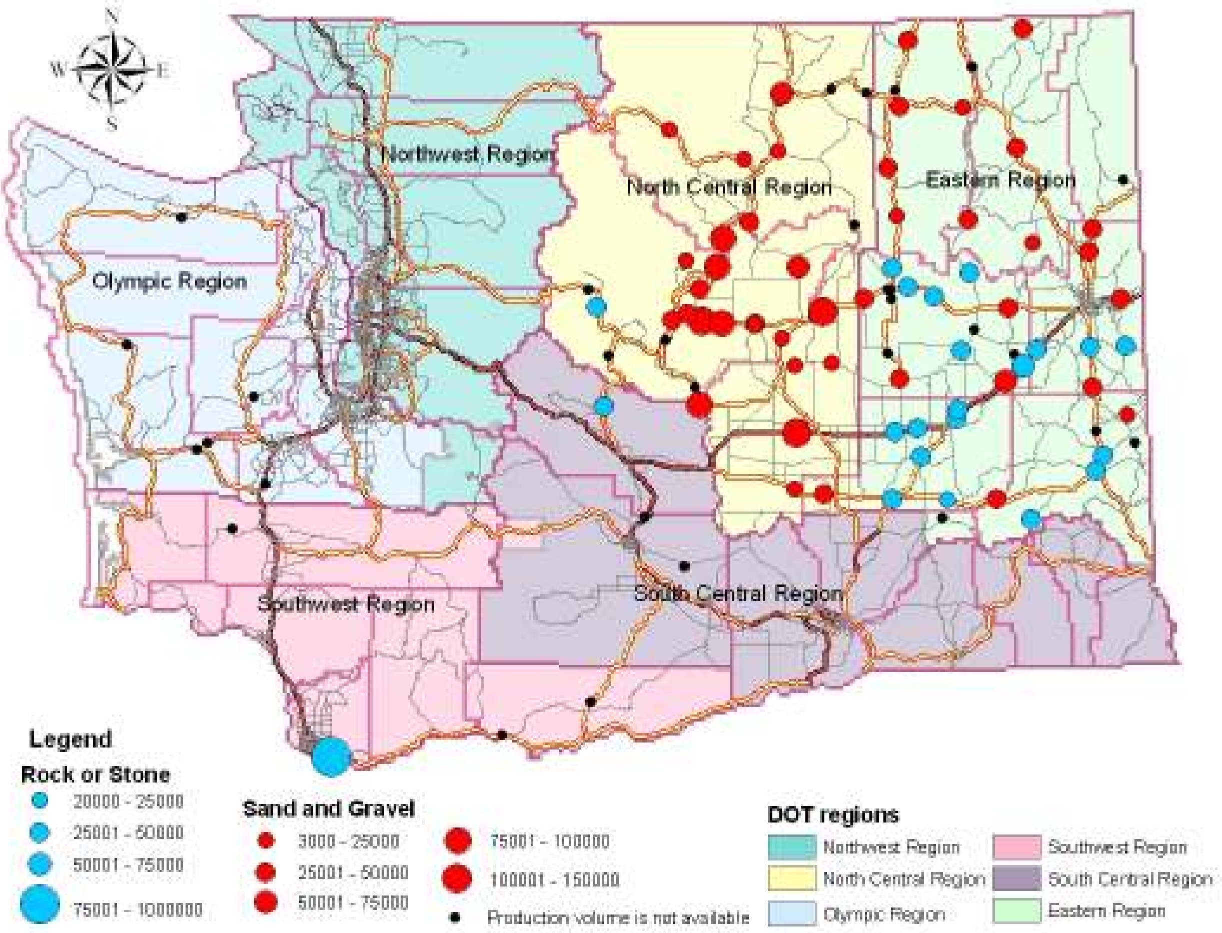
High transportation cost of construction materials such as sand and gravel or crushed stone is the largest component in determining the cost of materials in highway construction, which makes the proximity of the mine to the construction site a strong economic issue. As demonstrated in Figure 4.2.3, WSDOT owned operational and non-operational mines are heavily located adjacent to highways. Another related concern with the proximity of the mine to the point of use for highway construction is the potential deterioration of the highway segments used for hauling construction materials.

Figure 4.2.3 Washington State Department of Transportation owned mines: Operational vs. Non-operational



Data Sources: Geographic site information was obtained from Washington Department of Natural Resources, Division of Geology and Earth Resources. County and highway system GIS files were downloaded the WSDOT GeoData Distribution Catalog.

Figure 4.2.4 Washington State Department of Transportation owned mines by type of mineral and production volume

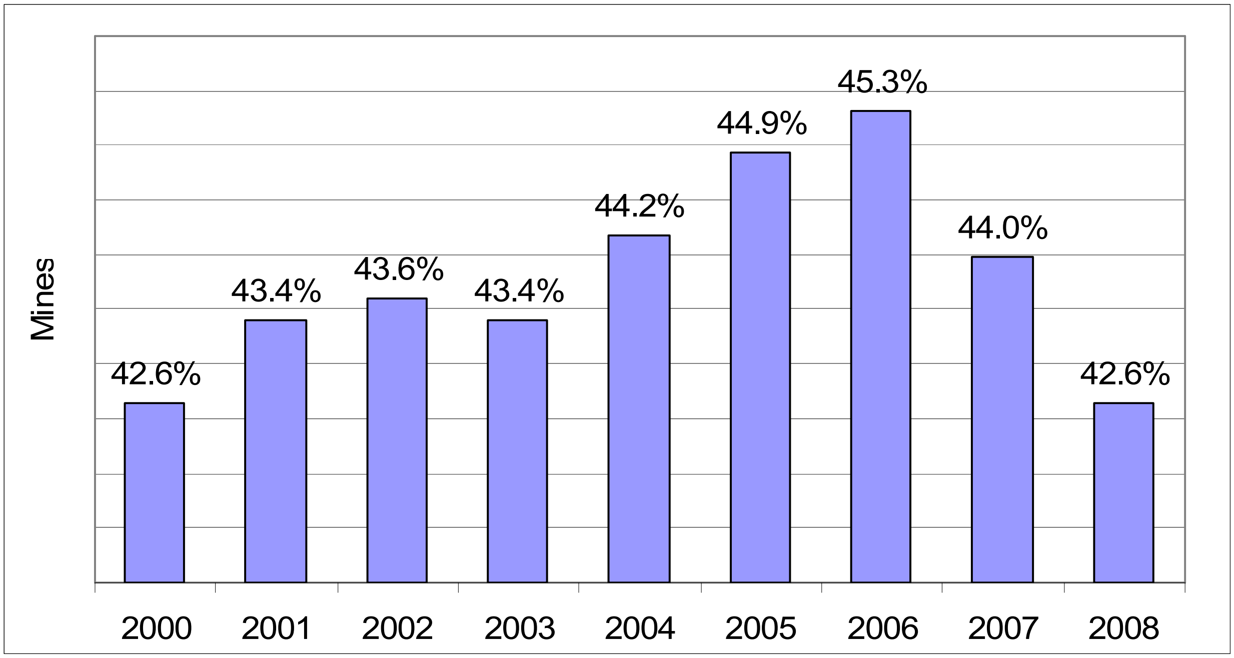


Data Sources: Geographic site information was obtained from Washington Department of Natural Resources, Division of Geology and Earth Resources. County and highway system GIS files were downloaded from the WSDOT GeoData Distribution Catalog.

Years of Operation

The study requested information over a 9 year period of mining operations from 2000 to 2008. From 2000 to 2006 the number of permitted mines in operation has shown small but steady growth (except 2003) over that period. However, according to surveyed company responses (Figure 4.3.1), projected number of mines to be in operation will be decreased about 2% between 2006 and 2008, reaching the level of mines in 2000. According to the Washington State Office of Financial Management, Washington's population is expected to grow by 30% between 2000 and 2020 (Washington State Office of Financial Management). Urbanization is usually positively related with aggregates consumption. Thus, with increasing population growth, the demand for aggregates will also be increased (Zettler, Rick). Potential for increasing aggregates use/demand, plus numerous concerns received from mining companies about various restrictions and obstacles for production (supply constraints) suggest careful monitoring of the industry's performance and needs would be appropriate.

Figure 4.3.1 Mines in operation from 2000 and projections for the next two years

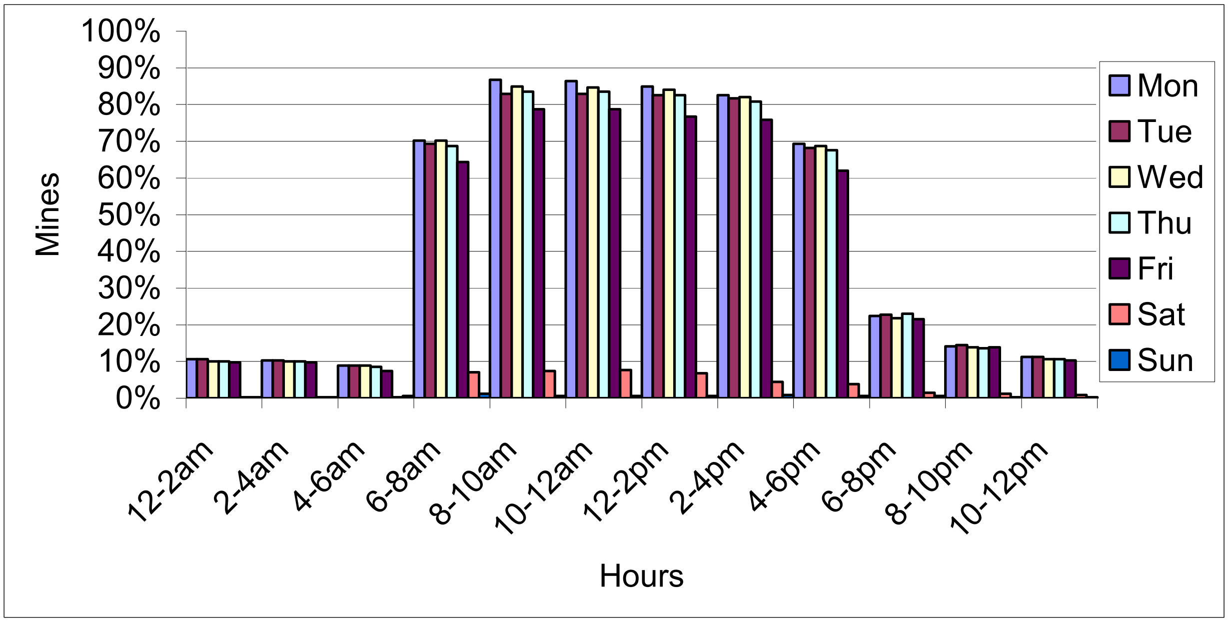


Source: Transportation of Mining/Mineral Survey results

Operational Times

While most mines operate on usual business day basis, there are some that operate 16 or up to 24 hours a day. About 65-85% of mines operate Monday through Friday from 6-8 am to 4-6 pm. Slightly more than twenty percent of the total mines stay opened from 6-8pm. The rest of operational hours after 8 pm to 6 am (the night shift) was used by around 10% of the mines. The proportion of mines operating on the weekend is less than 8% for Saturday and less than 1.5% for Sunday, mostly from 6 am to 6 pm. This information is potentially useful in assessing any addition of mining trucks to the rest of the traffic on Washington's road system (Figure 4.4.1).

Figure 4.4.1 Mines' operations by days and hours (global)

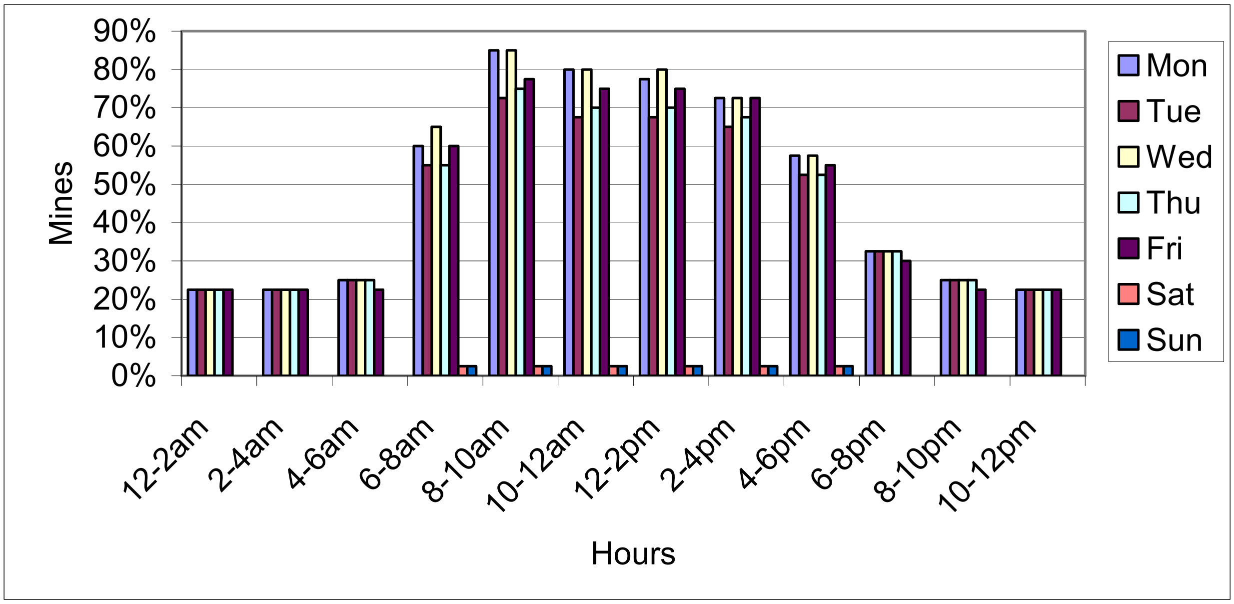


Source: Transportation of Mining/Mineral Survey results

In order to determine spatially varying relationships over the study area the state was split into four parts: North East, North West, South Central and South West. In this case, to better understand effects of mine sites' operational hours at different locations of the state, the data for each of the regions were examined separately. The geographic split is based on WSDOT Regions, such that DOT's Olympic and North West regions form the North West region/part for this study, and theNorth Central and North East regions form North East part. South West and South East separations for the study coincide with the geographical boundaries of DOT's regions. The same operational pattern was observed for all regions except for South Central, where in comparison with other regions or global pattern (much less than 20%) the number of mines operating a night shift is between 20 and 30% (Figure 4.4.2).

Sometimes mines' operational times can be affected by the local governments that are taking responsibility of noise control and abatement (Noise Control Act, Chapter 70.107 RCW). In addition to state regulations, local governments can enforce their own more restrictive regulations on noise standards, which can be construed as an additional constraint for mines operation. This suggests that 20-30% of mining sites located in the South Central regions may be affected more from local regulations than those located in other parts of the state. Alternatively, this may imply more volume or more availability of day-around supply of aggregates for construction sites located in the South Central part of the state, which will give more flexibility to the construction firms' operations. This discussion will be revisited in the "Seasonality of aggregate shipments and mine operations" section where the link between operational hours and operational/shipment months will be investigated.

Figure 4.4.2 Mines' operations by days and hours (South Central region)



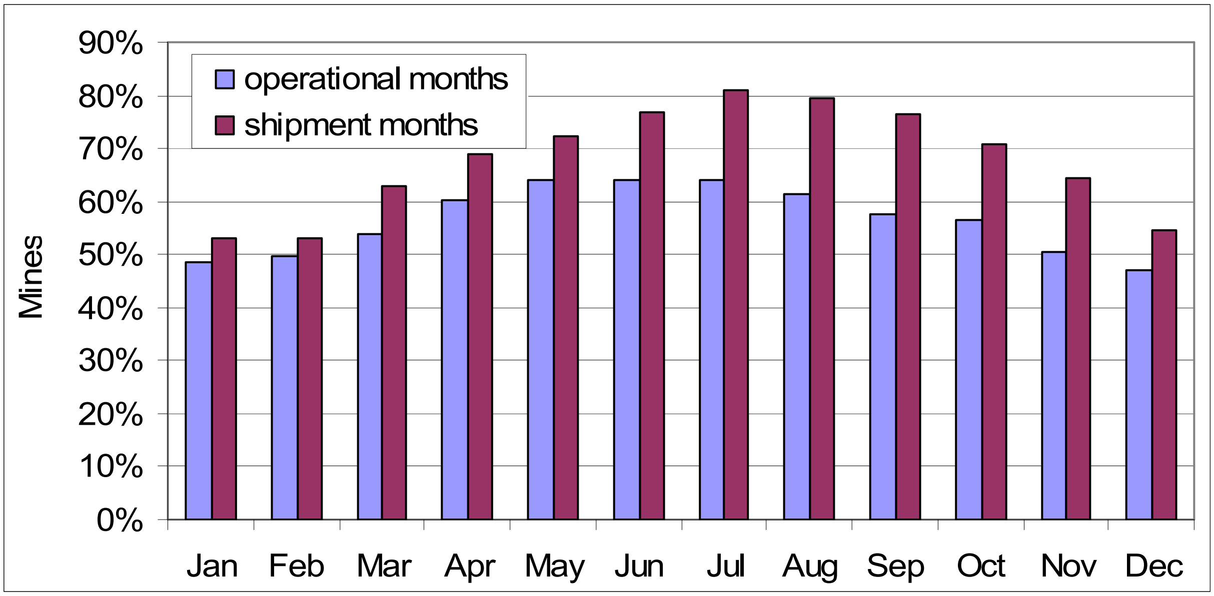
Source: Transportation of Mining/Mineral Survey results

Seasonality of aggregates shipments and mine operations

Seasonality of shipments and mine operations also affects traffic flows and infrastructure needs. As shown in Figure 4.5.1, operational months peaked in April to August months. A similar pattern can be observed for the months when shipments occur with July as the peak of operations. When analyzed in relation to number of hauling trucks, the pattern of shipment months may suggest relatively less number of trucks in November, December, January and February. Generally, as the study found out (when analyzing factors influencing shipments), variations in demand and weather conditions were most the most important factors affecting shipment operations. Linking this with operations and shipments characteristics allows two inferences: first, decreasing operations cause less shipment in the winter period (as the pattern shows in

Fig. 4.5.1); secondly, decreases in shipments from November to March period increases mine sites' inventories and causes slow down in operations[8].

Figure 4.5.1 Seasonality of mine operations and aggregate shipments (global)



Source: Transportation of Mining/Mineral Survey results

This overall average relationship (global form), however, may hide some interesting and important local variations. For example in the Western regions, the availability of many construction projects (demand) or favorable weather conditions may lead to a higher percentage of mines to be in operation than it would be in the Eastern part of the state. This variability caused a deeper look at the data, using local forms of spatial analysis in the research study.

Received pattern, by region, showed differences in operational and shipment patterns between Western and Eastern regions[9]. The Western region showed about

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[8] As shown in Table 2.1.2, the use of aggregates (gravel) for snow and ice control purposes accounted for only small portion of the total use.

twice as many operating mines from November to February. In addition, from March through October, on average 34% more mines were operating in the Western region (Figures 4.5.2 and 4.5.3).

As it was noticed in the “Operational Times” section earlier, mines in the South Central region (which was included in the Eastern region in this section) had longer operational hours for the night shift then mines in the rest of the regions, which could affect the seasonality of operational months pattern of the entire Eastern region. It does appear that weather conditions in the Eastern Washington can be less favorable for mining operations.

While the higher percentage of mines shipping during winter months provides more stability and flexibility to construction sites/projects in the Western region, it also generates increased usage of the state road system. The relationship between trucks payload and shipment distances will discussed later in the study.

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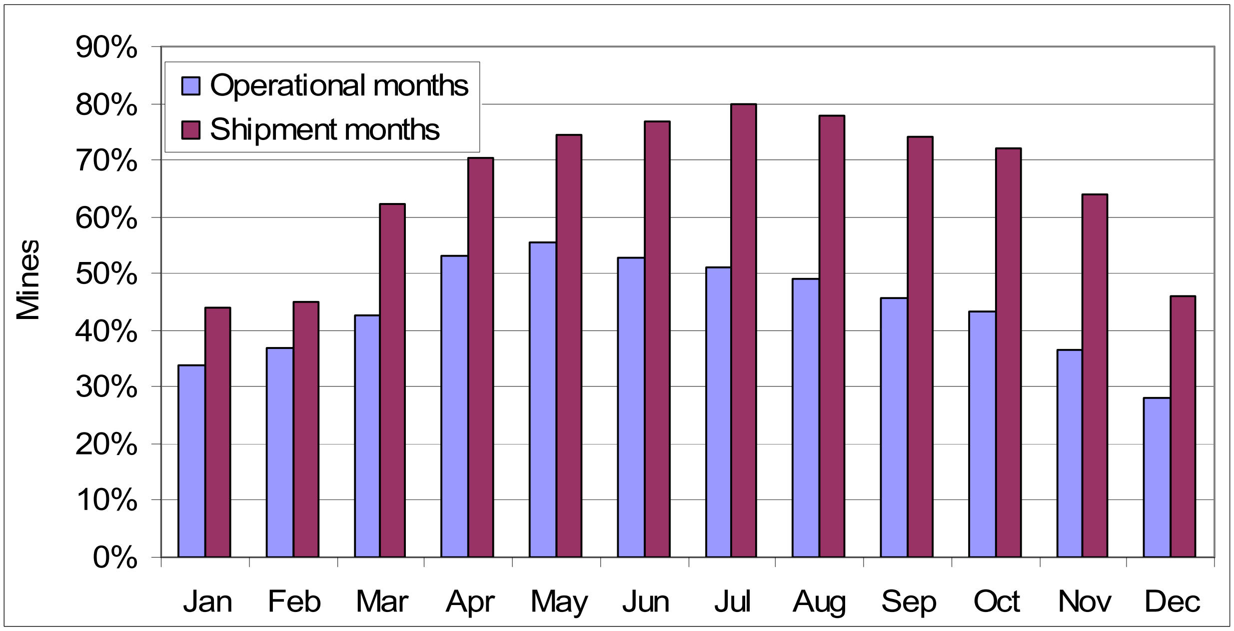
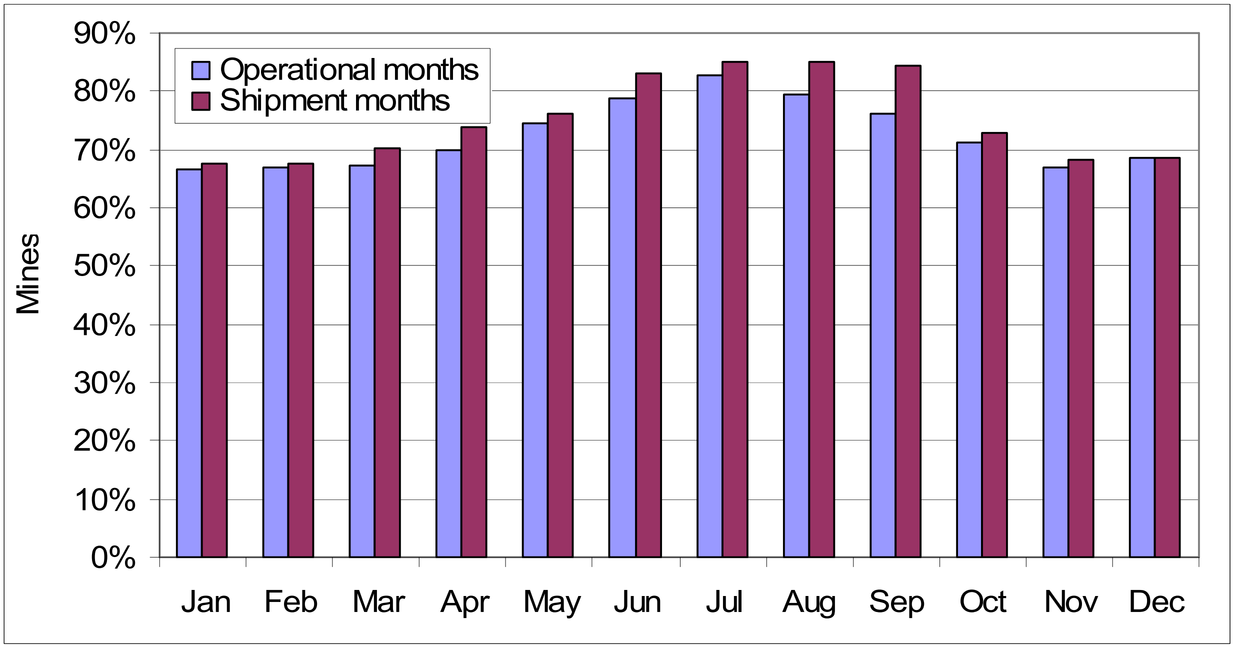
[9] Because North West and South West data formed similar pattern, as well as that of North East and South Central regions, in this section the split of the data will be examined as Western and Eastern regions.

Figure 4.5.2 Eastern region's seasonality of mine operations and aggregate shipments



Source: Transportation of Mining/Mineral Survey results

Figure 4.5.3 Western region's seasonality of mine operations and aggregate shipments

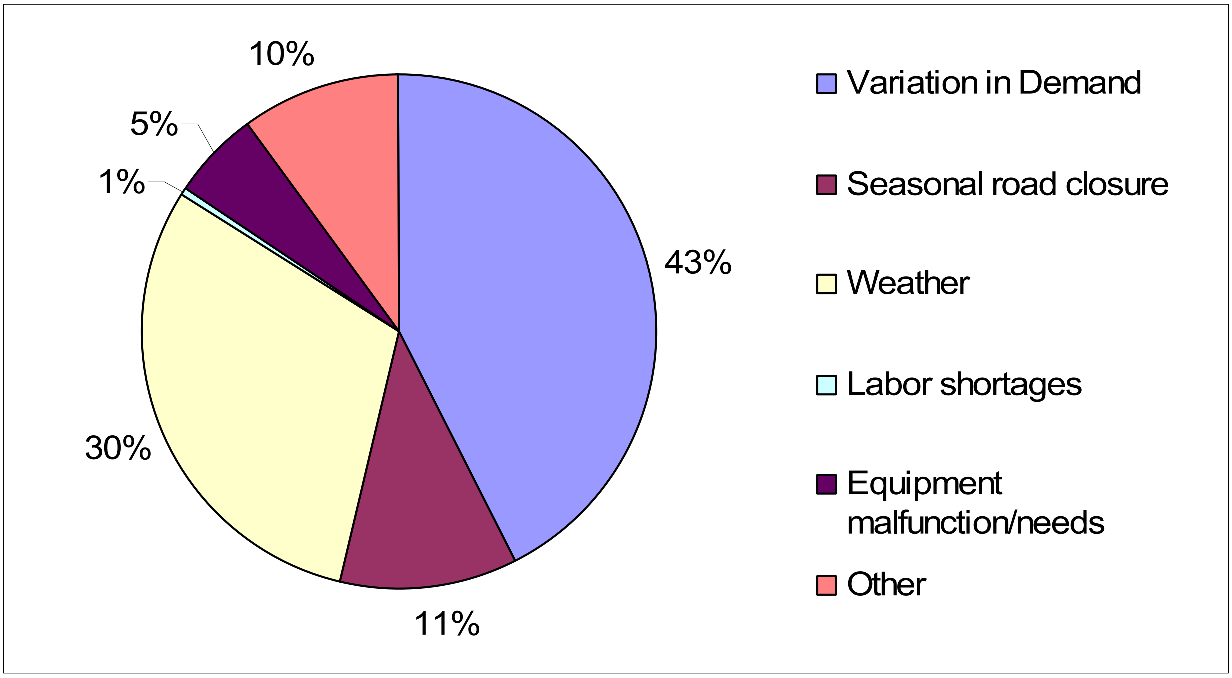


Source: Transportation of Mining/Mineral Survey results

Factors Influencing Shipments

Many factors influence shipments of mined minerals. As expected the largest source of influence is explained by the demand for the product. Forty three percent of the companies identified variation in demand as the main factor influencing their monthly shipments. "Weather conditions" accounted for 30% of responses. Seasonal road closure and "other" category were considered as next two factors with 11% and 10% of responses accordingly. "Other" category include identified factors such as competition, contractors' schedule, county limitations on number of trips, permit problems, construction project schedule, highway rehabilitation projects, and road maintenance projects. Equipment malfunction/needs and labor shortages affect mine commodities shipments by 5% and 1% accordingly (Figure 4.6.1).

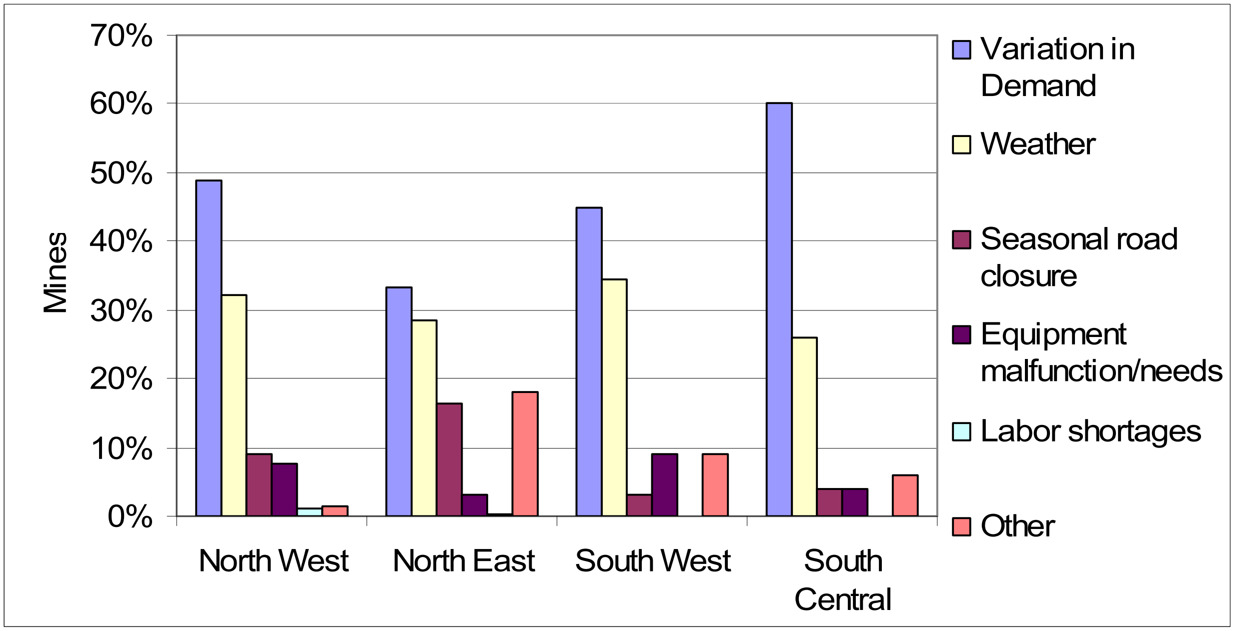
Figure 4.6.1 Factors affecting mined commodities shipments (global)



Source: Transportation of Mining/Mineral Survey results

However, global statistics described above are again very general. In contrast, local statistics emphasize the differences across areas, and it was found that variation in demand ranged across the state from 34% to 60%. Mines in South Central region are more dependent on demand availability than mines in the North East. In contrast, North East is more dependent on weather, seasonal road closures. Western regions had similar pattern of responses for factors influencing shipments except for seasonal road closures, which were higher for the mines located in the North West (Figure 4.6.2).

Figure 4.6.2 Factors affecting mined commodities shipments (split data)



Source: Transportation of Mining/Mineral Survey results

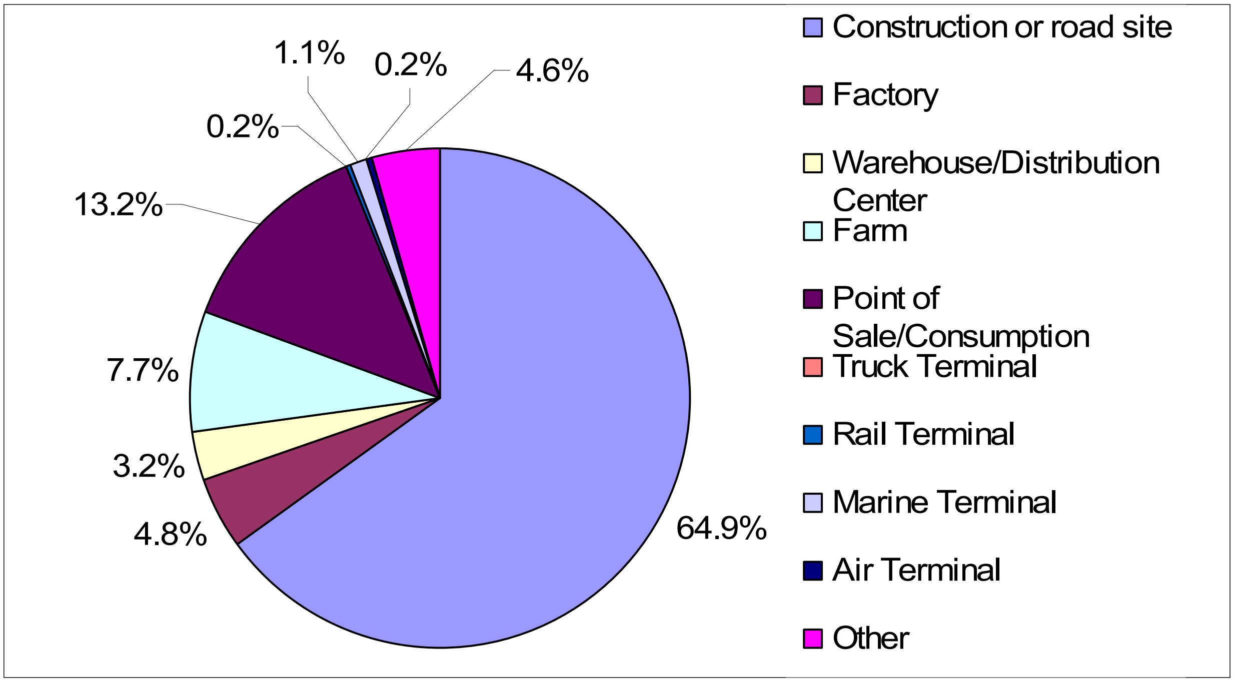
Shipment Destinations by Type (instate)

Instate shipments were divided into destination types in order to investigate end points and usage of aggregates shipments. The question was designed to collect relative proportional information about shipments destinations such as construction or road site, factory, warehouse/distribution center, farm, point of sale/consumption, truck terminal, rail terminal, marine terminal, air terminal and other destinations. Again as expected, the category, construction or road sites, was the destination (65%) for most of the shipments (Figure 4.7.1). Other destinations were:

- Point of Sale/Consumption 13%
- Farm 8%
- Factory 5%
- Warehouse/Distribution Center 3%
- Marine Terminal 1%
- Other 5% (logging roads, lumber log/storage yards, forestry, refinery, concrete plants and mine sites)

To analyze the relationship of proximity and various types of destinations from mines, the data was linked with the data collected on shipment distances. As is noticed later in the “Shipment Distances” section, aggregates were mostly (56%) shipped within 10 miles from mines. Sixty five percent of that volume was consumed by only construction or road sites that were located within 10 miles from mines, 13% was attributed to point of sales or consumption destination, 8% and 5% to farm and factory destinations.

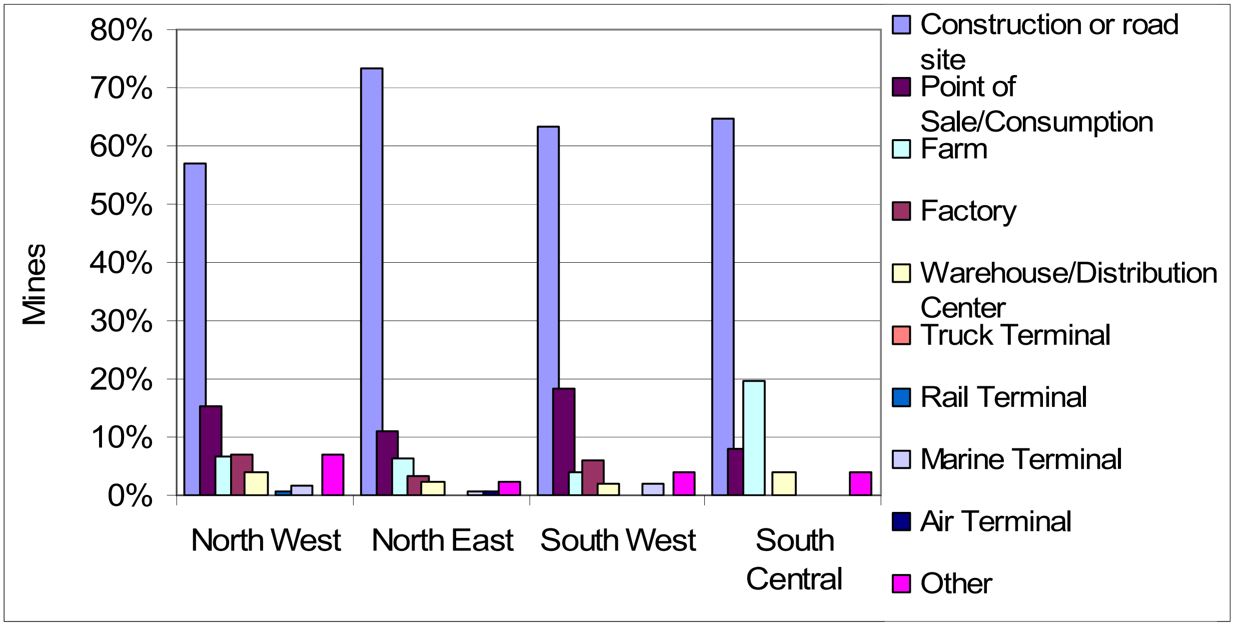
Figure 4.7.1 Shipment destinations by type (global)



Source: Transportation of Mining/Mineral Survey results

Variations were found as to several destination types across regions. “Construction or road site” destination ranged from 57% in the North West region to 73.4% in the North East, and “point of sale/consumption” ranged 7.8% in South Central to 18.4% in the South West regions. Variations in shipments to “farm” category were also noted, ranging from 4.1% in the South West to 19.6% in the South Central region (Figure 4.7.2).

Figure 4.7.2 Shipment destinations by type (split data)

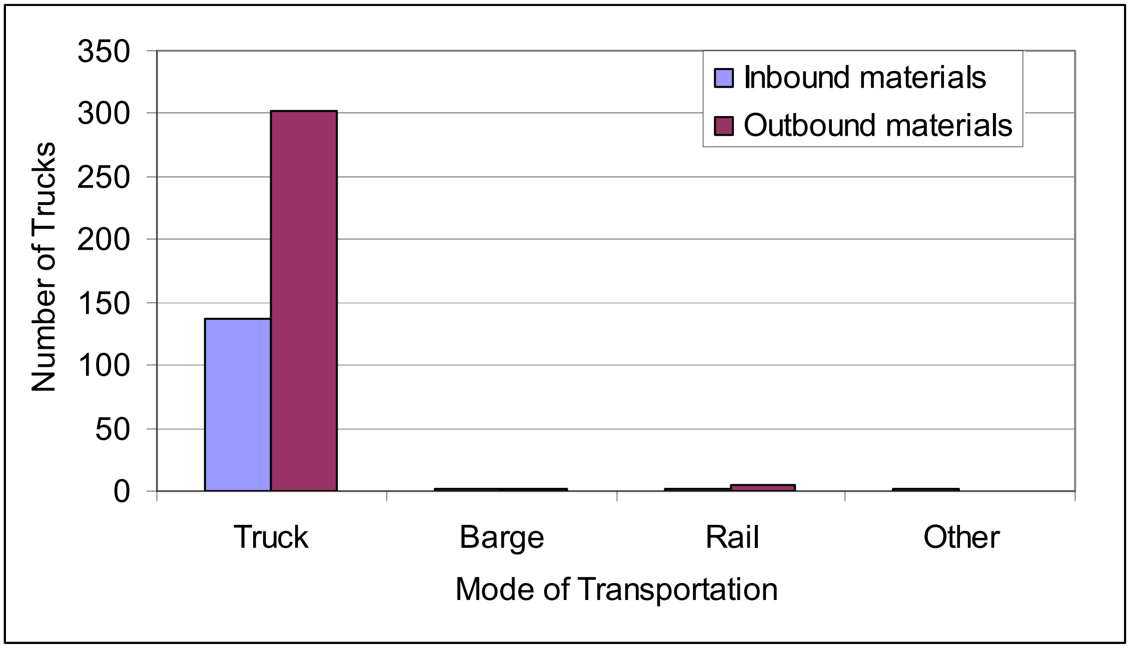


Source: Transportation of Mining/Mineral Survey results

Modal Usage

Information on the use of alternative transportation modes was sought for both inbound and outbound shipments. Ninety seven percent of inbound and 98.4% of outbound shipments relied on trucks for aggregates shipments (Figure 4.8.1). Only 33% of mines were found to have inbound shipments. Major materials shipped into mines consist of liquid asphalt, cement, soil, fine sand, recycled asphalt, topsoil, sand, dirt, crushed rock-concrete for recycle, rock phosphate, gypsum, coal, asphalt grindings, sand and gravel, waste soil, fuel, round rock, inert soil or wood ash, explosives and other supplies.

Figure 4.8.1 Shipments by mode

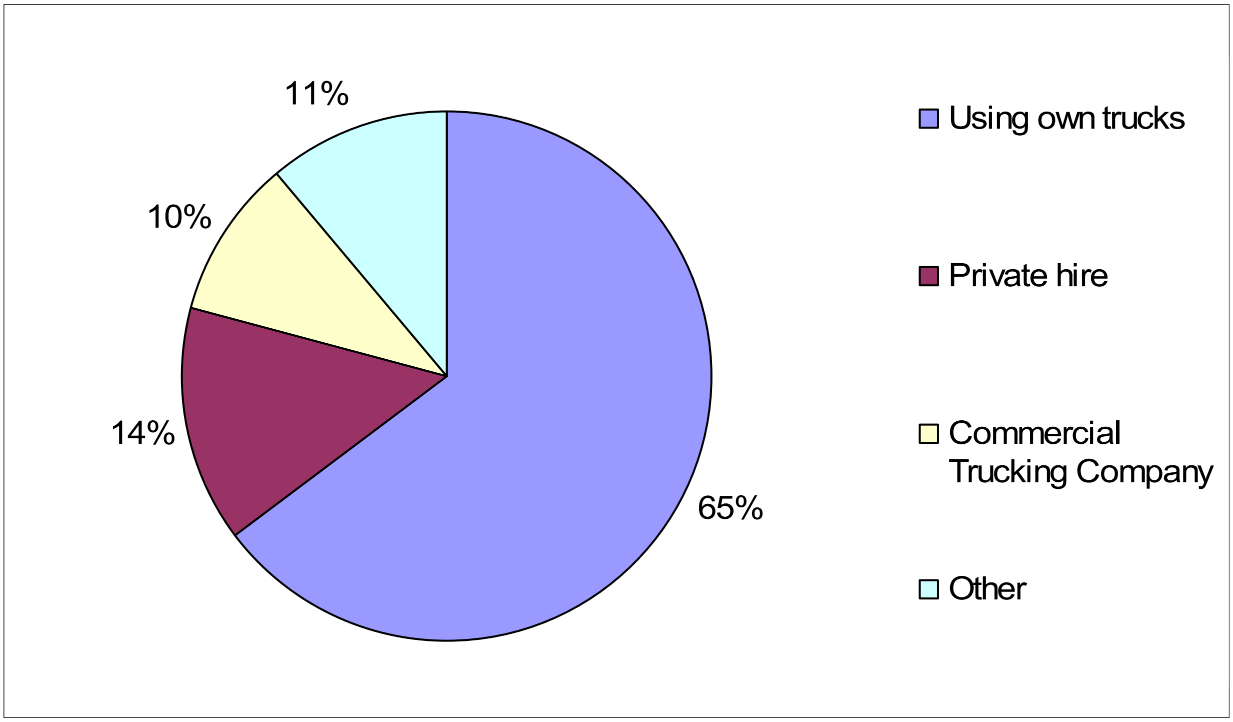


Source: Transportation of Mining/Mineral Survey results

Ownership of trucks

Some mines do use their own fleet of trucks, ranging from a low of 1 up to 47 trucks. The average number of trucks owned by mining firms was 16.5 with mode of 35. Companies owning their own trucks accounted for 65% of the total, with the remaining 35% being operated as private trucks for hire, as commercial trucking services or by other types of trucking options (Figure 4.9.1). Fourteen percent of companies use private trucks for hire, 10 % as commercial hire, and 11% make use of other options which include contractors, tenants at port site, consumers with their own trucks, affiliated company, state timber sale purchaser, county public works, DOT, governmental and lessee.

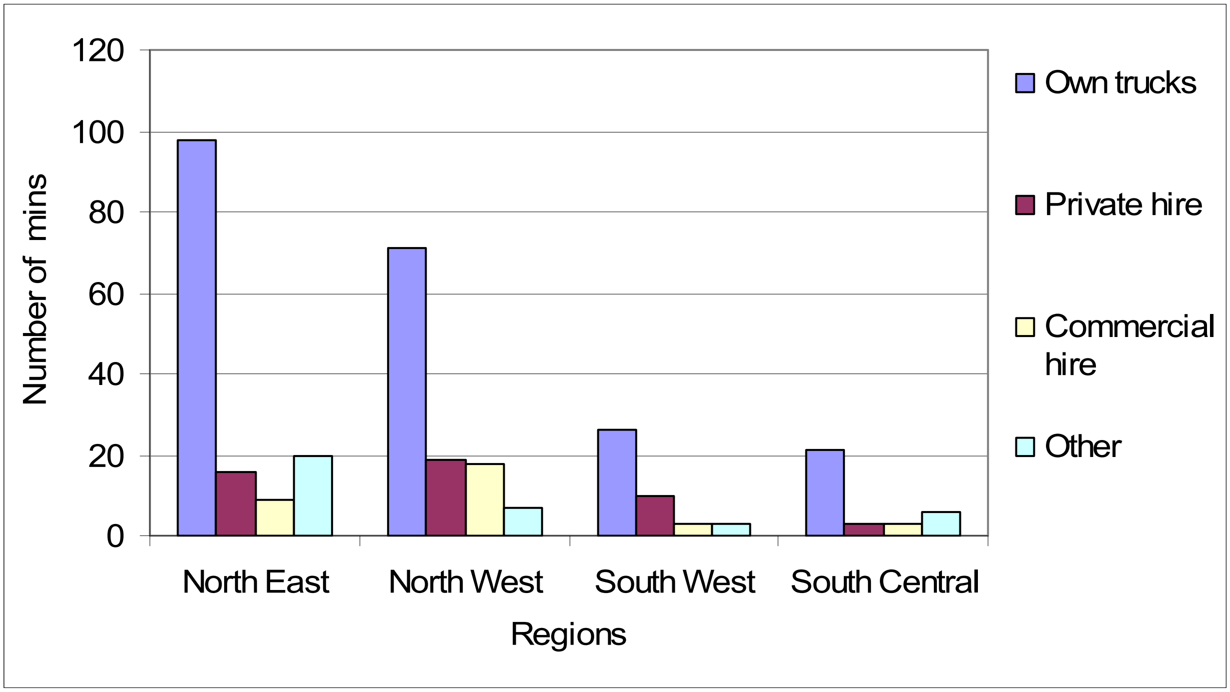
Figure 4.9.1 Ownership of trucks



Source: Transportation of Mining/Mineral Survey results

Regions displayed considerable differences in truck ownership characteristics across the study area (Fig. 4.9.2 The North East and North West regions had substantial amount of mines that operate with their own fleet of trucks. This could be partially explained by the higher volumes of mineral shipments for longer distances in the North West and North East regions (mentioned in the ”Shipment Distances by Volume and Road Network Used” section, Fig. 4.12.2).

Figure 4.9.2 Ownership of trucks (split data)



Source: Transportation of Mining/Mineral Survey results

Table 4.9.1 Variation of truck ownership information across regions (number of trucks)

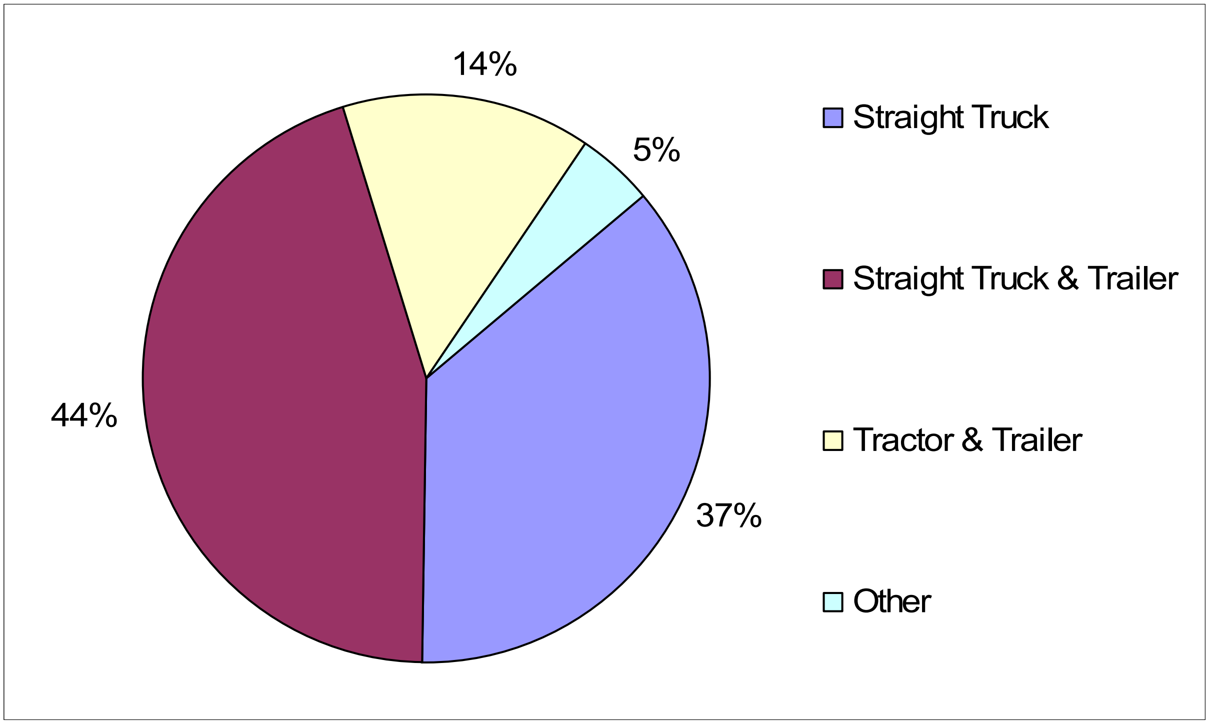
	North East Region	North West Region	South West Region	South Central Region
Average	19.8	14.8	12	12.8
Mode	35	12	17	20
Total	1800	992	300	257

Source: Transportation of Mining/Mineral Survey results

Truck configurations, payload weight and axles on ground

The configuration of the trucks, which can be affected by road availability and usage, as well as a desire for overall efficiency, were straight truck, straight truck & trailer, tractor & trailer and other. About 37% of aggregates are moved by straight truck, 44% by straight truck & trailer, and 14% by tractor & trailer. The remaining portion is shipped using dump trucks, train tractor & two trailers, tractor & double trailers, and truck & transfers (Figure 4.10.1).

Figure 4.10.1 Truck configurations used for aggregates hauling



Source: Transportation of Mining/Mineral Survey results

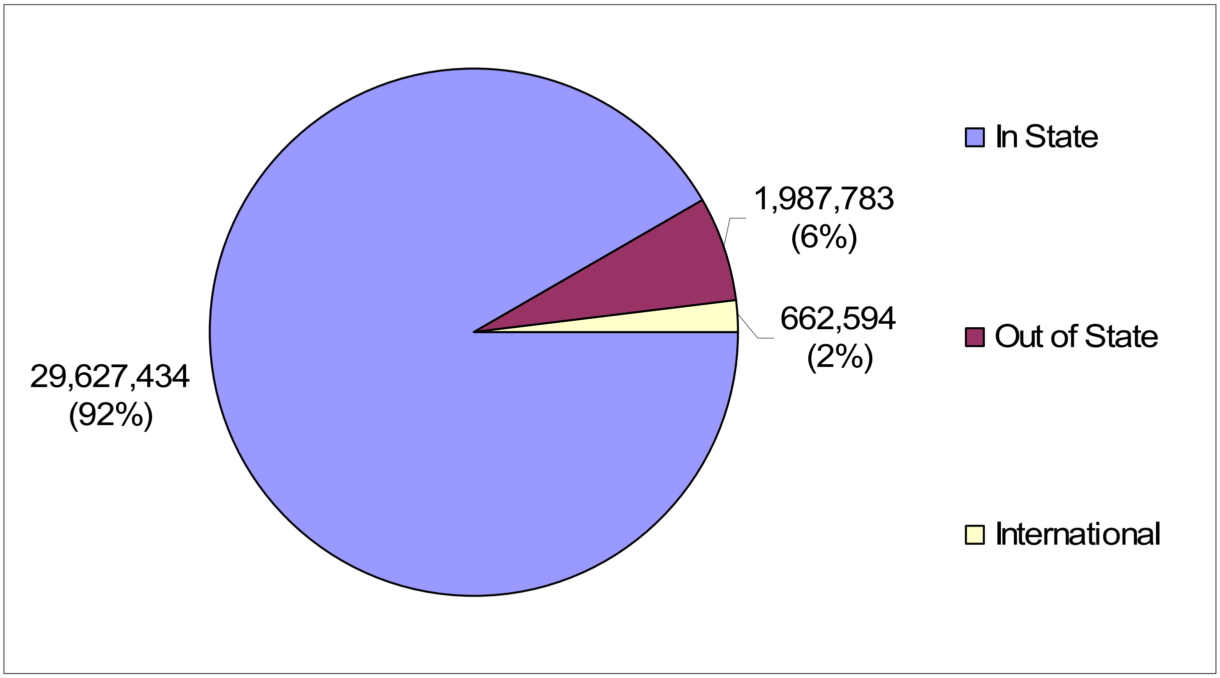
Payload weight for outbound truck shipments in this study ranged from 3.5 to 50 tons of aggregates. The average payload is 23.2 tons and the mode is 30 tons. Allowable weights for trucks driving on Washington road networks are set by the state legislature and regulated by Washington State DOT and Washington State Patrol, based on tire size, the number of axles, and the spacing of axles (or axle groups). However, weights are also subject to further limitations at the county level, which are sometimes more restrictive than state rules, especially during varying weather conditions.

Since the damage to pavements is closely related to the weight on each axle of the trucks, the survey questionnaire included questions to determine number of axles on the ground for the trucks leaving mining facilities. Number of axles typically on the ground varies depending on the type of a truck. According to survey results the number of axles that are typically on the ground ranges from 2 to 6 for trucks, with the average of 3.4 and mode of 3 axles. Trailer axles on the ground ranged from 2 up to 7 axles, with an average and mode of 3. Total number of axles for truck or tractor ranges from 2 to 9, with average of 3.6 axles. With an average of 3 axles, the total number of axles on 1st trailer varies from 2 to 5 axles.

Shipment Destinations

Three main destinations of shipments of interest were in-state, out-of-state and international. Not surprisingly, 92% of mined product is shipped within the State of Washington. The geography of shipments is probably explained mainly by high transportation cost of the low cost aggregates. Six percent of the shipments were out-of-state destinations and the remaining 2% was shipped out-of-country, mostly to Canada (Figure 4.11.1). The small portion of international and out of state shipments corresponds to the 2% of responses indicated for shipments over 100 miles in the "Shipment Distances by Volume and Road Network Used" section. It also supports the statement that aggregates industry is highly affected by transportation in terms of high cost of shipments and emphasizes that proximity of mine site location to the construction site or any other end use location is important, maybe even critical.

Figure 4.11.1 Mined products shipment destinations by production volumes (tons)

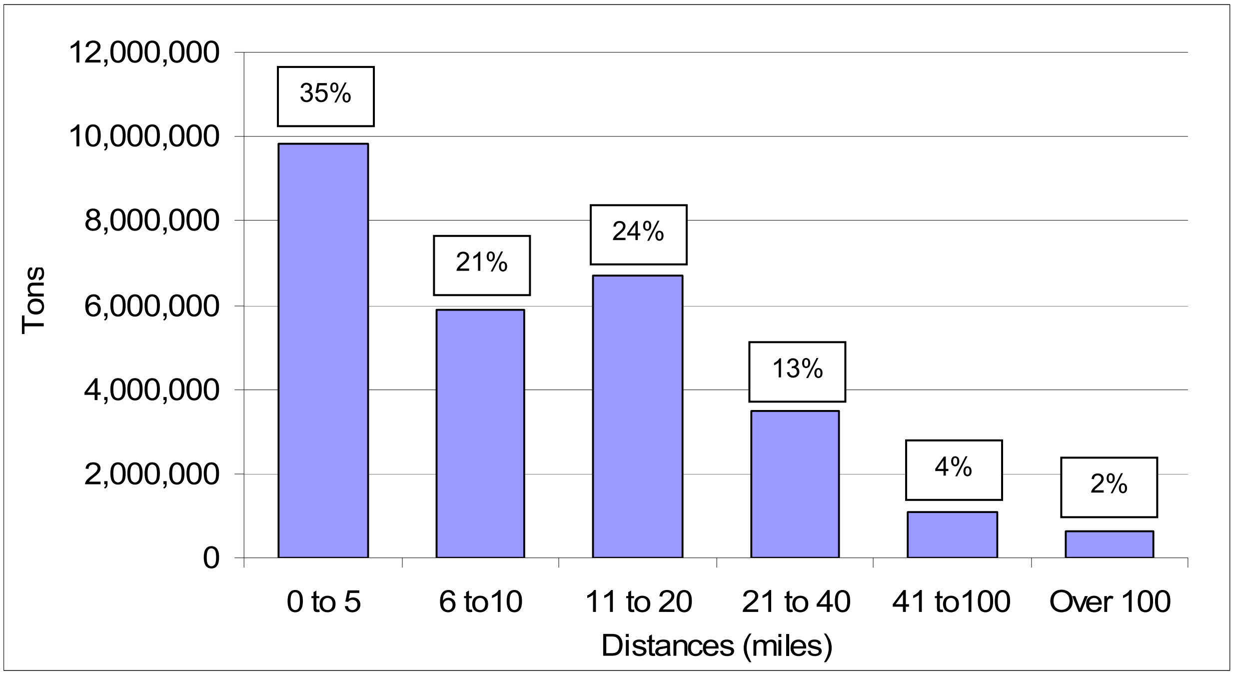


Source: Transportation of Mining/Mineral Survey results

Shipment Distances by Volume and Road Network Used

It was found most aggregate is hauled within close distances from its origin. Survey results showed 80% of total production (78% of mine sites) was hauled within 20 miles or less from the mine location. In highway construction the cost of construction materials plays a vital role in meeting a construction project's schedule and budget constraints (WSDOT, State Construction Office). An important cost component of the projects can be considered the delivery of construction materials to the sites. This relationship is supported by high proportion of shipments within 5, 10 and 20 mile distances from mine locations (Figure 4.12.1).

Figure 4.12.1 Aggregates shipment distances by production volume[10]



Source: Transportation of Mining/Mineral Survey results

Despite its low value per ton characteristic, an aggregate is heavy, which makes truck hauling very costly. Taking into account an average payload weight of 23 tons (survey results) and average transportation costs of $80 - $110 for an hour length haul, every additional 25 mile distance will add approximately $40 - $55 per truck[11]. Given 20,000 tons of aggregate per lane mile demand for a rural segment of interstate construction, every additional 25 mile distance of approximately 869 hauls (20,000/23 tons) will add about $41,000 per lane mile construction. Additionally, road deterioration

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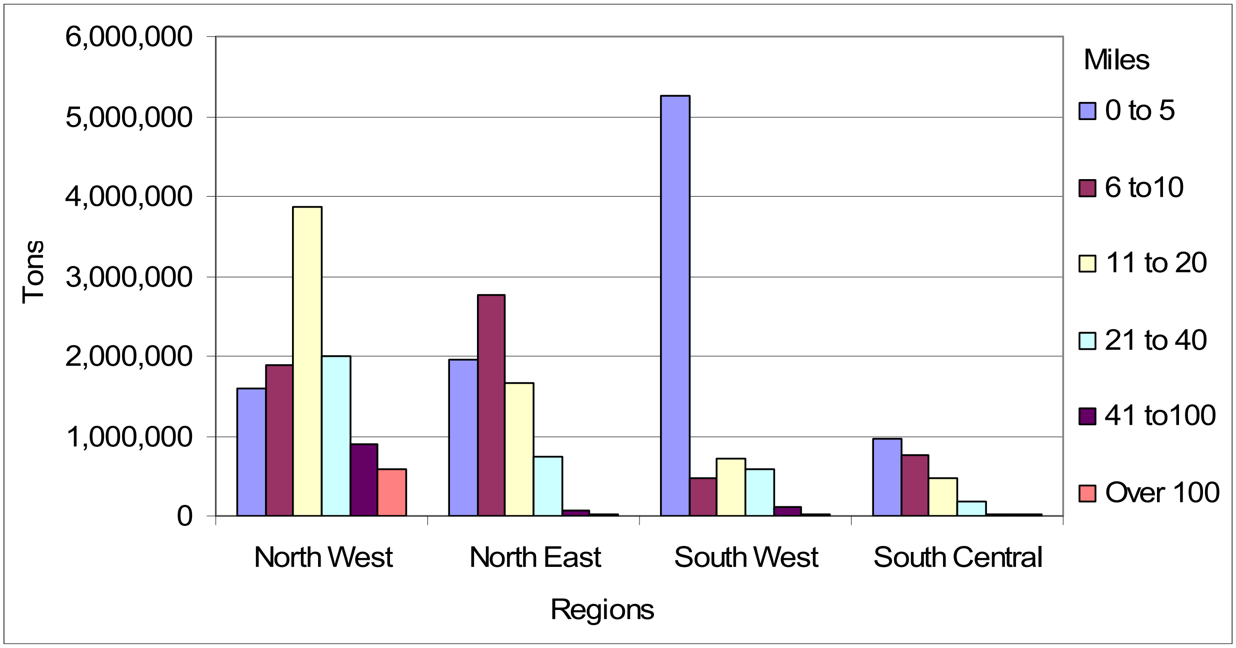
[10] Due to on-site use of mined production at several mine sites, the volumes indicated in this chart may differ from total production volumes.

[11] Trucking rates were averaged from phone interviews with mining firms.

level resulting from the trucks hauling the material also has to be carefully considered for projects planning, another topic investigated later in this report.

Comparison of regional statistics showed high volume of longer distance shipments for the mines in the North West region of the state. The South West region was differentiated by a high volume of shipments within 5 mile distances. Although local pattern of shipment distances varies across regions, generally most of the aggregates were hauled within 20 mile distances (Fig. 4.12.2). Shipment volumes over 40 miles were much higher in the North West region.

Figure 4.12.2 Variation of aggregates shipment distances across regions by production volume (split data)



Source: Transportation of Mining/Mineral Survey results

In order to assess the usage of roads by the mining trucks, mining firms were indicated routes of state highways used for transportation (Appendix D). As stated earlier, with the average payload of 23 tons, 81% of the total mining production was hauled within 20 mile distances of identified state highways and 57% of the total production within 10 mile distances. Appendix C represents maps created at specific county level with corresponding highway usage frequency tables.

CHAPTER THREE

INVESTIGATION OF TRANSPORTATION CHARACTERISTICS WITH SPATIAL ERROR MODEL

Introduction

Highway construction and maintenance relies heavily upon mined aggregates as a core ingredient. The proximity of aggregate mine sites to highway or other construction locations is an important issue since the total project costs are highly affected by transportation cost/efficiency and also deterioration of the existing highway infrastructure as influenced by frequent, heavy shipments traveling long distances. Likewise, the transportation costs for hauling mined aggregates are minimized when shipments are loaded to capacity payload weights.

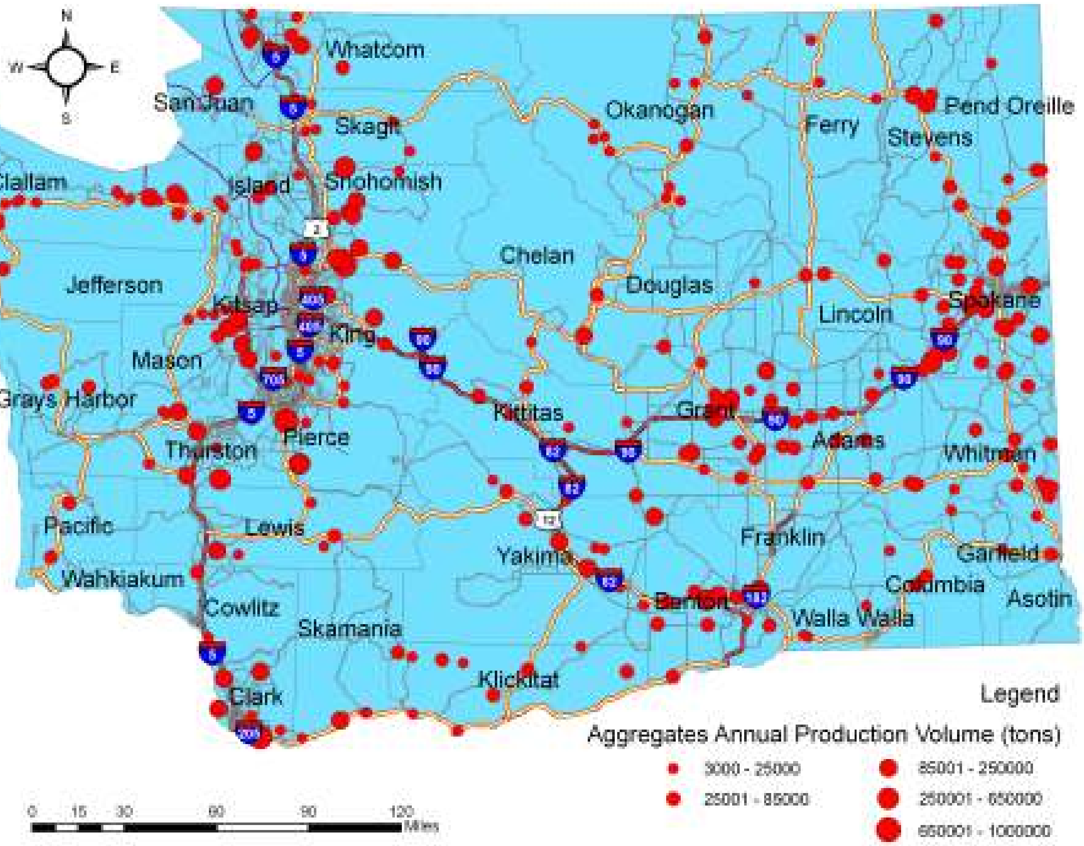
This chapter investigates the spatial relationships between construction aggregate shipments and the trucks' payload weights as it pertains to highway deterioration in the State of Washington. Many studies have examined the relationship between transportation cost and construction unit productivity but there's minimal information available pertaining to the relationship between payload weights, shipment distances and highway deterioration.

To identify impacted highway segments resulting from aggregates shipments, mine locations and shipment distances in cooperation with payload weights are examined. Naturally, spatial non-stationarity of the data is possible whenever any process takes place over many different geographical locations. As such, it's appropriate and necessary to test the mining industry data for spatial dependences. As a result, the paper employs a spatial error regression model with distance based weights matrix to address spatial autocorrelation, to capture the interaction between spatial unites and to predict the incremental change in payload weights resulting from increasing hauling distance. Results show a highly significant positive relationship between payload weights and increasing shipment distances.

Again, only construction aggregates (sand and gravel, rock/stone) related information was used in this chapter. To analyze and evaluate spatial processes, a Geographic Information Systems (GIS) and GeoDa (Anselin, 2003) were used as analytical tools to create desired maps and to conduct spatial analysis.

The geographic distribution of aggregates mines throughout the state is relatively evenly dispersed. However, upon closer investigation of these mine locations in relation to the road network and highly urbanized areas one may find local clustering (Figure 5.1). This is explained by a high concentration of highways, homes and office construction in highly urbanized areas (B. Finnie, J. Peet 2003).

Figure 5.1 Aggregates mines in relation to Washington State highways by annual production volume



In addition to the general visual inspection of the point pattern, exploratory data analysis using GIS and GeoDa showed systematic pattern in the spatial distribution of the data variables such as payload weights and annual production volumes. Global Moran's I (an indicator for spatial autocorrelation) value showed statistically significant spatial autocorrelation in the regression residuals, which then requires addressing the issue of spatial autocorrelation. The importance of this assumption in most of the statistics that the values of observations in each sample are independent can be violated by positive spatial autocorrelation if samples are taken from geographically close locations. Consequently, utilizing data on aggregate mine locations, production volumes, shipment payload weights, configurations of trucks, as well as information on number of axles and transportation characteristics in general, this paper employs a spatial error regression model to address spatial autocorrelation of the data and to predict the incremental change in payload weights resulting from an increase in hauling distance.

The regression results show a statistically significant, positive relationship between shipment distance (aggregates haulage) and payload weights. Additionally aggregate costs significantly increase with the increasing distance, causing longer hauls to potentially result in higher deterioration to state highways. In order to investigate the relationship between payload weights and shipment distance by axle load, forthcoming study will include data on truck configuration and number of axles per truck.

Literature Review

Prior studies focusing on mine operations have focused on issues related to route selection, as with Peter Berck 2005. Berck presents a least cost route selection model for aggregates hauling as a part of constructors' cost minimization strategy, suggesting that the opening of the new quarry would change the aggregates transportation pattern. As a result of the new quarry opening the study found no significant increase in the demand for construction aggregates as well as a decrease in some environmental externalities (emissions reduction). Another public cost consideration may be the deterioration of road networks used for aggregates hauling, which involves investigation of data on payload weights and/or number of axles per truck. This also follows with the desire of construction contractors attempting to increase productivity by maximizing the payload weights of the truck shipments (Schexnayder, et. all. 1999).

Additionally, because the shipments represent a major component of construction costs payload weights may even exceed allowable measures, thus creating a strong relationship between the distance and the payload weights (Chironis, 1987). Chironis 1991, also suggests that overloading trucks by 20% may lead to a decrease in per ton cost of aggregate, since labor costs will not change and the fuel price is relatively unaffected. This assumption might not hold with recent fuel price advances, as well as it does not consider corresponding public cost, externalities like highway damage or environmental impacts. In this aspect, many prior research efforts mention the relationship between aggregate hauling and construction unit productivity, and there is only minimal information available to understand the relationship with hauling distances as they pertain to highways deterioration (Day 1991).

This study explores the relationship between incremental changes in payload weights as shipment distances increase, while simultaneously detecting and accounting for spatial autocorrelation in the data. The identified positive relationship between the aforementioned variables suggests that not only longer distances cause higher cost to construction contractors, but may also result in higher deterioration level to the roads.

Descriptive evaluation of the mining industry data received from the Transportation of Mining/Mineral Survey results showed substantial variation across Washington's regions. Naturally, spatial non-stationarity is involved in any process which takes place over real geographical locations (A. Unwin, D. Unwin, 1998). In other words, the process under investigation might not be constant over the entire study area.

In this aspect, the global statistics will fail to properly represent relationships between processes, especially when translated into local investigation of those processes. Therefore, because the transportation characteristics of the mining/mineral industry involves data containing geographic location information, in most cases the data was expected to have spatial dependence or in other words spatial autocorrelation (the weaker form of spatial dependence). Consequently, spatial dependence in the data would mean that most of the classical estimation procedures and methods are inappropriate for this analysis.

The wide array of studies in the field of spatial econometrics represents diverse approaches for addressing spatial autocorrelation in the data. However, a search of the economic literature did not bring favorable results on investigation of spatial autocorrelation of the data representing aggregates mining industry.

Data

The precise geographic site information for each mine was obtained from the Washington Department of Natural Resources, Division of Geology and Earth Resources. The county and state highway system GIS files were downloaded from the WSDOT GeoData Distribution Catalog. Annual production (tons) was obtained from Transportation of Mining/Mineral Survey results.

Information related to mining operations and characteristics was obtained from the Transportation of Mining/Mineral Survey results conducted by the research and implementation project Strategic Freight Transportation Analysis (SFTA).

Spatial Autocorrelation

The first law of geography states "everything is related to everything else, but near things are more related than distant things"—Waldo Tobler. The simplest definition of spatial autocorrelation is a correlation of one variable with itself throughout space. Many authors state that spatial autocorrelation exists as a systematic spatial variation in values across space, where high values at one location are associated with high values at neighboring location creating positive autocorrelation. Whereas high and low value patterns between neighboring areas represent negative autocorrelation (Upton and Fingleton, 1985).

As such, spatial autocorrelation is a problem for regression models when the error terms introduce some spatial pattern in which areas or points close together display similar values than areas or points further away (in this study points are represented by x y coordinates of mine site locations).

The number of local and global spatial statistics is available for the test for the complete spatial randomness of the data depending on its form. One of the oldest indicators of global spatial autocorrelation is Moran's I (Moran, 1950), which (applied to polygon or point data) compares the value of specific variable at any one location with that of all other locations and emphasizes similarities over space (Fotheringham et. al. 2002).

$$I = \frac{N \sum_i \sum_j W_{i,j} (X_i - \bar{X})(X_j - \bar{X})}{(\sum_i \sum_j W_{i,j}) \sum_i (X_i - \bar{X})^2}$$

where N is the number of point observations (locations), X_i is the value of variable at location *i, X*$_j$ is the value of variable at location *j*, $\overline{X}$ is the mean of the variable and *W*$_{ij}$ is a spatial weight matrix applied to the comparison between locations *i* and *j*.

In contrast, local statistics emphasize differences over space and can be used to check for the spatial stationarity of the data. While global statistics assumed invariant, local statistics vary over space and are spatial, thus can be mapped. In other words, global Moran I's major limitation is that it tends to average local variations in the strength of spatial autocorrelation.

In the case of the mining industry the global forms of statistics might not be representative of the situation in any particular region of the state and may hide some interesting and important local variations of the characteristics that the study investigates. For example, as mentioned earlier, in the Western regions of the state, due to availability of many construction projects or favorable weather conditions, larger percentage of mines can be found in operation, or more aggregate shipments than it would be in the Eastern part of the state. Thus, an important local variation in relationships would be partially or completely unnoticeable. Preliminary manipulation of the data showed some dissimilarity in the data across study area regions, which ensures the idea of investigating the data using local forms of spatial analysis.

The localized version of Moran's I statistic (LISA) has the following form:

$$I_i = \frac{(X_i - \overline{X})\sum_j W_{ij}(X_j - \overline{X})}{\sum_i (X_i - \overline{X})^2 / N}$$

where N is the number of observation, X_i is the observed value of the variable *X* at location *i,* $\bar{X}$ is the mean of the variable, and W_{ij} is a spatial weight matrix, which represents the strength of the linkage between *i* and *j* locations (Anselin L. 1995).

Spatial Weight Matrices

The potential interaction between two spatial units can be expressed by the spatial weight matrix *W*. Contiguity based spatial matrices can be used for the data involving areas such as counties, regions, states or even countries. Distance based weights can be appropriate for point data, as well as for polygon data if centroids are calculated. Each type in turn can be different according to specified order of contiguity, distance band or number of neighbors. Although, each type of spatial weights can be formed based on specific situations or nature of the spatial data, however, there is no precise agreement about the type of weight matrix to be employed for spatial analysis (Anselin, 1988). In the spatial N by N weight matrix, each element w_{ij} = 1 when *i* and *j* are neighbors and w_{ij} = 0 otherwise, the diagonal elements of which are set to zero. Rows of the N by N weight matrix are standardized such that $w_{ij}^{s} = \frac{w_{ij}}{\sum_{j} w_{ij}}$. Resulting weights matrix is no longer symmetric, which ensures averaging neighboring values (Anselin and Bera 1998).

For the contiguity type weight matrices "neighbors" can be classified spatial units that share a border. Anselin, 2005, provide details on higher order contiguity weight matrices – queen, rook. Distance based matrices can be based on either the distance between *i* and *j* locations of observations or number of neighbor observations. Where, in the first case "neighbors" for one location can be considered all points/locations that are within the specified distance from that point. While for the "number of nearest neighbor" approach, number of points/neighbors should be specified in order to be considered as neighbors. For example, if for some specific purposes 4 nearest neighbors approach is adopted, the weights matrix will consider only 4 nearest points for each of the point in the study area. Weights with number of nearest neighbors (KNN) approach standardize the number of neighbors, which assumes that an equal number of neighbors are more important than the distance between neighbors.

Spatial Error Dependence Model

One reason for spatial dependence in an estimated model could arise as a result of mine site location near to highly urbanized regions of the study area. Urbanization is usually positively related with aggregates consumption. Thus, mine sites located near to densely populated areas might operate with higher annual production levels, than those located in less populated regions. Similar local demand characteristics could partially explain production levels or shipment's payload weights, as well as shipment distances. As mentioned earlier, spatial autocorrelation is a problem for regression models when the error terms introduce some spatial pattern in which areas or points close together display similar values than areas or points further away. Widely used specification is a spatial autoregressive process in the error terms. The spatial error model assumes the following linear regression:

$y = X\beta + \varepsilon$, with $\varepsilon = \lambda W \varepsilon + \upsilon$, Where λ is the spatial autoregressive coefficient for the error lag $W\varepsilon$, and υ is homoskedastic error term.

Spatial Regression Model Selection

Spatial regression model selection decision was made according to Luc Anselin's comprehensive guide to GeoDa statistical software – "Exploring Spatial Data with GeoDa^{TM}: A Workbook". Regression analysis started with Ordinary Least Squares regression; further, Lagrange Multiplier (LM) diagnostics provided basis for the spatial autoregressive model selection. Both LM-Error and LM-Lag tests showed statistically significant results, which led to examination of their Robust form statistics. At this step Robust LM-Error statistic showed statistically significant results, accordingly the spatial error model was chosen for next stage of the regression analysis.

Results

To investigate the relationship between payload weights and shipment distances, payload weights of aggregates shipments by trucks was selected as a dependent variable; proportion of shipments within 5 – 10, 11 – 20, 21 – 40 and 41 – 100 mile distances were analyzed as explanatory variables.

The regression results indicate that payload weights and all distance categories are positively related, with an adjusted R^2 of 0.28. In addition to the less favorable fit, there are quite a few specification problems. Particularly, regression diagnostics disclose considerable non-normality and high spatial autocorrelation. Moran's I, LM-Error, LM-Lag and LM-Sarma tests are all significant. Moran's I scatter plot (Figure 5.2) visualizes the statistic indicated in the Table 5.1, under the “Diagnostics For Spatial Dependence” section. As it was described in the “Spatial Error Dependence” section, the decision for the model selection was based on LM-Error and LM-Lag test statistics. Because both tests showed statistically significant results, the Robust forms for both tests were examined. Consequently, as a result of significant Robust LM-Error statistic, spatial error regression was employed.

Table 5.1 Regression summary of output: ordinary least squares estimation

Dependent Variable	Payload weights	Number of Observations	288
Mean dependent var.	19.9097	Number of Variables	6
S.D. dependent var.	12.6885	Degrees of Freedom	282
R-squared	0.290294	F-statistic	23.0695
Adjusted R-squared	0.277711	Prob(F-statistic)	2.06E-19
Sum squared residual	32907.2	Log likelihood	-1091
Sigma-square	116.692	Akaike info criterion	2193.99
S.E. of regression	10.8024	Schwarz criterion	2215.97
S.E of regression ML	10.6893		

Variable	Coefficient	Std.Error	t-Statistic	Probability
CONSTANT	2.381654	1.79817	1.324488	0.1864126
0_5_MILE	17.24359	2.74068	6.29172	0.0000000
6_10_MILE	23.31129	2.956789	7.883989	0.0000000
11_20_MILE	16.8195	3.084599	5.452736	0.0000001
21_40_MILE	23.32615	4.375268	5.331365	0.0000002
41_100_MILE	31.64233	7.334185	4.314362	0.0000222

REGRESSION DIAGNOSTICS

MULTICOLLINEARITY CONDITION NUMBER 5.926111

TEST ON NORMALITY OF ERRORS

TEST	DF	VALUE	PROB
Jarque-Bera	2	27.7393	0.0000009

DIAGNOSTICS FOR HETEROSKEDASTICITY

RANDOM COEFFICIENTS

TEST	DF	VALUE	PROB
Breusch-Pagan test	5	8.05721	0.1531107
Koenker-Bassett test	5	7.023928	0.2188668

SPECIFICATION ROBUST TEST

TEST	DF	VALUE	PROB
White	20	39.02313	0.0066234

DIAGNOSTICS FOR SPATIAL DEPENDENCE

FOR WEIGHT MATRIX : treshold distance based (row-standardized weights)

TEST	MI/DF	VALUE	PROB

Moran's I (error)	0.111457	3.503859	0.0004587
Lagrange Multiplier (lag)	1	7.213300	0.0072365
Robust LM (lag)	1	0.357543	0.5498742
Lagrange Multiplier (error)	1	10.86660	0.0009791
Robust LM (error)	1	4.01084	0.0452086
Lagrange Multiplier (SARMA)	2	11.22414	0.0036535

Next, the residual standard deviational map (high-high and low-low values suggesting positive autocorrelation, high-low and low-high values – negative autocorrelation) is examined, which suggests the presence of spatial autocorrelation from "visual inspection", but only the proper specification tests can permit for an assessment of the significance of this autocorrelation and for an indication of the use of alternative spatial model. Figures 5.3 and 5.4 represent locations (hot spots) with significant local Moran statistics of the study area. The legend for the significance map provides p-values in different shades of green.

Figure 5.2 Moran scatter plot for OLS residuals

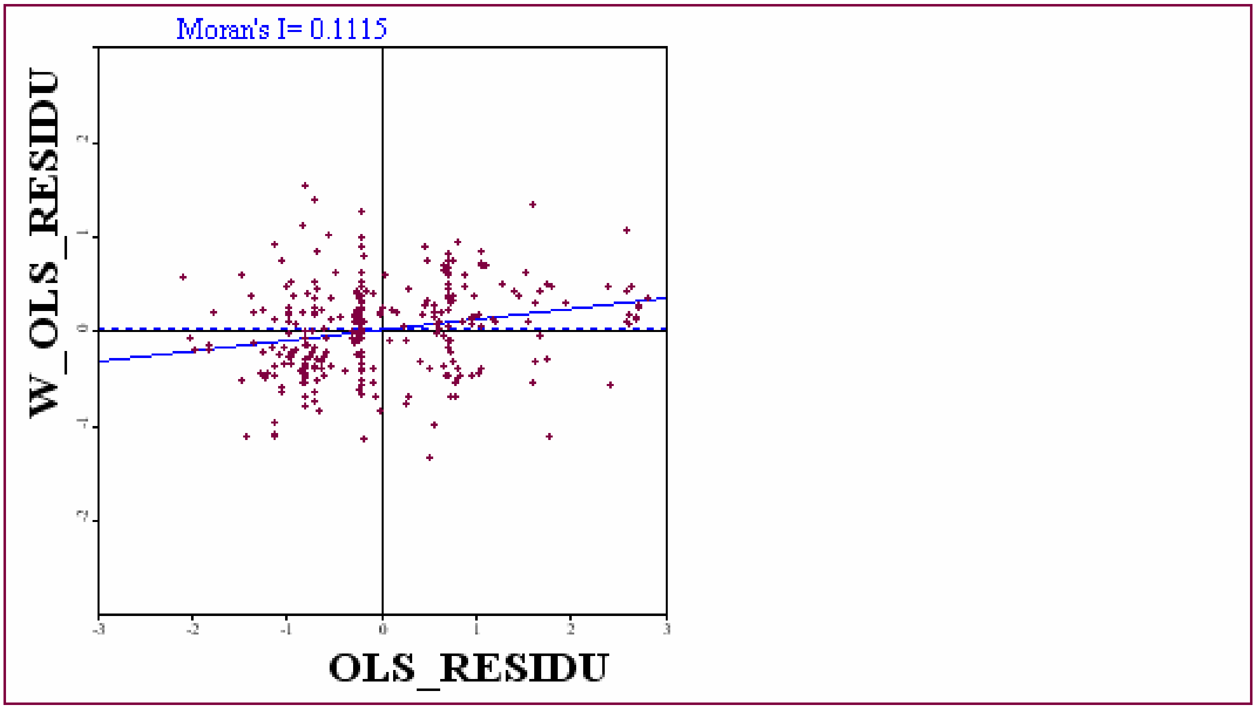
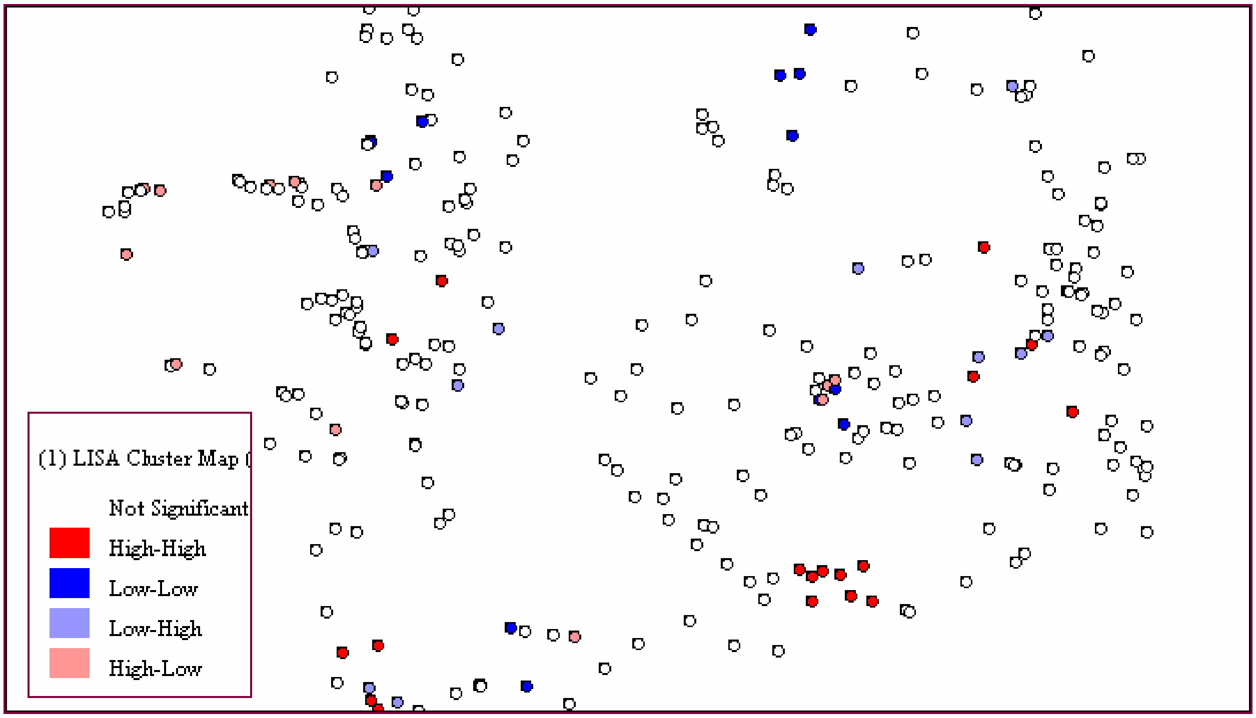
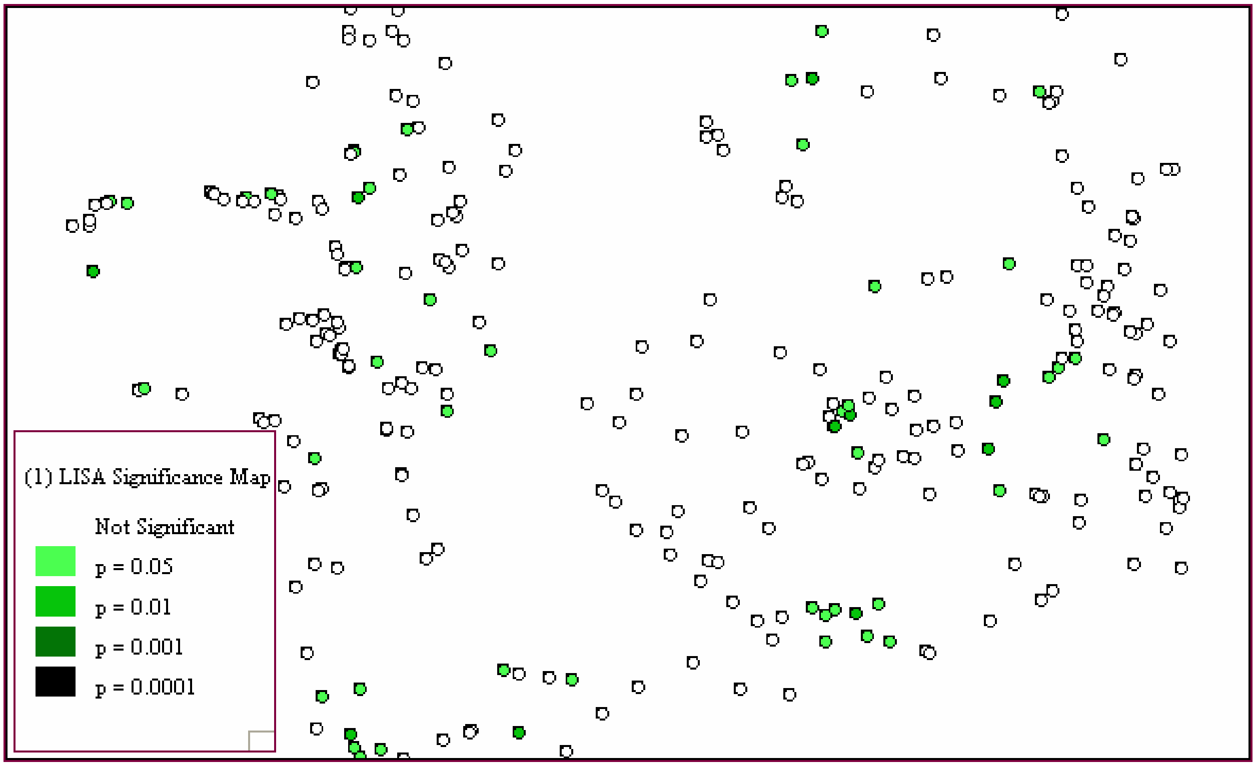


Figure 5.3 LISA cluster map for OLS residuals



Note: significance filter is set to 0.05

Figure 5.4 LISA significance map for OLS residuals



*Note: significance filter is set to 0.05

The results of spatial error regression are represented in the Table 5.2, where the estimates for the autoregressive parameter of the error process are represented next to Lambda. The result is positive and significant, which more time ensures the suggestion from the OLS estimation diagnostics (based on LM-Error, LM-Lag, and Robust form test statistics).

Table 5.2 Regression summary of output: spatial error model – maximum likelihood estimation

Spatial Weight: based	Threshold distance		
Dependent Variable	Payload weights	Number of Observations	288
Mean dependent var.	19.9097	Number of Variables	6
S.D. dependent var.	12.6885	Degrees of Freedom	282
Lag coeff. (Lambda)	0.301007		
R-squared	0.325897	R-squared (BUSE)	
Sum squared residual		Log likelihood	-1085.85
Sq. Correlation		Akaike info criterion	2183.71
Sigma-square	108.529023	Schwarz criterion	2205.69
S.E of regression	10.4177		

Variable	Coefficient	Std.Error	z-value	Probability
CONSTANT	1.68742	1.867309	0.9036638	0.3661736
0_5_MILE	18.26757	2.630924	6.943402	0.0000000
6_10_MILE	22.13488	2.895299	7.645112	0.0000000
11_20_MILE	18.7434	3.039997	6.165599	0.0000000
21_40_MILE	26.32215	4.305979	6.112932	0.0000000
41_100_MILE	31.56302	7.050658	4.476606	0.0000076
LAMBDA	0.3010072	0.084690	3.554222	0.0003792

REGRESSION DIAGNOSTICS

DIAGNOSTICS FOR HETEROSKEDASTICITY

RANDOM COEFFICIENTS

TEST	DF	VALUE	PROB
Breusch-Pagan test	5	8.024456	0.154893

DIAGNOSTICS FOR SPATIAL DEPENDENCE

SPATIAL ERROR DEPENDENCE FOR WEIGHT MATRIX weights_treshhold.GWT

TEST	DF	VALUE	PROB
Likelihood Ratio Test	1	10.28267	0.0013429

In this estimation the R^2 is listed as a pseudo-R^2, and it cannot be compared with that of OLS results. Instead, for this model the Log-likelihood, Akaike information criterion (AIC) and Schwarz criterion (SC) are appropriate measures of the fit. Compared to the OLS diagnostics all three are improved in this specification. Particularly, Log-likelihood is increased from -1091 (for OLS) to -1085.85, AIC is slightly decreased from 2193.99 (for OLS) to 2183.71, and SC - from 2215.97 to 2205.7. The spatial autoregressive coefficient (λ) is estimated as 0.30 and is statistically highly significant.

While the relationship between the dependent and explanatory variable is also positive and highly significant, the coefficients are slightly changed compared to the OLS results. In the process of spatial error regression predicted values ($\hat{y}$), prediction errors (the difference between the observed and predicted values, $y - \hat{y}$), and model residuals ($\hat{\upsilon}$) are saved in the attributable table as vectors, which will be used to map or to recalculate Moran's I index for comparison with previous results. In Figure 5.5 a new scatter plot indicates Moran's I statistic of -0.00042, which is essentially the same as zero. As expected, this is the indication of proper use of the spatial error specification, which led to elimination of spatial autocorrelation. Note that residuals here are estimates for spatially filtered (uncorrelated) model error term, $\hat{\upsilon} = (I - \hat{\lambda}W)\hat{\varepsilon}$ where $\hat{\varepsilon} = \hat{\lambda}W\hat{\varepsilon} + \hat{\upsilon}$.

Figure 5.5 Moran scatter plot for spatial error residuals

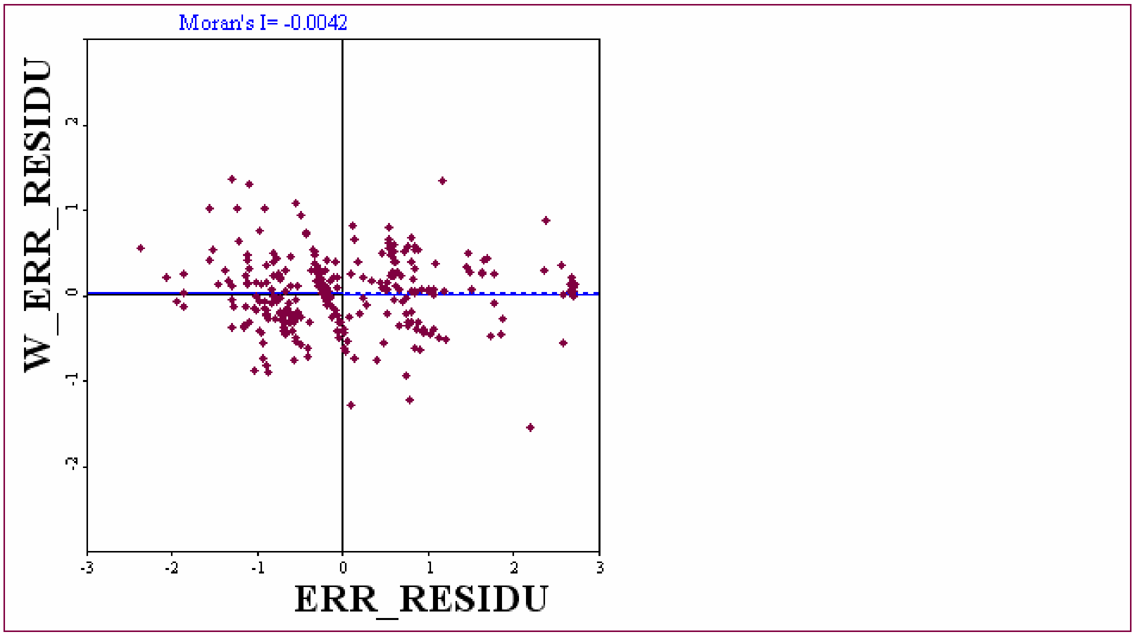


Figure 5.6 LISA cluster map for error residuals

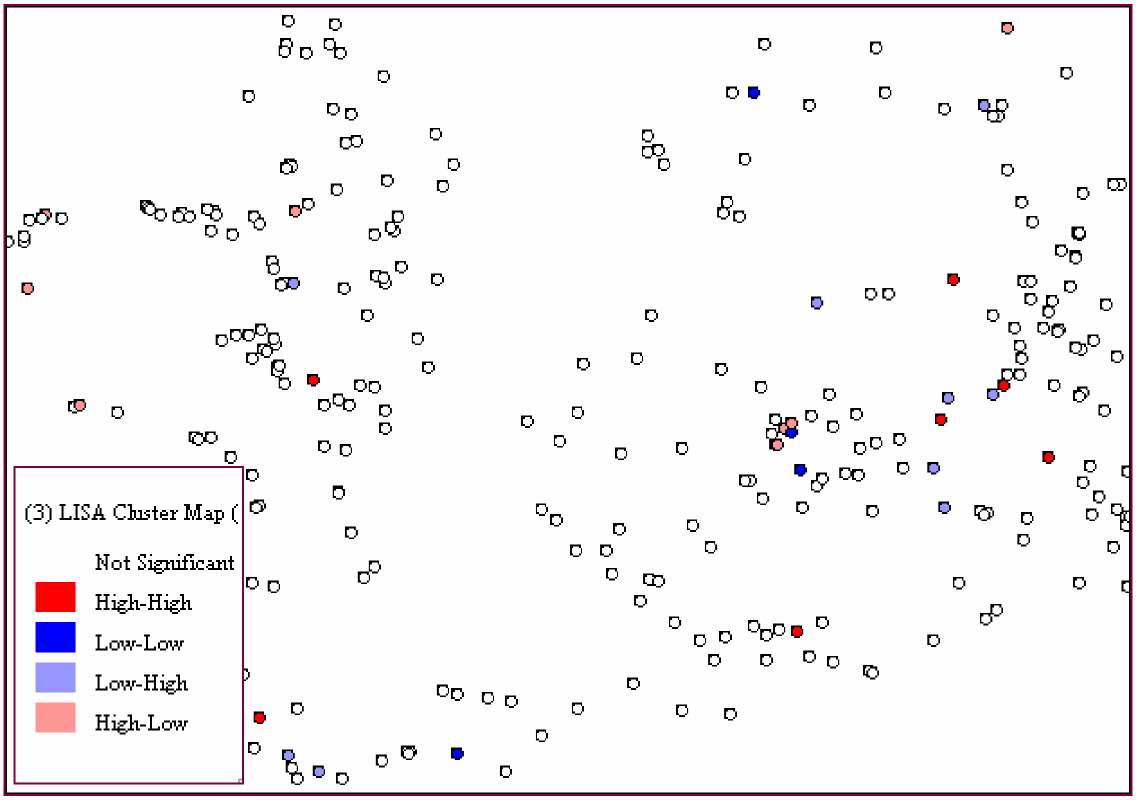
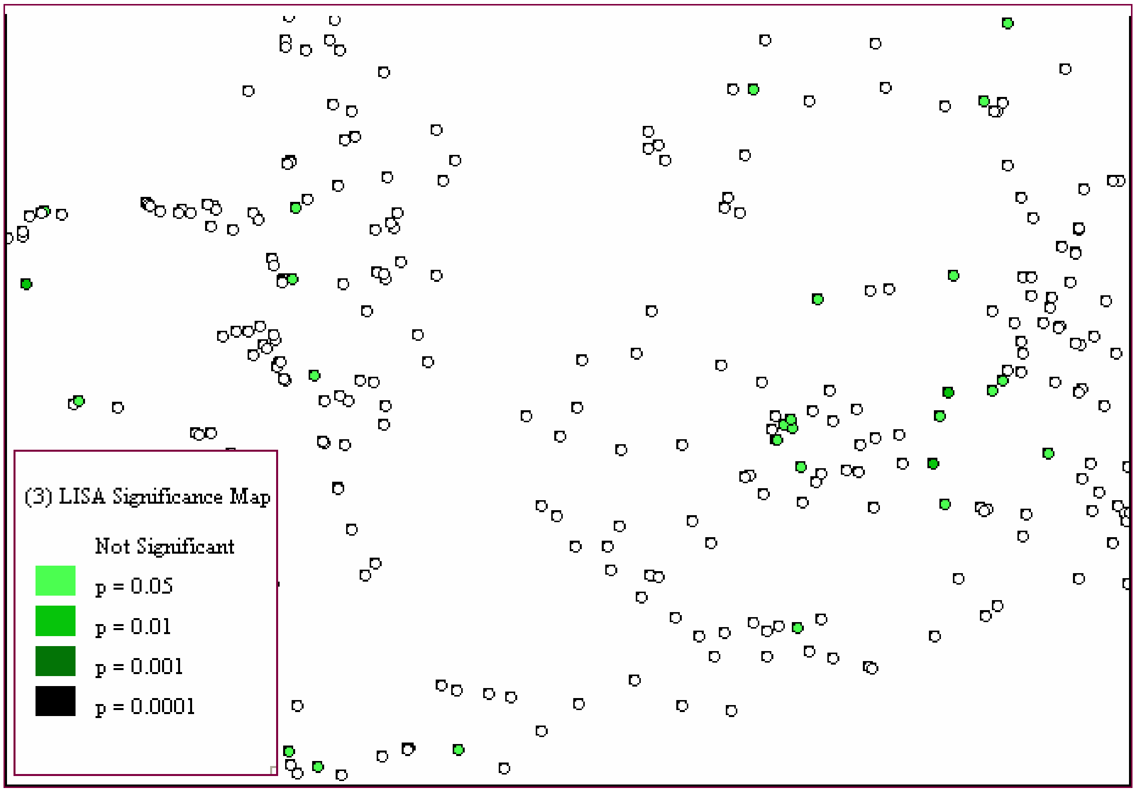


Figure 5.7 LISA significance map for error residuals



Figures 5.6 and 5.7 represent the cluster activity and significance map using error residuals received from the spatial regression model. The results of the cluster map show the elimination of spatial autocorrelation in the data, which is supported by the probability significance map. In comparison with the mapped OLS regression residuals, considerable reduction of hotspots can be observed.

The spatial error regression results (Table 5.2) show a sizeable increase (about 4 tons) in payload weight from 0 – 5 to 6 – 10 mile distance shipments. For the next distance change, the payload weights are reduced by 3.4 tons (to 18.3 tons). This can partially be explained by local, more restrictive regulations on truck size and weight (in addition to the state level regulation), which eventually leads to transportation cost per-ton-mile increases. Shipment distances from 21 – 40 and from 41 – 100 miles were estimated with an increase by 7.5 and 5.2 tons accordingly.

In addition to the shipment distances and payload weight data, the GIS database designed and used in this study will allow querying and easy manipulation of aggregates transportation related data, such as annual production tons, configurations of aggregate hauling trucks, number of trucks operating for particular mine site, number of axles on trucks and/or trailers, highway routes used for shipments, mine operational hours, production shipment and operational months, as well as information on factors that influence monthly shipments, proportions of shipments to different end uses (construction or road site, warehouse, factory, etc.).

Conclusions and Recommendations

The main objective of this study was to investigate the relationship between payload weights and shipment distances. Visual examination of the data followed by exploratory data analysis detected a systematic pattern in the spatial distribution of the variables of main interest. The data involved geographic locations of mine sites, which led to the investigation of spatial dependences or spatial autocorrelation over the study area. Accordingly, the appropriate statistical tests for the assessment of the level of the spatial autocorrelation were performed. Significant results confirmed and ensured the use of spatial autoregressive model to address that issue of the autocorrelation.

The second objective of this study was to create a supportive basis for continuing research activities where axle load and truck configurations are involved and examined to assess the relationship with distance of shipments in order to estimate the “contribution” of the mining industry to pavement deterioration.

For cost minimization purposes many mining operations fully utilize payload weight capacities for truck shipments, thus eliminating public costs of highway system deterioration. The adopted spatial error regression model suggested highly significant positive relationship between payload weights and increasing shipment distances. With the exception for shipments within 11 – 20 mile distances, all other distances showed an increase in payload weights by approximately 4 to 7 tons. This directly relates to the above-mentioned payload weight maximization goal and emphasizes the importance of the mines proximity to the construction sites due to the high cost of aggregates transportation. Meanwhile, the relationship suggests accurately monitoring of truck configuration selection in accordance to the payload weights and shipment distances, which will partially ensure the durability of the highway system as it pertains to the transportation of mining industry production.

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Appendix A

Mining/Mineral Production Data

Table 1. Construction sand and gravel sold or used by producers in the United States in 2004, by geographic division and method of transportation (Thousand metric tons)

Region/division	Truck	Rail	Water	Other	Not transported	Not specified	Total
Northeast:							
New England	12,700	353	--	20	3,530	33,400	50,000
Middle Atlantic	23,000	18	--	1,200	3,860	45,200	73,300
Midwest:							
East North Central	77,200	406	4,930	141	10,900	137,000	231,000
West North Central	37,600	538	2,620	204	10,700	83,400	135,000
South:							
South Atlantic	41,300	351	14	--	4,700	42,600	89,000
East South Central	13,900	239	3,440	46	751	28,500	46,900
West South Central	45,900	1,260	92	--	12,600	62,500	122,000
West:							
Mountain	68,600	254	--	86	16,500	166,000	251,000
Pacific	117,000	2,820	2,470	1,260	22,800	92,500	239,000
Total	437,000	6,240	13,600	2,960	86,300	691,000	1,240,000

The table was adapted from U.S. Geological Survey *Construction Sand and Gravel Statistics and Information, 2004* publication

Table 2. Number of surveyed mines, annual production volumes and types of commodities by county

	Sand & Gravel	Rock or Stone	Coal	Carbonate	Clay	Peat	Metals	Ash	Diatomite	Silica Sand	Soil	Gold	Other	Total	# of mines as %	Annual Production (tons)
Adams	16	17									1			34	6%	650,000
Asotin	1	1												2	0%	105,000
Benton	11	11												22	4%	1,640,000
Chelan	5	4												9	2%	213,000
Clallam	20	4			1									25	5%	383,480
Clark	7	7												14	3%	1,425,200
Columbia	2	4												6	1%	140,000
Cowlitz	3	6			1								1	11	2%	70,100
Douglas	10	5												15	3%	761,000
Ferry	9						1					1		11	2%	567,550
Franklin	2													2	0%	100,000
Garfield		1						1						2	0%	25,000
Grant	35	3											1	39	7%	1,582,750
Grays Harbor	6	2												8	1%	160,200
Island	5													5	1%	197,013
Jefferson	4	2												6	1%	51,500
King	10	3			2					2			1	18	3%	1,481,000
Kitsap	12	3												15	3%	920,000
Kittitas	8	8												16	3%	208,500
Klickitat	3	13												16	3%	250,000
Lewis	3	4	1											8	1%	5,260,000
Lincoln	23	14												37	7%	1,020,000
Mason	6	4												10	2%	1,434,050
Okanagan	22	1		2										25	5%	453,300
Pacific		2												2	0%	85,000
Pend Oreille	5	3												8	1%	411,500
Pierce	5	3			1						3			12	2%	3,010,000
San Juan		3												3	1%	153,000
Skagit	4	3												7	1%	425,000
Skamania	3	4												7	1%	105,000
Snohomish	10	8									2			20	4%	2,865,711
Spokane	22	23			3									48	9%	2,130,000
Stevens	14	6								2			1	23	4%	933,152
Thurston	6	2			1									9	2%	950,100
Walla Walla	3	3												6	1%	66,000
Whatcom	6	1												7	1%	375,030
Whitman	24	12												36	6%	1,140,003
Yakima	4	7												11	2%	479,673
Total	**329**	**197**	**1**	**2**	**9**	**0**	**1**	**1**	**0**	**4**	**6**	**1**	**4**	**555**		**32,227,812**
Comm as %	59%	35%	0%	0%	2%	0%	0%	0%	0%	1%	1%	0%	1%			
Max														48		5,260,000
Min														2		25,000
Average														15		848,100

Data Source: Transportation of Mining/Mineral Survey results

Table 3. Operational mines' annual production volumes and types of commodities by county

County	Sand/ Gravel		Rock/ Stone		Clay		Silica		Coal		Total
	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%	Tons
Lewis	120,000	2%	90,000	2%					5,000,000	96%	5,210,000
Snohomish	1,725,000	60%	1,140,711	40%							2,865,712
Spokane	1,315,000	66%	620,000	31%	50,000	3%					1,985,001
Pierce	1,080,000	71.52%	425,000	28.15%	5,000	0.33%					1,510,001
Clark	274,000	20%	1,121,200	80%							1,395,200
Grant	887,000	77%	268,750	23%							1,155,751
Benton	600,000	56%	475,000	44%							1,075,001
Thurston	700,100	74%	250,000	26%							950,101
Kitsap	656,000	72%	260,000	28%							916,001
King	499,000	60%			62,000	7%	270,000	32%			831,001
Stevens	394,605	48%	168,647	21%			254,000	31%			817,253
Lincoln	140,000	22%	500,000	78%							640,001
Adams	175,000	34%	345,000	66%							520,000
Whitman	70,003	14%	445,000	86%							515,004
Yakima	176,520	39%	273,153	61%							449,674
Clallam	285,480	76%	91,000	24%							376,481
Whatcom	310,030	86%	50,000	14%							360,031
Mason	76,000	23%	255,050	77%							331,051
Klickitat	24,000	10%	221,000	90%							245,001
Island	197,013	100%									197,014
Douglas	180,000	100%									180,001
Grays Harbor	90,200	56%	70,000	44%							160,201
Okanogan	112,000	100%									112,001
Skamania	0		105,000	100%							105,001
Franklin	100,000	100%									100,001
San Juan			95,000	100%							95,001
Kittitas	90,500	100%									90,501
Pacific			85,000	100%							85,001
Pend Oreille	71,500	100%									71,501
Columbia			60,000	100%							60,000
Jefferson	10,500	20%	41,000	80%							51,500
Cowlitz	50,100	100%									50,101
Ferry	46,000	100%									46,001
Chelan	40,000	100%									40,001
Walla Walla	20,000	50%	20,000	50%							40,001
Asotin	30,000	100%									30,001
Skagit	24,000	96%	1,000	4%							25,001
Garfield	0										0
Total	10,569,551		7,476,511		117,000		524,000		5,000,000		23,687,093

Data Sources: Transportation of Mining/Mineral Survey

Appendix B

Operational Mines' Locations and Data (by WSDOT Regions)

Data Sources:

- Transportation of Mining/Mineral Survey
- Geographic site information for all figures was obtained from Washington Department of Natural Resources, Division of Geology and Earth Resources.
- County and highway system GIS files were provided by the WSDOT GeoData Distribution Catalog.

Figure 1. Washington State Department of Transportation Eastern Region: mines by type and production level in relation to highway system

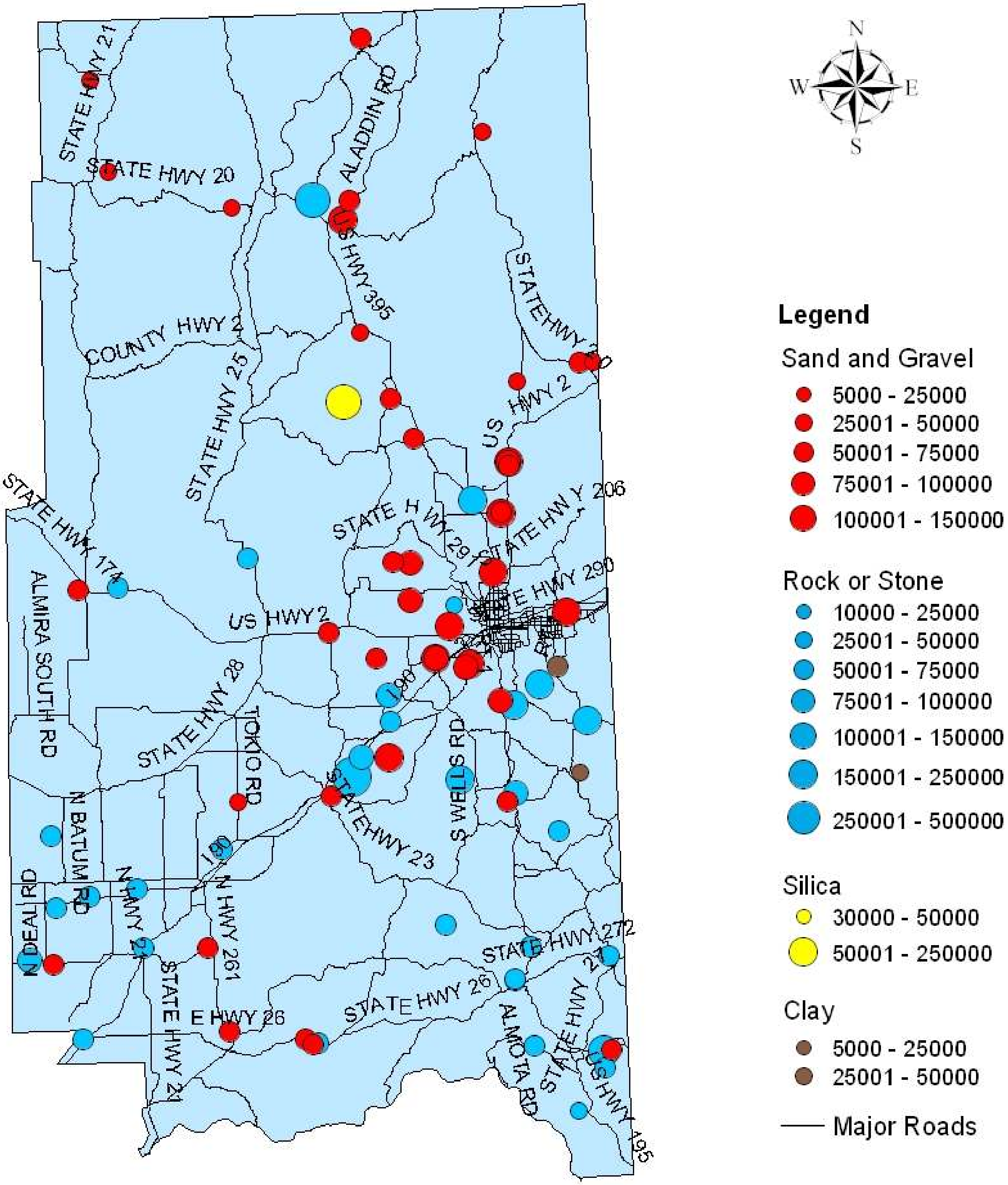


Figure 2. Washington State Department of Transportation North Central Region: mines by type and production level in relation to highway system

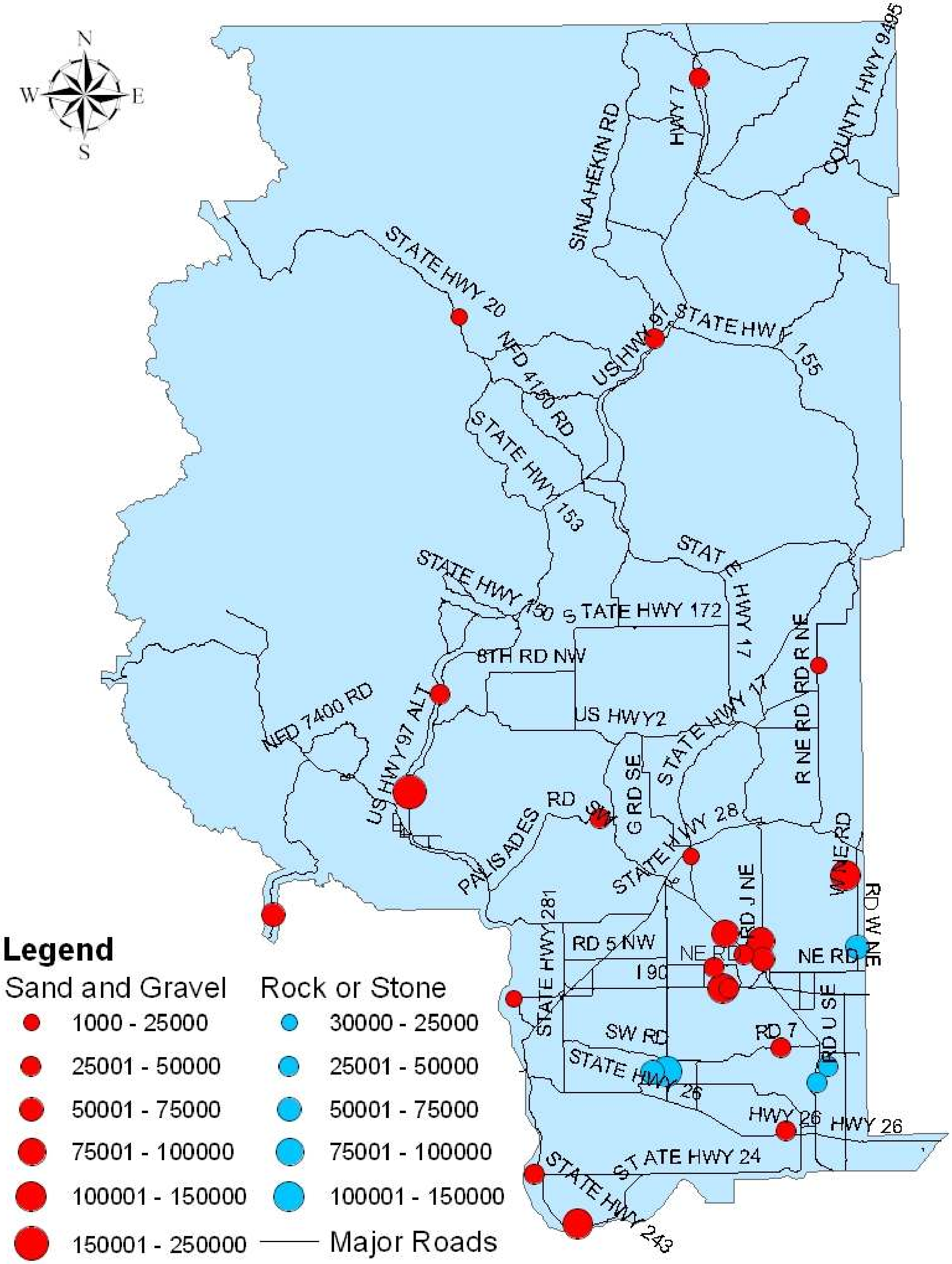


Figure 3. Washington State Department of Transportation Northwest Region: mines by type and production level in relation to highway system

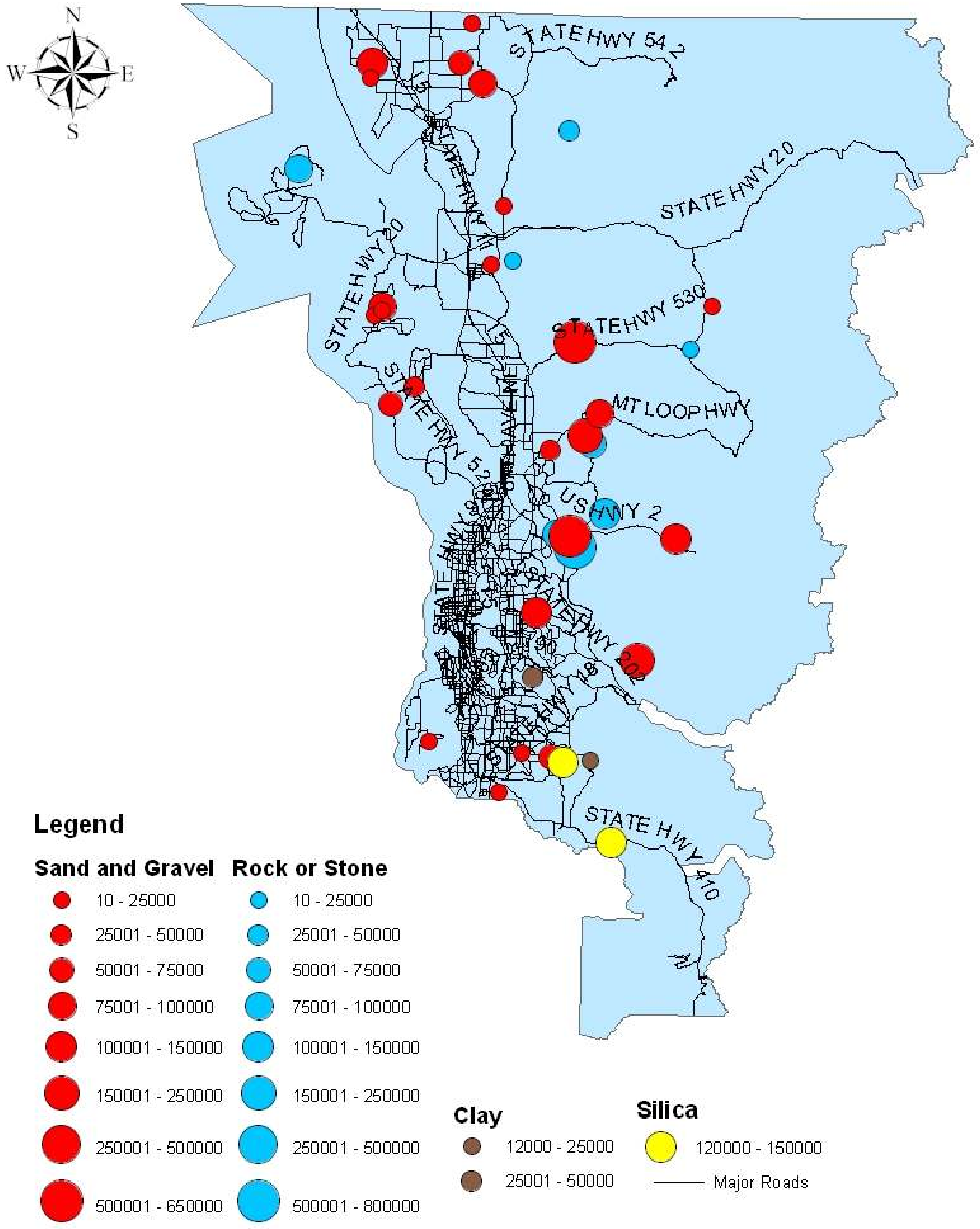


Figure 4. Washington State Department of Transportation Olympic Region: mines by type and production level in relation to highway system

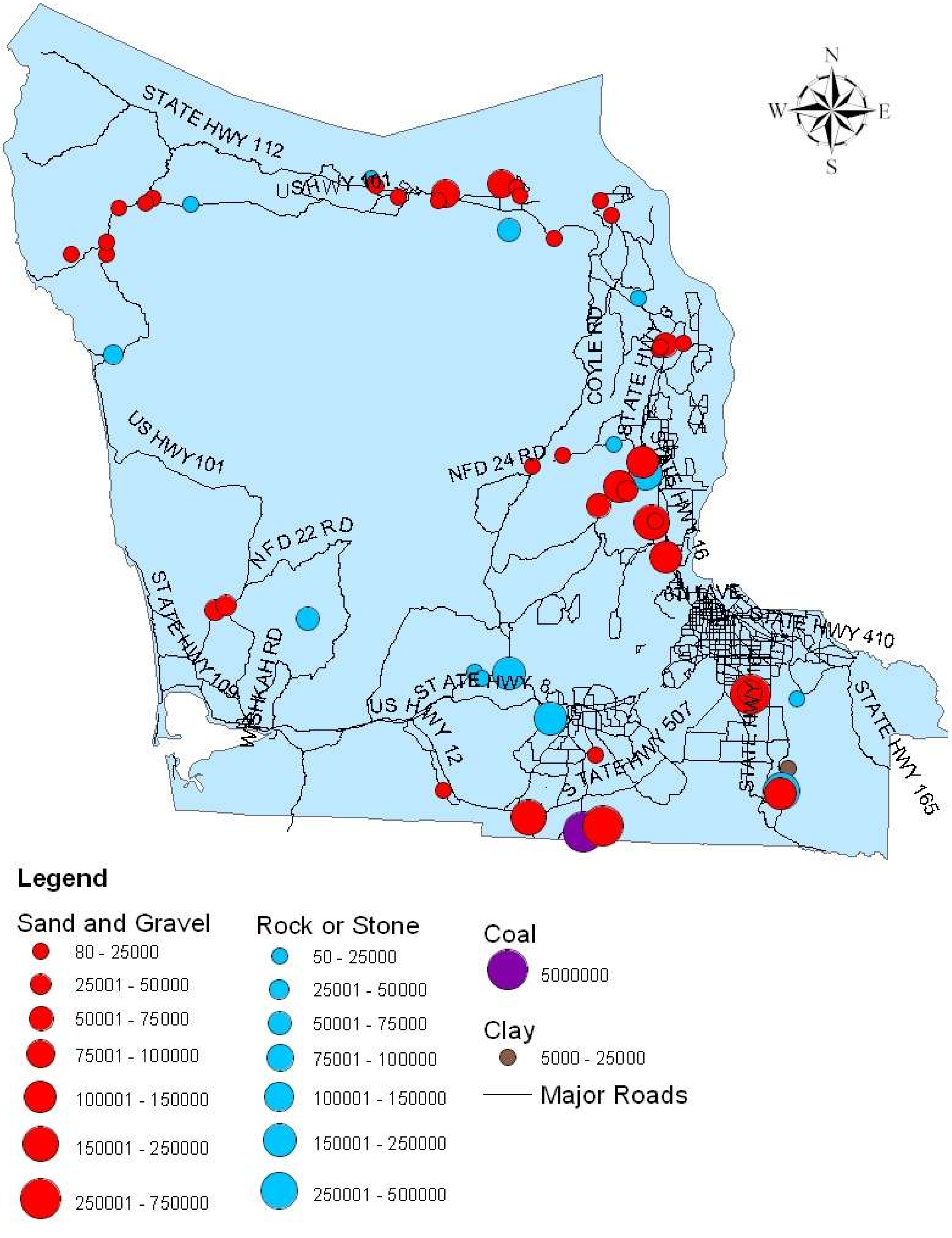


Figure 5. Washington State Department of Transportation Southwest Region: mines by type and production level in relation to highway system

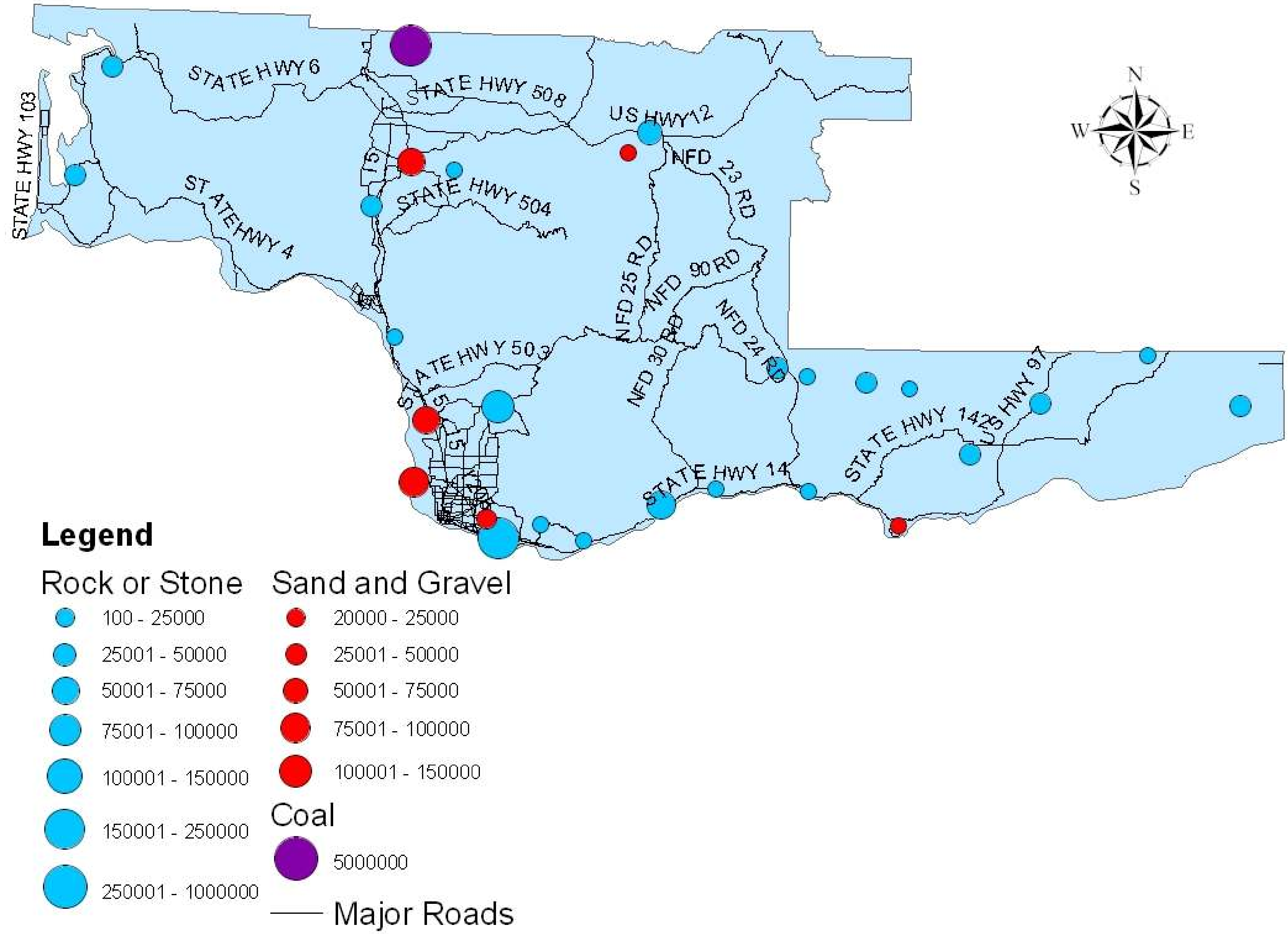
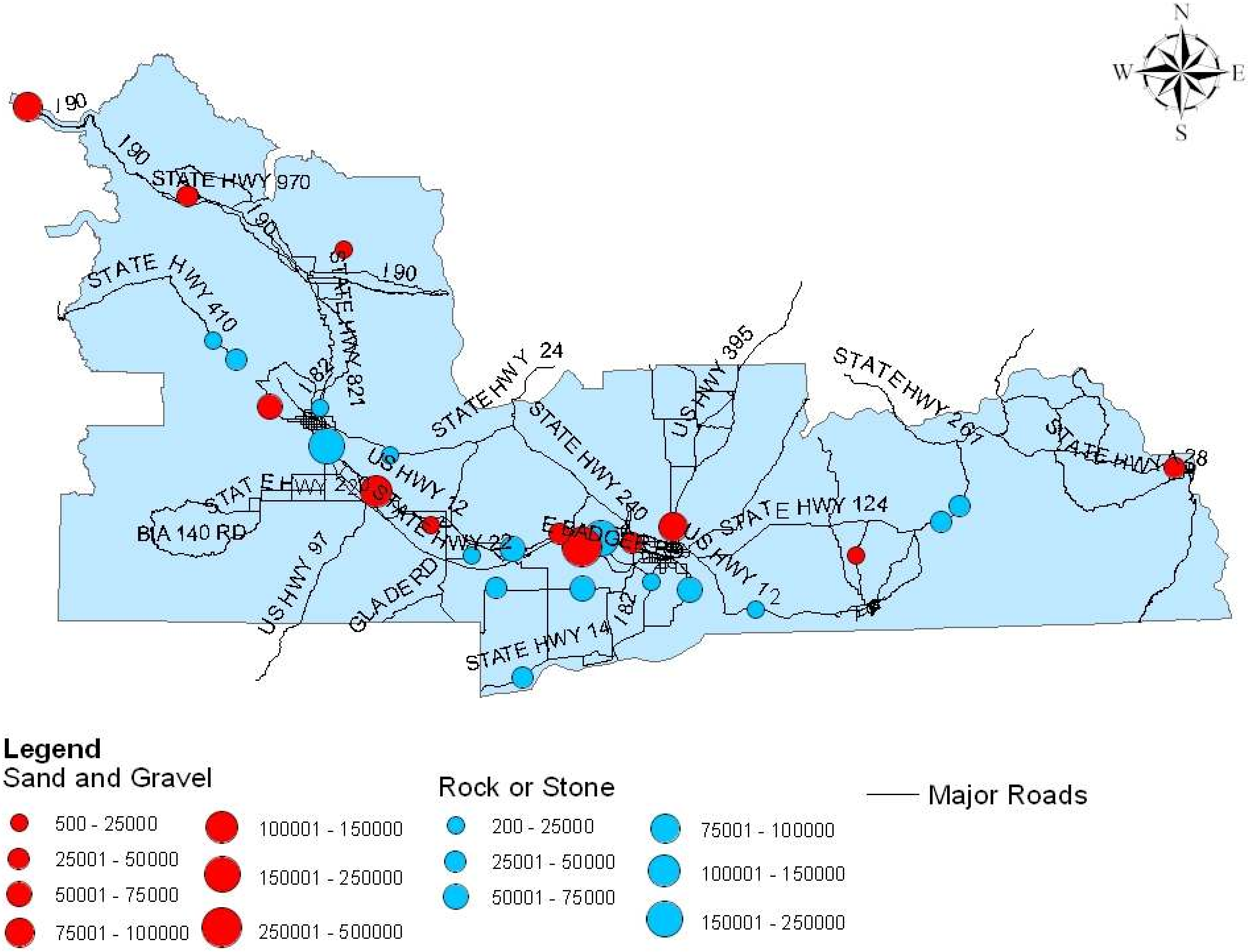


Figure 6. Washington State Department of Transportation South Central Region: mines by type and production level in relation to highway system



Appendix C

Operational Mines' Locations and Data (by County)

Data Sources:

- Transportation of Mining/Mineral Survey
- Geographic site information for all figures was obtained from Washington Department of Natural Resources, Division of Geology and Earth Resources.
- County and highway system GIS files were provided by the WSDOT GeoData Distribution Catalog.

Figure 1. Adams County mines by type and production level in relation to highway system

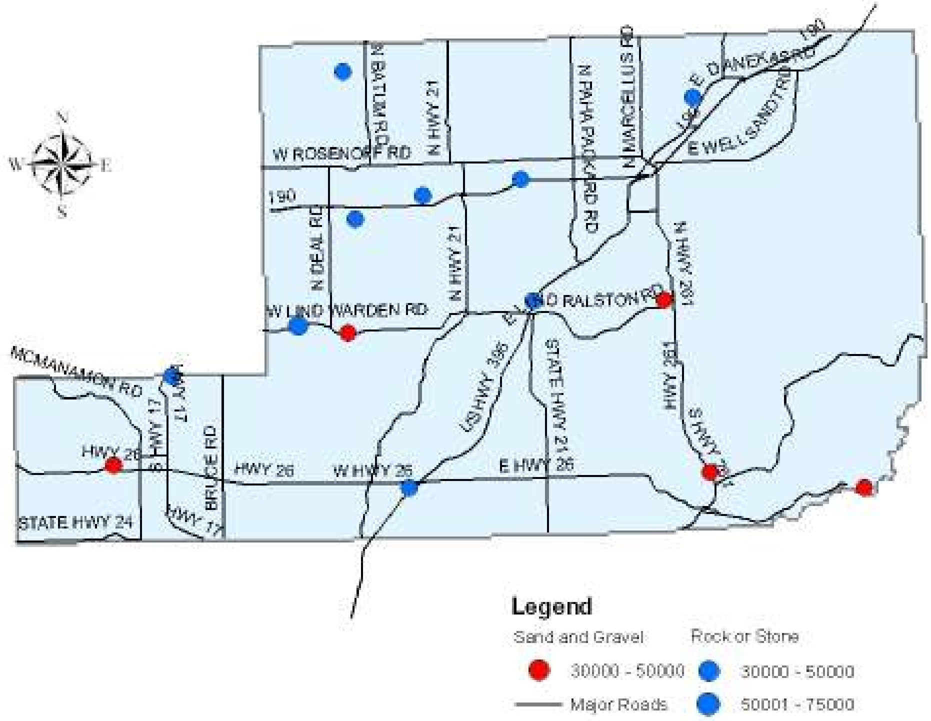


Figure 2. Frequency of roads used for aggregates hauling in Adams County

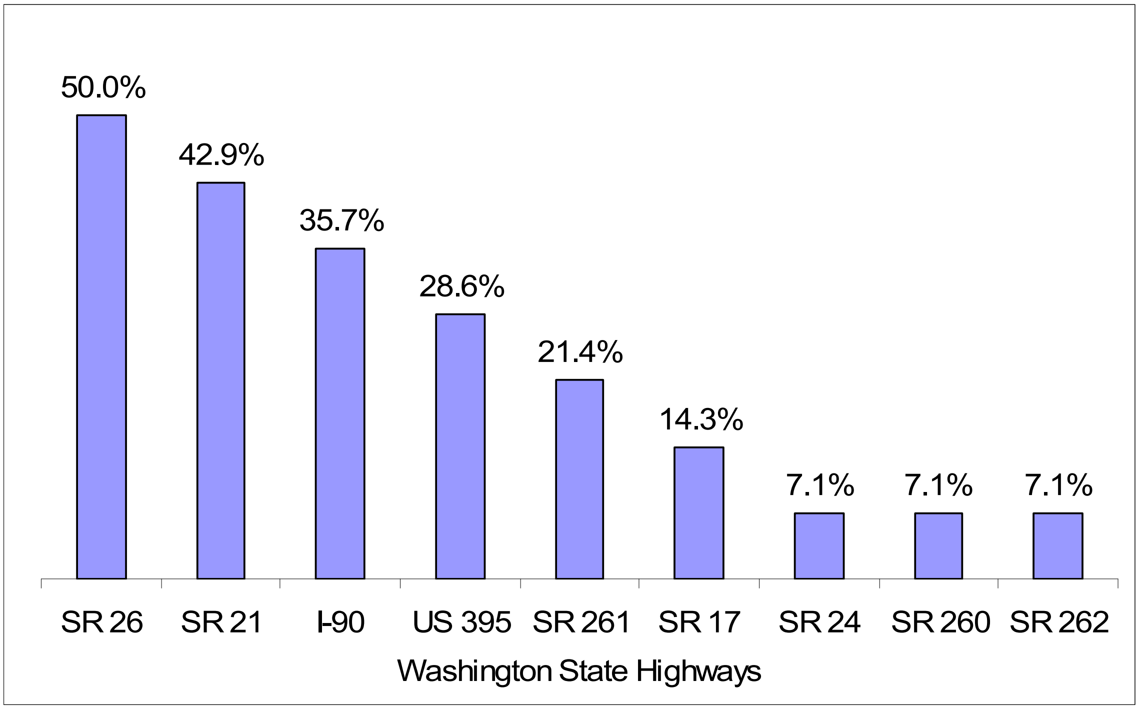


Figure 3. Asotin County mines by type and production level in relation to highway system

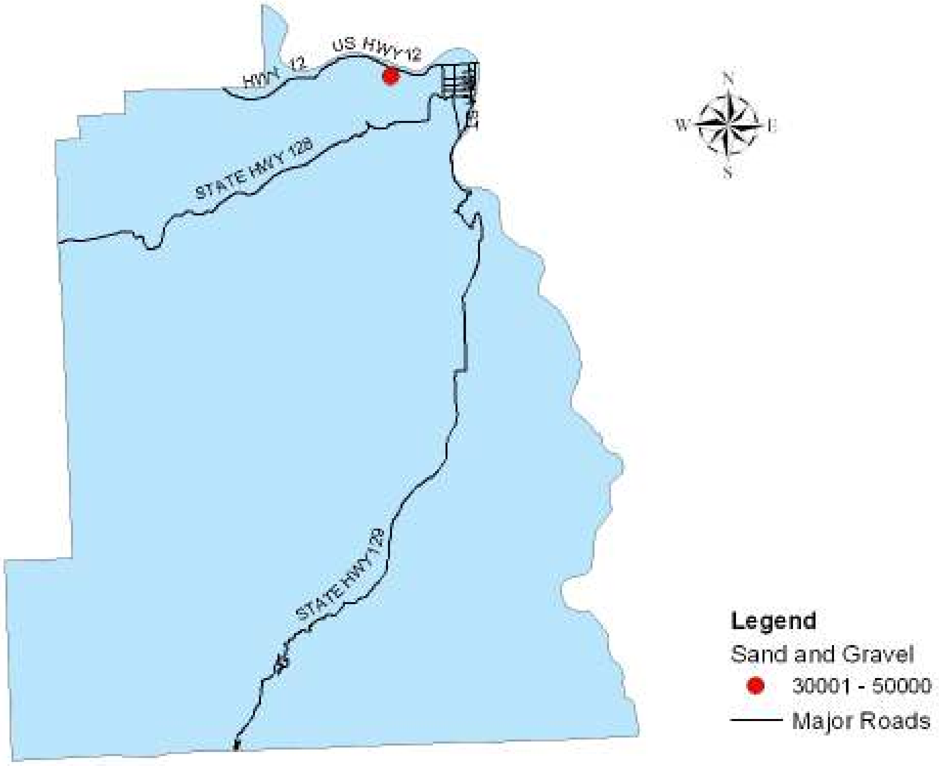


Figure 4. Frequency of roads used for aggregates hauling in Asotin County

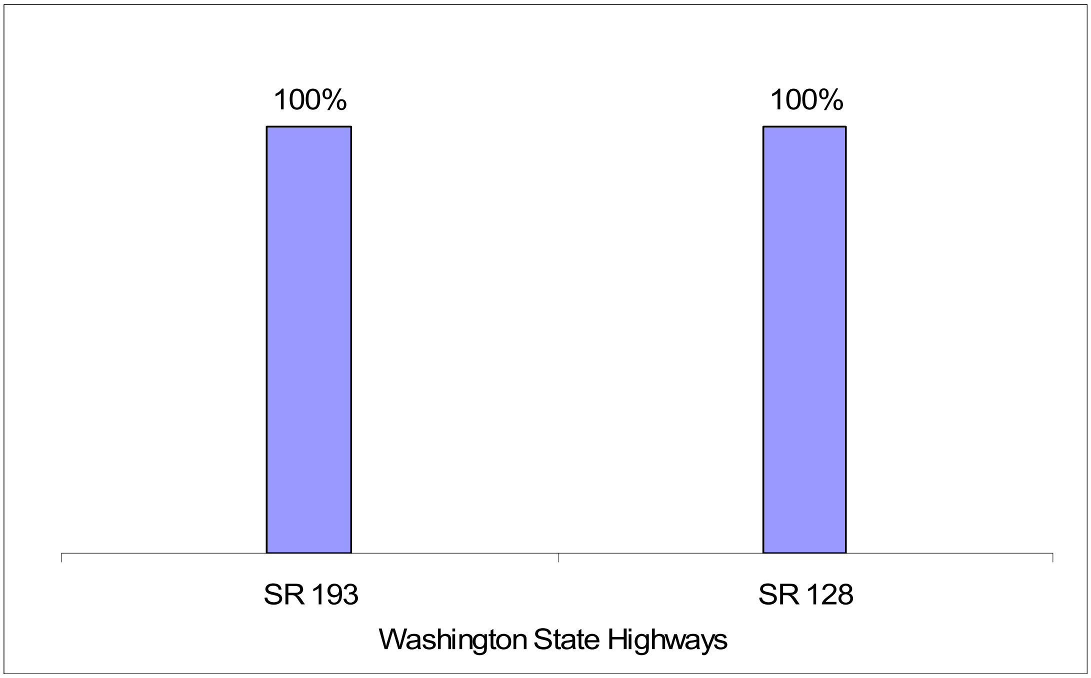


Figure 5. Benton County mines by type and production level in relation to highway system

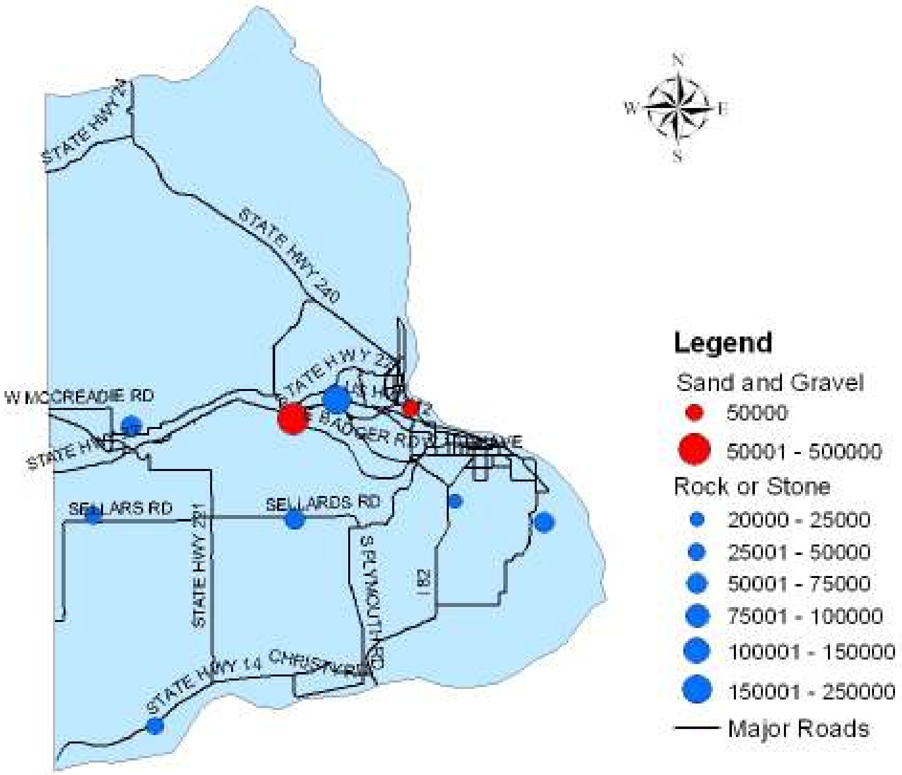


Figure 6. Frequency of roads used for aggregates hauling in Benton County

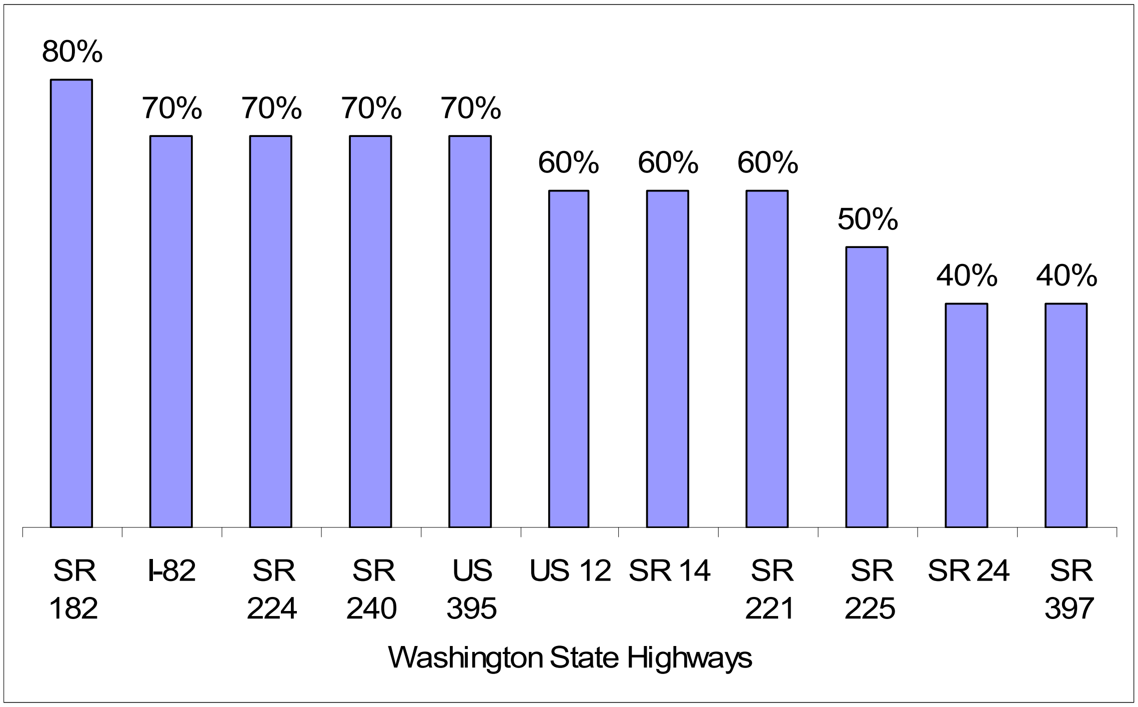


Figure 7. Chelan County mines by type and production level in relation to highway system

Figure 8. Frequency of roads used for aggregates hauling in Chelan County

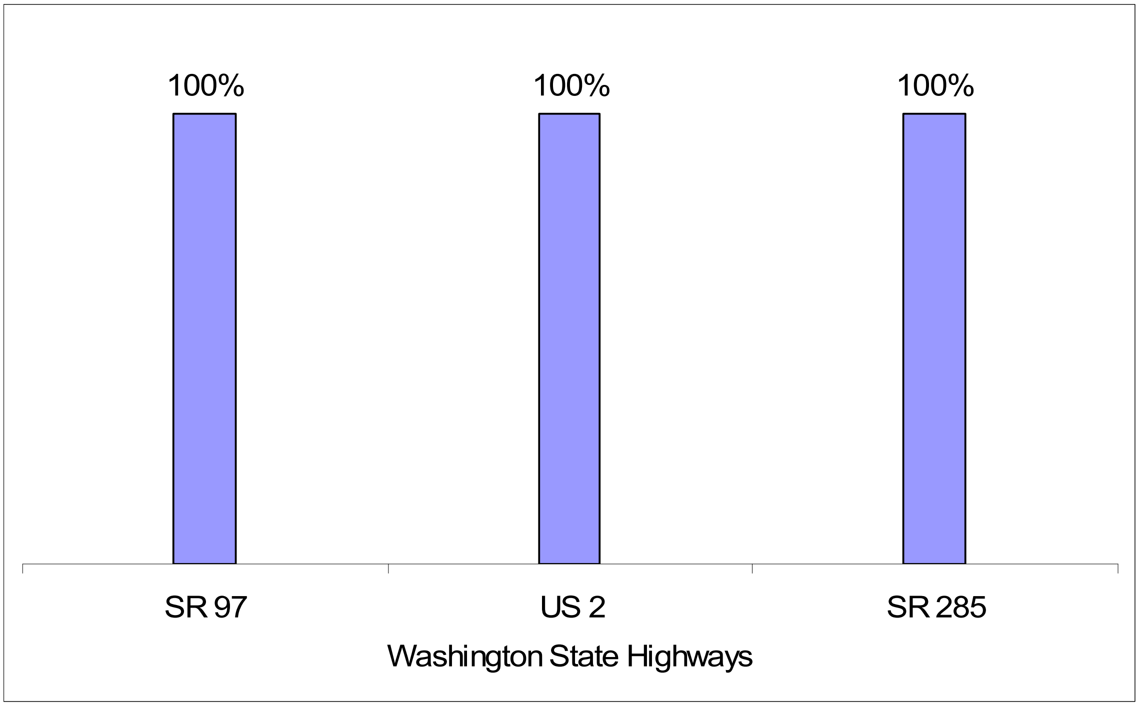


Figure 9. Clallam County mines by type and production level in relation to highway system

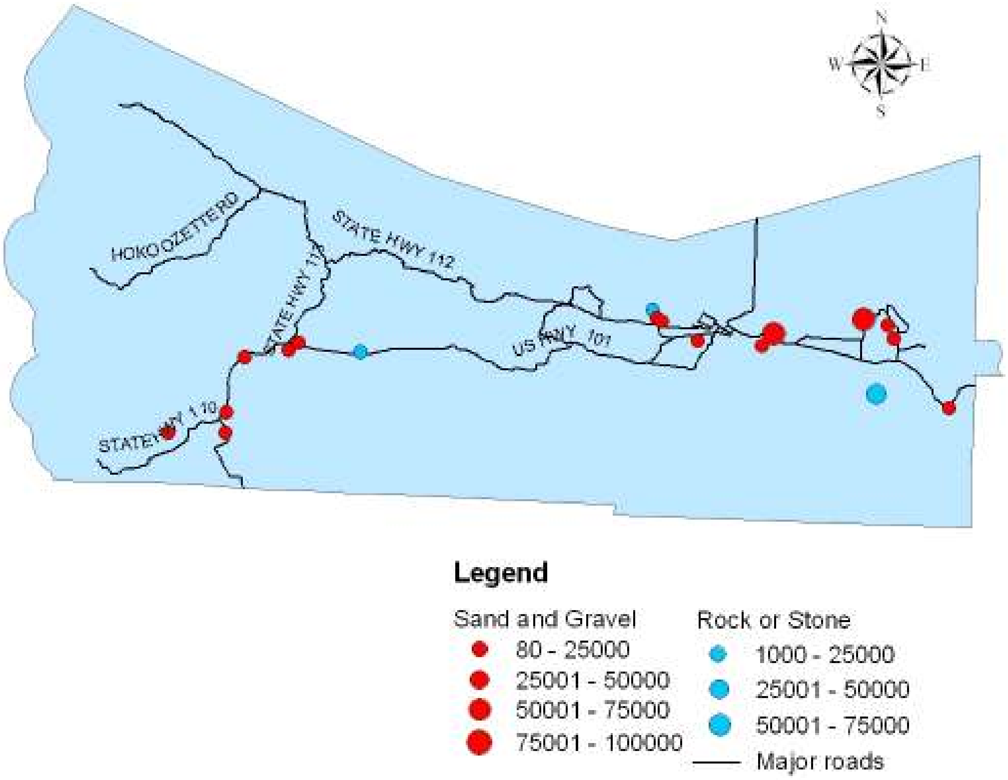


Figure 10. Frequency of roads used for aggregates hauling in Clallam County

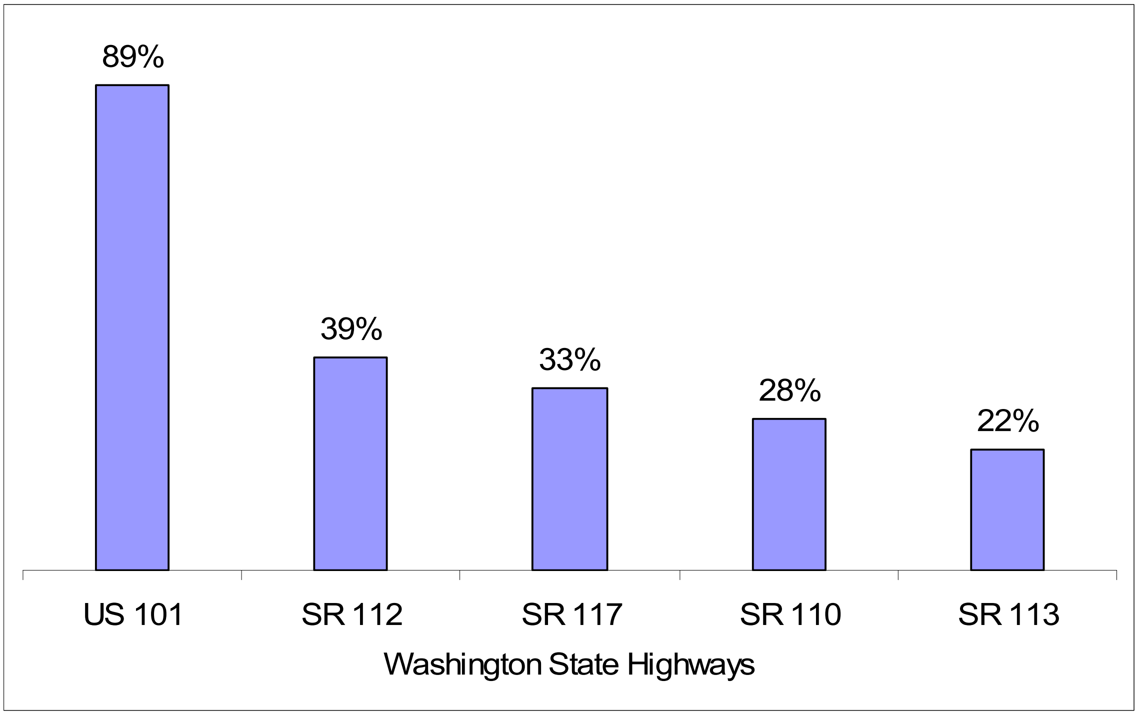


Figure 11. Clark County mines by type and production level in relation to highway system

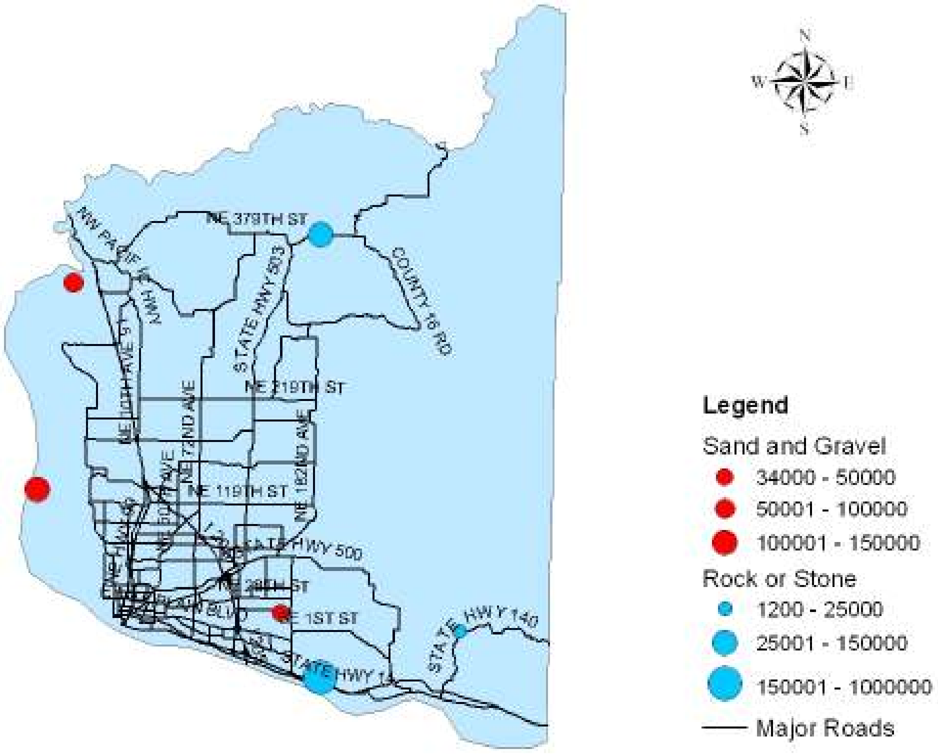


Figure 12. Frequency of roads used for aggregates hauling in Clark County

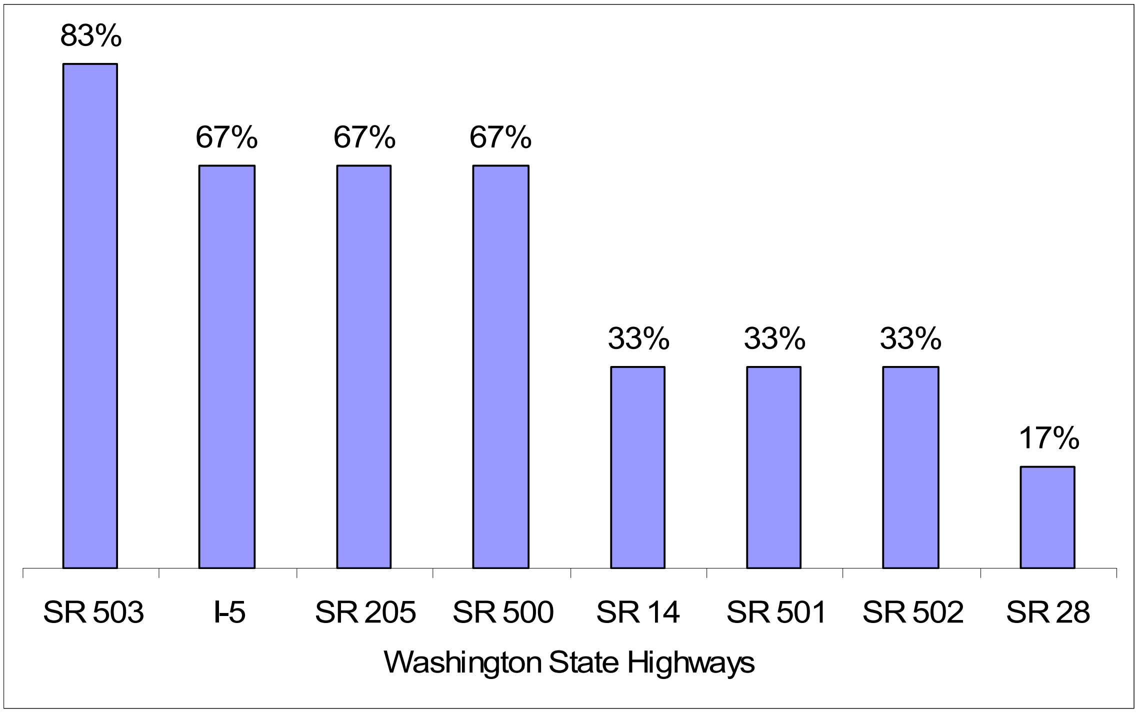


Figure 13. Columbia County mines by type and production level in relation to highway system

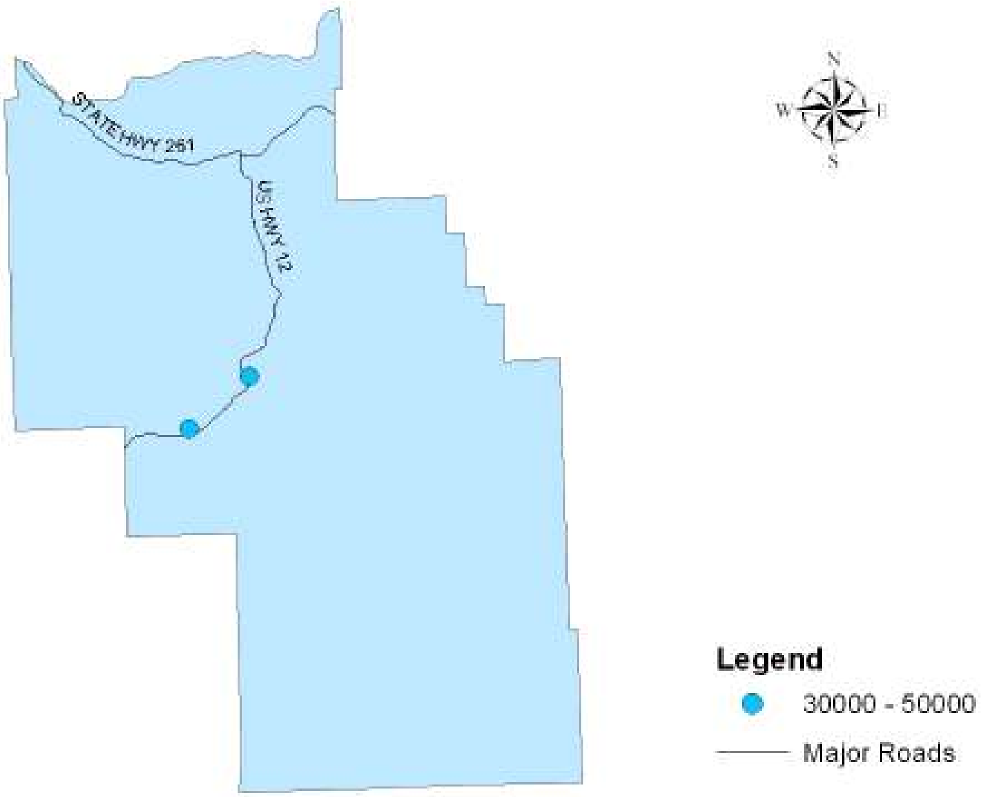


Figure 14. Cowlitz County mines by type and production level in relation to highway system

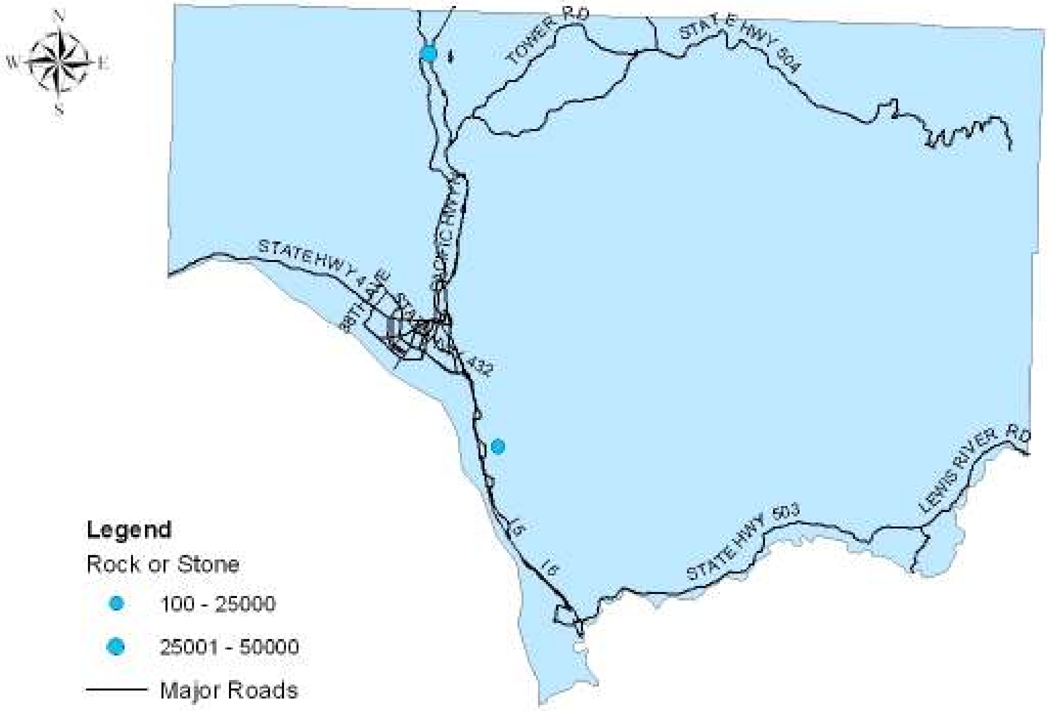


Figure 15. Frequency of roads used for aggregates hauling in Cowlitz County

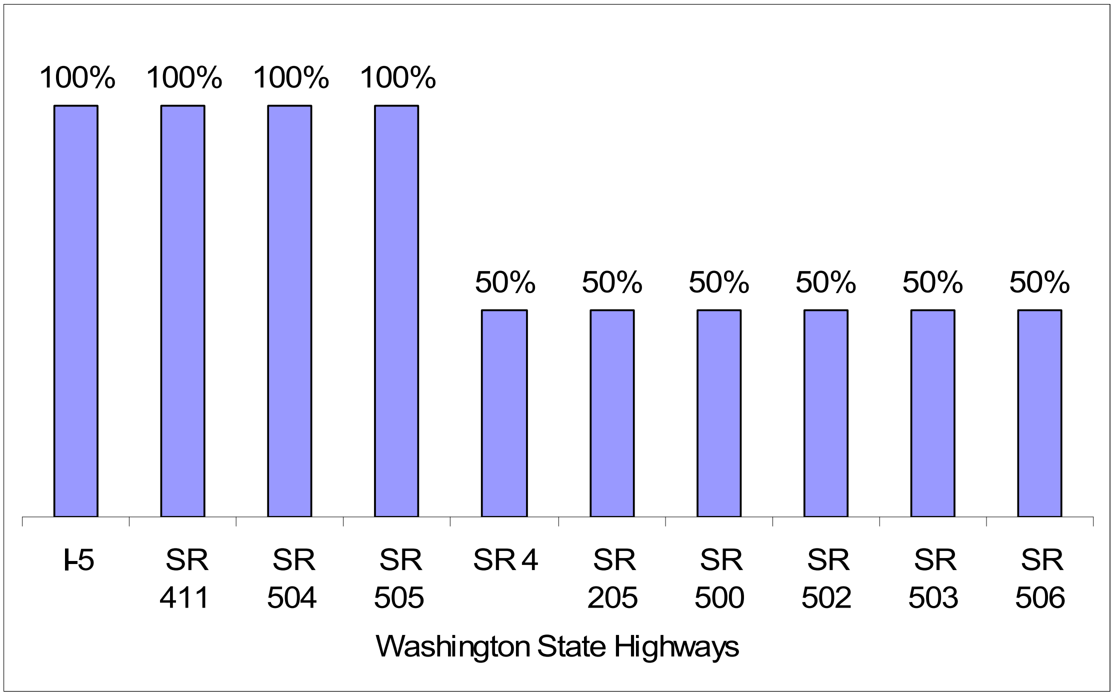


Figure 16. Douglas County mines by type and production level in relation to highway system

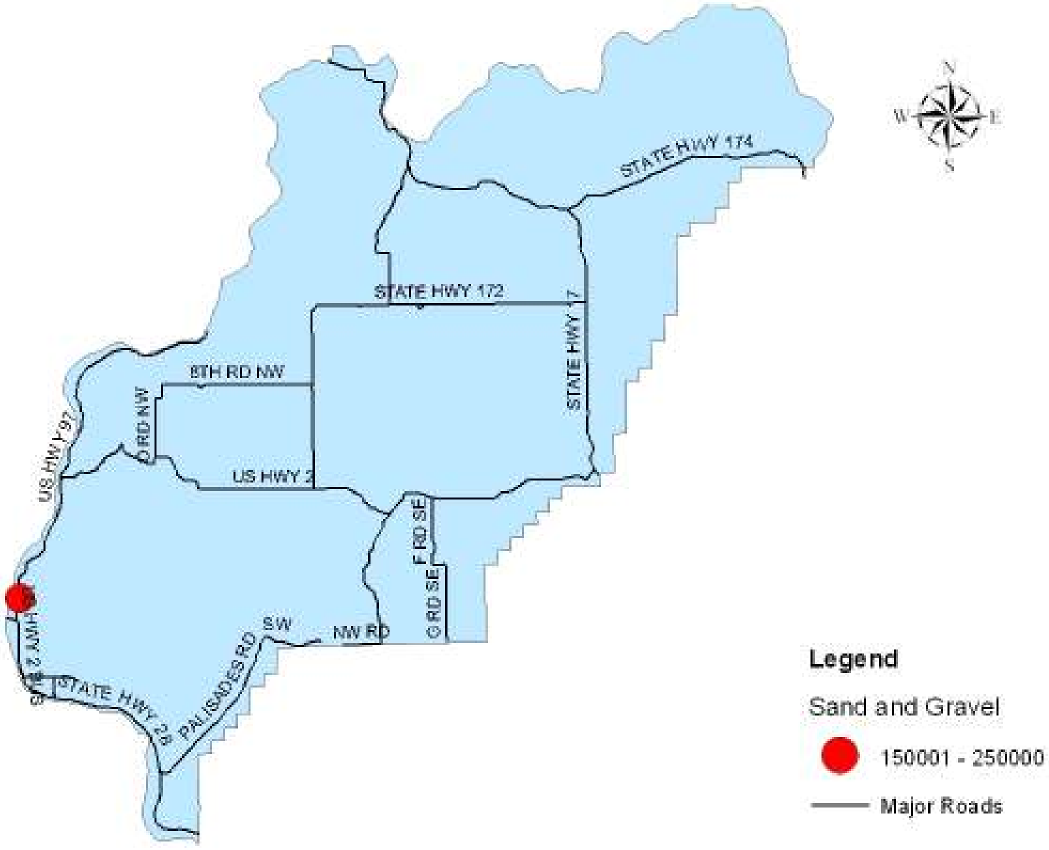


Figure 17. Frequency of roads used for aggregates hauling in Douglas County

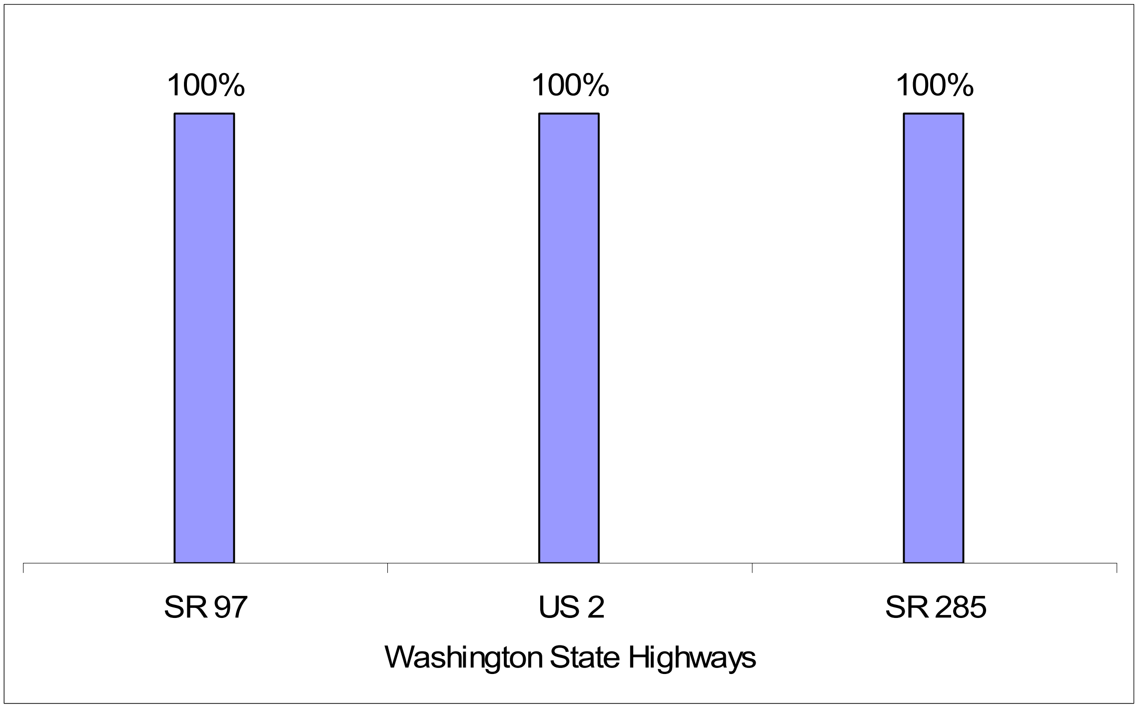


Figure 18. Ferry County mines by type and production level in relation to highway system

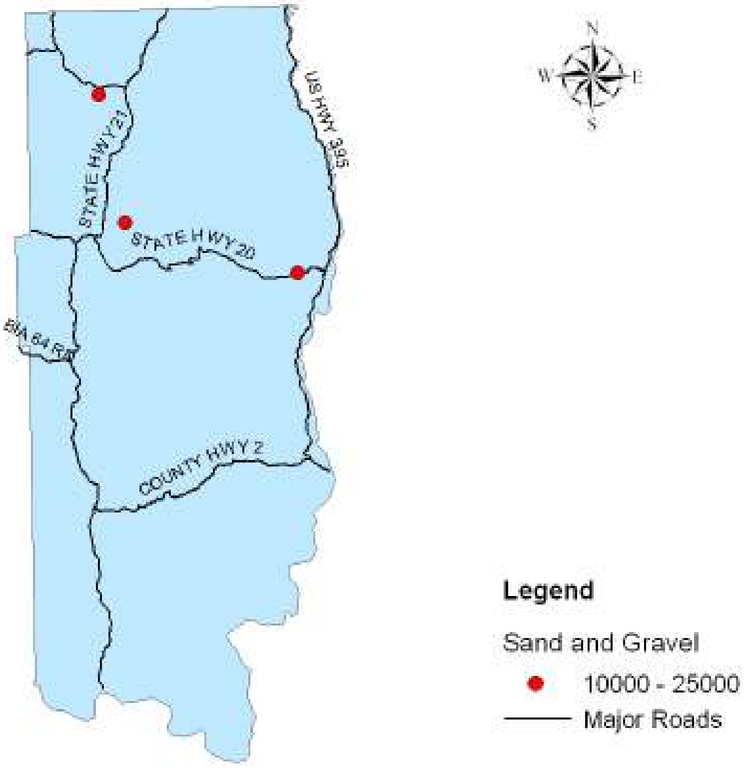


Figure 19. Frequency of roads used for aggregates hauling in Ferry County

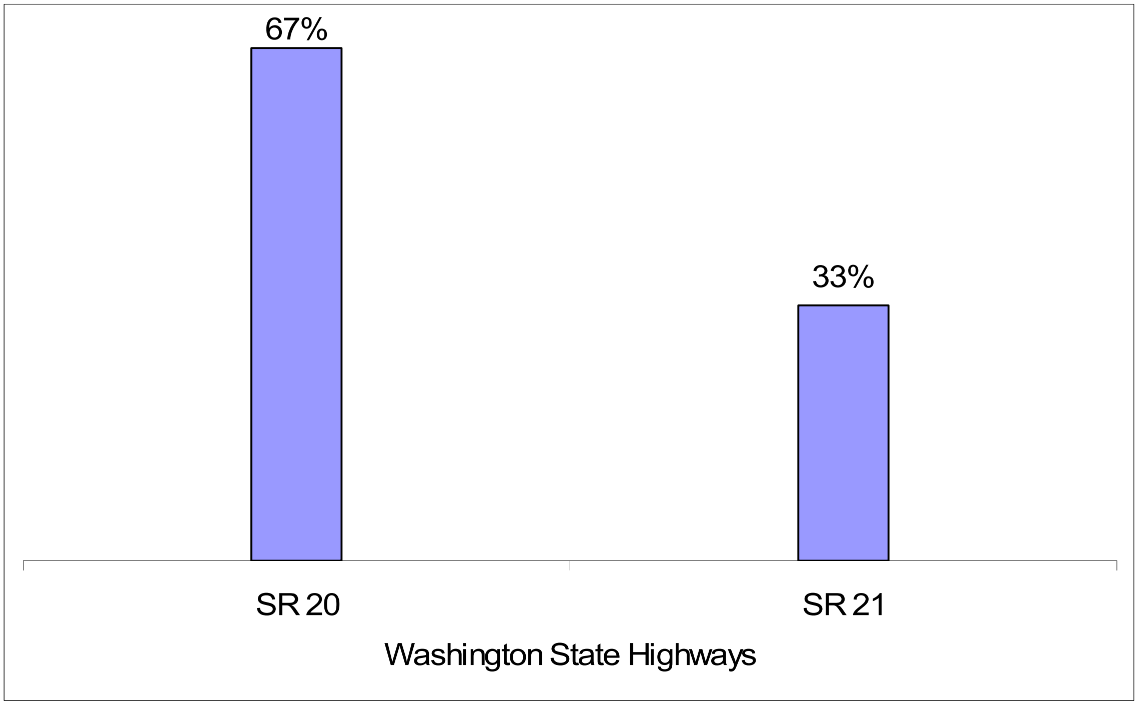


Figure 20. Franklin County mines by type and production level in relation to highway system

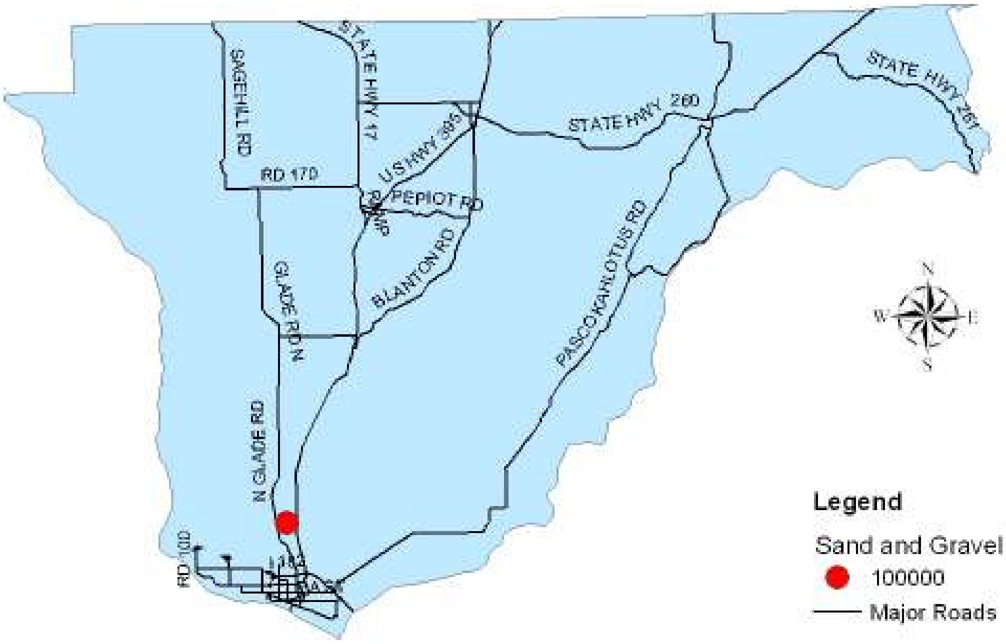


Figure 21. Frequency of roads used for aggregates hauling in Franklin County

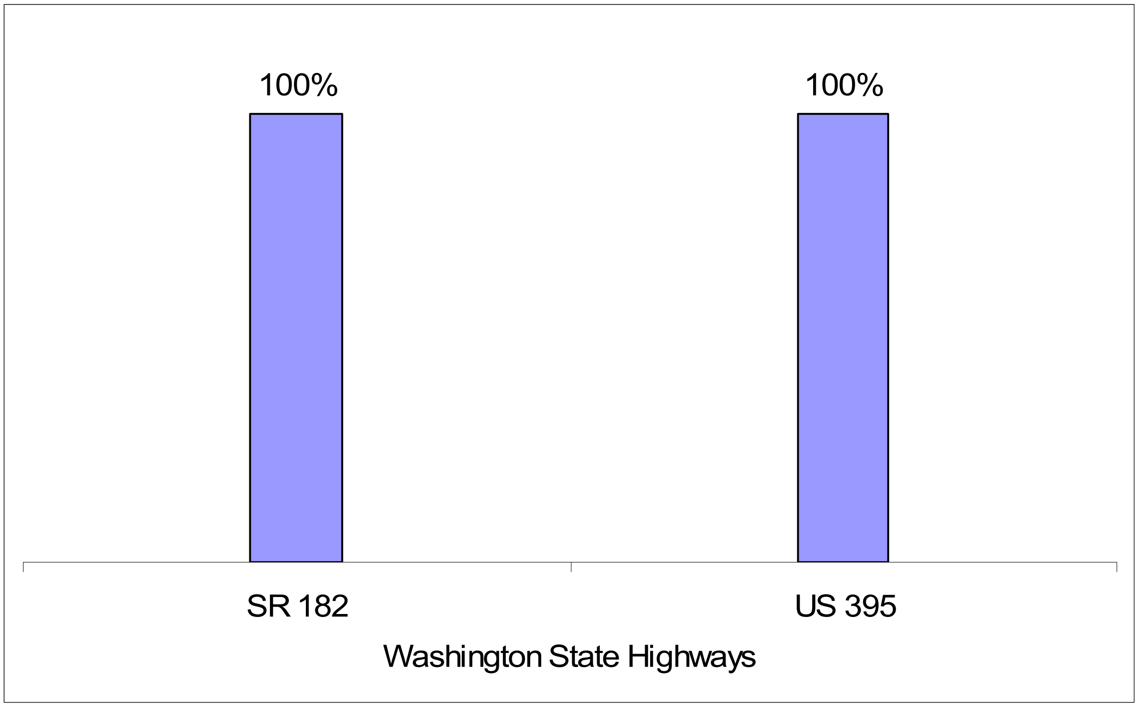


Figure 22. Grant County mines by type and production level in relation to highway system

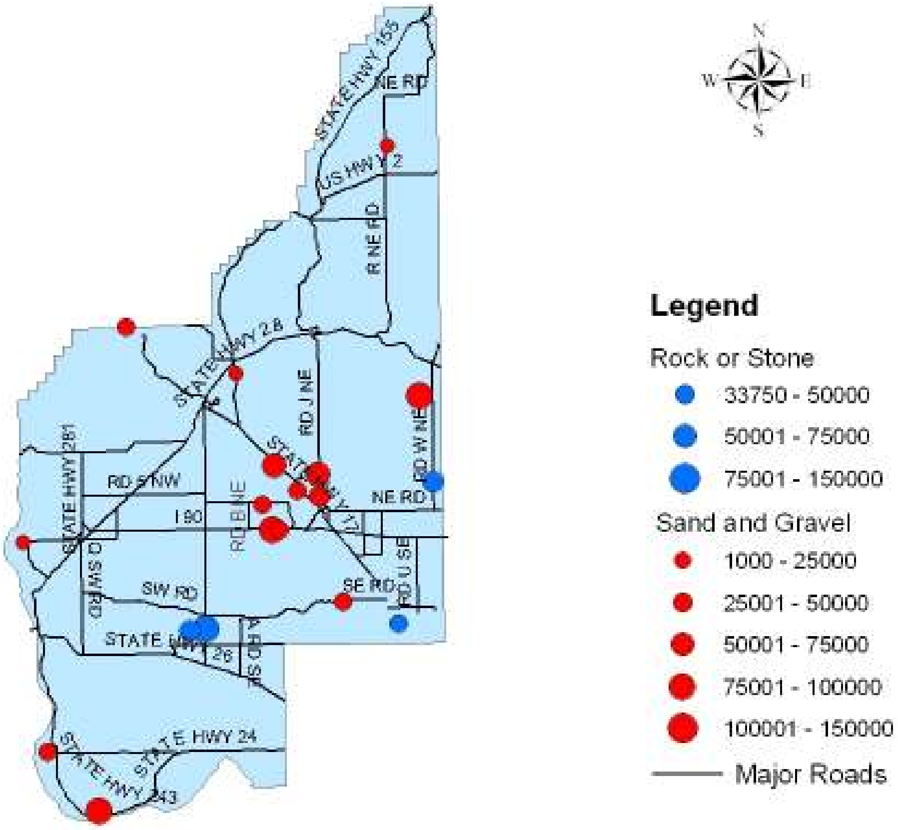


Figure 23. Frequency of roads used for aggregates hauling in Grant County

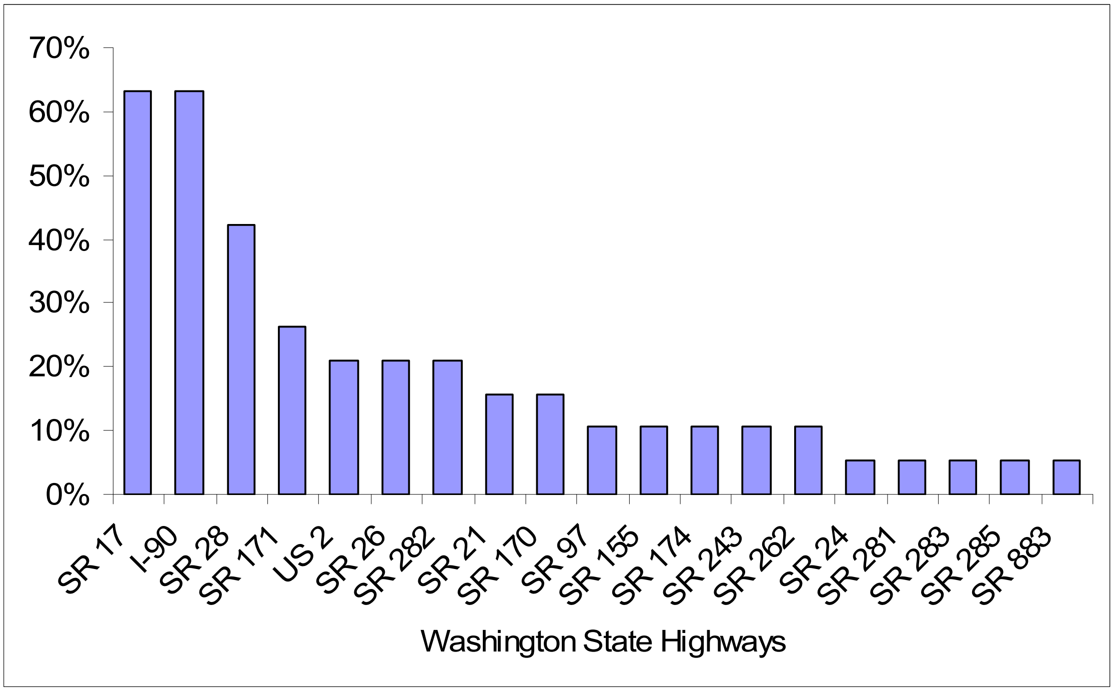


Figure 24. Grays Harbor County mines by type and production level in relation to highway system

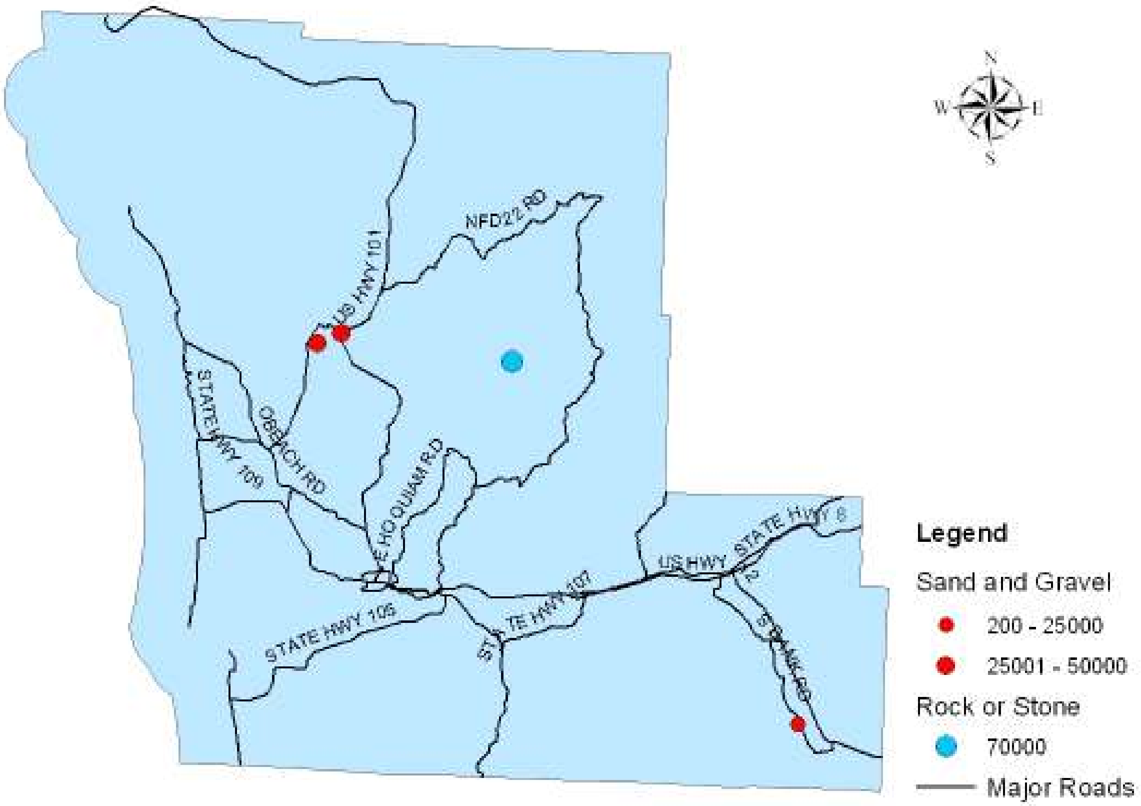


Figure 25. Frequency of roads used for aggregates hauling in Grays Harbor County

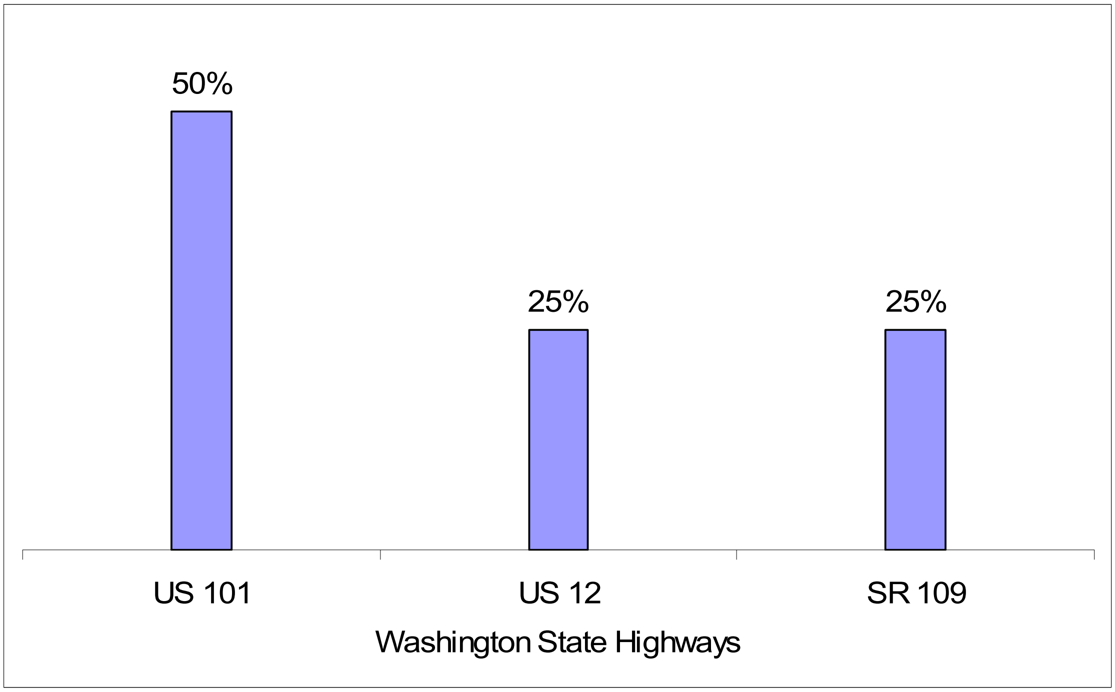


Figure 26. Island County mines by type and production level in relation to highway system

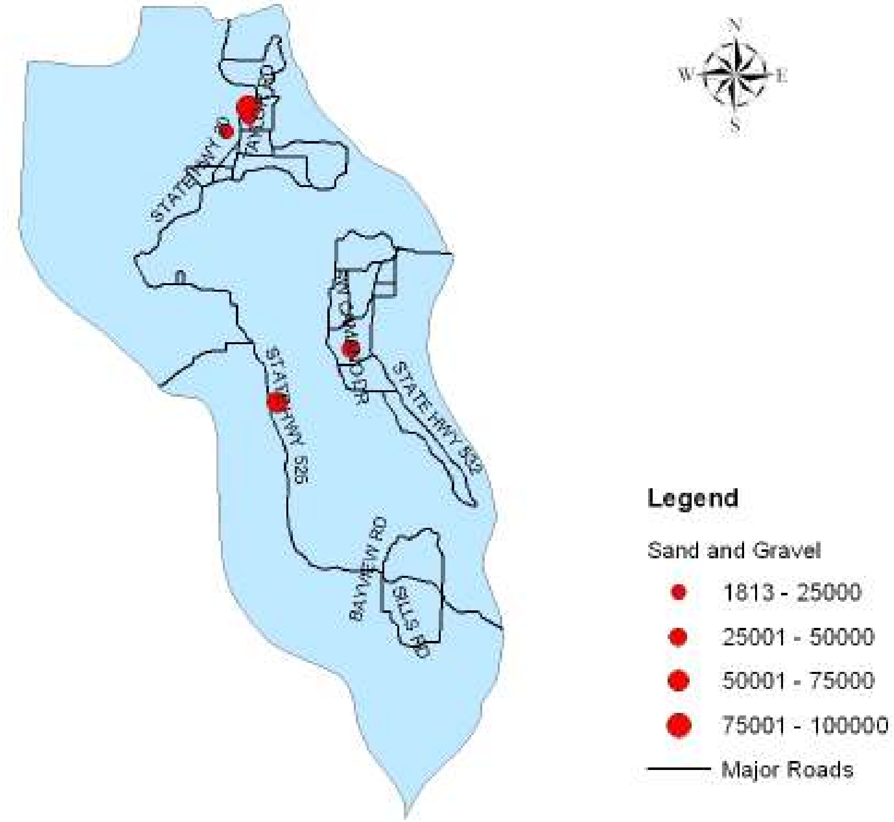


Figure 27. Frequency of roads used for aggregates hauling in Island County

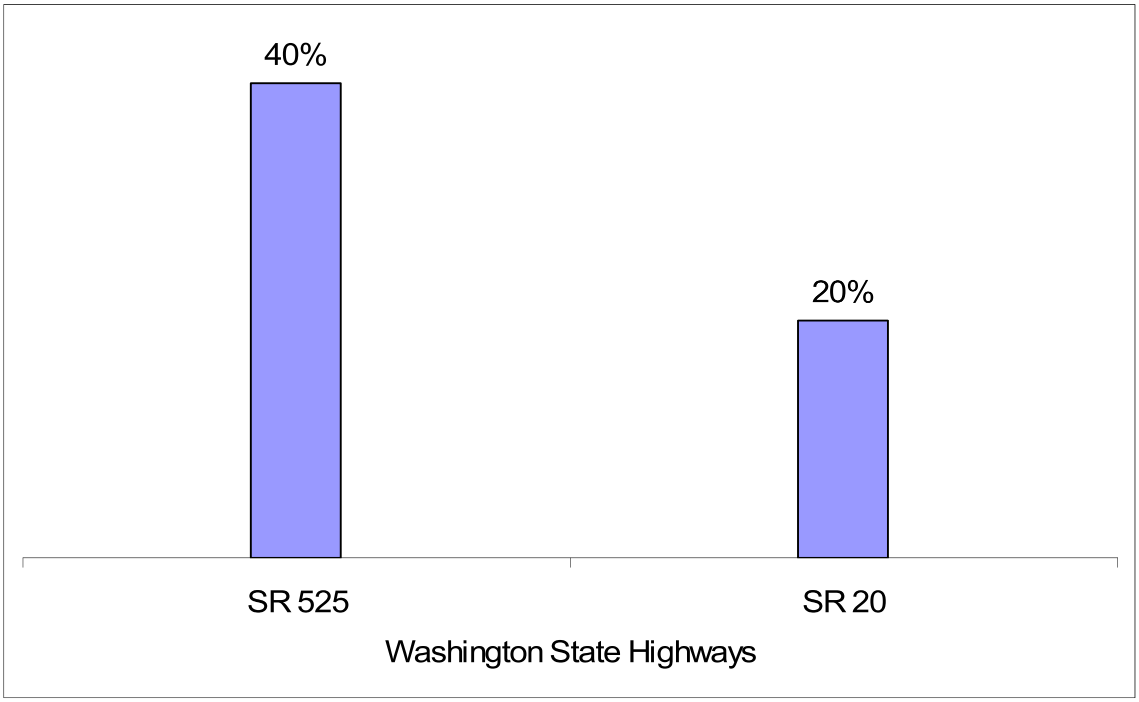


Figure 28. Jefferson County mines by type and production level in relation to highway system

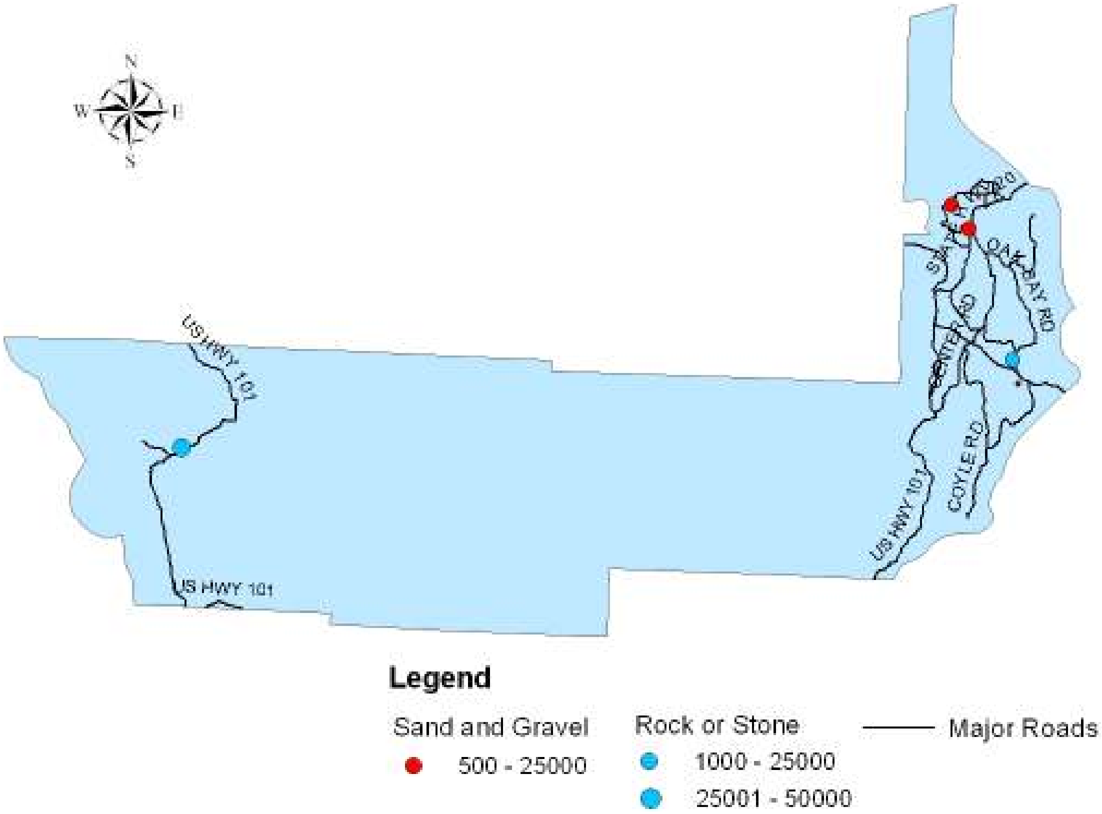


Figure 29. Frequency of roads used for aggregates hauling in Jefferson County

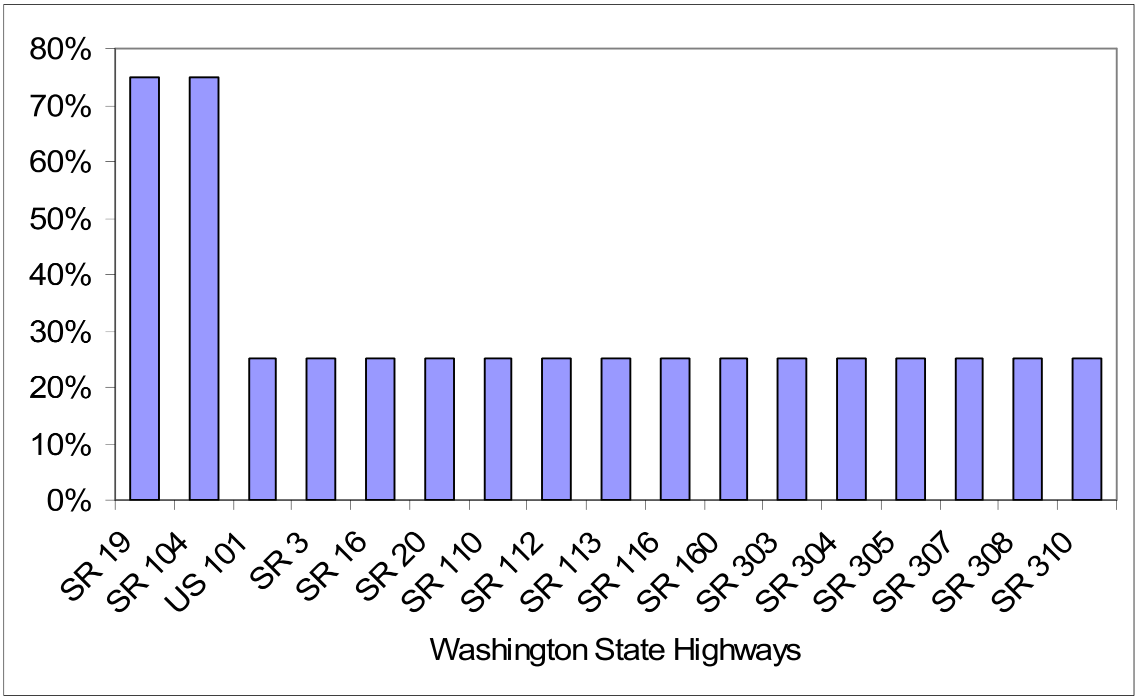


Figure 30. King County mines by type and production level in relation to highway system

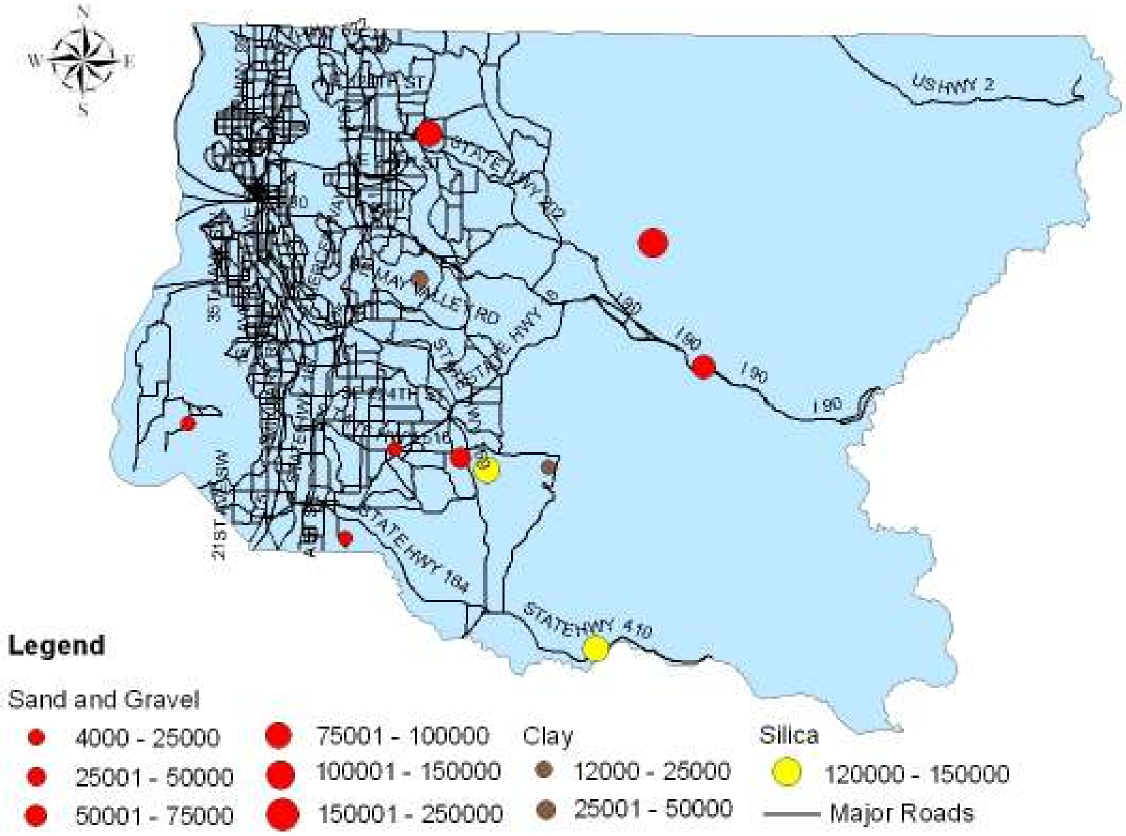


Figure 31. Frequency of roads used for aggregates hauling in King County

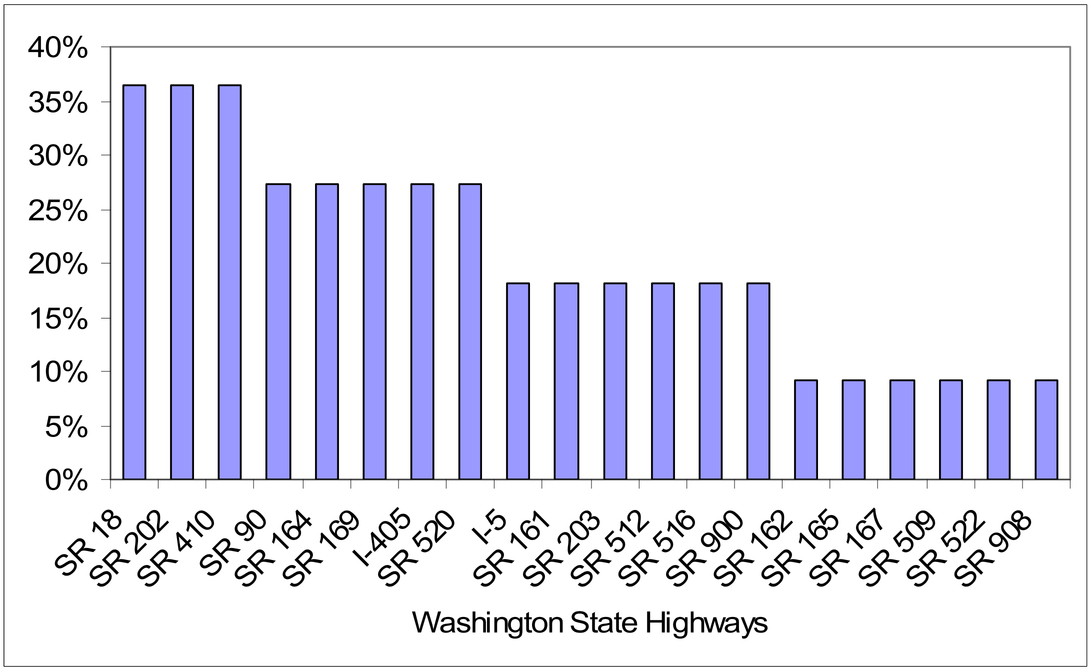


Figure 32. Kitsap County mines by type and production level in relation to highway system

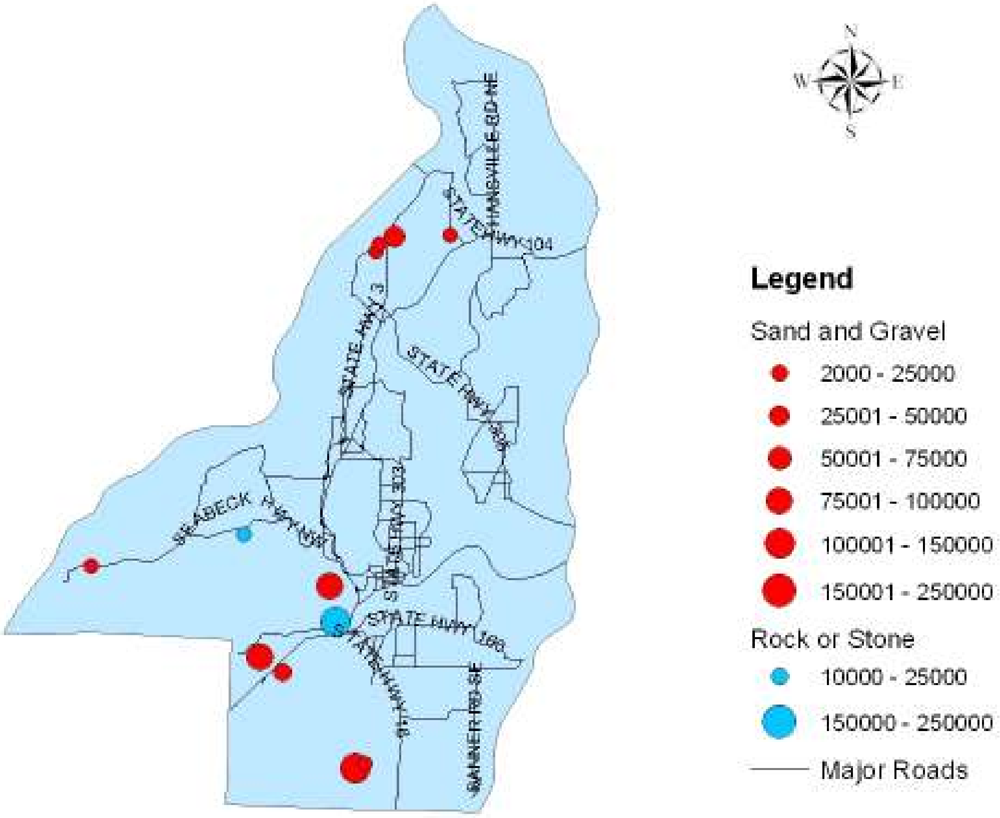


Figure 33. Frequency of roads used for aggregates hauling Kitsap County

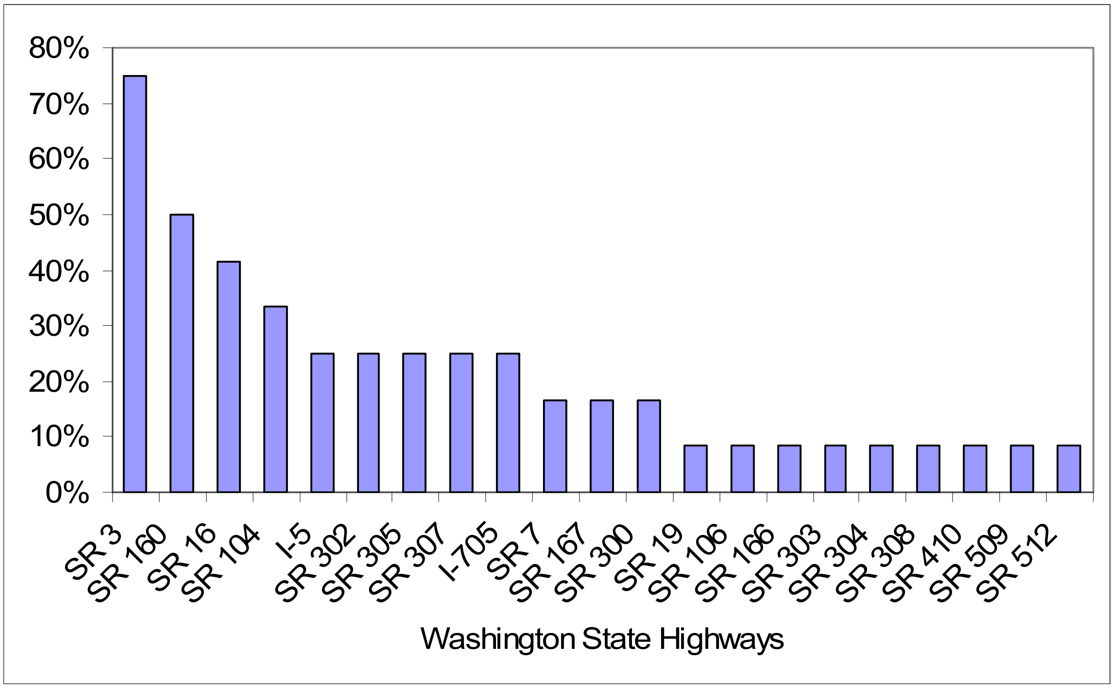


Figure 34. Kittitas County mines by type and production level in relation to highway system

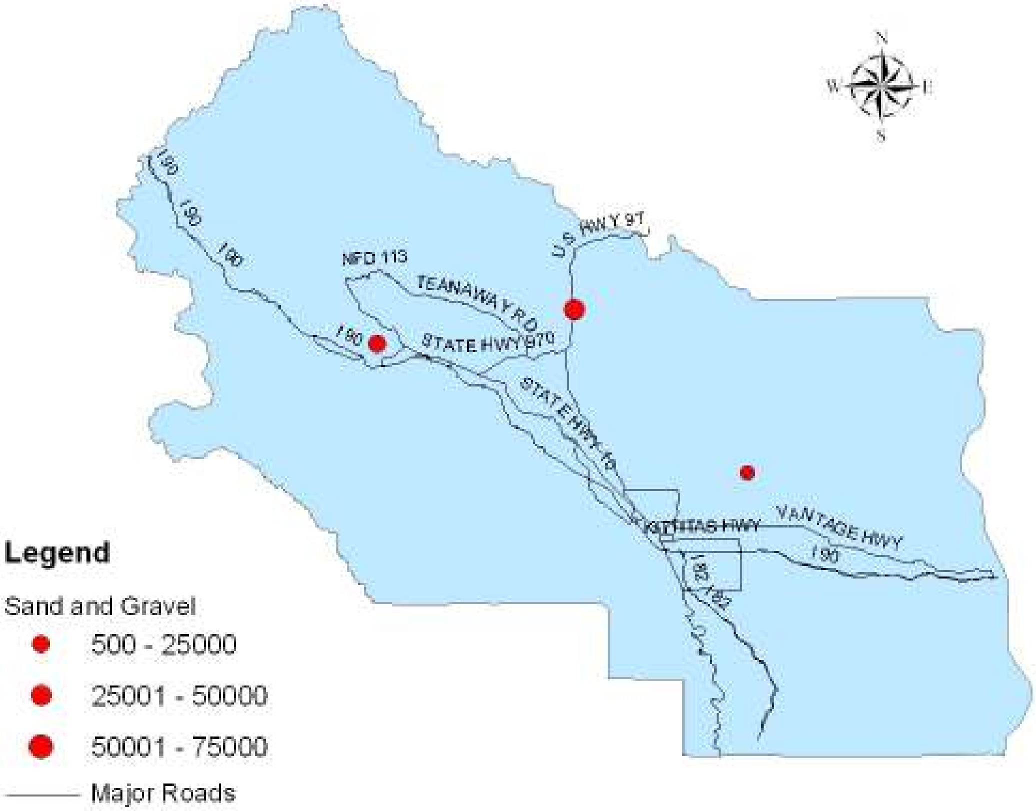


Figure 35. Frequency of roads used for aggregates hauling in Kittitas County

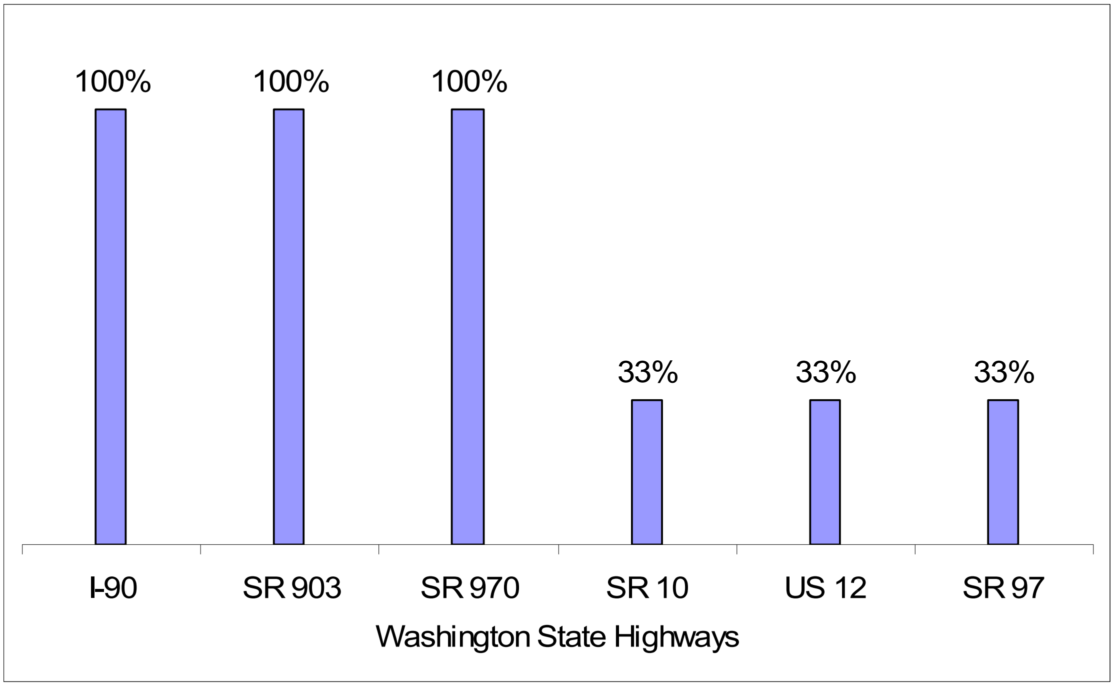


Figure 36. Klickitat County mines by type and production level in relation to highway system

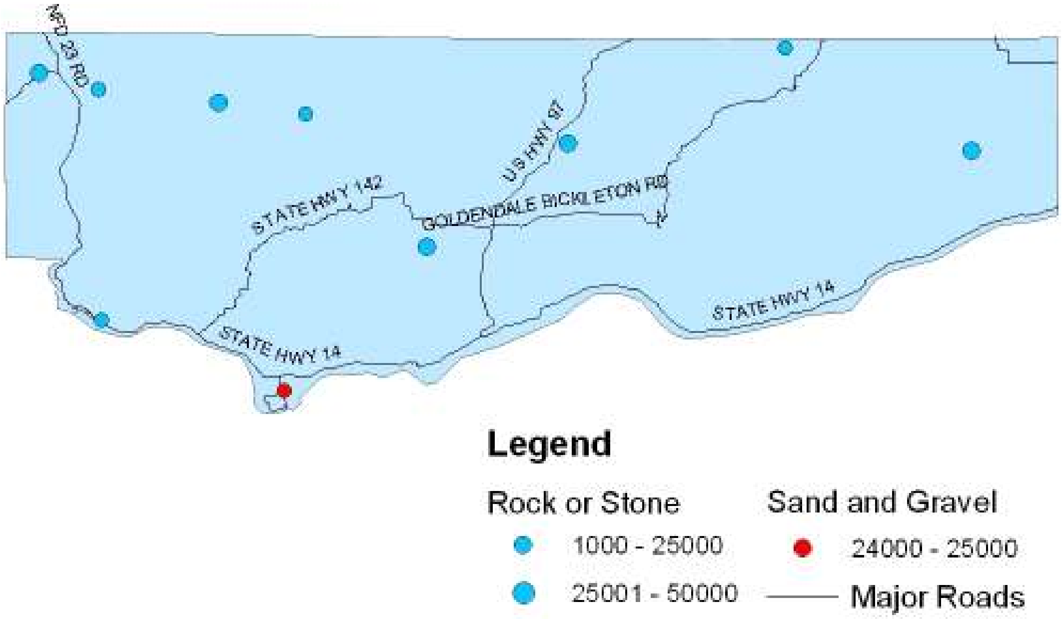



Figure 37. Frequency of roads used for aggregates hauling in Klickitat County

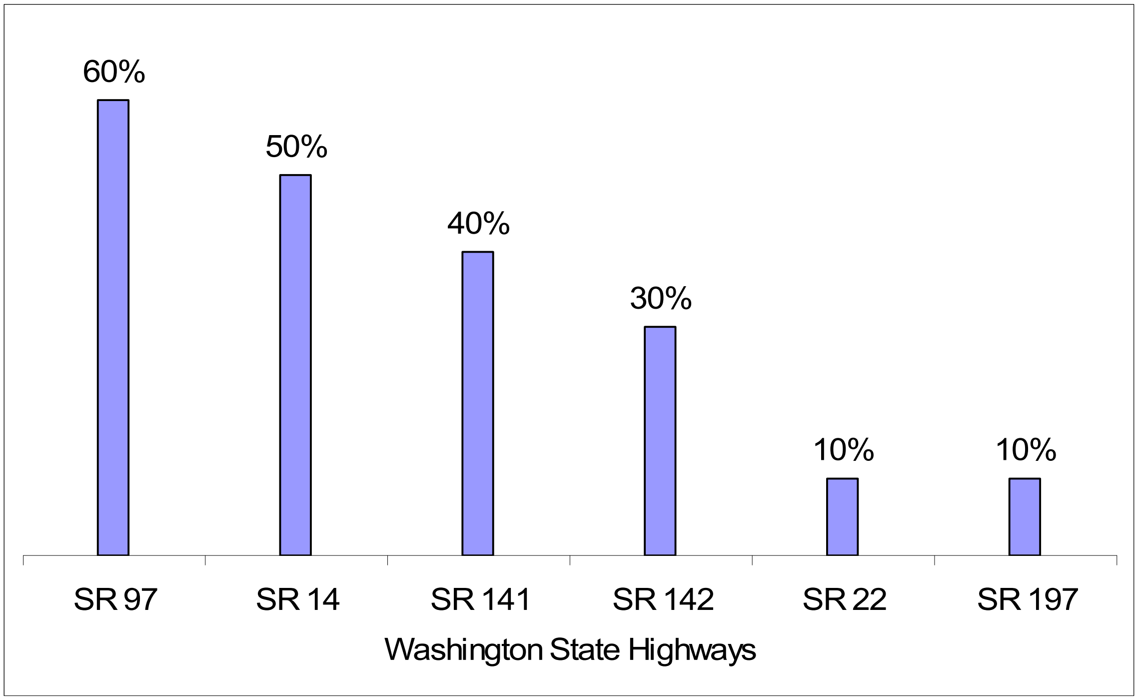


Figure 38. Lewis County mines by type and production level in relation to highway system

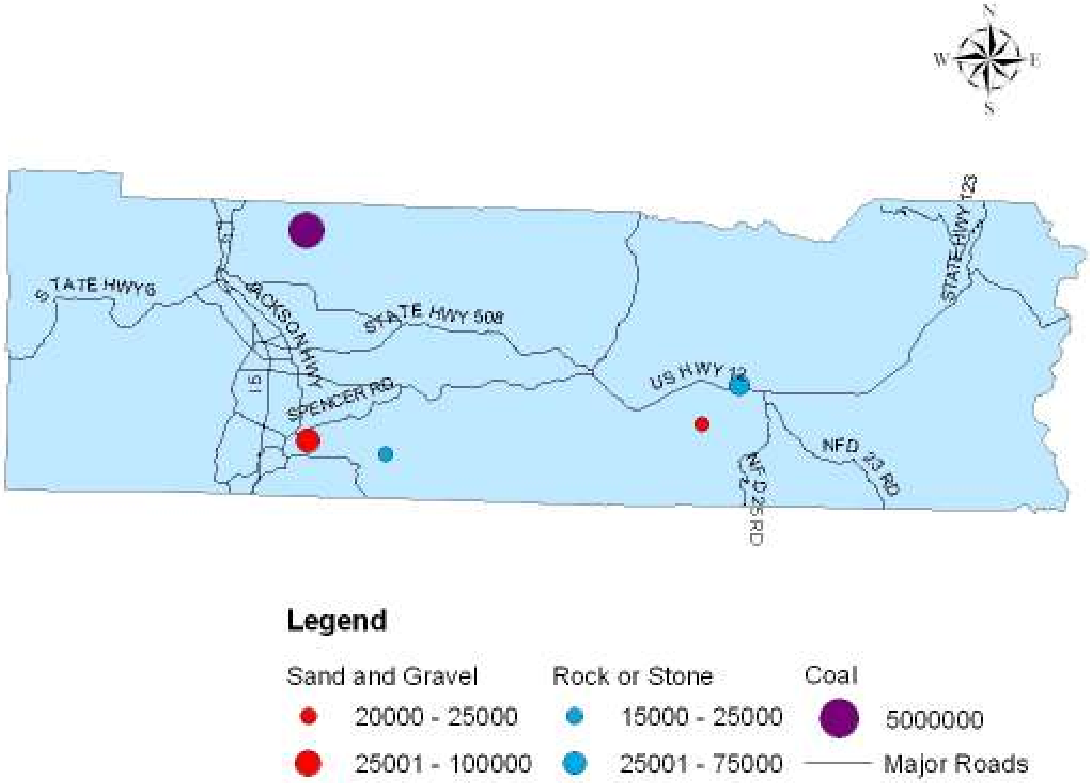


Figure 39. Frequency of roads used for aggregates hauling in Lewis County

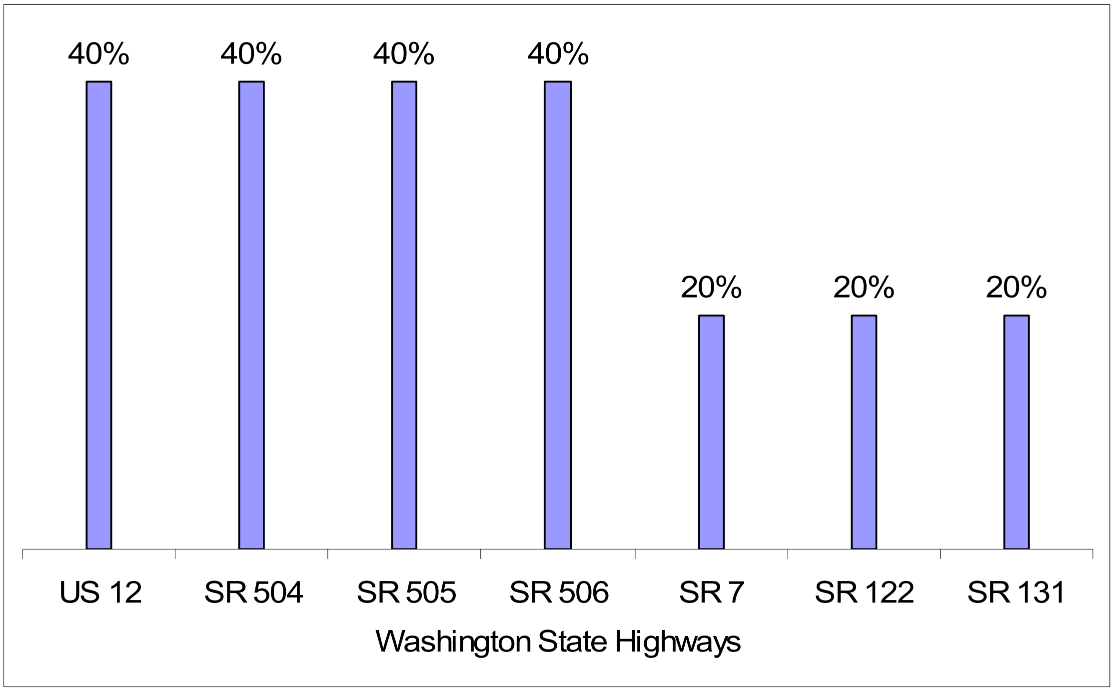


Figure 40. Lincoln County mines by type and production level in relation to highway system

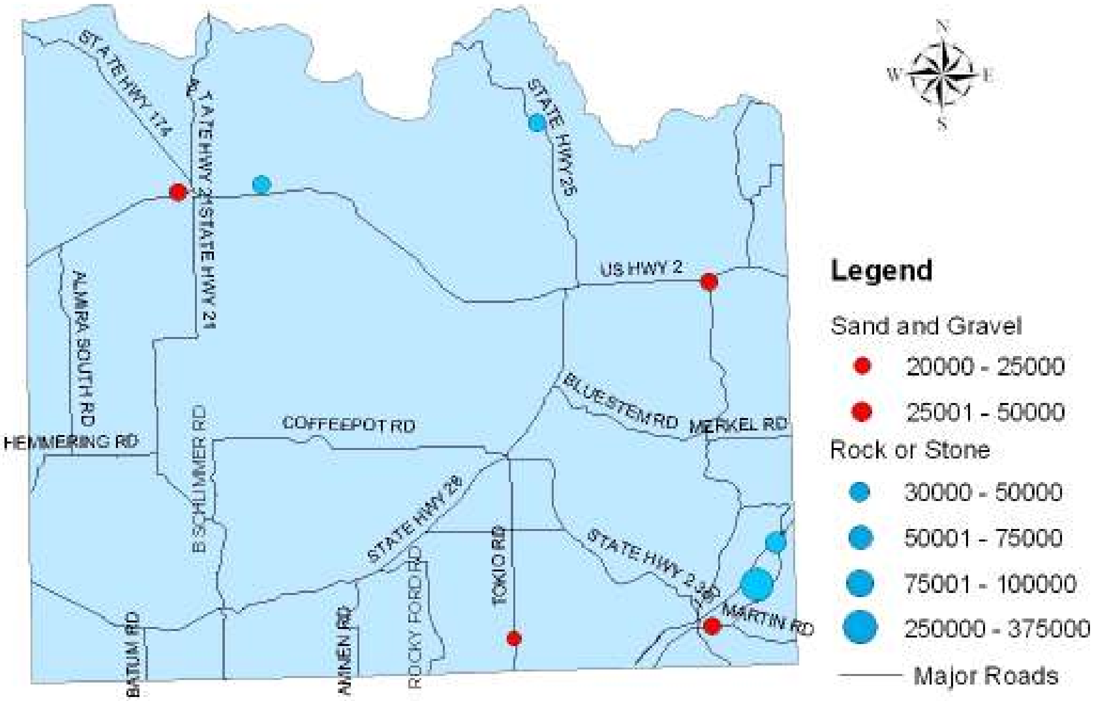


Figure 41. Frequency of roads used for aggregates hauling in Lincoln County

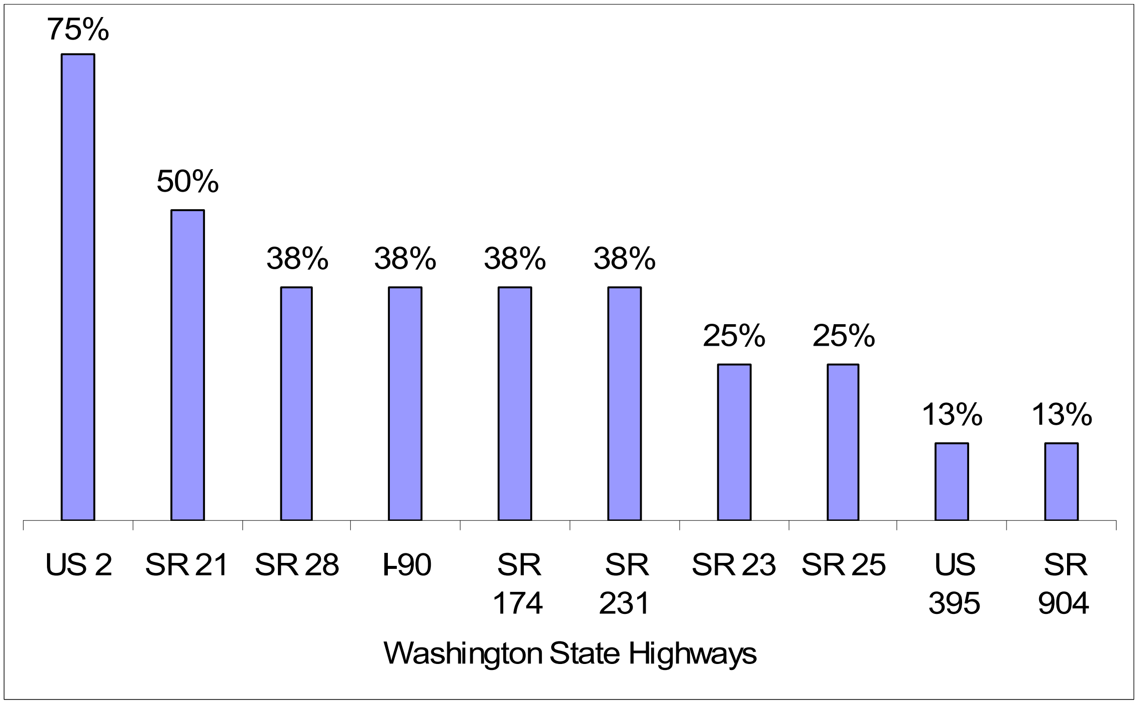


Figure 42. Mason County mines by type and production level in relation to highway system

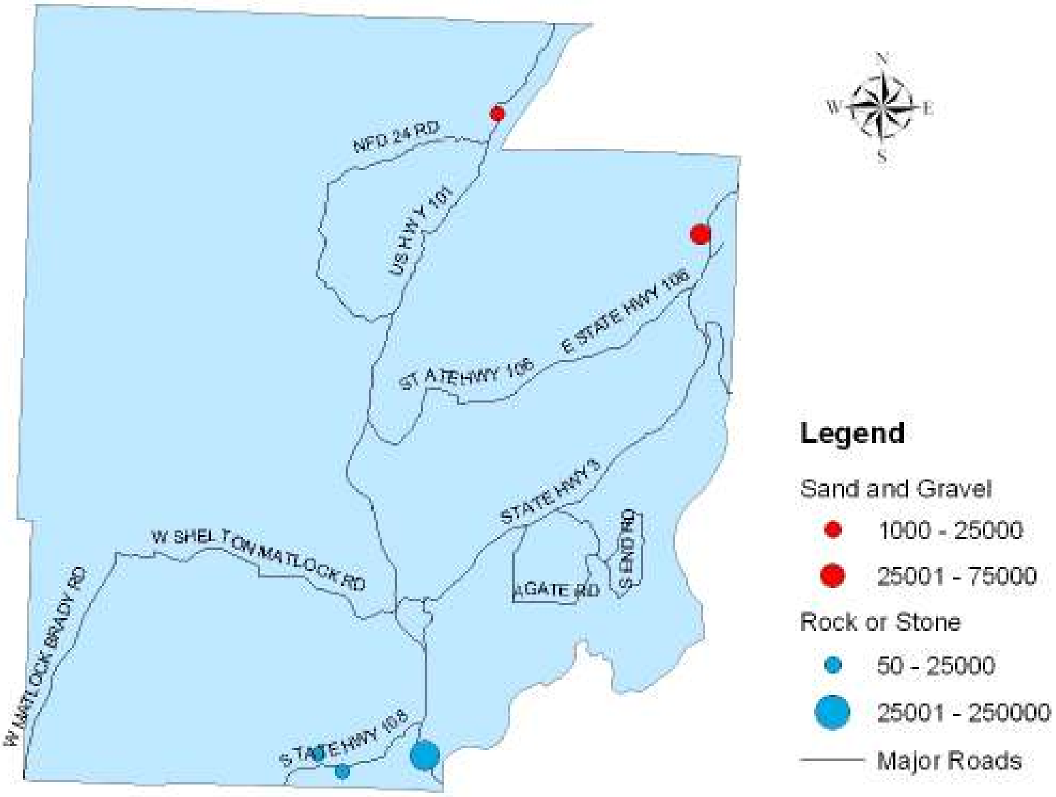


Figure 43. Frequency of roads used for aggregates hauling Mason County

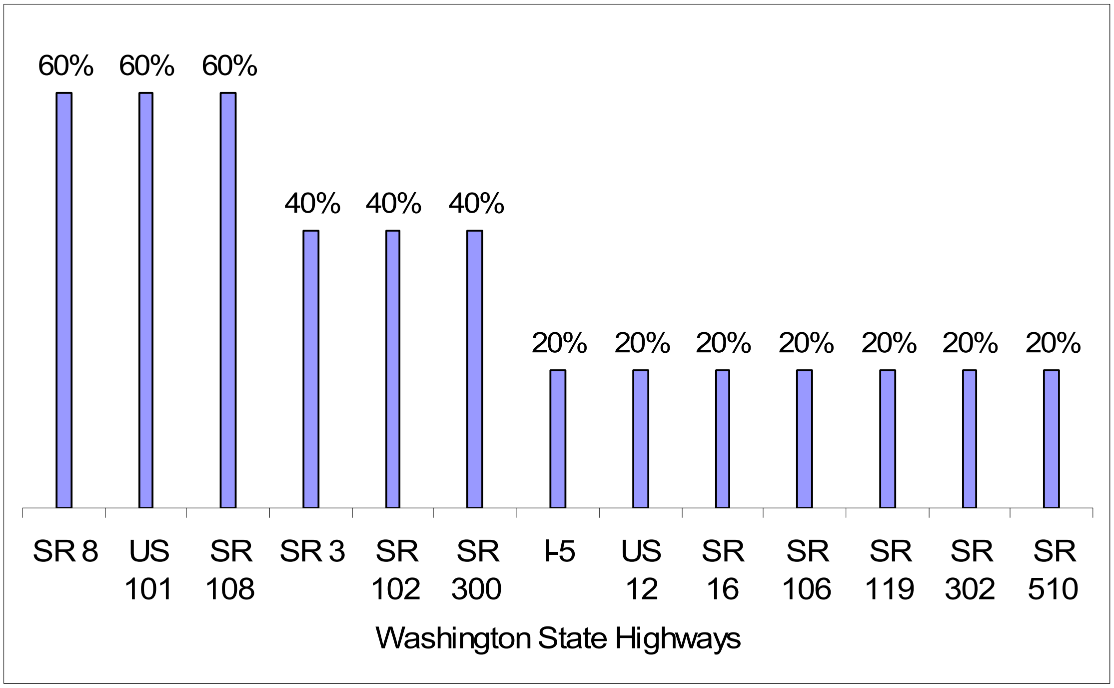


Figure 44. Okanogan County mines by type and production level in relation to highway system

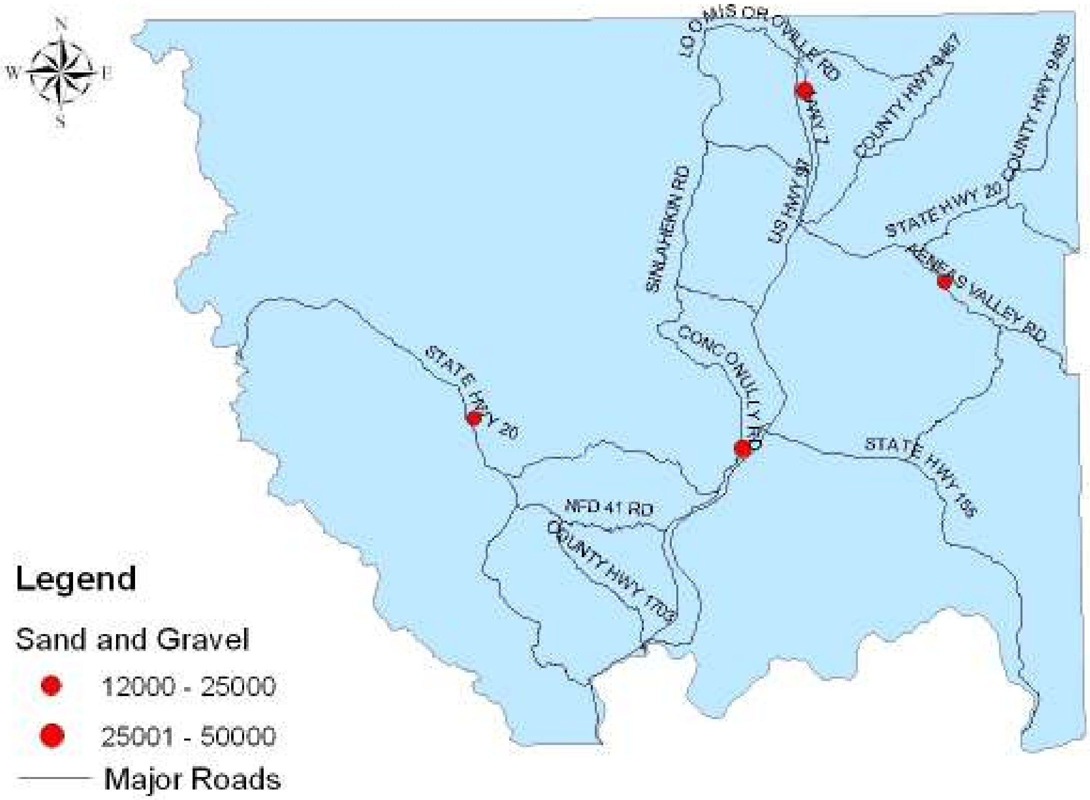


Figure 45. Frequency of roads used for aggregates hauling in Okanogan County

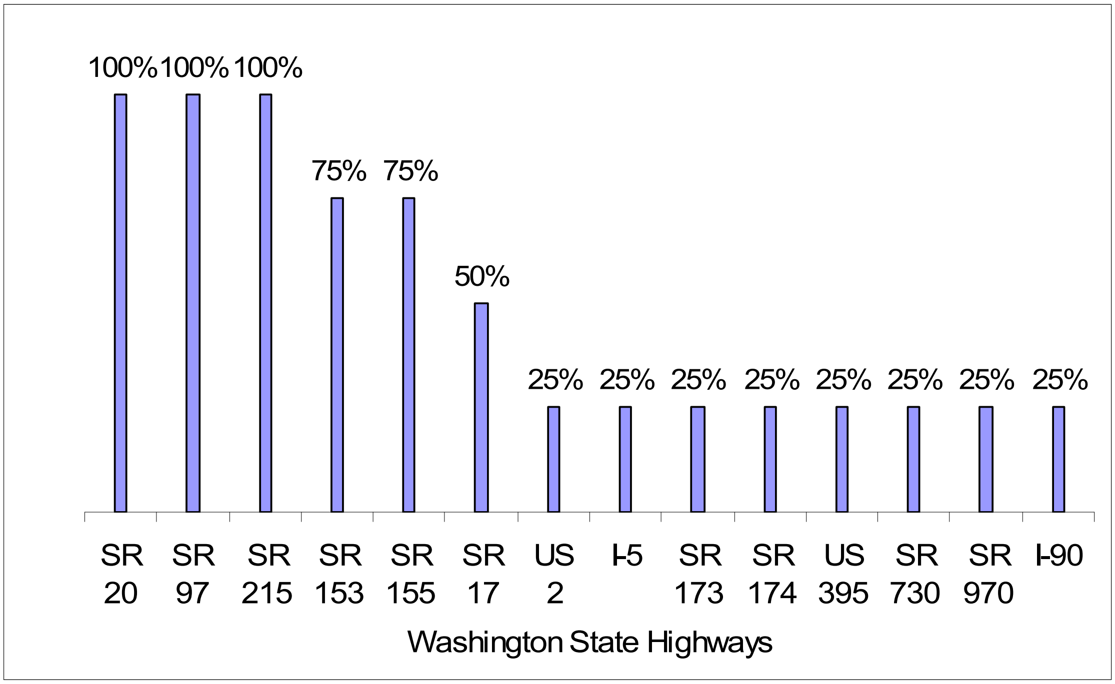


Figure 46. Pacific County mines by type and production level in relation to highway system

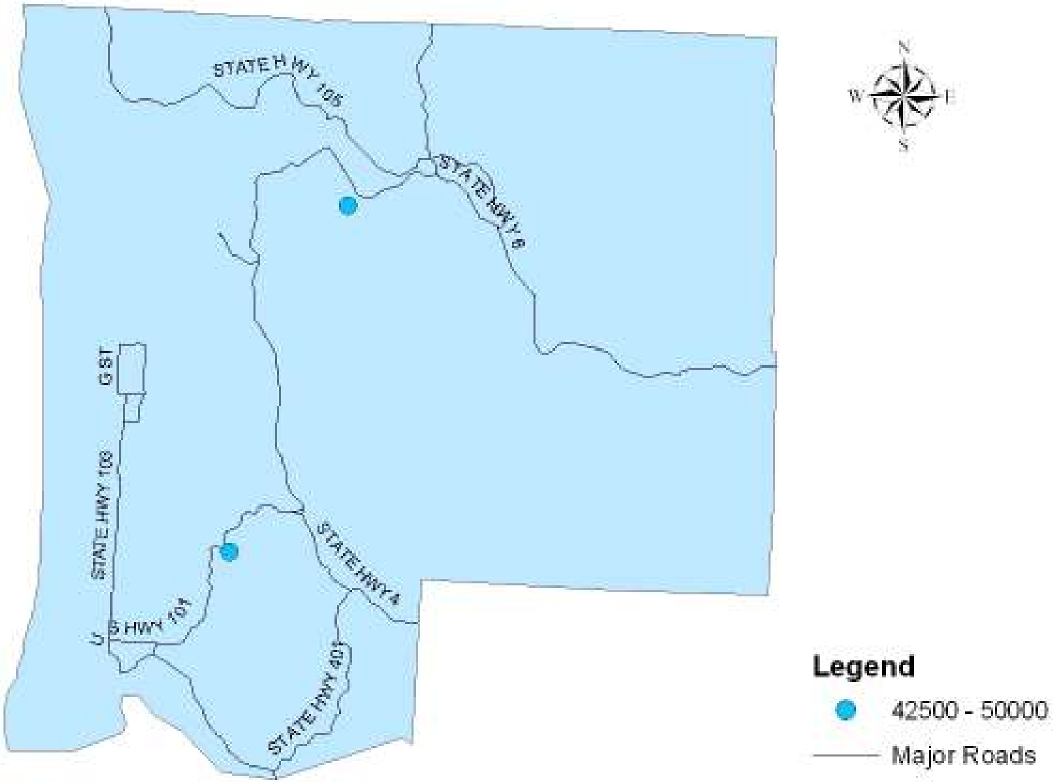


Figure 47. Frequency of roads used for aggregates hauling in Pacific County

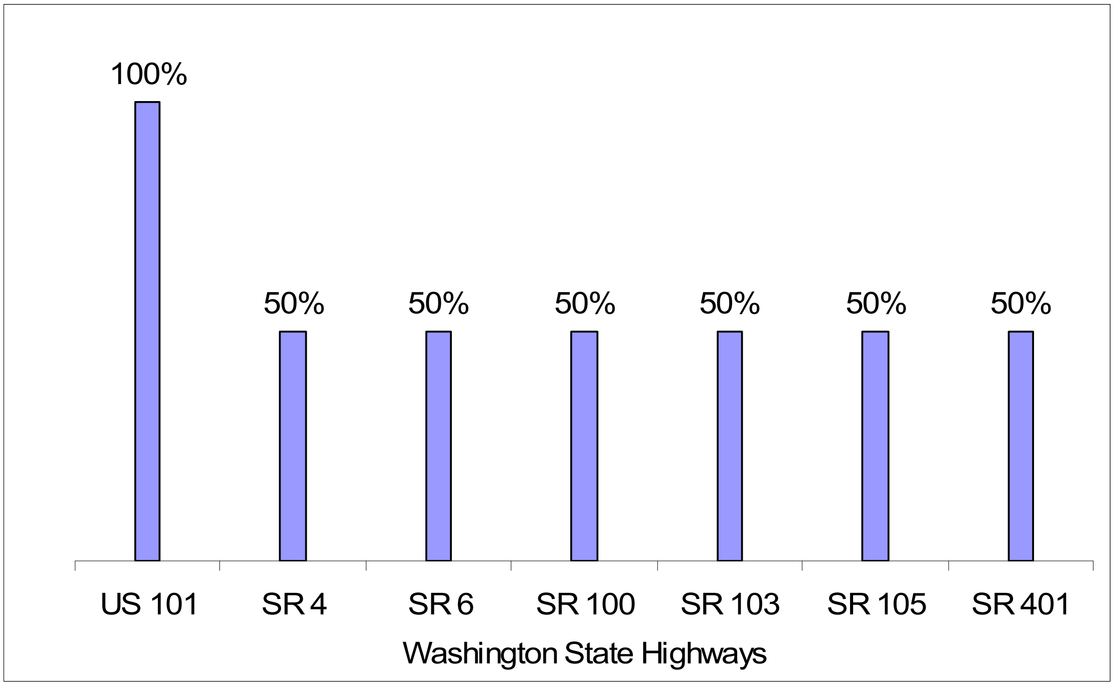


Figure 48. Pend Oreille County mines by type and production level in relation to highway system

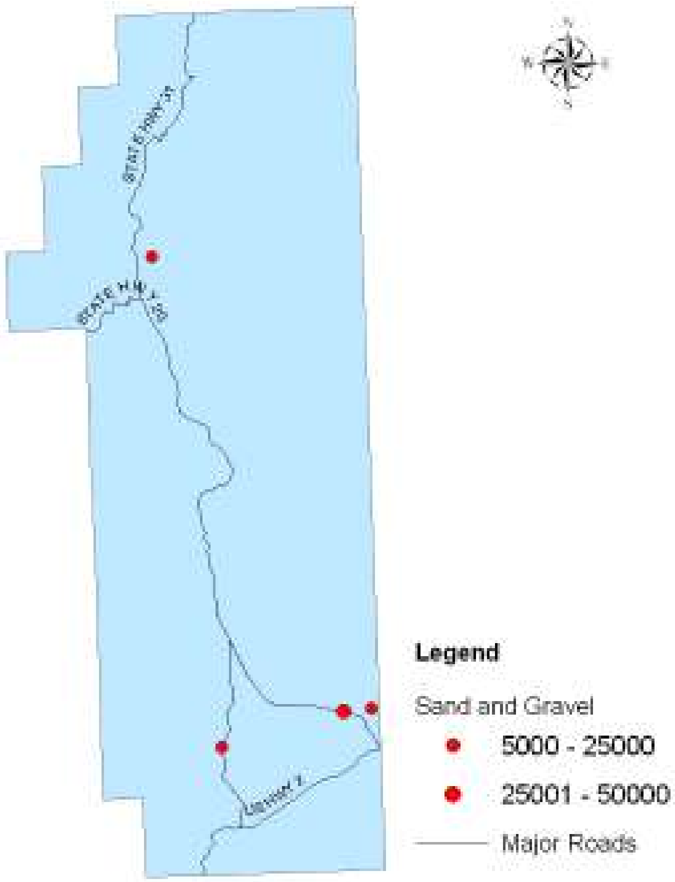


Figure 49. Frequency of roads used for aggregates hauling in Pend Oreille County

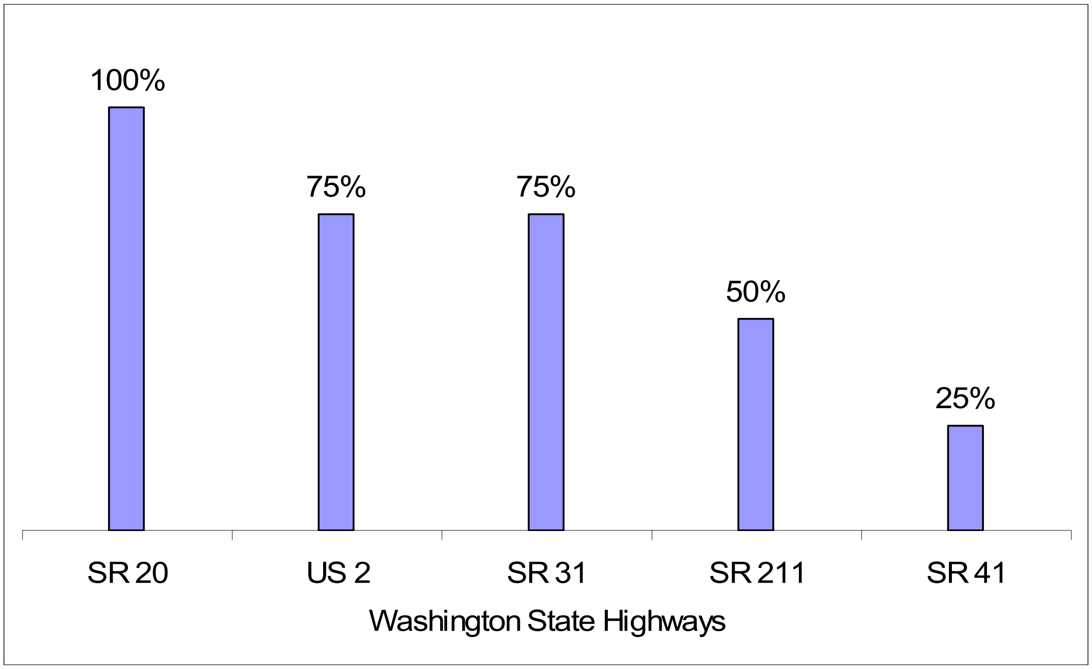


Figure 50. Pierce County mines by type and production level in relation to highway system

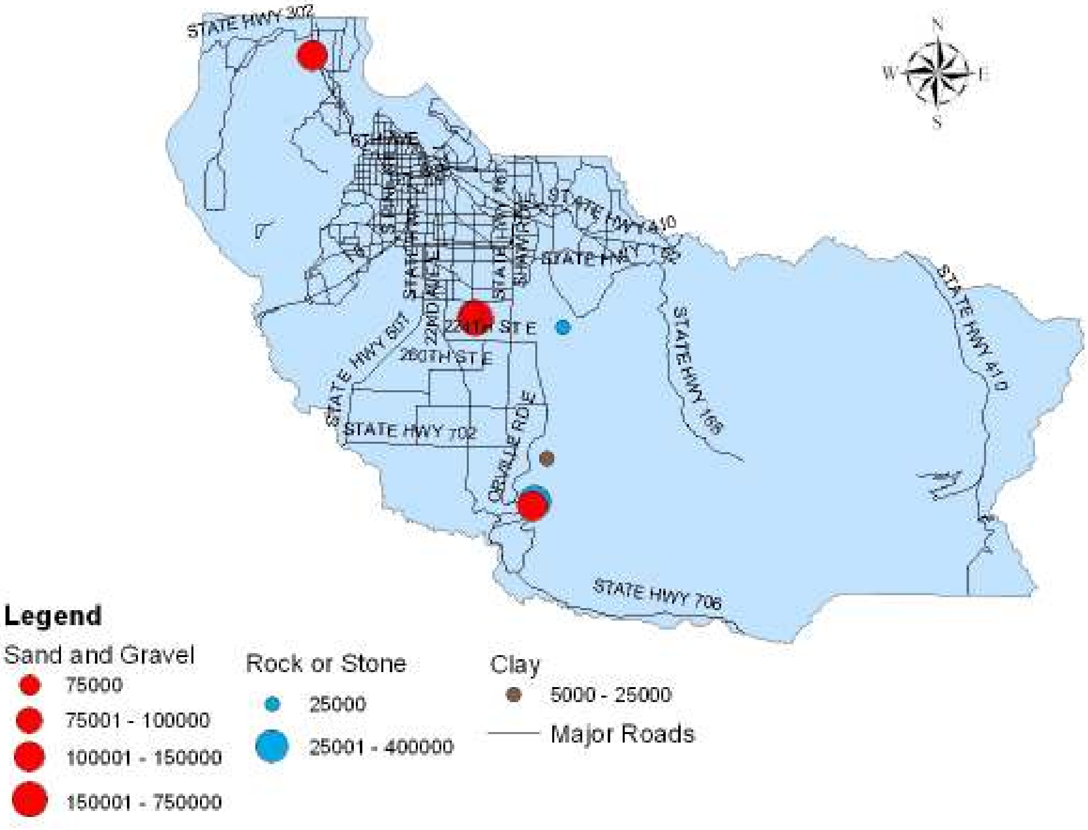


Figure 51. Frequency of roads used for aggregates hauling in Pierce County

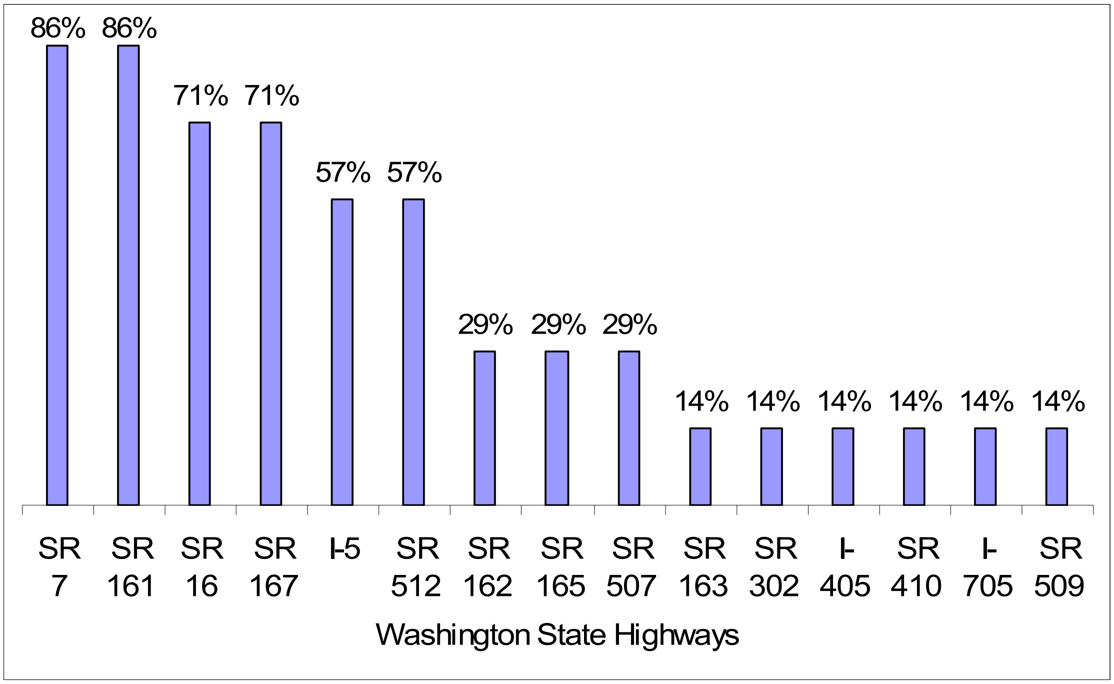


Figure 52. San Juan County mines by type and production level in relation to highway system

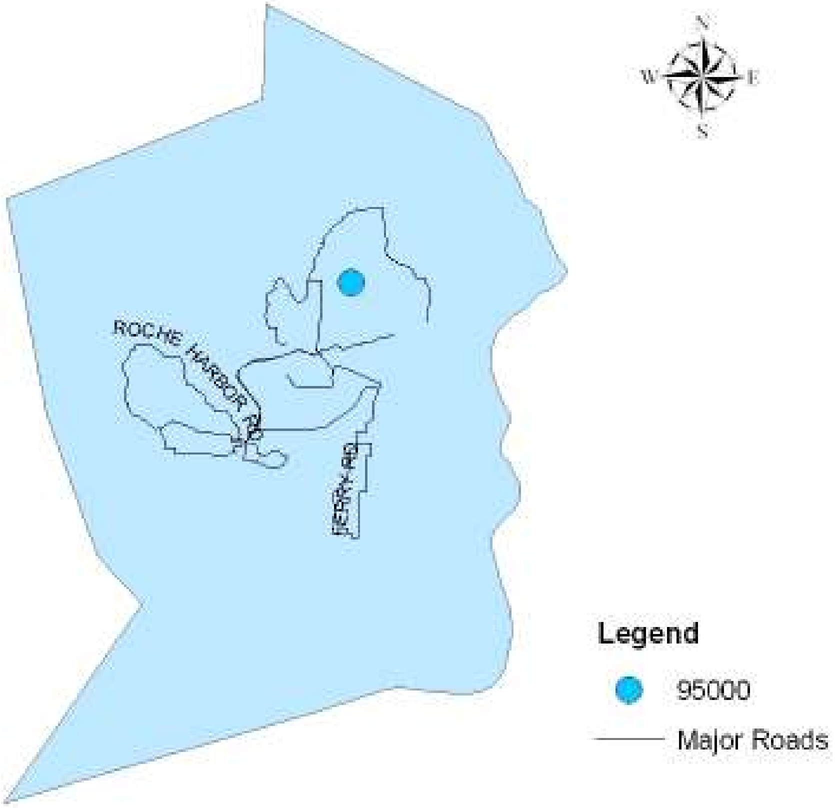


Figure 53. Skagit County mines by type and production level in relation to highway system

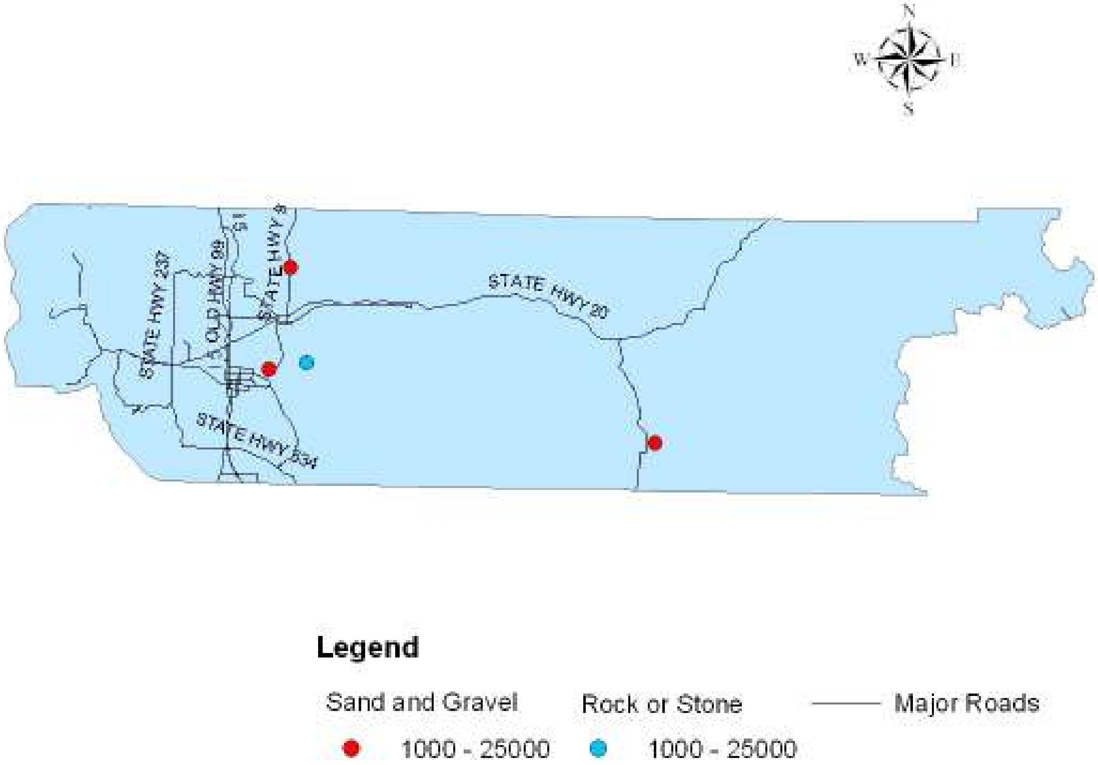


Figure 54. Frequency of roads used for aggregates hauling in Skagit County

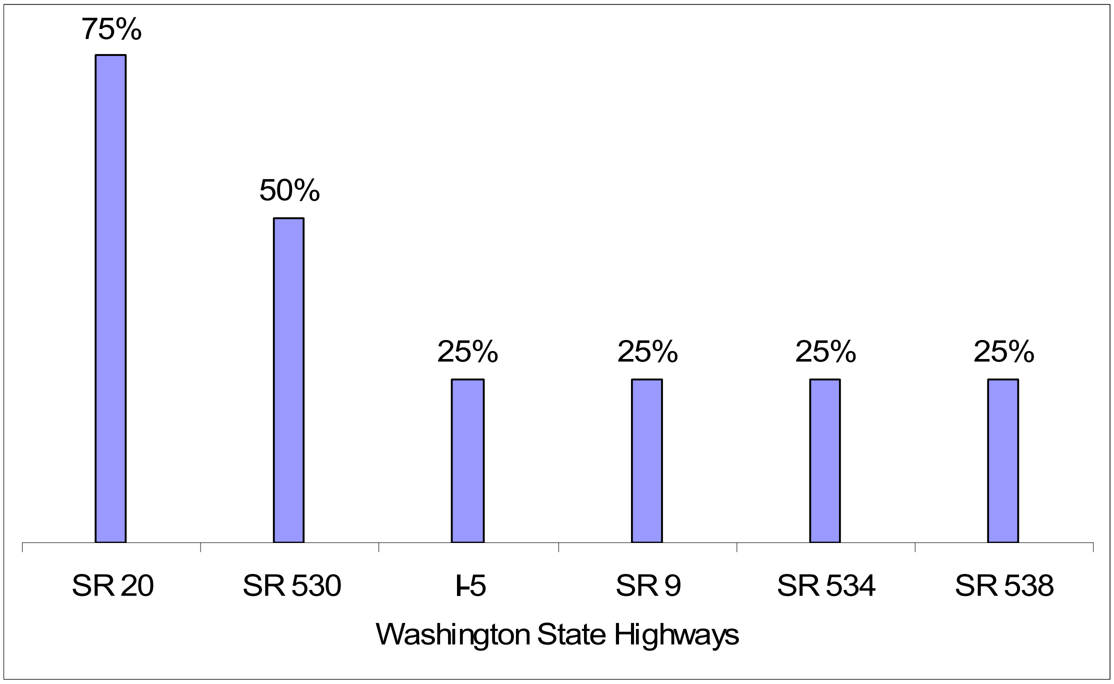


Figure 55. Skamania County mines by type and production level in relation to highway system

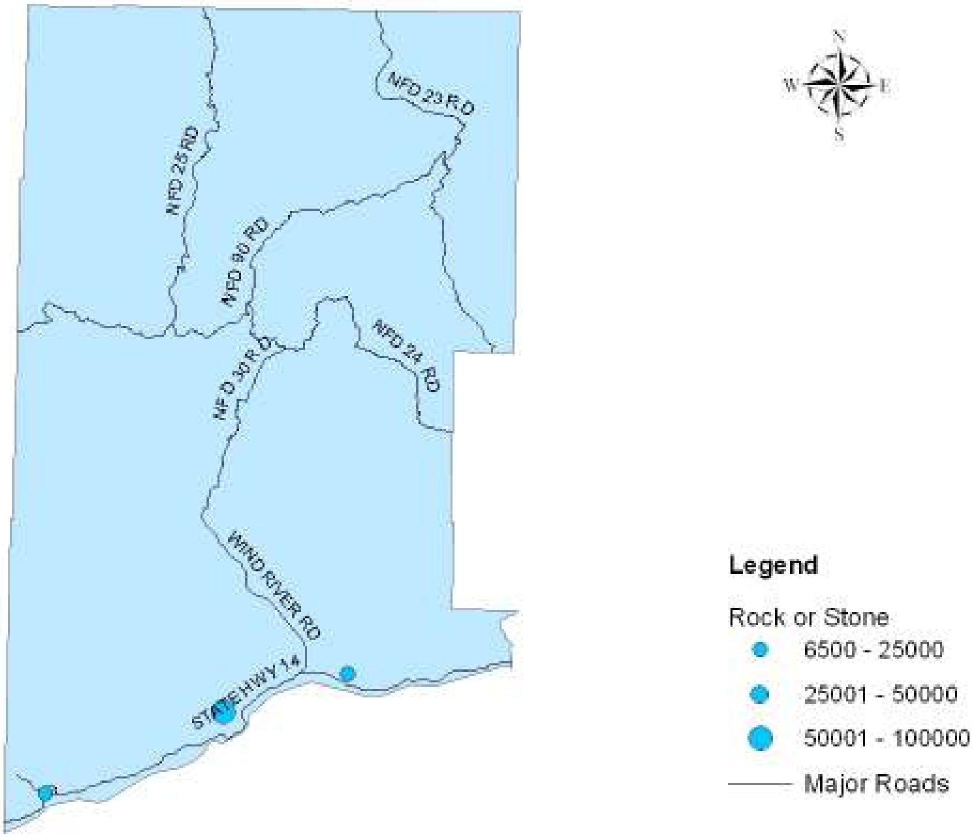


Figure 56. Frequency of roads used for aggregates hauling in Skamania County

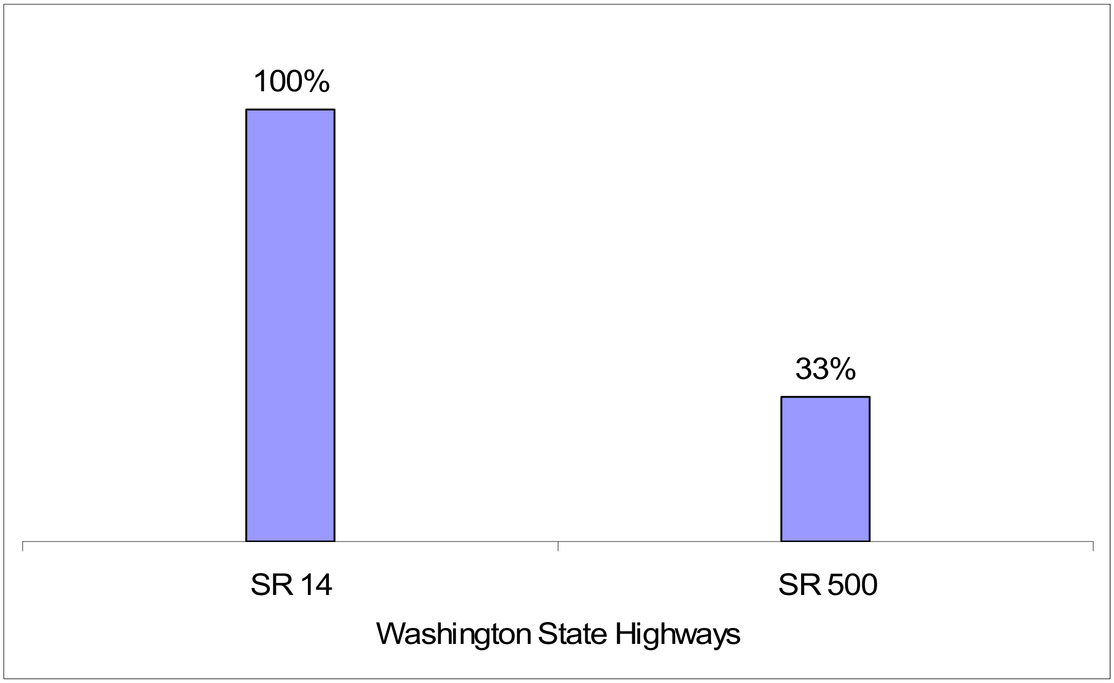


Figure 57. Snohomish County mines by type and production level in relation to highway system

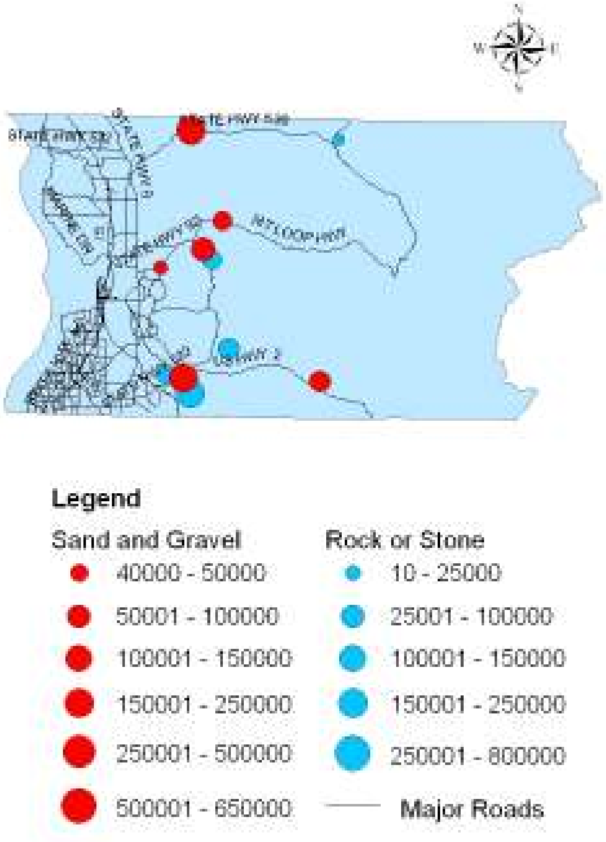


Figure 58. Frequency of roads used for aggregates hauling in Snohomish County

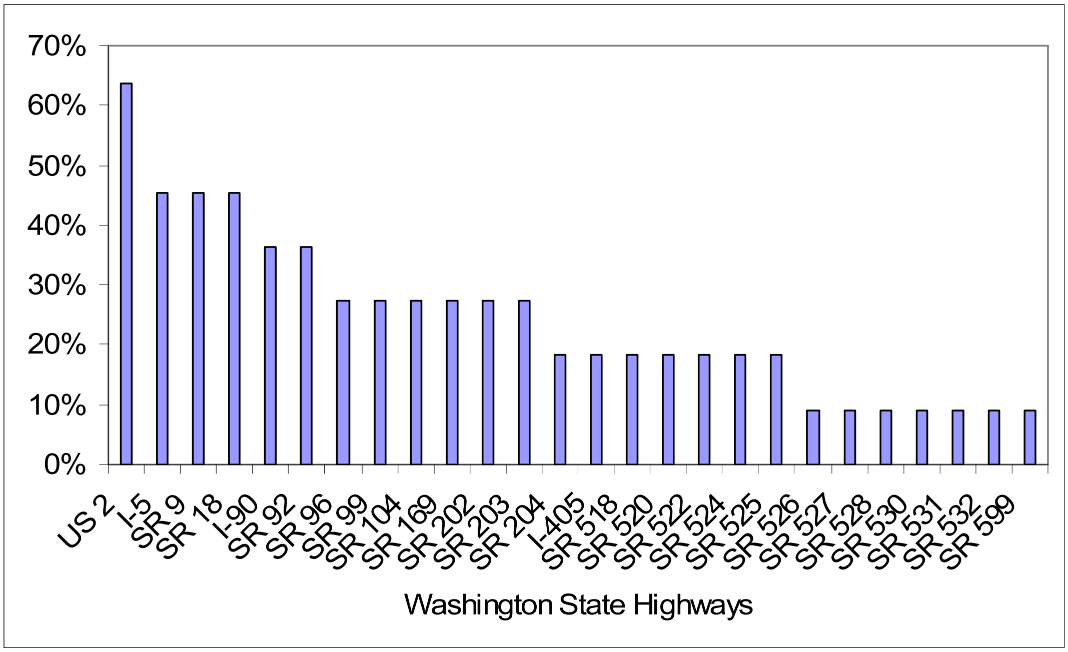


Figure 59. Spokane County mines by type and production level in relation to highway system

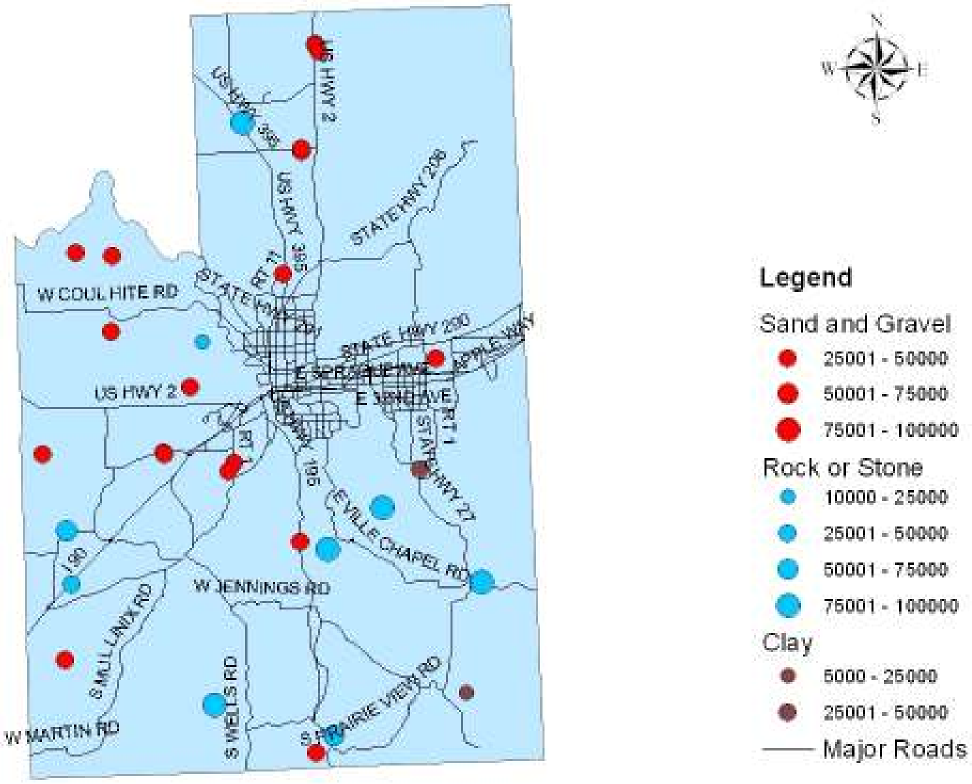


Figure 60. Frequency of roads used for aggregates hauling in Spokane County

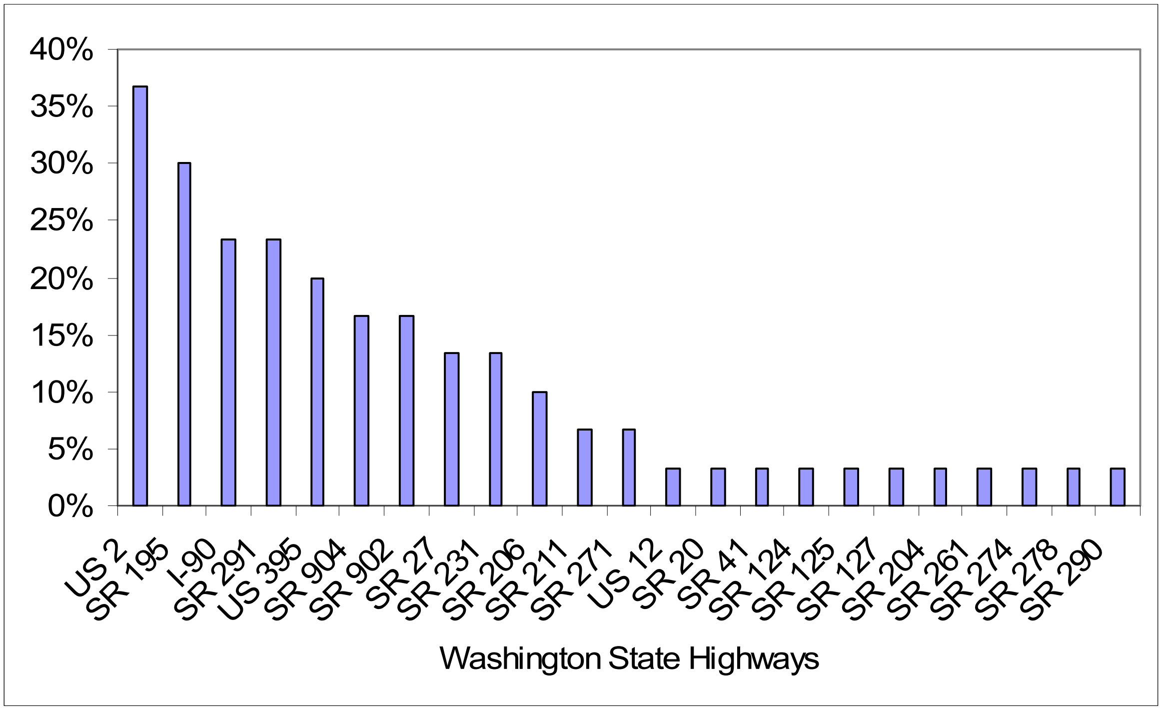


Figure 61. Stevens County mines by type and production level in relation to highway system

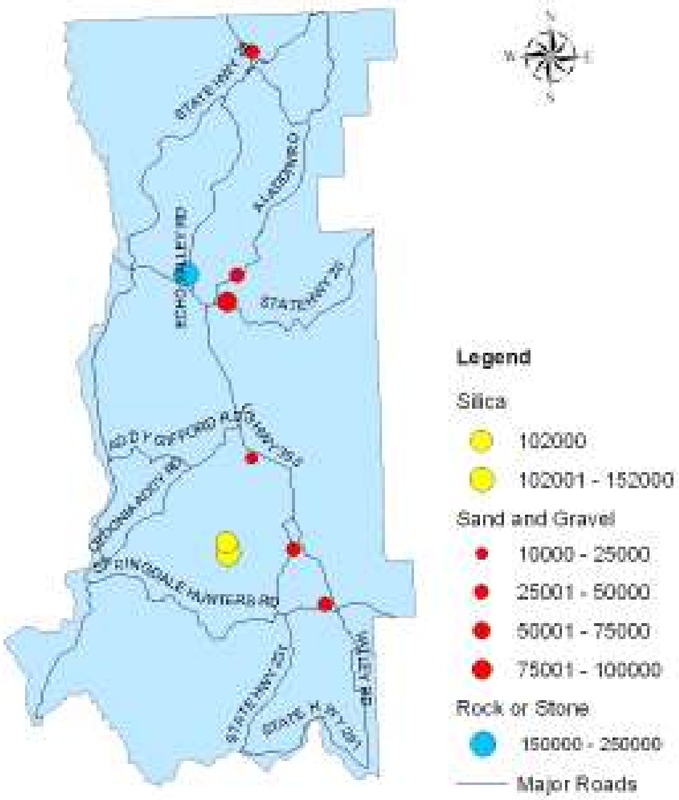


Figure 62. Frequency of roads used for aggregates hauling in Stevens County

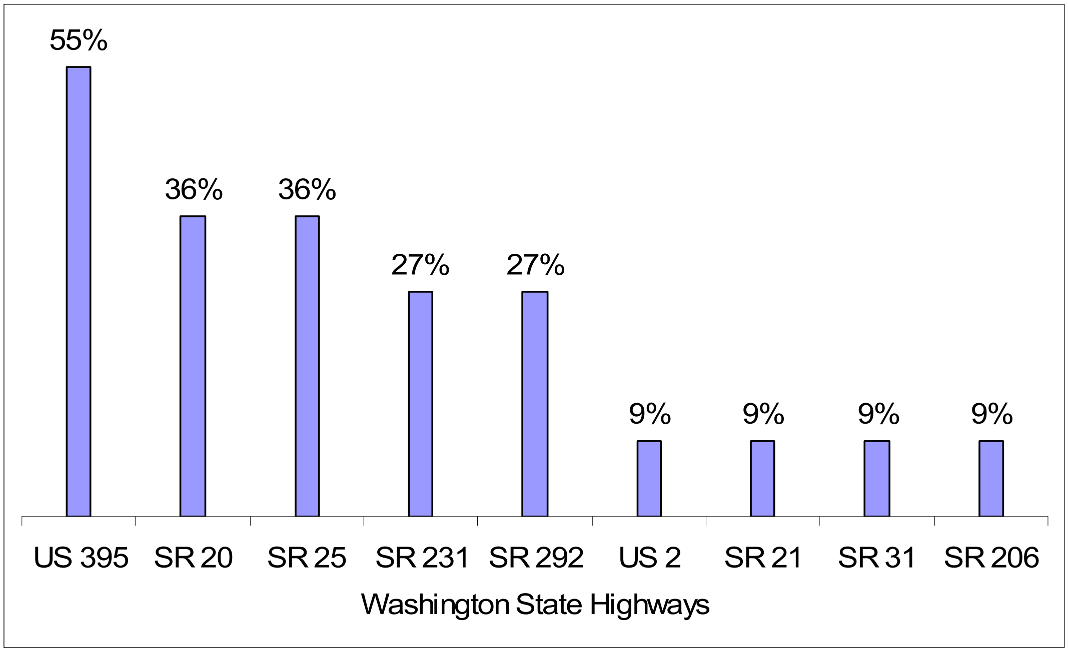


Figure 63. Thurston County mines by type and production level in relation to highway system

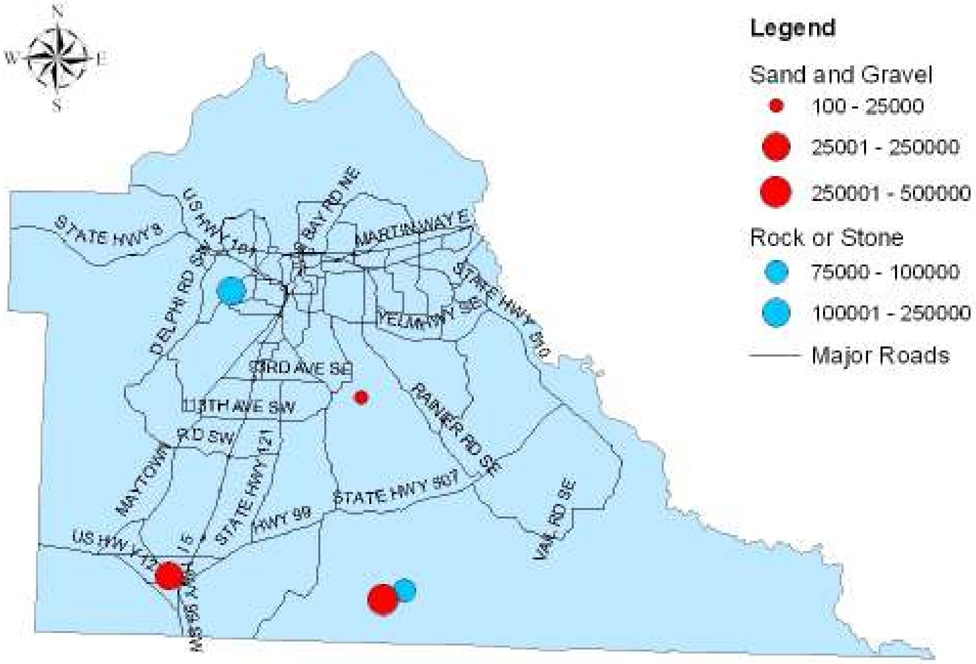


Figure 64. Frequency of roads used for aggregates hauling in Thurston County

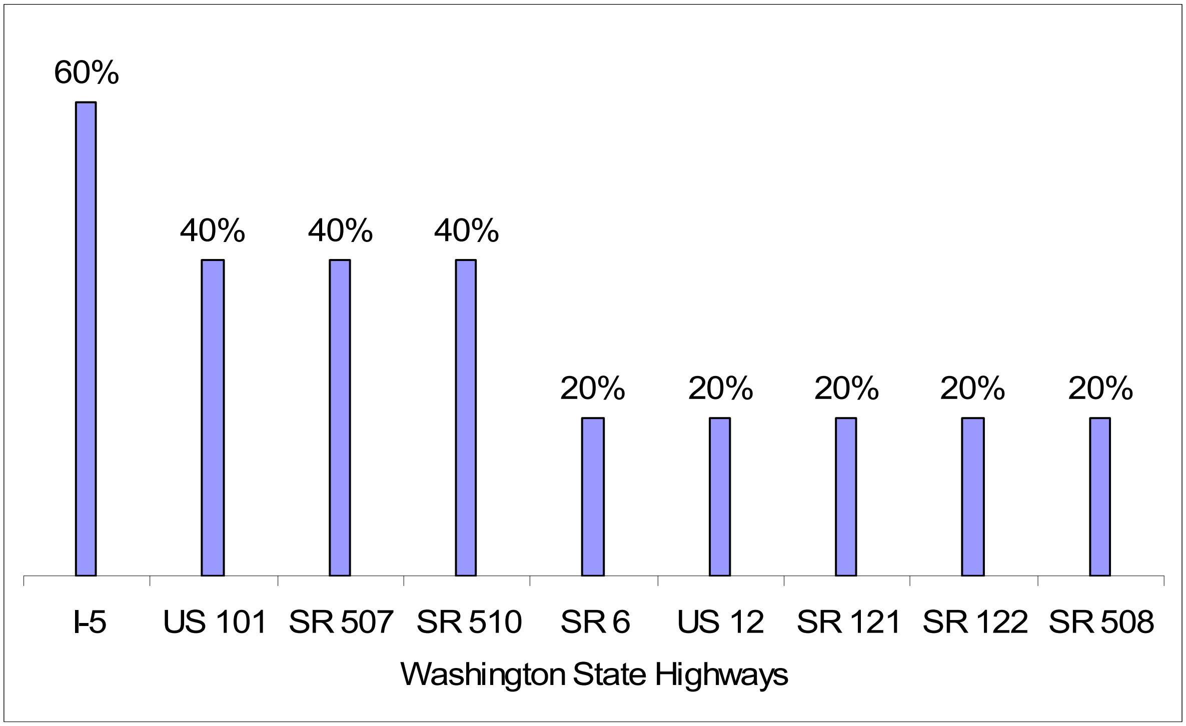


Figure 65. Walla Walla County mines by type and production level in relation to highway system

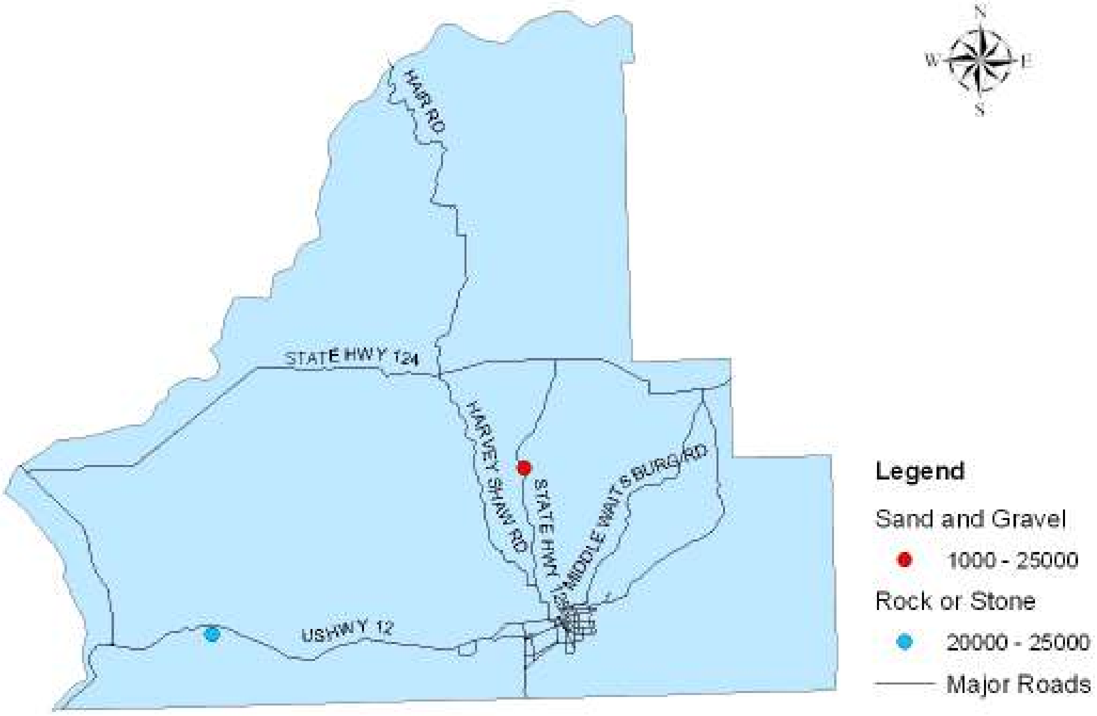


Figure 66. Frequency of roads used for aggregates hauling in Walla Walla County

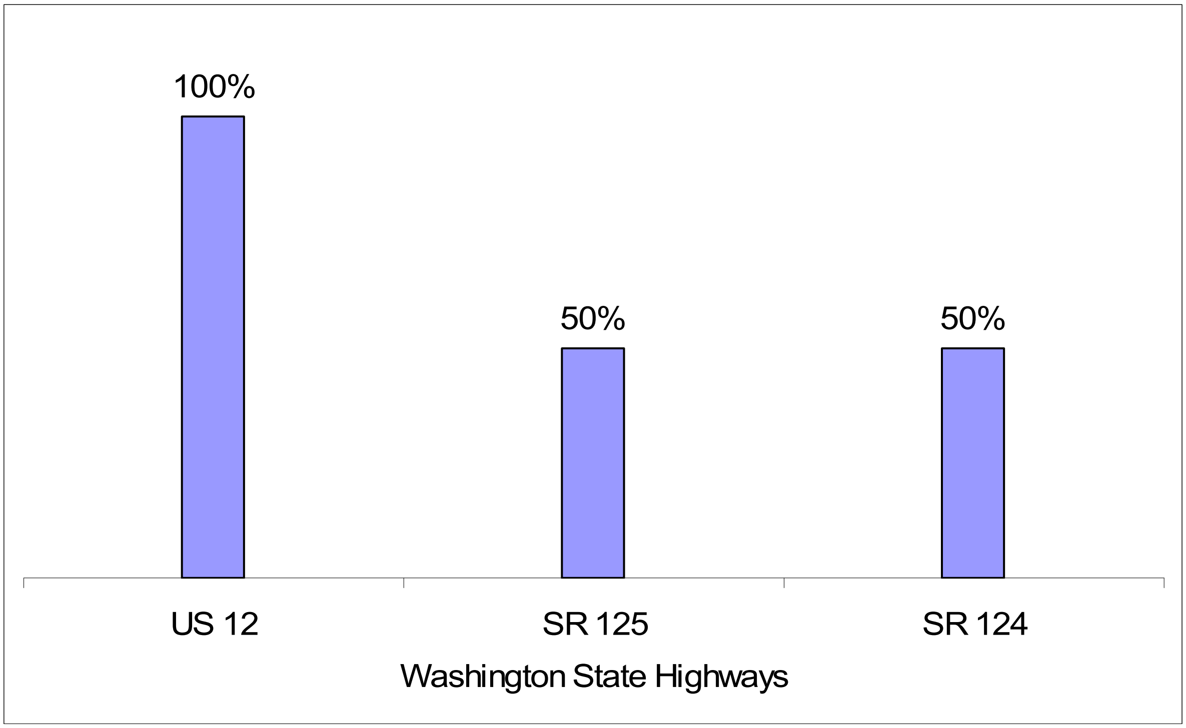


Figure 67. Whatcom County mines by type and production level in relation to highway system

Figure 68. Frequency of roads used for aggregates hauling in Whatcom County

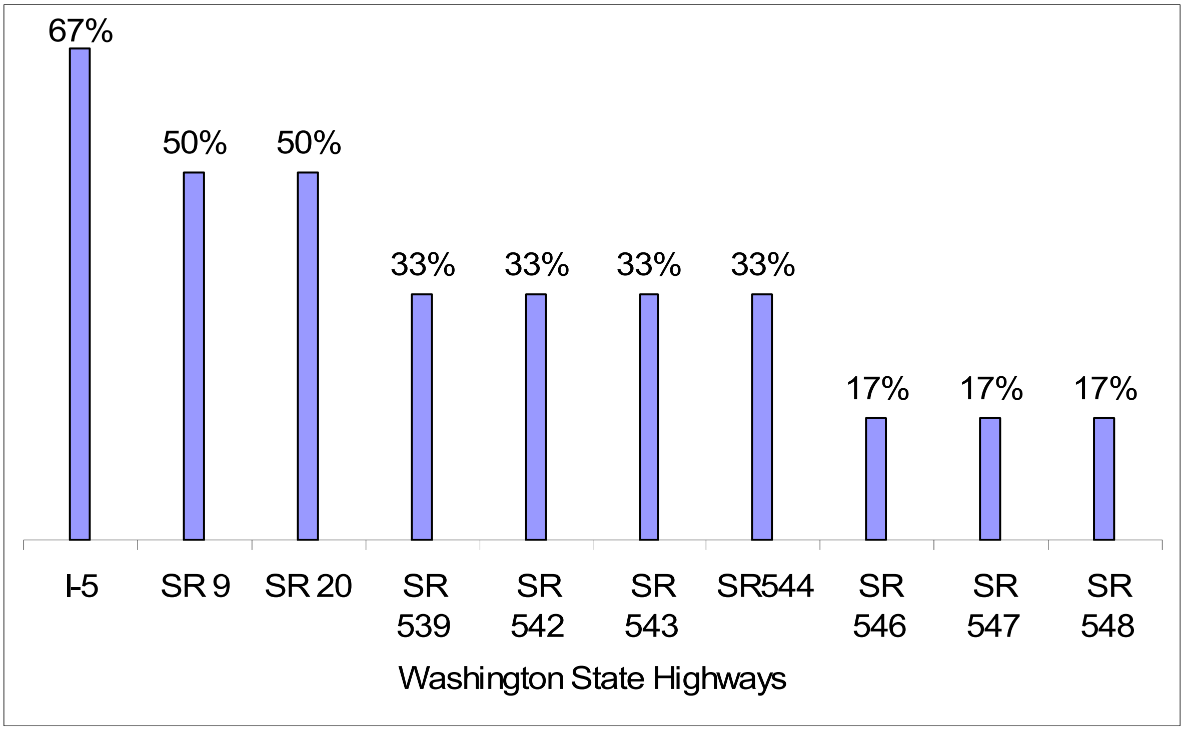


Figure 69. Whitman County mines by type and production level in relation to highway system

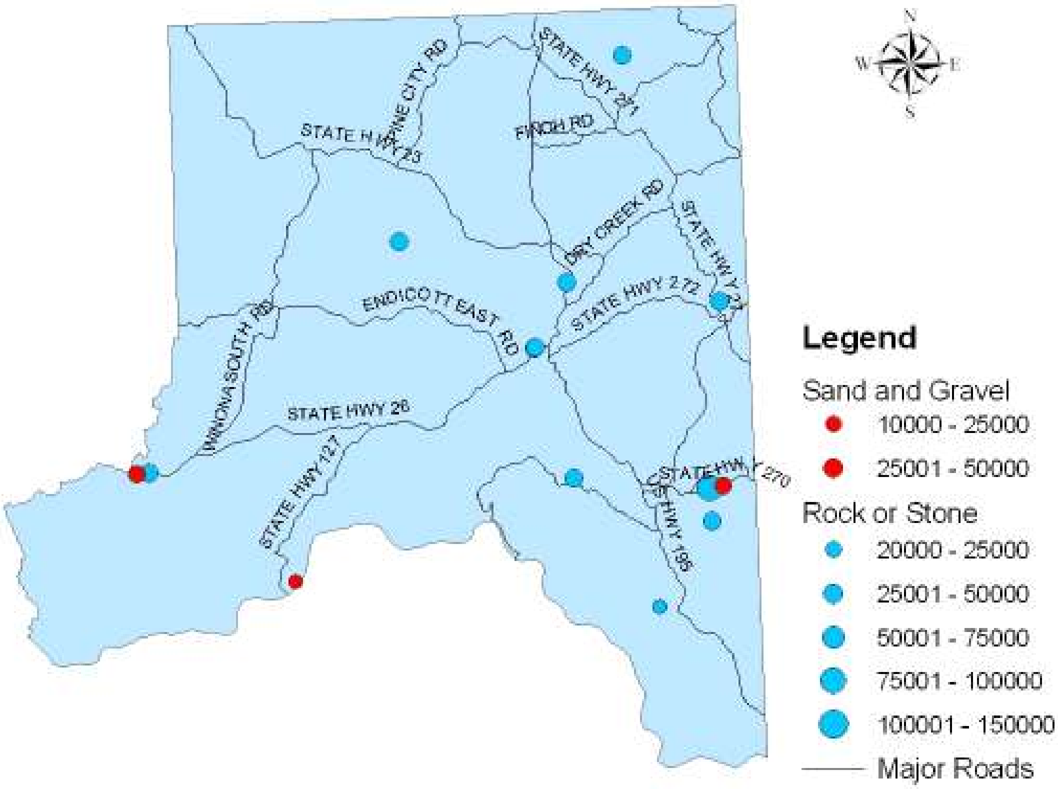


Figure 70. Frequency of roads used for aggregates hauling in Whitman County

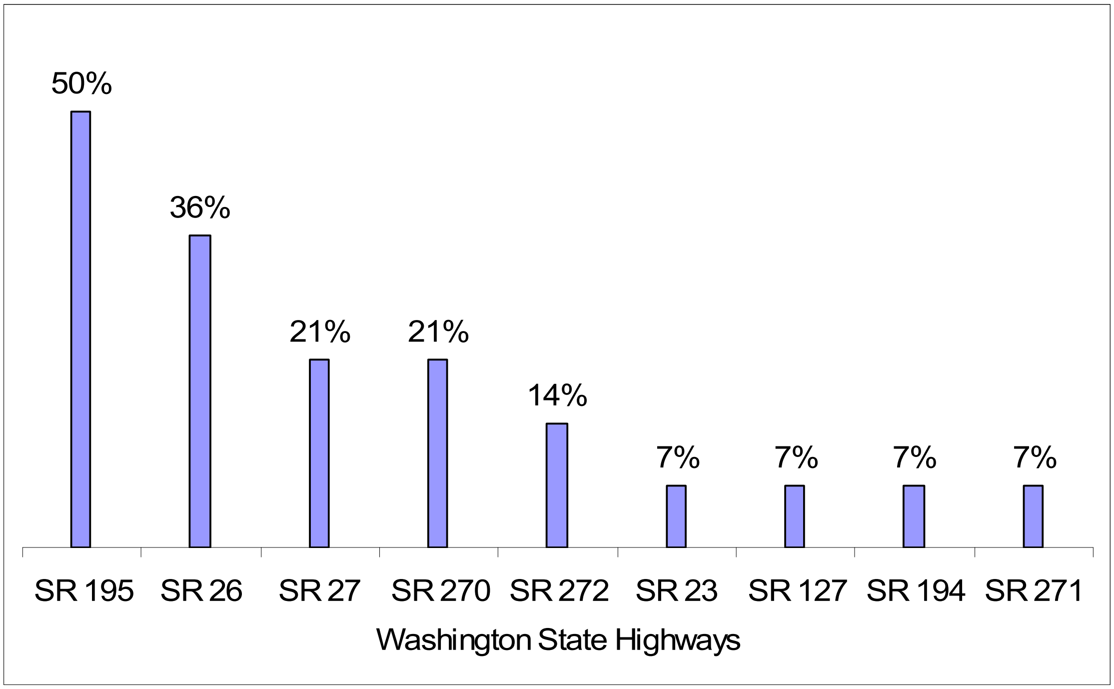


Figure 71. Yakima County mines by type and production level in relation to highway system

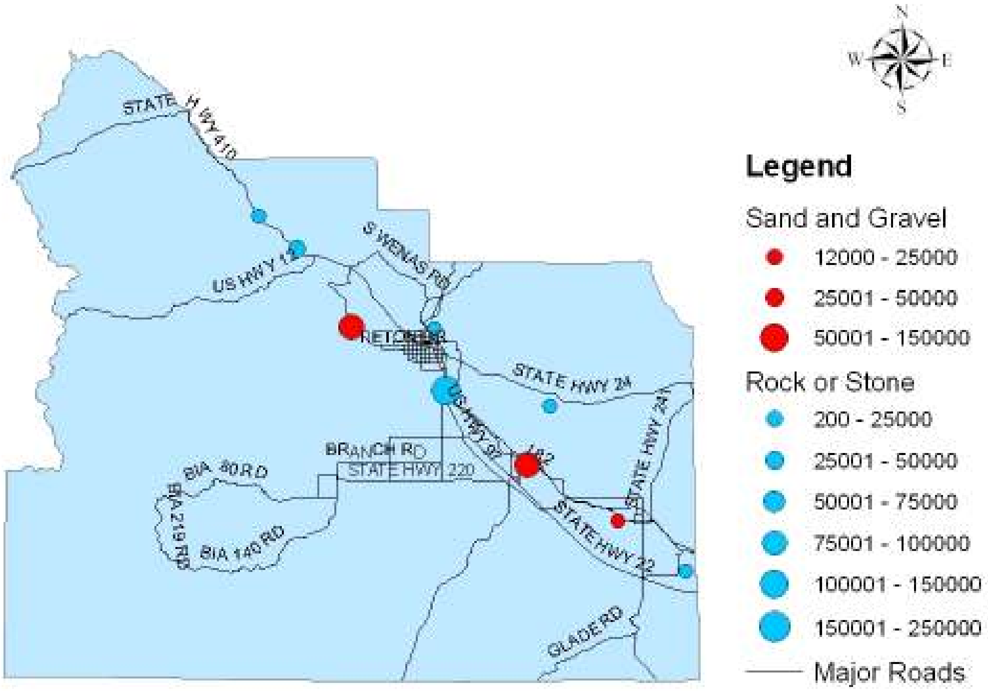
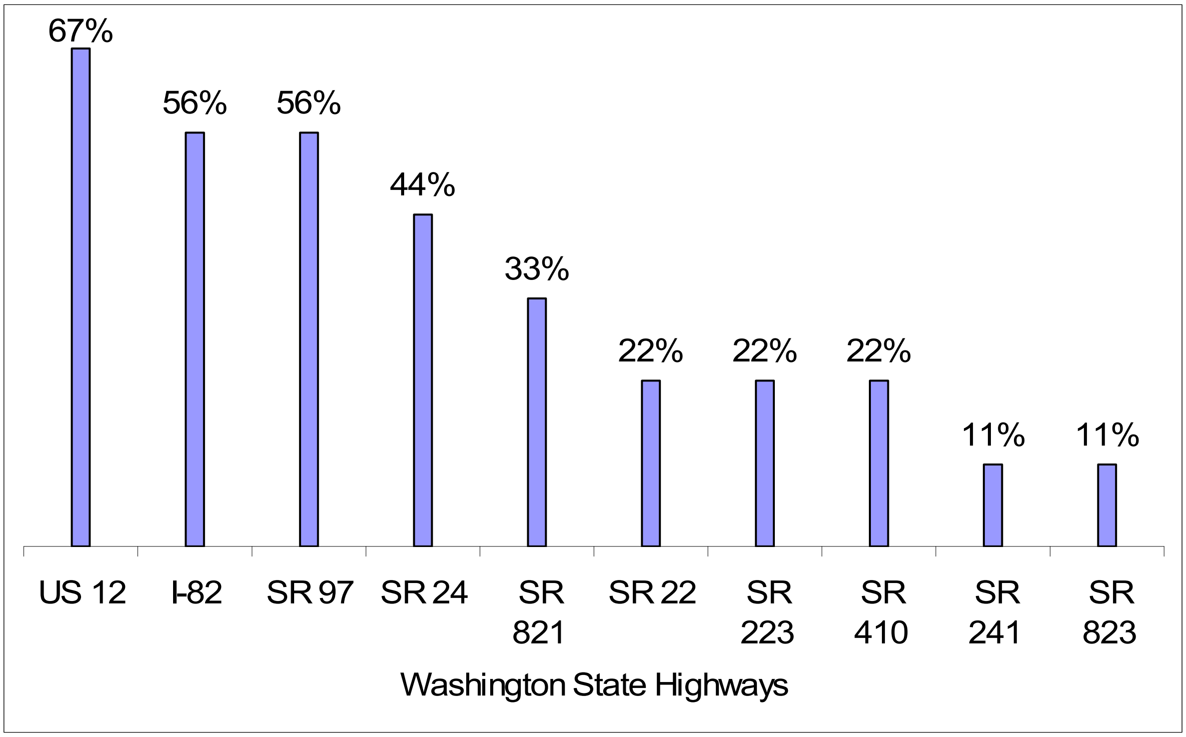


Figure 72. Frequency of roads used for aggregates hauling in Yakima County



Appendix D

Washington State highways used for mineral hauling

Interstate	US	SR	SR	SR	SR	SR	SR	SR	SR	SR	SR	SR	SR
5	2	3	21	99	117	160	182	223	281	397	509	531	821
82	12	4	22	100	119	161	193	224	282	401	510	532	823
90	101	6	23	102	121	162	194	225	283	410	512	534	883
405	395	7	24	103	122	163	195	231	285	411	516	538	900
705		8	25	104	124	164	197	240	292	500	518	539	903
		9	26	105	125	165	202	241	300	501	520	542	904
		10	27	106	127	166	203	243	302	502	522	543	908
		14	28	108	128	167	204	260	303	503	524	544	970
		16	31	109	131	169	205	261	304	504	525	546	
		17	41	110	141	170	206	262	305	505	526	547	
		18	92	112	142	171	211	270	307	506	527	548	
		19	96	113	153	173	215	271	308	507	528	599	
		20	97	116	155	174	221	272	310	508	530	730	

Appendix E

Transportation of Mining/Mineral Survey Questionnaire

WASHINGTON STATE UNIVERSITY

World Class. Face to Face.

School of Economic Sciences

Transportation of Mining / Mineral Survey

Thank you for your participation in this study. If you have questions or concerns as you are completing this form, or if you would like more information on this project, feel free to contact Eric Jessup, at (509) 335-5558 or at Eric_Jessup@wsu.edu. Once again, thank you for your assistance.

Site information

Company	«Company_Landowner»
Site Name	**«Property_Name»**
Township, Range and Section	«Township» «Range» «Section»
DNR Registration Number	«DNR_Permit»

CONFIDENTIAL

****Please provide information specific to the site identified on the front of this questionnaire****

Name of person completing the survey:

____

Phone Number: ________________________________

1. What is the primary commodity mined at this location?

Commodity (Check all that apply)

☐ Sand & Gravel
☐ Rock or Stone
☐ Coal
☐ Carbonate
☐ Clay
☐ Peat

☐ Metals
☐ Ash
☐ Diatomite
☐ Silica Sand
☐ Soil
☐ Gold
☐ Other: (please identify)
____

2. What is the average annual tons of product that is **mined** at this facility in a typical year when it is in operation?

_______________ tons per year

3. In which years has this site been operated since 2000? Check appropriate line.

___ 2000 ___ 2003 ___ All six years
___ 2001 ___ 2004 ___ Not operational in the last
___ 2002 ___ 2005 10 years *(END SURVEY. Please return the questionnaire to us in enclosed envelope)*

4. What are the future plans of operation? Check if the mine may be operating in: 2006____ 2007____ 2008____

5. Please check the days and times when this site typically is in operation.

	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
a.m. 6-8							
8-10							
10-12							
p.m. 12-2							
2-4							
4-6							
6-8							
8-10							
10-12							
a.m. 12-2							
2-4							
4-6							

6. Below, check the boxes to identify 1) the months during which this site is operated, and 2) the months during which mined products are shipped from this site.

	Jan	Feb	Mar	Apr	May	Jun
1) operational months						
2) shipment months						

	Jul	Aug	Sep	Oct	Nov	Dec
1) operational months						
2) shipment months						

7. Please identify any factors that influence the monthly shipments of mined materials. (Check all that apply)

- ☐ Variation in demand
- ☐ Seasonal road closures
- ☐ Weather
- ☐ Labor shortages
- ☐ Equipment malfunction/needs
- ☐ Other: ________________

8. In percentages, indicate the amount of products shipped from this site in-state, out-of-state, and internationally.

a) In-state _______

b) Out-of-state _______

c) International _______

Total 100%

please specify major country: ______________________

9. What percentage of shipments are delivered to the following destinations after they leave this site?

Destination

☐ Construction or road site _____(%)
☐ Factory _____(%)
☐ Warehouse / Distribution Center _____ (%)
☐ Farm _____(%)
☐ Point of Sale / Consumption _____(%)
☐ Truck Terminal _____ (%)
☐ Rail Terminal _____ (%)
☐ Marine Terminal _____ (%)
☐ Air Terminal _____ (%)
☐ Other: _____________ (%)

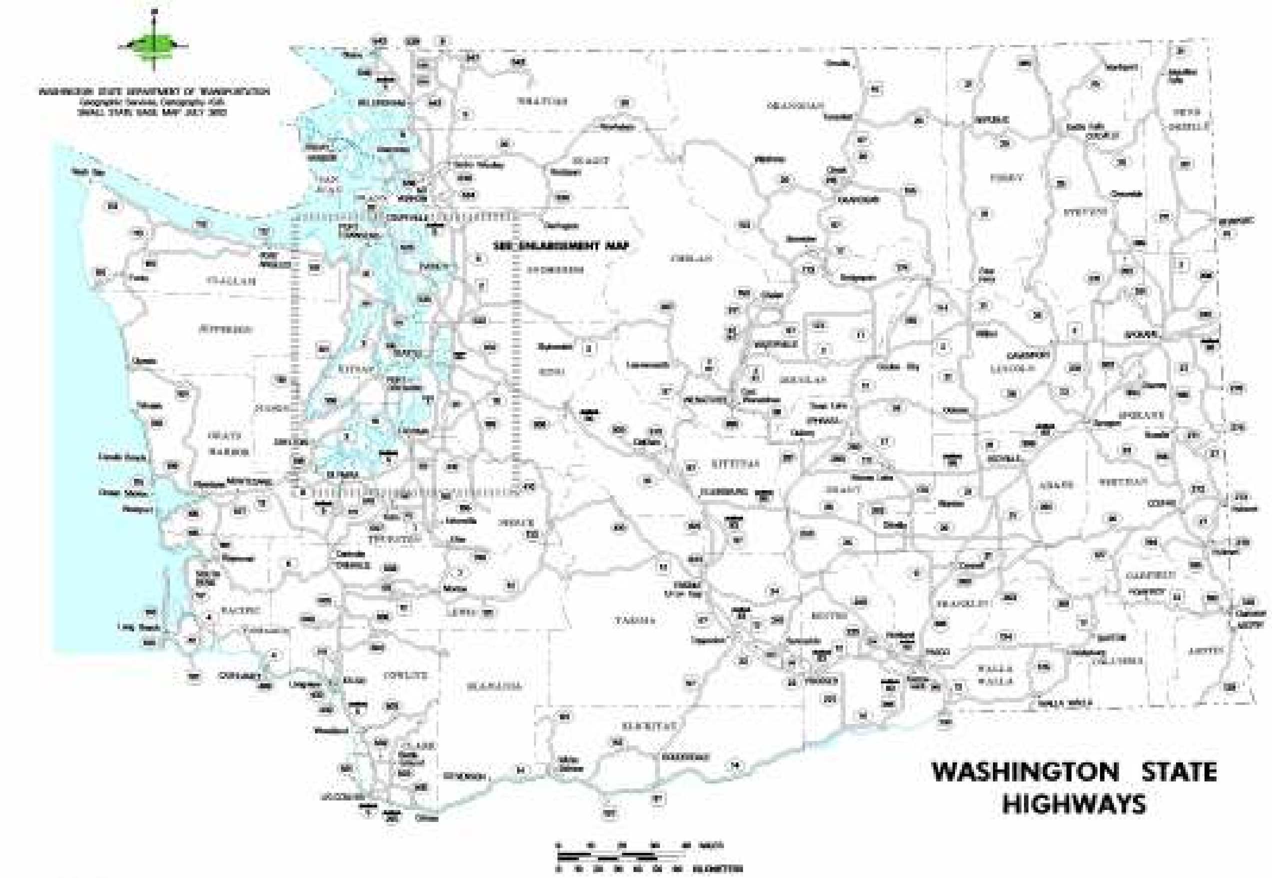
Total 100%

10. **Roadway Usage Identification**

On the **following** Washington State road map, please place an “X” on the location of the mining site.

Using a pen (highlighter, marker, or colored pen, if possible), please highlight the roads this site uses most frequently when transporting materials off-site.

If your mine is located in the Puget Sound region, you have also been provided with a more detailed enlargement map. Please highlight the mining site and roadways used on this map as well.


WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
SEE ENLARGEMENT MAP
WASHINGTON STATE
HIGHWAYS
MILES
KILOMETERS

11. What proportion of inbound and outbound shipment moved by following modes at this site?

Inbound Materials (If any)	**Outbound** Mined Products
%___ Truck	%___ Truck
%___ Barge	%___ Barge
%___ Rail	%___ Rail
%___ Other: ________	%___ Other: ________
100% Total	**100%** Total

12.If any materials shipped by rail, what is the typical load configuration?

☐ 1 car
☐ 2-5 cars
☐ 5-24
☐ 25-50 units
☐ 50-100 units
☐ More than 100 units

13. Does your mining operation own its own fleet of trucks?

☐ Yes

If yes, how many trucks? _____

☐ No

If no, please identify who provides your shipping services.

☐ Private for hire
☐ Commercial Trucking Company
☐ Other: (please identify) __________________

14. What is the typical payload weight for outbound truck shipments?

_______________ tons

15. Please estimate the percentage of shipments that travel from this facility within each mileage category (e.g. 20% of mined product might be hauled more than 100 miles away, and 80% might be hauled 11 – 20 miles from this site.)

a) 0 – 5 miles	_____%	d) 21 – 40 miles	_____%
b) 6 – 10 miles	_____%	e) 41 – 100 miles	_____%
c) 11 – 20 miles	_____%	f) Over 100 miles	_____%
		Total	**100%**

16. What is the typical truck configuration for shipments leaving this facility?

☐ Straight Truck
☐ Straight Truck & Trailer
☐ Tractor & Trailer
☐ Other: _______________

17. For trucks leaving your facility, how many axles are typically on the ground?

    for the truck __________

    for the trailer (if used) __________

Total number of axles on Truck or Tractor	Total number of axles on 1st Trailer
_______	_______

18. Through which ocean or river ports, if any, do materials from this site travel?

    ☐ None
    ☐ Seattle
    ☐ Tacoma
    ☐ Portland
    ☐ Snake River Ports (Lewiston, Pasco)
    ☐ Columbia River Ports (Umatilla, Morrow)
    ☐ Other: _______________

19. Are any materials shipped into this site?

    ☐ No
    ☐ Yes
    If yes, please list these major materials below:

    ____

Below, please include any other comments you would like to make about the transportation issues important at this site.

Would you like a copy of the results of this survey? Yes___ No___

THANK YOU for taking time to fill out this survey! Your help is much appreciated by Washington State Department of Transportation and Washington State University.

All information reported in this survey will be kept confidential.

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