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# Structural and Geographic Shifts in the Washington Warehousing Industry: Transportation Impacts for the Green River Valley

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ABSTRACT

Establishment level employment data indicate that the warehousing industry has experienced rapid growth and restructuring since 1998. This restructuring has resulted in geographic shifts at the national, regional, and local scales. Uneven growth in warehousing establishments across the Pacific Northwest has likely exerted a significant impact on the regional transportation system, but the extent of these transportation impacts remains unknown. Identifying these impacts is the goal of our proposed study. Recent and ongoing research indicates that growth in the warehousing industry is profound. County Business Patterns data published by the US Census Bureau indicates that at the national level, the number of warehousing establishments grew by just over 100 percent from 1998 to 2005. In 1998 there were 6,712 warehousing establishments in the US. By 2005, that number had increased to 13,483. Although a wide range exists within the warehousing industry, interview data collected by the authors of this proposal indicate that each warehouse handles between 25 and 100 trucks, or 50 and 200 trips, hence the location of warehousing establishments has a significant impact on transportation systems. At the county level, we see that in Washington, King County experienced the strongest absolute growth, adding 59 establishments to the 61 reported in 1998. In relative terms, however, Pierce County added warehousing establishments at a faster rate (159 percent) than any other county. The preliminary data produced in Goodchild and Andreoli's pending report clearly indicate that there has been strong growth in warehousing establishments at the national and state levels, but that the growth has not been even across states and counties. From a transportation perspective, these findings suggest that future research needs to focus on how these structural and geographic shifts impact regional and local transportation systems.

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# DISCLAIMER

## Abstract

Over the last decade the U.S. warehousing industry has experienced rapid growth, structural change and a discernable geographic shift in the location of new facilities. Part of this can be attributed to the emergence of mega distribution centers (mega DCs) that employ more than 100 workers, are larger than 500,000 square feet, and utilize a wide range of information technologies to manage operations. These changes have resulted in a geographic restructuring and indirectly contributed to increased dependence on transportation and truck travel, and a heightened exposure to high and volatile fuel prices.

Within Washington State, the warehousing industry has also changed. Historically, Washington had enjoyed a competitive advantage in the warehousing industry. While the state has experienced rapid growth in both the number of warehousing facilities and the number of employees in the sector, the state has lost *concentration* of the industry relative to other states both with respect to overall employment, and the presence of mega DCs.

Within the Puget Sound region there has been significant growth in employment within the Green River Valley, an industrial region served by SR 167 that stretches from I-405 to Sumner. While it is generally believed to have been an area of significant concentration over the study period (1998-2006), the Green River Valley has actually lost employment relative to employment in warehousing in the state, and the number of mega DCs has been stable over the study period, whereas the number has grown in Washington State.

## 1. Introduction

The interplay between emerging technologies and forces of globalization has permitted warehouses to grow in size and benefit from economies of scale. Previous work by the authors identified the resultant geographic shifts in warehousing at the national scale, in particular the growth and distribution of Mega DCs (Andreoli, Goodchild, and Vitasek). We begin with a brief review of the forces that have enabled the dramatic developments in the warehousing industry over the study period (1998-2006). While the common approach to facility location is to study site selection, this work does not predict the location of facilities, rather identifies their locations from observed data. We then compare growth in employment in warehousing in the Green River Valley, an area of significant warehousing activity and traffic volumes shown in Figure 1, below, to increases in imported containers at the Port of Seattle.

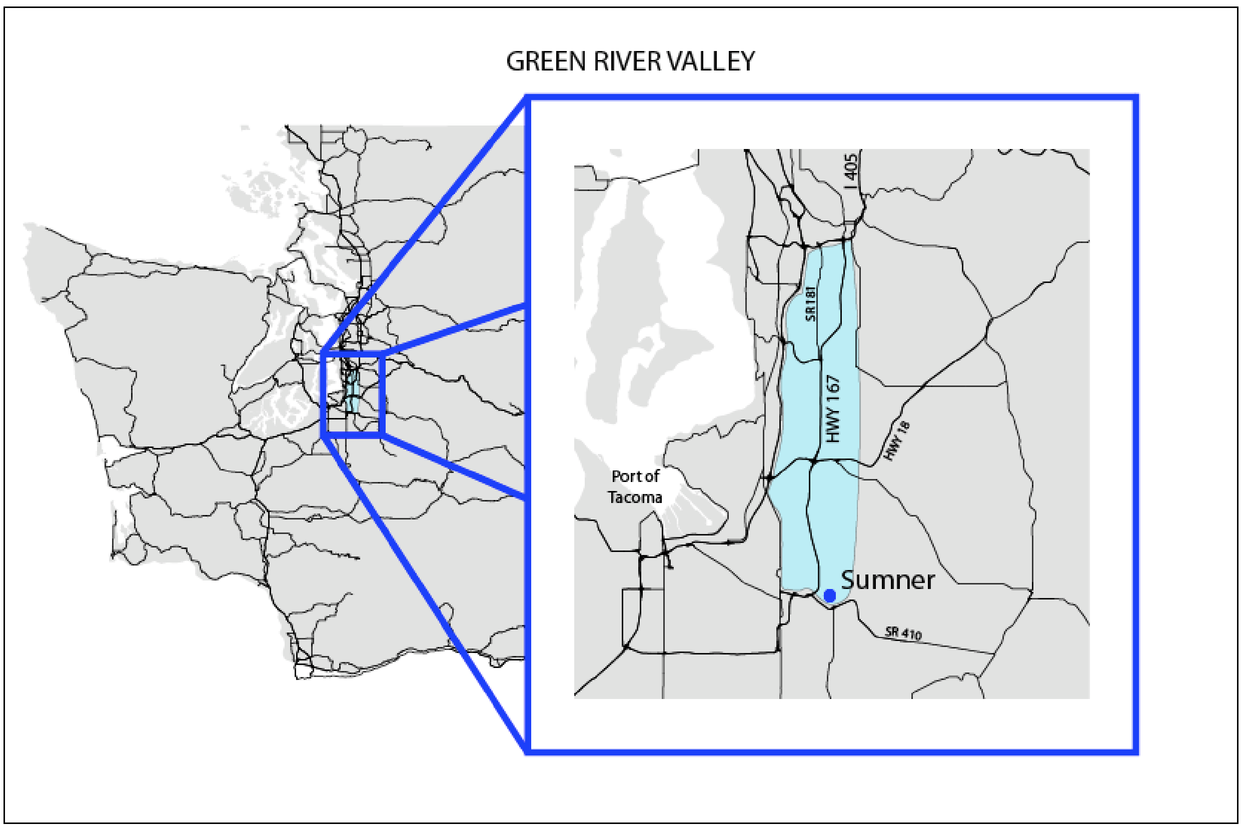


Table 1 The Green River Valley area of Washington

Common opinion is that there has been an increased concentration of warehousing activity in the Green River Valley, and a consequent increase in truck traffic, however, we suggest the area has actually lost warehousing concentration relative to the state.

## 2. National Trends and their Implications for Washington

A number of geographic analyses were conducted to consider the locations of warehousing facilities over the study period. At the state level, location quotients were calculated for both 1998 and 2006, and a shift-share analysis was also conducted using data from those same years.

2.1 *Warehousing Employment: State-by-State Comparison of Location Quotients*

Of the many analytical tools that can be deployed to compare economic activity in one area against the same economic activity in another, location quotients are a popular metric among geographers and location analysts. Location quotients (LQ) represent the relative concentrations of warehousing employment by state and offer a measure of competitive advantage. Location quotients are calculated by dividing the percentage of the total workforce employed in warehousing at the state level by the percentage of the workforce employed in warehousing at the national level. Values over 1.0 indicate that a state enjoys a competitive advantage, while values less than 1.0 indicate the opposite.

The US Census Bureau publishes establishment-level data on employment, wages, and employment-by-establishment-size in the County Business Patterns database (CBP). County Business Patterns data is available in digital format beginning in 1998, and the latest year reported at the time data was gathered for this study was 2006. These years therefore bookend the study period. In order to identify growth trends, industry data was analyzed at the national, state, and county levels. The map on the left in Figure 2 shows that in 1998 the states in the highest category – where location quotients are greater than 1.25 – were distributed evenly across the U.S. By 2005, a new geography had emerged. The map on the right shows that by 2005 competitive advantage had shifted to the corridor bounded by Indiana to New Jersey in the North and Mississippi to Georgia in the South. Within this band only 5 of 15 states are *not* in the highest cateogry. Of them only one state is classified in the lowest category, three have relatively neutral LQs (.91 to 1.10), and Virginia, with a LQ of 1.21 only narrowly misses inclusion in the highest category. Of the 35 states not located in this band, only two - Nevada and Rhode Island - are top performers. The final trend to note, is that in 1998, data was suppressed in eleven states in order to protect the privacy of individual respondents. By 2005, that number had dropped to only three. Notice that Washington State moves from the highest category, to the second lowest category, indicating a significant loss in concentration of warehousing.

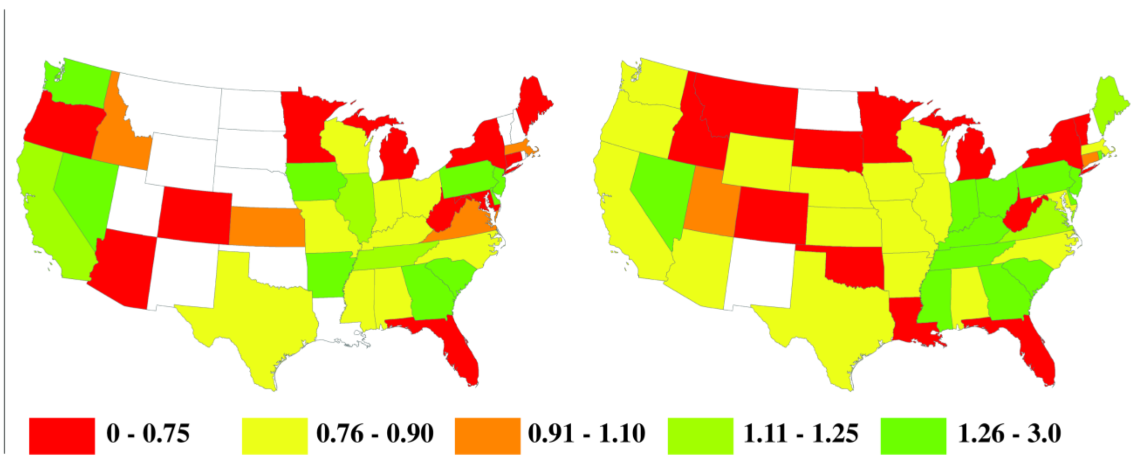


**Figure 2 Warehousing location quotients by state: 1998 (left) and 2006 (right).**

*2.2 Warehousing Employment: State-by-State Comparison of Local Factors Components*

Location quotients are useful metrics for comparing performance across areas. However, because they are ratios of ratios, shifts in total local employment and total national employment impact the final value as much as shifts in industry-specific employment. In order to overcome this obstacle, a shift-share analysis was conducted using the same CBP data that was used to calculate the location quotients.

Shift-share analyses break growth/decline into three components. Because we are only considering one industry, we are only concerned with one: the local factors (LF) component. The LF component of growth is calculated by subtracting observed industry change at the national level from the observed industry change at the local level. The LF component is a measure of shifts in competitive advantage. It can be expressed in relative (% growth) or absolute terms (number of jobs). Positive LF values indicate that a state experienced gains in competitive advantage whereas negative values indicate a loss of competitive advantage.

The shift-share analysis indicates that competitive position was significantly advanced in eighteen states. These states added at least 20% more warehousing jobs than they would have added had warehousing employment in these states simply grown at the same rate as the nation on the whole. Ten of these states added at least twice as many warehousing jobs.

By plotting location quotients (1998) against local factors components (see Figure 3 below), we can simultaneously identify: 1) the states that enjoyed a competitive advantage in 1998, and 2) the states that have advanced their competitive position. In a stable industry, one would expect a strong, *positive* relationship between location quotients and local factors values because states with a competitive advantage at the beginning of the study period should find it easier than lagging states to increase their advantage. Alternatively, as firms restructure and seek economies of scale made possible by emerging technologies and made feasible by forces of globalization, we may expect to see a spatial reconfiguration where new establishments are located according to a new distribution logic. Figure 3 shows that the correlation coefficient between location quotients (1998) and local factors components is strong but negative (*r* = -0.59). States with high location quotients were more likely to have lower local factors components than 'less competitive' states.

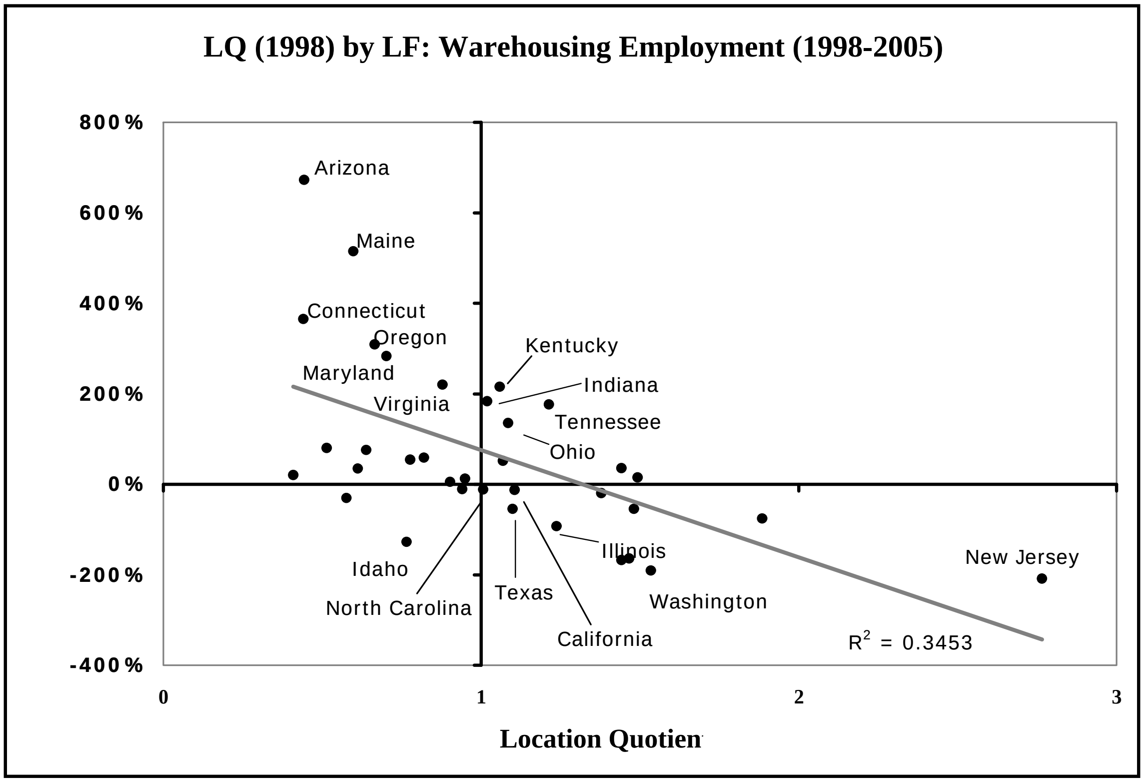


Figure 3 Location quotients and local factors.

What becomes clear from this analysis of location quotients and local factors components is that the structural change experienced by the industry is associated with a new spatial logic. If this were not the case, then we would expect to see a strong, *positive* correlation between the two indicators. Of interest is that the port states of California, Washington, and New Jersey all lost competitive advantage to interior states like Kentucky and Tennessee despite their proximity to both markets and points of entry.

## 3. Growth of Mega DCs at the National Level

*3.1 Growth in the Number of Establishments Categorized by Employment*

The data in Figure  reveals that – with the exception of the largest size category (warehouses employing more than 1,000 workers) – Mega DCs in the US employing more than 100 workers grew in number at roughly double the rate of small and medium size establishments.  When these nine categories are aggregated into just two: mega DCs and other warehouses, we see that other warehouses grew at a rate of 82.1% while mega DCs grew at a rate of 238.5%.

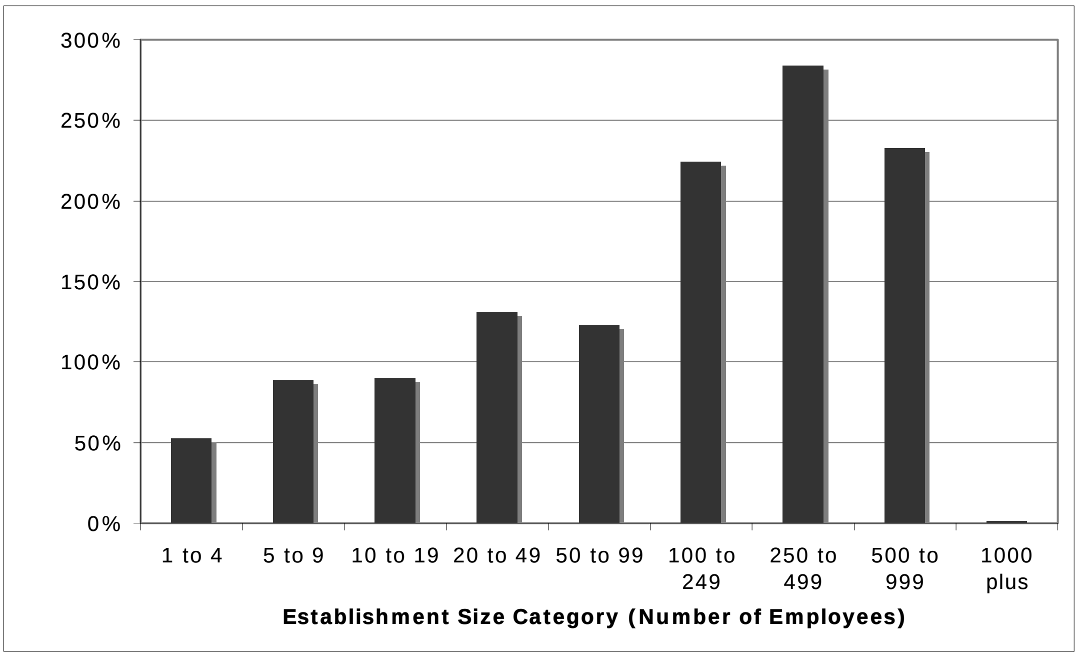


**Figure 4 Relative growth in the number of warehousing establishments by employment category 1998 – 2006.**

### *3.2 Growth in Number of Establishments by Physical Plant Size*

The growth characteristics revealed by the analysis of CBP data is validated by our analysis of a proprietary database of warehouse starts and completions created and maintained by ProLogis (warehousing development firm).  In

Figure  we see that completions roughly follow starts and that the strongest growth occurred between 1996 and 2001.

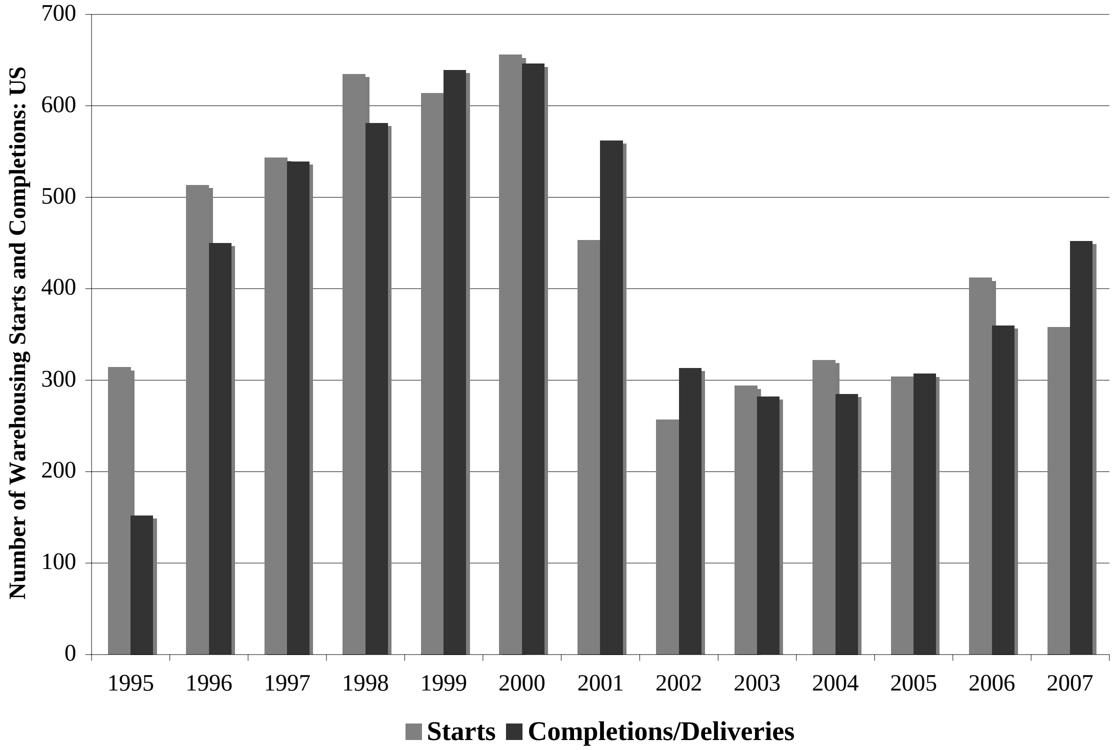


Figure 5 Warehouse starts and completions by year.

Like the CBP data, the ProLogis data indicates that growth rates were fastest among the largest warehouses when size is defined by the square footage of the facility rather than employment. When grouped by size a familiar trend emerges from the ProLogis data. We see in Figure that both of the two largest size categories – 500K to 1M sq ft and those over 1M sq ft – grew as a share of total warehousing starts. In 1998, less than 5% of all warehouse starts were over 500,000 square feet. By 2006, warehouses larger than 500,000 square feet comprised more than 25% of all starts. By contrast, small facilities experienced cyclical declines and medium size facilities remained relatively flat.

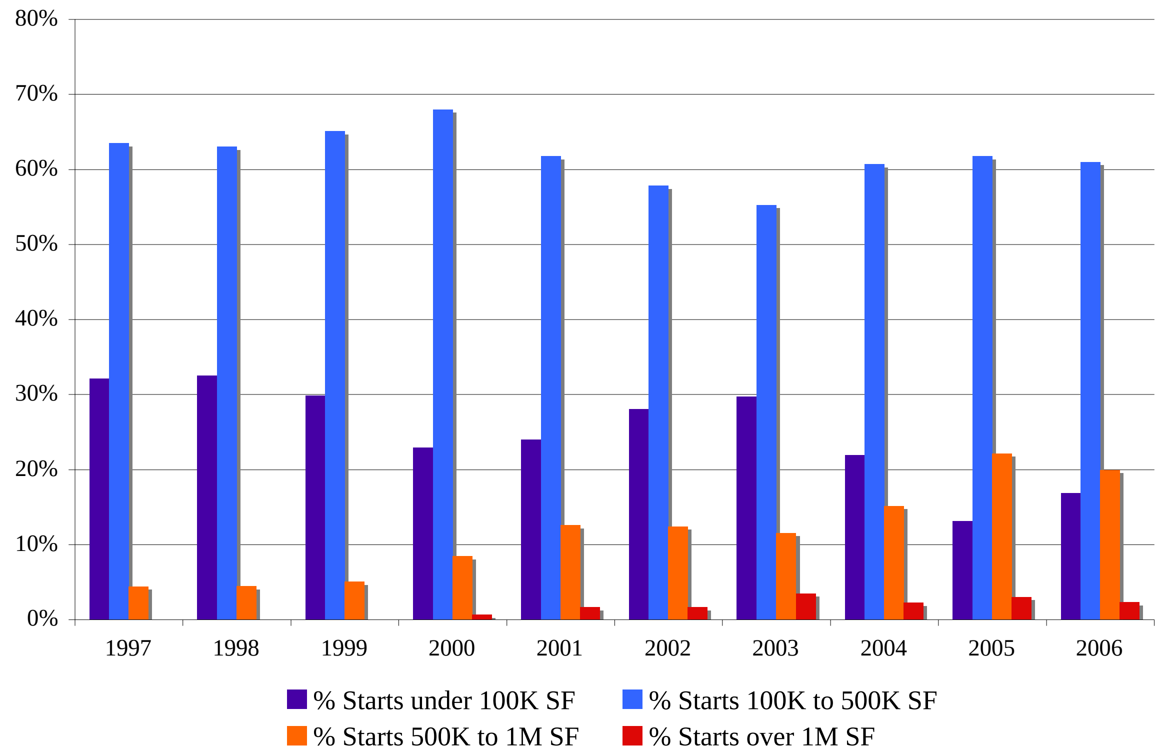


**Figure 6 Warehouse starts by size category: 1997 to 2006.**

### *3.3 Drivers and Enablers of Change*

Of the myriad conditions underpinning globalization including the reduction of trade barriers, certainly the constant downward pressure on logistics costs is a major factor. As a percentage of U.S. GDP, logistics expenditures declined from 13.5% in 1984 to 8.5% in 2003 (Andel 2007). Transportation costs make up the largest component of total logistics costs (61.5% in 2007), and the cost of transportation is directly related to the price of transportation fuels. A $10 increase in the price of crude leads to a 24 cent increase in the per gallon price of diesel and a 4 cent per mile increase in transportation rates (Simchi-Levi, Nelson, Mulani, and Wright 2008). Despite the rapid price hikes associated with the 1973 oil embargo and the 1979 oil crisis, the cost of refined petroleum products per Btu has remained incredibly low and it was during this period of inexpensive transportation fuels that globalization greatly accelerated. At the same time, the cost benefits of containerization were realized. Whereas low fuel prices have minimized the line-haul costs of transportation, containerization has greatly reduced the labor costs associated with intermodal transfers. Containerization has also permitted cargo vessels and freight trains to realize economies of scale. Finally, containerization reduces the need to break shipments at the point of entry, and the location of these activities can now be located at sites that minimize cost (Levinson 2006).

Mega DCs permit economies of scale in construction, and supervisory and management costs are spread across a larger number of employees. Per employee overhead labor expenses are thereby minimized. An analysis of occupation employment statistics (OES) data published by the U.S. Bureau of Labor Statistics shows that employee-to-management ratios grew by almost 300% over the study period. In 1998, the average warehouse manager was in charge of 12 employees. By the end of the study period, this number had grown to 32.

Larger warehouses are also able to handle the high volumes of traffic required to make 24-hour operations economically feasible. In turn, operating around-the-clock allows management to better schedule truck loading and offloading and reduce driver wait times. Extending the hours of operation also allows deliveries to be scheduled around times of typical highway congestion or to match port or rail operations hours.

Improvements and cost reductions in management technologies such as information management systems, automation, and sensors have allowed for the management of increasingly complex supply chains, and larger warehouses, for example JIT delivery strategies.

### *3.4 County-by-County Comparison*

Figure  maps the number of mega DCs by county using the CBP data. We are able to see that many are located in, or in close proximity to, major metropolitan centers. As can be observed in

Figure , the greatest number of Mega DCs, and the largest gains in the number of new mega DCs, were experienced in coastal counties of California and the Northeast. When statistics on mega DCs are normalized to population, however, these highly populated counties fall into the lowest category. This is shown in Figure . By conducting a global Moran's I analysis on the index of mega DCs by county we are able to establish that their location is neither randomly nor evenly distributed. Instead, the results show a high degree of clustering, suggesting the location decisions are influenced by geographic characteristics.

An examination of these maps indicates that much of the new growth is located in relatively remote counties like Shelby County, Tennessee and its neighbor, De Soto County, Mississippi. The population of these two counties combined is roughly 973,000. Despite the low population, 23 mega DCs are located there. By comparison, the population of King County, Washington was over 1.8 million in 2005, yet the CBP data indicates that only seven mega DCs are located there. The map of new mega DCs echos this pattern. By example, 22 of the 23 mega DCs located in Shelby and De Soto Counties were established during the study period. To contrast these statistics with a similar county with much more immediate market access, we turn to Middlesex County, New Jersey. With a similar population (790,000), and an equal representation of mega DCs (23 in 2005), it is interesting that only 16 of the mega DCs located there are newly established.

The geographic size of a market area required to justify a mega DC depends on the attributes of the product and the spatial and temporal demand for the product. In Washington State the Mega DCs are primarily concentrated in the South Puget Sound region. This is the industrial region that serves the most populous area of Washington State, the Puget Sound. Through local knowledge of warehouse operators, and individual conversations with several, we understand Western Washington to be the service area associated with  many of these facilities.

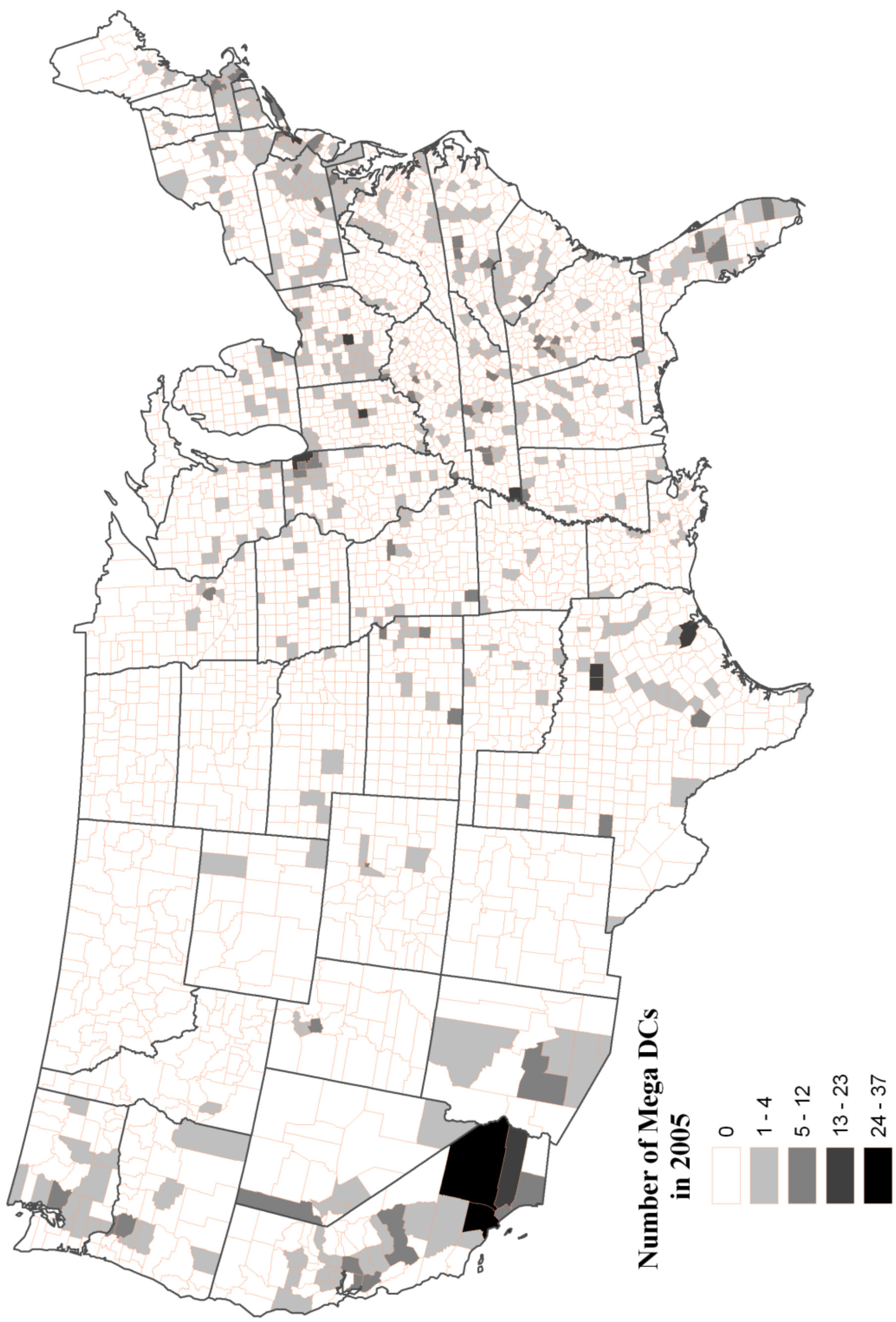

**Figure 7 Number of mega DCs by county in 2006.**

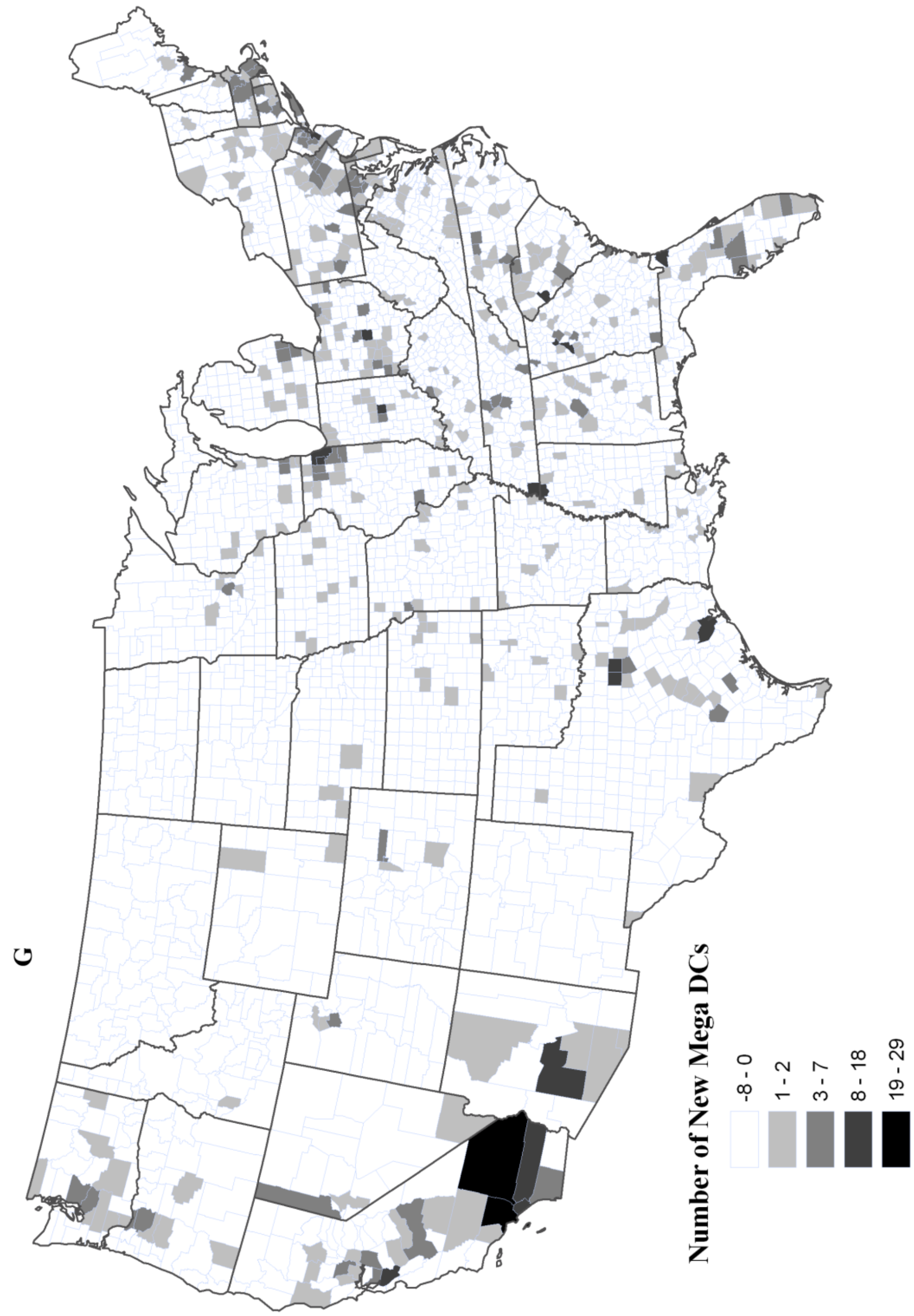


**Figure 8 Growth of mega DCs by county: 1998 to 2006.**

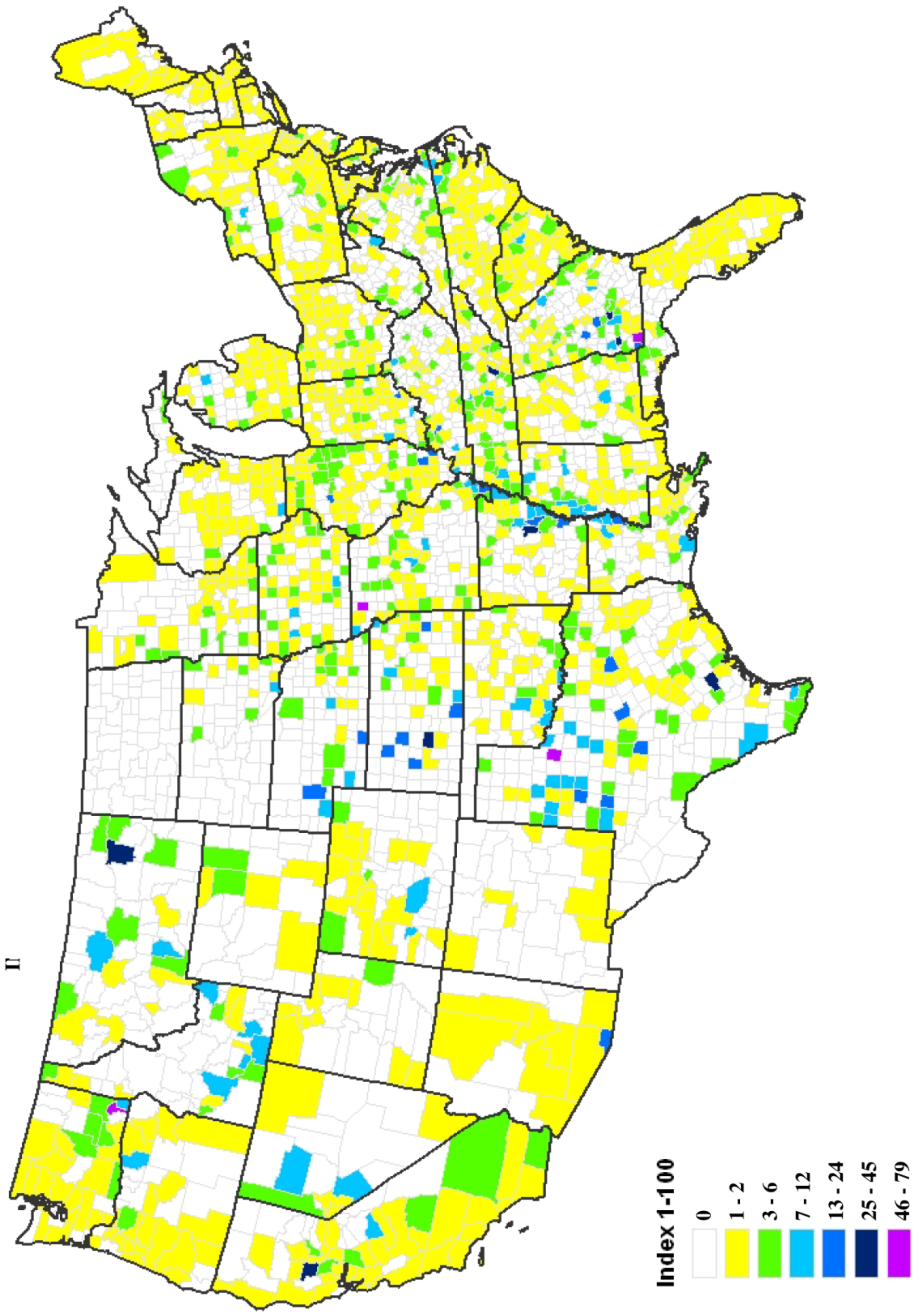


Figure 9 Index of warehousing establishments per worker, 2005.

## 4. Transportation Implications of the National Shifts

Relatively inexpensive transportation fuels contributed to the geographic dispersion of mega DCs. While trucking is the most expensive mode of surface transportation (air transport is prohibitively expensive for most products). The road network is much more expansive than the rail network, and unlike rail, trucks are not limited to strict time schedules. Persistently affordable fuels and flexible schedules have allowed supply chains to organize around truck-based Just-In-Time delivery strategies despite the fact that trucking is more costly per ton-mile. Many of the current distribution strategies including JIT, quick and fragmented deliveries, and using one's dedicated fleet are all based on the assumption of cheap oil. (Simchi-Levi, Nelson, Mulani, and Wright 2008).

Mega DCs serve mega markets that tend to cover a geographically dispersed service area. Therefore the final leg of the distribution network is – on average – longer than with smaller DCs. Because the final leg of the distribution network must be made by truck, the most costly mode of transportation per ton-mile, organizing supply chains around mega DCs increases truck miles travelled from these DCs to their destination markets and exposes these supply chains to higher transportation costs. As transportation costs increase so too do inventory carrying costs (Simchi-Levi, Nelson, Mulani, and Wright 2008), and net savings accrued to mega DCs decreases.

At some point, and this point will vary from firm to firm and network to network, additional transportation costs will eventually outweigh savings. Between 2002 and 2006 the price of crude more than doubled from $29 per barrel to just over $67 per barrel. Levinson (2008) argues that high fuel costs, converging international wage rates, and limits to economies of scale in transportation will soon reverse trends in globalization. Similarly, researchers at MIT show that substantial geographic reorganization will likely occur if prices rise to, and remain above, $150 per barrel. Their model indicates that moving from $125 to $150 per barrel increases the optimal number of DCs. Heuristically they argue that a single DC in Las Vegas may be replaced by three regional DCs: one in Portland, one in Los Angeles, and one in Albuquerque (Simchi-Levi, Nelson, Mulani, and Wright 2008).

Given the rates of natural decline for existing production and a lack of sufficient investment in exploration and production (IEA 2008), it is likely that fuel prices will eventually recover from their current values, and also become more volatile.

## 5. Warehousing Shifts and within Washington

As described in Section 2, Washington State has lost concentration in warehousing employment over the study period, although the state has still experienced substantial growth in the *number* of establishments, and the *number* of employees. Table 2 shows the employment in Washington as compared to the country.

**Table 2 Recent Growth in the Wareshousing Industry: US and Washington State, 1998 to 2005 (source: CBP).**

| Warehousing Employment | | | | |
|---|---|---|---|---|
| | 1998 | 2005 | 7-year Growth Rate | Equivalent Compound Annual Growth Rate |
| US | 119,493 | 578,040 | 383.7% | 25.3% |
| Washington | 3,620 | 10,613 | 193.2% | 16.6% |

Over the study period, growth in employment in Washington has been largest in King and Pierce Counties (Figure ).

In terms of mega DCs, Washington is not within the area of most significant growth in number of mega DCs, which, as shown in Figure  extends from Southern California through the manufacturing belt.

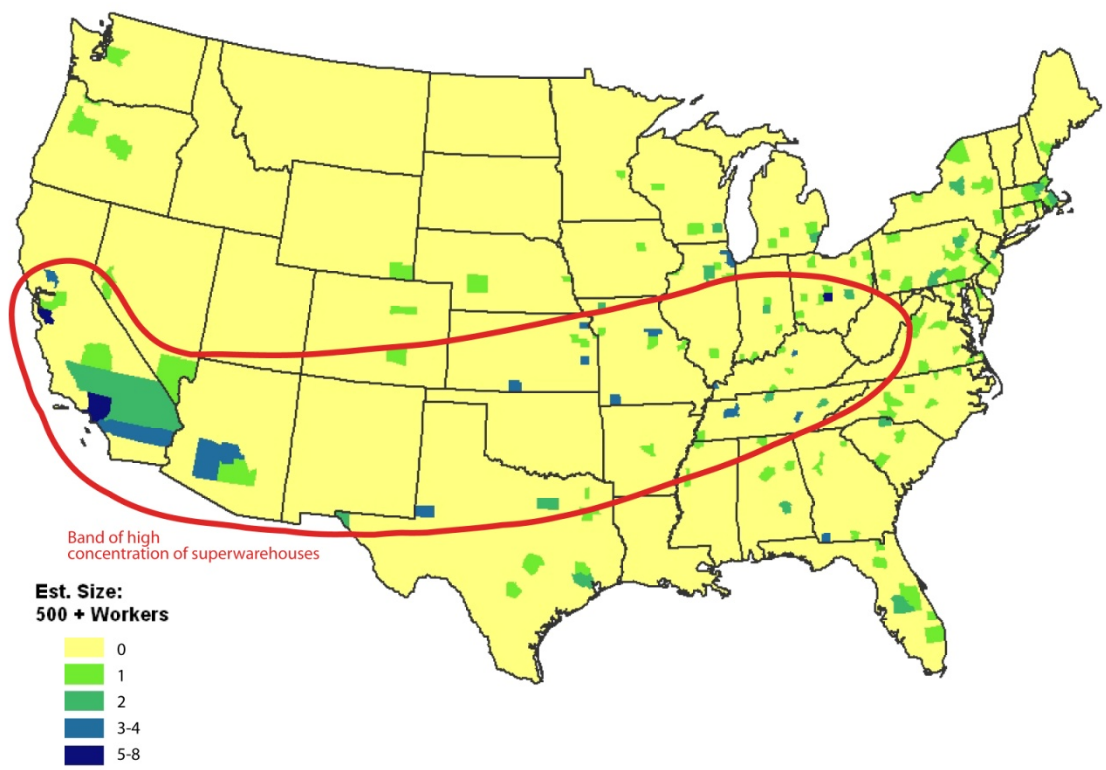


Figure 10 Number of Mega DCs (here showing 500+ employees) by country, 2005 (Source: CBP).

We now shift from a discussion of national trends, to a detailed analysis of changes within the Green River Valley (recall Figure 1).  The perception within the Puget Sound has been that this area serves the Ports of Seattle and Tacoma, and that warehousing activity has grown dramatically over the study period.  The Green River Valley is defined as the area bounded by I-405 on the north, Sumner to the south, I-5 to the west, and just east of SR167 to the east (shown in Figure 1).  The original impetus for this work was developed through conversations with the International Longshore and Warehouse Workers Union who were concerned about the “March Inland” – the movement of warehousing away from ports and towards the Green River Valley. It is for this reason that we carefully examine the Green River Valley, and estimate truck trips between this region and the Port of Seattle.

This analysis was conducted using establishment level ES202 data made available for the project through contract with the Washington State Department of Community, Trade, and Economic Development. This data was collected through the ES 202 program. Under the ES 202 program, each establishment is required to report covered employment and wages by quarter. NAICS codes, industry descriptions, and company names and contact information are also included in the dataset. However, we are obliged to strictly protect the privacy of these companies in any analysis of the data, so information can only be reported at an aggregated level.

Establishments identified as General Warehousing (NAICS 4931--)[1] were drawn from the larger dataset, and then filtered to only identify establishments reporting employment in the first quarter of each year during the study period (1997 to 2006) in order to eliminate any seasonal variations from the analysis. As such these employment totals are representative of the year, but in some isolated cases, employment levels varied by quarter. In general, however, the warehousing industry tends to employ to the trough of the business cycle. In periods of higher volume, temporary workers are brought in. Temporary workers are not reported as working in general warehousing because temporary employment agencies have a unique NAICS code. For this reason, employment is higher than the levels indicated, however, employment was not

[1] Note that the research on mega DCs utilized a broader definition which includes general warehousing, refrigerated warehousing, farm products warehousing, and other warehousing.

used to generate trips. Instead, employment levels were simply used to adjust trips generated at the Port of Seattle. Table 3 shows a summary of some data elements of the ESD data.

**Table 3 growth in employees in the Green River Valley and Washington over the study period.**

| Year | Green River Valley Employees in General Warehousing (NAICS 4931) | Percent Growth over Previous Year (GRV) | All Washington Employees in General Warehousing | Percent Growth over Previous Year (WA) | Percent of Washington Warehouse Employees in Green River Valley |
|---|---|---|---|---|---|
| 1997 | 1,480 | | 4,671 | | 31.7% |
| 1998 | 1,467 | -1% | 4,793 | 3% | 30.6% |
| 1999 | 1,598 | 9% | 4,337 | -10% | 36.8% |
| 2000 | 1,415 | -11% | 3,903 | -10% | 36.3% |
| 2001 | 1,544 | 9% | 3,705 | -5% | 41.7% |
| 2002 | 1,455 | -6% | 3,715 | 0% | 39.2% |
| 2003 | 1,275 | -12% | 3,554 | -4% | 35.9% |
| 2004 | 1,399 | 10% | 4,434 | 25% | 31.6% |
| 2005 | 1,726 | 23% | 5,114 | 15% | 33.8% |
| 2006 | 2,418 | 40% | 6,496 | 27% | 37.2% |

Several observations can be made from Table 3, which shows the number of employees in the Green River Valley and in Washington. First, there was substantial growth in warehousing employment in both Washington and the Green River Valley in the last three years of the study period. This pattern mirrors the pattern observed nationwide. Second, growth is quite variable, with jumps from -10% to 10% between years prior to 2003. Third, the percent of Washington warehousing employees located in the GRV has stayed relatively constant, and the Green River Valley does not possess a substantially higher share of the state industry.

The Green River Valley is known to serve a substantial proportion of containers entering the US at the Ports of Seattle and Tacoma. A 2003 a study by Heffron Transportation estimated that 23% of the containers leaving the Port of Seattle were headed to the Green River Valley (Heffron, 2003). This is the only available data that estimates the percentage of Port of Seattle trucks headed to the region. If we assume that trips to the Green River Valley increase or decrease from 23% at the same rate as concentration of employment within the region, we can estimate the percentage of trips going to Green River Valley for years other than 2003. This is the same assumption made by truck models that assume that truck trips can be estimated by employment levels (NCHRP, 2001). Between 2003 and 2006 we do observe an expected increase in truck trips to the GRV from the Port of Seattle from about 250 to almost 400 (this analysis is summarized in Table 4). However, this increase was not due to an increased *concentration* of warehousing activity in this region as was commonly reported by industry experts. Our data show that growth was instead driven almost entirely by the increase in imported container volumes through the ports.

When we consider the number of mega DCs in the Green River Valley we observe that the number has stayed relatively constant over the study period. The growth from 2 to 3 or 3 to 4 from one year to the next should not be seen as a 50% or 33% growth but rather a small sample problem and a small deviation in the number of employees at a particular facility. If for instance, a DC employed 92 workers in 2000, 103 in 2001, and 98 in 2002, it might appear from the data that a new mega DC was built in 2001 and went out of business a year later when in reality small fluctuations in employment around the cut-off (100 workers) is what is being reflected by the data. However, we can observe strong growth in Mega DCs in Washington State in the last 3 years of the study period.

**Table 4 Estimated truck trips from the Port of Seattle to the Green River Valley over the study period. Number of mega DCs in the Green River Valley and in Washington State over the study period.**

| Year[2] | Port of Seattle Import TEUs | Difference between Green River warehousing employment and the 2003 level | Percentage of trips going to Green River Valley (23% + difference between whs employment concentration year X and emp conc. In 2003) | Truck Trips per Day Going from Port of Seattle to Green River Valley | Total Mega DCs in GRV | Total Mega DCs in WA | % of WA Mega DCs located in GRV |
|---|---|---|---|---|---|---|---|
| 1997 | 575,640 | -4.2% | 18.8% | 208 | 4 | 10 | 40% |
| 1998 | 602,160 | -5.3% | 17.7% | 205 | 3 | 8 | 38% |
| 1999 | 583,822 | 1.0% | 24.0% | 269 | 4 | 9 | 44% |
| 2000 | 594,991 | 0.4% | 23.4% | 268 | 3 | 7 | 43% |
| 2001 | 497,068 | 5.8% | 28.8% | 275 | 4 | 7 | 57% |
| 2002 | 537,503 | 3.3% | 26.3% | 272 | 3 | 7 | 43% |
| 2003 | 542,863 | 0.0% | 23.0% | 240 | 2 | 6 | 33% |
| 2004 | 704,664 | -4.3% | 18.7% | 253 | 2 | 7 | 29% |
| 2005 | 846,311 | -2.1% | 20.9% | 340 | 3 | 11 | 27% |
| 2006 | 799,138 | 1.3% | 24.3% | 374 | 4 | 14 | 29% |

Assuming each truck leaving the Port of Seattle can carry 2 TEUs (the equivalent of a single container), we estimate the truck trips generated each day from the Port of Seattle to the Green River Valley. These trips will almost exclusively use SR 167, which serves the length of the valley and has suffered from significant congestion due in part to the contribution to traffic from these truck trips.

Warehousing employment in the Green River Valley could also be used to estimate truck trips using established truck trip generation rates. Many regional transportation models, for example that used by the Puget Sound Regional Council (PSRC) use employment to estimate truck trips for a variety of landuses (PSRC, 2003). While warehousing is not an explicit landuse

[2] The Port of Seattle import TEU volumes are estimated for 1997 and 1998 as this data was not available from the Port of Seattle. The ratio of import TEUs to total TEUs in 1999 was applied to published total container volumes in 1997 and 1998 in order to estimate values for 1997 and 1998.

in the PSRC model, the model does include unique truck trip generation rates for retail, wholesale, and transportation/communication/utilities. The modeling is based on the assumption that any retail facility generates the same number of trips per employee. Trips are estimated separately for light, medium, and heavy duty trucks. Similarly, and transportation, communication, or utility facility generates the same number of heavy duty truck trips in each time period. Trip generation rates from a variety of models and for a variety of landuses are summarized in a recent NCHRP report (NCHRP, 2001). 8.3% of studies reviewed explicitly estimate truck trip rates for warehousing facilities or terminals. In the marine port context trips are generated using ship arrivals or terminal acres. In the warehousing case, trips are generated using square footage or employees. In some cases tonnage is estimated instead of trips. The NCHRP report provides a summary of values used in a variety of models. These range from .02 to .5 trips per day per 1000 square foot, but are typically in the range of .2 to .5. Per employee these range from 0.3 to 0.7 trips per day. These ranges were estimated from a variety of data collection methods, but are based on empirical observation (NCHRP, 2001). A full comparison of truck trips estimated in Table 4 cannot be made using these factors, as the percentage of trips within the GRV that serve the Port of Seattle is not known, however, using 0.3 trips per employee, 725 trips would be estimated in 2006, implying the Port of Seattle traffic would account for 50% of trips. Using 0.7, almost 1700 total trips are generated in the Green River Valley, implying about 22% of the trips can be attributed to the Port of Seattle.

## 6. Conclusions

The warehousing industry is dynamic and between 1998 and 2006 has experienced rapid growth and restructuring, including the development of mega DCs. In fact, we can expect this industry to be constantly changing as it is shaped by economic and technological forces. Within Washington, the industry has also grown rapidly, although at a slower rate than the growth at the national level. The growth of warehousing and mega DCs within the state has not occurred in specific regions but has been spatially ubiquitous. While the Green River Valley is an area of significant warehousing and distribution activity, the concentration of warehousing in this area has not grown. Although not more concentrated, growth in this area has had significant impacts on traffic congestion due to the limited accessibility of the Valley (SR167). Growth in warehousing in this region can be attributed to growth in trade through the Ports of Seattle and Tacoma. Almost 400 truck trips a day can be attributed to the Port of Seattle alone.

We have clearly demonstrated that warehousing is a dynamic industry with a changing spatial logic. Earlier work by the authors also suggests there is a changing employment structure within warehousing organizations (Andreoli, Goodchild and Vitasek, 2009). On-site observations and interviews with DCs in the GRV indicate that current methods for generating truck trips using employment levels or square footage are not defensible due to the diversity of warehouse types and activities, but in aggregate may provide reasonable estimates. In many cases, additional employees actually imply additional processing and therefore fewer trips per employee.

## 7. Future Work

The warehousing industry is very diverse, and includes activities such as self storage, traditional storage facilities, and distribution centers. It also includes facilities that rely very little on labor through automation, or through limited activity, and heavily on labor to process goods. It includes facilities that emphasize storage, and those that do almost no storage and have high throughput. However, current methods use one trip generation rate for all facilities of this type. Through warehouse visits completed in support of this research, we observed a broad range of facilities including a very large grocery distribution center serving regional grocery stores, a cross-docking facility that can turn around trucks in less than 10 minutes, and distribution centers that store substantial product, but also perform significant processing. Even within this limited sample, we observe facilities that would vary by an order of magnitude in the truck trip generation rates per employee or per 1000 square feet. Current practice, which uses constant trip generation rates per square foot or employee cannot capture this diversity. Given the limited resources for the study, we have identified rich areas for future work. Clearly this includes:

- An improved understanding of trip generation rates for a variety of warehousing facility types
- Expansion of the transportation analysis to other areas within the Puget Sound, and other ports
- Consideration of other changes in industrial activity in the Puget Sound
- Development of a predictive model to forecast future warehousing activity and location nationally
- Better validation of the trip rates through truck counts

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