JOINT TRANSPORTATION COMMITTEE

Washington State Air Cargo Movement Study

APPENDIX B
AIR CARGO CONGESTION

Submitted by

WSP and KPA

JOINT TRANSPORTATION COMMITTEE

WASHINGTON STATE AIR CARGO MOVEMENT STUDY

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ACRONYMS

AADT ... Average Annual Daily Traffic
ACI ... Air Connectivity Index
ACRP ... Airport Cooperative Research Program
ASPM ... Aviation System Performance Metrics
ATFI ... Air Trade Facilitation Index
EFFI ... eFreight Friendliness Index
FAA ... Federal Aviation Administration
LOS ... Level of Service
LPI ... Logistic Performance Index
PSRC ... Puget Sound Regional Council
VMT ... Vehicle Miles Traveled

AIRPORT CODES

ALW ... Walla Walla Regional Airport
BFI ... Boeing Field International
BLI ... Bellingham International Airport
EAT ... Pangborn Memorial Airport
GEG ... Spokane International Airport
LAX ... Los Angeles International Airport
MWH ... Grant County International Airport
OAK ... Oakland International Airport
ONT ... Ontario California International Airport
PAE ... Snohomish County Airport/Paine Field
PDX ... Portland International Airport
PSC ... Tri-Cities Airport
SLC ... Salt Lake International Airport
Sea-Tac (or SEA) ... Seattle-Tacoma International Airport
SFO ... San Francisco International Airport
YKM ... Yakima Air Terminal/McAllister Field

Executive Summary

The Joint Transportation Committee of the Washington State Legislature initiated this study to evaluate the current and future capacity of the statewide air cargo system. This Air Cargo Congestion report presents a technical definition of air cargo congestion, assesses the extent of air cargo congestion in the state, and describes the impacts of this congestion to the local economy. This report builds on the *Market, Facilities and Forecast Technical Report* that is also part of this study.

Air cargo congestion is defined as the operating conditions approaching capacity when one or more system components becomes stressed, resulting in unreliability and increased costs. A set of performance indicators are proposed to assess whether airside, landside, and access system components are congested. These indicators are interrelated, and their importance depends on market needs, leading to a complex picture where no single indicator fully captures all the symptoms of congestion.

By combining this approach with the findings of the *Market, Facilities and Forecast Technical Report*, we concluded that congestion is a more pressing concern at Seattle-Tacoma International Airport (Sea-Tac) than at other airports in the state, which do face some concerns although they can be easily managed. More specifically, we found the following:

- **Airside capacity** is adequate throughout the state to accommodate expected cargo volumes. Performance data shows that Sea-Tac operates better than regionally competing airports such as SFO and LAX, and on par with other regionally important airports such as PDX, OAK, and SLC. Other air cargo airports in the state likely have adequate airside capacity given this measure. Congestion costs from airside delay and unreliability are low relative to other nearby states. Planned infrastructure investments and improvements at airports throughout the state are expected to maintain adequate airside capacity.
- **Landside capacity** is inadequate to meet the cargo needs of the main air cargo airports in the state, particularly at Sea-Tac. Planning analysis shows that Sea-Tac will begin having a deficit in cargo buildings in 2021, which will reduce the efficiency of handling cargo at this airport and could lead to system congestion. This deficit could be worsened by the rapid growth of passenger demand at this airport and increasing competition for on-airport space. As there are limited on-airport opportunities for expanding cargo building capacity, alternative strategies such as off-site facilities are required. Several properties in the immediate vicinity of the airport, north of SR-18, have been investigated previously and are being considered as part of the Sea-Tac master plan. In addition, air cargo related businesses have begun to locate in Kent. While distribution center availability in Kent has tightened considerably in the recent past, air cargo volumes are relatively small compared to regional trucking and distribution, so that the real consequence of warehouse market conditions needs to be further explored. A similar situation is occurring at Spokane International Airport, although in this case there is ample on-airport land available for capacity enhancements. The planning analysis also showed that there is currently a truck and passenger parking deficit at Sea-Tac, Boeing Field International (BFI), and Spokane International. Reducing this deficit for Sea-Tac and BFI will be a challenge because of land availability.

- **Access capacity** is restricted in Seattle airports (Sea-Tac and BFI) because the main access interstate, I-5, is rapidly becoming congested. This increases costs to shippers and trucking companies, and affects the way shipments are dispatched and managed. Even so, roadway conditions may not be a material competitive disadvantage compared to the congestion surrounding the rival airports SFO and LAX. Washington DOT's Puget Sound Gateway Program includes several highway projects that will improve accessibility to Sea-Tac. Access capacity is adequate at other airports in the state.

Air cargo congestion at Sea-Tac would not only reduce the performance of the airport and increase costs to shippers, but it could possibly force shippers to consider other regionally (West Coast) competitive airports. An analysis was conducted to assess the impacts of a hypothetical shift of 10 percent of cargo demand at Sea-Tac to other airports. It was found that VMT in Washington State would increase by 320,000 to 740,000 per year. This increase would generate significant emissions of pollutants and increase the accident risk on highways. Moreover, having to truck freight to regionally competitive airports would cost shippers from $760,000 to $5 million per year, depending on which airports the demand would shift to.

Many industries stand to be affected by air cargo congestion. Airports in Washington state handled $47.6 billion in freight in 2015, and looking to the future air cargo value is anticipated to surge to $174 billion by 2045. Air cargo is used by high-value supply chains that are critical to the region's economy, and are expected to become even more important in the future. These supply chains typically use just-in-time strategies that place a very high premium on travel times and reliability. Congestion that diminishes the performance of airports and causes delays and unreliability can be particularly costly for these supply chains. It has been estimated that shippers value travel time by air 18 times higher than travel time by truck, and reliability 142 times higher by air than by truck.[1] It is clear that reliability is the most important reason for shippers deciding to rely on air freight services, and that risks to reliability from air cargo congestion impose a substantial economic penalty to these industries.

[1] De Jong, G., et al., *New SP-values of time and reliability for freight transport in the Netherlands.* Transportation Research Part E: Logistics and Transportation Review, 2014. **64**: p. 71-87

1 Introduction

The Joint Transportation Committee of the Washington State Legislature initiated this study to evaluate the current and future capacity of the statewide air cargo system. The study objectives are the following:

- Educate policy makers about air cargo movement at Washington airports.
- Explore possibilities for accommodating the growing air cargo market at more airports around the state.
- Identify the state's interest and role in addressing issues arising from air cargo congestion.

This study will identify opportunities and constraints for using existing capacity at other airports around the state to meet the increasing demand for cargo operations, potentially reducing the growth that SeaTac must accommodate.

This specific technical report includes the following:

- A thorough review of the literature identifying and tracking congestion in the air cargo system
- A clear definition of air cargo congestion with associated metrics that can be operationalized throughout the state
- An assessment of the extent to which the state's air cargo system is congested, considering airside, landside and airport access system components
- An analysis highlighting the potential impact of congestion at Sea-Tac International on air cargo logistics, affected industries and the state economy

This report builds on the *Market, Facilities and Forecast Technical Report* submitted previously by making use of the facility requirements analysis to infer existence of congestion in various system components, considering the air cargo market capture analysis when determining how different industries are impacted by congestion, and using information in the air cargo inventory to identify potential causes of congestion. Finally, the analysis will support development of strategies to better utilize existing capacity and meet projected demand at state airports.

2 Congestion Definition and Metrics

The definition of congestion will vary in different conditions and different contexts. In air cargo, congestion is broadly used to describe conditions when the air cargo system has difficulty keeping up with shipper demand. This could result from a variety of constraints, and have a wide range of negative impacts. Congestion imposes costs on shippers, who may absorb them as the price of doing business but at a penalty to profit. Large or persistent penalties could lead them to restructure their supply chains or utilize air cargo differently. Congestion at hub airports could lead shippers to seek out other hub airports, which are often located far away. Over the long-run, it could even reduce the competitiveness of some local companies and cause them to move production or to lose business.

This section first describes the most commonly used definitions of air cargo congestion and then it proposes a framework that can be used to assess the degree to which the air cargo system in Washington state is congested, and the possible effects of congested conditions in the future.

The term *air cargo congestion* is commonly used to describe situations when demand increases in the short-run beyond what airports and carriers can handle. For example, when air cargo demand from Asia to the U.S. and Europe surged during the 1st quarter of 2017, it was said that Asian and Gulf air hubs were becoming congested,[2] as the system had trouble keeping up with demand, resulting in longer lead times and higher rates. In another example, changes in routes, personnel cuts, and higher passenger volumes were seen as risk factors with the potential to cause air cargo congestion during the upcoming holiday season.[3] This type of congestion is system-wide and results from the inability to meet short-run surges in demand. Carriers and airports try to anticipate these surges to minimize costs and disruptions, particularly during the holiday season, although sometimes demand can be higher than expected or unforeseen operational issues can affect their performance. In the media, congestion is often synonymous with rate hikes, as carriers attempt to adjust resources to meet demand.

In contrast, researchers usually think about air cargo congestion in the long-run, which is more appropriate for investigating questions about investment priorities and system efficiency. In the long-run, airports and airlines have the ability to adapt and respond to changes in demand, by making investments or changing service patterns. In the short-run, it is assumed that these stakeholders have limited ability to redeploy assets or change operations, leading the capacity of the system to remain fixed for the time being. In the short-run, congestion results from demand spikes or performance issues, while in the long-run, congestion results from structural constraints that may be resolved with significant capital investments.

The rest of this section focuses on congestion in the long-run. Short-run congestion is discussed in Section 3 as arising from the lack of freight service to certain markets, particularly when there are seasonal or short-term spikes in demand.

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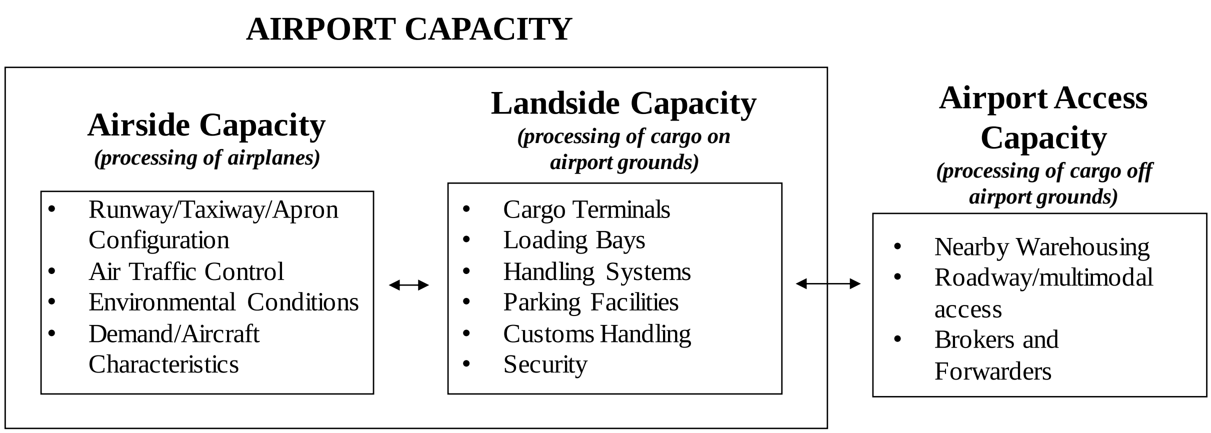
[2] Lennane, Alex (2017, March) Air freight rates out of Asia soar as capacity tightens. *The LoadStar*
[3] King, Lewis (2017, July) Panalpina warns shippers to book now to offset early peak-season congestion, *Air Cargo World*

2.1 SYSTEM COMPONENTS

The air cargo system is complex and any one of its components can cause congestion. Figure 2-1 shows a useful way to conceptualize the components involved. Air cargo capacity can be broken down into three elements:

- **Airside capacity** is determined by all the subsystems needed to process airplanes. This includes the configuration and characteristics of the runways, taxiways and ramps, which is particularly important for larger freighter airplanes. The characteristics of the airplanes and the environmental conditions also affect the processing of planes by the airport. Air traffic control is often taken as a given, although technical issues or personnel shortages can also severely restrict capacity. The services provided by carriers also determines capacity for different types of demand. Cargo service in the belly of passenger airplanes is fundamentally determined by the economics of passenger travel and not by freight demand. The widebody aircraft needed for belly space vary in size, and the amount of cargo that can be carried is also affected by the weight of fuel required to reach destination.
- **Landside capacity** is determined by all of the subsystems on airport grounds that process cargo. Once off the airplane, cargo is transported and handled through a terminal for processing and customs clearance. Warehousing space, personnel availability, and mechanical issues can cause delays. Security and screening can be time-consuming and have resource limitations. Cargo is then transferred onto awaiting trucks, which can be restricted by the number of loading bays and parking spaces, particularly on land-constrained airports. The internal configuration of the airport, including the internal system of roads, also affects landside capacity.
- **Access capacity** is determined by the ability shippers to reach the airport. The road configuration leading to the airport and the incidence of traffic congestion can impose costs and delays to shippers. Severe delays caused by accidents, for example, could lead cargo to miss scheduled flights. The availability of nearby brokers, forwarders, ground carriers and warehouses also affects the ability of shippers to use an airport efficiently. Off-airport facilities not only relieve pressure for on-airport terminals, but in many cases are part of a larger customer distribution system.

Figure 2-1: Air Cargo System Components Affecting Capacity

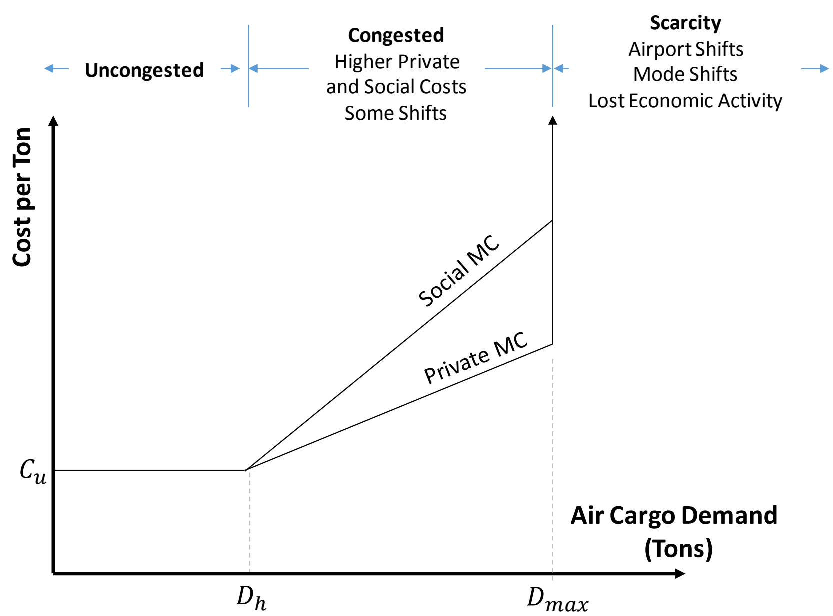


All these components, working together, determine the ability of an airport to process cargo. Delays in any one component can quickly spread to another, snowballing into affecting large portions of the system. Most of these components are interrelated, and to an extent, the performance of the whole system depends critically on the weakest component. Not having enough truck parking can impose constraints just as not having enough airplanes. Without enough parking, trucks could back up along the access roads during peak hours of the day, while arriving cargo sits in the terminal. This then stresses other parts of the system, such as the capacity of the terminals. Airport managers and airlines rely on experience and careful planning to ensure cargo is processed efficiently.

2.2 CONGESTION DEFINITION

In economic terms, congestion occurs when the marginal cost of moving through a system—the cost of one additional unit—increases with demand. Congestion is easier to visualize for automobile traffic than for air travel. As traffic volumes on a road increase, a point is reached when speeds begin to decrease and eventually gridlock sets in. Similarly, in air cargo, congestion refers to the situation when airports and carriers have insufficient resources to process seamlessly all cargo demand. This can be visualized in Figure 2-2. The vertical axis displays the total costs (per ton) of shipping through an airport, which include the prices paid by shippers as well as other non-priced costs such as travel time, delay, and unreliability. In economics these are often called *generalized costs*. These could also include other negative factors or inconveniences that are hard to monetize by nonetheless impose frictions in the air cargo system. The horizontal axis displays the amount of cargo (in tonnages) moving through the system. While the figure is conceptual, it helps to define basic dynamics.

Figure 2-2: Air Cargo Congestion and Capacity



In this idealized example, the airport is able to serve cargo demand lower than D_h at an uncongested cost per ton C_u. Below this level, all system components work well and demand can be served without friction. As demand increases past D_h, one or several of the system components shown in Figure 2-1 will become stressed, starting to cause performance issues. Carriers at first will strive to maintain performance by adding assets, including labor, which diminishes productivity and increases costs. Rates could be maintained at current levels, affecting short-term profitability, but they are likely to be increased in the long-run to cope with persistently higher costs. Shippers may pay these rates, but the market becomes more expensive to serve and less attractive as a business location. If problems continue, some carriers might move operations off-site, which could add to costs. Further degradations of performance will lead airports to lose business, as shippers seek out alternative airports with usable service, which typically are hubs in another geographic region. Manufacturing for some products could even be moved to a plant in a different location.

The higher rates and worse system performance represent additional costs to shippers. In Figure 2-2, this is represented by the *private marginal cost* curve sloping upward, which considers all the costs faced by shippers. As demand continues to increase, the airport will reach capacity D_{max}, after which no additional demand can be served. According to the standard definition of congestion, this idealized airport can be said to be congested between demand levels D_h and D_{max}. It is important to emphasize that an airport can be congested, but still operate well below its capacity. It might be desirable to make investments to reduce congestion, even though the airport has ample capacity to accommodate additional throughput. Often airport planning analyses focus on capacity, when in fact investments or improvements in operations should be taking place well before capacity is reached. Once capacity is reached, the system is likely to have been experiencing congestion for a prolonged period of time, during which shippers will have faced higher costs.

An airport can be congested, but still operate well below its capacity.

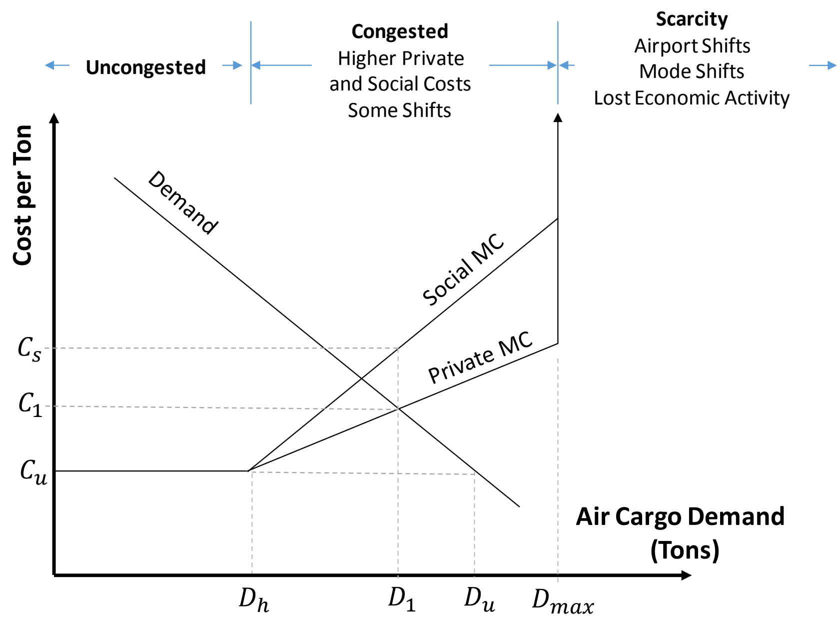
As demand approaches capacity D_{max} and congestion worsens, the costs of shipping through the airport will increase to the point when shippers will start considering other alternatives. If demand increases past capacity D_{max} there will be a scarcity of air cargo service and shippers will be forced to employ one or several of these alternatives. At this point, the region will find itself at a competitive disadvantage relative to other regions with better air cargo service. Airports have the ability to avoid this by making investments that increase capacity and ameliorate the onset of congestion. Section 2.5 in this report lists several measures that could be used by airports to determine when they are operating in a congested regime (past D_h) and approaching capacity D_{max}.

If demand increases past capacity D_{max} there will be a scarcity of air cargo service and shippers will be forced to employ one or several of these alternatives. At this point, the region will find itself at a competitive disadvantage relative to other regions with better air cargo service

Figure 2-2 also shows the *social marginal cost* curve for a congested airport. This curve includes the costs accrued to society from serving additional cargo demand, including to other shippers and non-freight users. Private marginal costs are the main component of social costs and are shown also in this figure. When an airport is congested, each additional unit of cargo will face a higher cost than the previous one (as shown by the upward sloping private marginal cost curve), but it will also cause an additional cost on other shippers using the airport. For example, as demand increases, delays will increase for everyone, not just the shipper that sent the last package. The *social marginal cost* curve in addition includes costs accrued by other users; for instance, if cargo terminal capacity must be found off-airport, trucks traveling to and from these facilities will add to congested highway volumes that affect all travelers on the roads and reduce mobility for nearby communities. When considering the costs of congestion in any transportation network it is important to consider all of these social costs so that policy recommendations can be comprehensive.

Whether an airport is congested depends critically on the demand for that airport. The demand curve is drawn in Figure 2-3 as a downward sloping line, indicating that demand for air cargo will be higher at lower per unit costs. With this demand curve the market would equilibrate at demand D_1 and cost C_1, reflecting the cost to shippers. In this case, any additional cargo would face a congestion cost $C_1 - C_u$, which is equal to the equilibrium cost minus the uncongested cost.

Figure 2-3: Air Cargo Supply-Demand



2.3 DEFINITION

The framework presented above allows for a technical definition of air cargo capacity and congestion. **Air cargo airport capacity**—as determined by the capacities of its constituent airside, landside, and airport access components—is defined by D_{max}. **Air cargo congestion** is defined as the operating state where an airport sees demand lower than capacity D_{max}, but higher than a threshold D_h at which certain system components become stressed. In other words, congestion is when costs start to climb because demand is approaching the limits of capacity.

Ideally, levels of congestion should be measured with performance data, including carrier costs. Every system component should be monitored closely in order to observe degradations of performance, in the way of increased processing times or unreliability. However, alternative approaches are required to assess whether operations are congested and approaching capacity. This is because this type of information is only available for some of the components involved (as detailed in the following section), the interaction of components is complex, and carrier costs are confidential. One alternative employed in this study is to compare the physical characteristics of the airport to industry benchmarks. Section 2.5 details a set of measures that combine performance data (where available) and benchmarking of physical assets to identify the extent of congestion in air cargo airports. In effect, this approach is capturing symptoms of congestion (or lack of it) as indicators of overall conditions.

2.4 REVIEW OF POTENTIAL MEASURES

Over the years, different measures have been proposed to quantify airport performance. Some of these relate more directly to congestion, and others were developed to assess investment needs. Below is a list of measures found with an assessment of their usefulness in this study. Of these measures, the CANSO Performance Measures and the Federal Aviation Administration's (FAA) Aviation System Performance Metrics (ASPM) are most applicable in the JTC study.

- **Reynolds-Feighan and Button (1999)**[4] studied the performance of airports around Europe to identify those affected by congestion. It used delay as a proxy for congestion, focusing on two sources of data coming from the Association of European Airlines, and the Center for Delay Analysis at EUROCONTROL. Both of these report different measures of delay (observed and modeled) and other information about factors causing delay and other issues. The study ranked the most congested airports and did a correlation analysis to help determine potential causes. This study did not focus on congestion affecting air cargo specifically.

  Implications: Implementing this in the JTC study would require observing delay to infer congestion. It would require analyzing the FAA's ASPM database, which shows the scheduled arrival, actual arrival, and delay for flights to and from major airports in the United States. In Washington state this only includes Sea-Tac. (ASPM findings are presented further below.)

- **World Bank's Logistic Performance Index (LPI)**[5] is a survey of freight and logistics users that is conducted every couple of years to assess the performance of various countries along six criteria that facilitate trade (customs, infrastructure, international shipments, logistic quality, tracking, and timeliness).

  Implications: Implementing this in the JTC study would require conducting an expansive survey of freight and logistics users to help identify where and how system congestion is affecting them, and is well beyond the scope of this study.

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[4] Reynolds, A. J. and Button, K. J. 1999. "An assessment of the capacity and congestion levels at European airports," *Journal of Air Transport Management* 5, pp. 113-134.
[5] Arvis, J., Saslavsky, D., Ojala, L., Shepherd, B., Busch, C., Raj., A. Naula, T. 2016. Connecting to Compete 2016: Trade Logistics in the Global Economy. The World Bank.

- **Air Connectivity Index (ACI)**[6] is an index that summarizes a region's level of integration with the rest of the world by analyzing passenger and cargo airplane data. In essence, a higher ACI indicates that a region has lower air shipping costs to the rest of the world than regions with lower ACIs. This measure considers the availability of service to various destinations globally, not just from the closest trading partners. This indicator is calculated by estimating an endogenous gravity model on region-to-region flow data and calculating the average impedance for a region to the world, weighted by attraction level. This measure considers both passenger connectivity and freight connectivity.

  Implications: Because the ACI has only been calculated at a country level, using this approach in our study would require estimating the ACI for different states in the United States, which would be difficult given the data available and potentially not very insightful because domestic hub operations affect every state. Moreover, this analysis does not describe how congestion at airports might be affecting connectivity or service, which is the main focus of the JTC study.

- **Air Trade Facilitation Index (ATFI)** and **eFreight Friendliness Index (EFFI)**[7] are indices that use a multi-criteria analysis to assess how well a region is served by air cargo. The ATFI focuses more broadly on air cargo trade (looking at a variety of international databases), while the EFFI focuses more narrowly on the usage and penetration of electronic transactions in air cargo. The weights in the multi-criteria analysis were developed using expert judgment.

  Implications: Using a multi-criteria analysis is more useful for comparative analysis (evaluating how one airport or region stacks against another), which is not the goal of the JTC study. Moreover, this analysis would not indicate if an airport is congested or the impacts on the local economy.

- **CANSO Performance Measures**[8] lists several airport delay, capacity and operational measures, primarily focusing on airside systems. These measures do not address freight specifically; however, they cover a wide range of areas, including delay and capacity. No data sets are recommended.

  Implications: Many of the capacity measures recommended in this study were adapted to freight and may be used in the JTC study to report congestion in Washington state. Additional measures relating to belly and freighter capacity available and load factors could be useful to assess service availability. Tracking these measures provides an understanding of the different pieces that could be causing frictions in the movement of freight, and together provide an understanding of whether congestion is negatively affecting operations.

- **Francis, Humphreys, and Fry (2002)**[9] discussed the history of airport performance measurement worldwide and conducted a survey of airport managers to ascertain current benchmarking

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[6] Arvis, J. and Shepherd, B. 2016. Measuring Connectivity in a Globally Networked Industry: The Case of Air Transport, The World Economy.
[7] Shepherd, B., Shingal, A., and Raj. A. 2016. *Value of Air Cargo: Air Transport and Global Value Chains*. December 6, 2016
[8] CANSO. 2015. *Recommended Key Performance Indicators for Measuring ANSP Operational Performance*. March 2015.
[9] Francis, G., Humphreys, I. and Fry, J. 2002. "The benchmarking of airport performance," *Journal of Air Transport Management 8*, pp. 239-247.

practices. It includes a general discussion about delay benchmarking, as a proxy of congestion, but does not discuss air cargo specifically.

Implications: Results are not applicable to the JTC study because it does not affect air cargo specifically.

- **Air Freight Logistics Sustainability Accounting Standard (2014)**[10] proposes measures centered on reducing the environmental footprint and safety of logistics activities.

  Implications: No measures were proposed that focused on capacity or congestion, so it is not useful for the JTC study.

2.5 RECOMMENDED CONGESTION MEASURES

A set of measures emerges from the literature review that can be tracked to evaluate if an airport is operating under congestion and approaching capacity. The measures either quantify performance directly related to congestion, or describe physical characteristics of airside, landside, and access systems. Performance measures quantify outcomes, such as travel times and reliability. The list below includes a couple of measures on calculating airside and access congestion. The on-time performance and delay of arrival and departures are tracked closely by the FAA in the ASPM. These measures provide a clear sense of how the airport configuration handles the demand for aircraft takeoffs and landings. Other measures listed to monitor airside congestion describe the characteristics of the airport (quantity of parking spaces or quantity of square feet of on-airport warehousing, for example), which can then be benchmarked against other airports. This was the approach taken with the Facility Requirements analysis contained in the *Market, Facilities and Forecast Technical Report*.

Not all these measures are required; however, this report and the *Market, Facilities and Forecast Technical Report* attempt to provide information for as many of them as possible. The focus of this list is on freight-specific measures; however, it also includes passenger measures to the extent they affect freight.

- Airside congestion:
  - Average on-time performance and delay from FAA's ASPM
  - Average weekly freighter and belly aircraft operations
  - Average daily passenger aircraft operations
  - Arrival and departure peaking throughout the day
  - Number of aircraft parking pads allocated to cargo, square feet of ramp space
  - Current and forecasted aircraft parking needs by FAA aircraft type
  - Air space restrictions
  - Adverse weather frequency

[10] Sustainability Accounting Standards Board. 2014. *Air Freight & Logistics Sustainability Accounting Standard.* September 2014.

  - Runway and ramp pavement strength
  - Runway capacity
- Landside congestion:
  - Square feet of cargo warehouses by belly, integrator, and freighter uses
  - Square feet of refrigerated cargo warehouses
  - Airport warehouse utilization factor (yearly tonnage/warehouse square feet)
  - Percentage of cargo warehouse area leased
  - Number of truck parking spaces
  - Truck queuing capacity
  - Air cargo facility planning requirements met from Airport Cooperative Research Program (ACRP) Report 143
  - Security and screening times and queues
- Access congestion:
  - Average speeds of roads immediately accessing airports
  - Average travel time and 95th percentile travel time for reaching airport from five key freight generating destinations. Time-of-day detail could be included to assess impact on meeting aircraft schedules.
  - Off-airport warehousing square feet
  - Current and forecasted Level of Service (LOS) on roads accessing airport

No single measure alone will indicate whether air cargo operations at an airport are congested. Airports are complex systems with many interrelated parts, that each need to work well for freight to move seamlessly between trucks, facilities and airplanes. The recommended approach collects information from a variety of sources that describes how freight is being served. The metrics span airside, landside and airport access features system components.

A wide range of measures is needed as well because different types of information are available for different airports. For example, the ASPM measures of delay and reliability are very useful in assessing airside congestion; however, these are only available for Sea-Tac. For airports that do not have performance measures, it will be necessary to rely on the benchmarking of descriptive measures. This will provide a reasonable estimate of whether an airport has the adequate systems to handle a certain volume of freight.

3 Capacity

3.1 AIRSIDE CAPACITY

3.1.1 Freight Service

Airside capacity is fundamentally determined by the availability of air cargo service to markets all over the world. The supply of cargo service by carriers depends on various factors, including the level of cargo and passenger demand for specific markets and the existing pricing structure. Low demand for any particular market will inevitably result in a fewer number of flights being offered, if any. Air carriers generally provide two different types of cargo service: freighter and belly. Freighter service relies on airplanes that carry only freight, while belly service uses the undercarriage of passenger flights. Some air cargo can travel by either freighter or belly, although other types of cargo are not allowed in bellies because they are too large or contain components potentially dangerous to passengers. Freighter service can be provided by integrators, such as FedEx and UPS, operating large widebody airplanes to small feeder aircraft. This is predominant model in the domestic market. Freighter service can be provided as well by specialty carriers and some passenger airlines, with freight forwarders providing the customer interface and arranging necessary services such as truck drayage and customs handling. Forwarding via freighters and widebody passenger bellies is the predominant model in the international market. Some overlap exists between the goods and markets served by integrators and forwarders, although they largely have different operating requirements.

The availability of air cargo service is generally considered flexible in the long-run. If enough demand materializes for a certain market, carriers will look to meet that demand. Freighter service is most prominent in markets where freight demand outstrips passenger demand, such as to and from some countries in Asia. In these cases, the availability of belly capacity is insufficient to meet freight demand or exists for the wrong locations, creating a market for freighter service. Belly capacity is also determined by the size of airplanes used. Widebody airplanes have significantly greater belly cargo capacity than narrow-body airplanes (the exclusive type in the domestic passenger market), and the overall size of the aircraft matters as well (e.g., the newer 787s have more belly capacity than older 767s).

In the long-run, a mismatch between passenger demand and freight demand should lead to greater demand for dedicated freighter service. However, spikes in freight demand (such as seasonal surges), mismatches of aircraft types, or other factors could lead to capacity constraints in the short-run. Resolving these short-run capacity constraints can be costly for carriers and shippers, and lead to air cargo congestion.

Capacity constraints can also arise in the long-run in markets where demand does not support frequent flights. For many shippers, considering air cargo as an alternative requires that a flight be available within a timeframe amenable to their supply chains. Having to wait for many days before the next flight might defeat the travel time savings of air, or simply fail to meet delivery requirements. This is particularly the case for domestic shipments as trucking can reach most destinations in the U.S. within a few days, even on transcontinental shipments. For international shipments, shippers have fewer options, potentially leading them to consider lengthy truck drays to alternative airports that provide better and more frequent service. Time-definite delivery schedules may not require immediate transport, allowing shippers to find lower cost flights. Many shippers find that draying cargo directly to large regional hubs is an effective way to utilize this strategy.

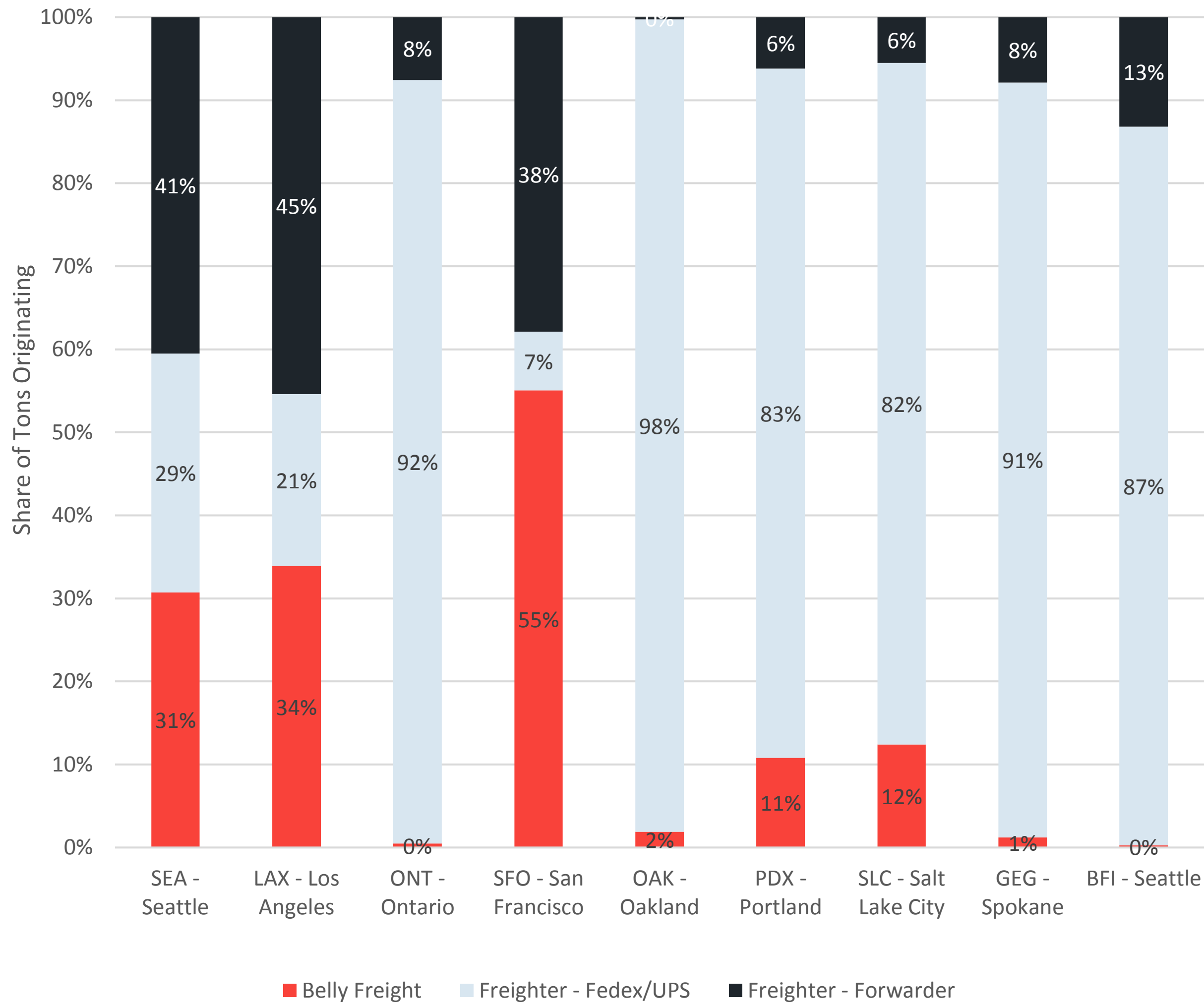
This section reviews data on the supply of cargo service at the three main cargo airports in the state: Sea-Tac, BFI, and Spokane International Airport. The objective is to identify how these three airports serve a wide range of international markets and compare service availability with other major freight airports within a two-day truck dray. These competing airports include the following:

- Los Angeles International Airport (LAX)
- Ontario California International Airport (ONT)
- San Francisco International Airport (SFO)
- Oakland International Airport (OAK)
- Portland International Airport (PDX)
- Salt Lake International Airport (SLC)

Figure 3-1 shows the tonnage share of these airports by service type: belly, FedEx/UPS (integrators), and freight forwarders. Freighter service was divided into FedEx/UPS and forwarders because they serve a different function. (In the remainder of this section these service types are combined because there of overlap in customers and similar demand characteristics, particularly for purposes of characterizing capacity.) Sea-Tac, LAX, and SFO have a large share of belly freight and freight forwarders. At these airports, the integrators account for a minority of tons moved. On the other hand, ONT, OAK, BFI and Spokane International focus primarily on FedEx/UPS, although they also support some freight forwarder services. ONT and OAK in particular are West Coast hubs for UPS and FedEx respectively, and include overseas freighter flights. These hubs are accessible from Washington through the carriers' systems. PDX and SLC are dominated by integrators to a lesser extent, and have significant belly and forwarder service.

Table 3-1 shows the average number of departing flights per week by market area. For belly service, narrow-body airplanes were not considered because they offer limited freight capacity. The data was obtained from the Bureau of Transportation Statistics T-100 dataset, detailed at the segment level (tracking flight departures and landings). Table 3-1 shows the frequency of departing flights while Table 3-2 shows the frequency of arriving flights. These tables are similar; therefore, we will focus on the results of Table 3-1.

Figure 3-1: Freight Service at Competing Airports



Source: Bureau of Transportation Statistics T-100 Segment Data, 2016

Table 3-1. Average Number of Outbound Flights per Week by Market, 2016

	Belly Widebody (flts/wk)					Freighter (flts/wk)				
Origin Airport	Asia	Eur.	N. Amer.	S. Amer.	Total	Asia	Eur.	N. Amer.	S. Amer.	Total
SEA - Seattle	100	44	39	0	**182**	15	0	94	0	**110**
GEG - Spokane	0		0	0	**0**	0	0	87	0	**87**
BFI - Seattle	0	0	0	0	**0**	0	0	48	0	**48**
LAX - Los Angeles	454	154	188	27	**824**	70	17	201	2	**290**
ONT - Ontario	0	0	0	0	**0**	17	0	200	0	**217**
SFO - San Francisco	254	119	160	0	**533**	23	0	24	0	**47**
OAK - Oakland	17	6	1	0	**23**	10	0	173	0	**183**
PDX - Portland	13	8	9	0	**30**	0	0	132	0	**132**
SLC - Salt Lake City	7	16	13	0	**36**	0	0	100	0	**100**

Source: Bureau of Transportation Statistics T-100 Segment Data

Table 3-2: Average Number Inbound Flights per Week by Market, 2016

	Belly Widebody (flts/wk)					Freighter (flts/wk)				
Origin Airport	Asia	Eur.	N. Amer.	S. Amer.	Total	Asia	Eur.	N. Amer.	S. Amer.	Total
SEA - Seattle	99	44	39	0	**182**	0	3	115	0	**118**
GEG - Spokane	0	0	0	0	**0**	0	0	97	0	**97**
BFI - Seattle	0	0	0	0	**0**	0	0	51	0	**51**
LAX - Los Angeles	454	154	189	27	**824**	83	5	183	3	**274**
ONT - Ontario	0	0	0	0	**0**	7	0	199	0	**206**
SFO - San Francisco	254	119	159	0	**533**	0	0	58	0	**58**
OAK - Oakland	17	6	0		**23**	9	0	166		**175**
PDX - Portland	13	8	9	0	**30**	0	0	157	0	**157**
SLC - Salt Lake City	7	16	13	0	**36**	0	0	94	0	**94**

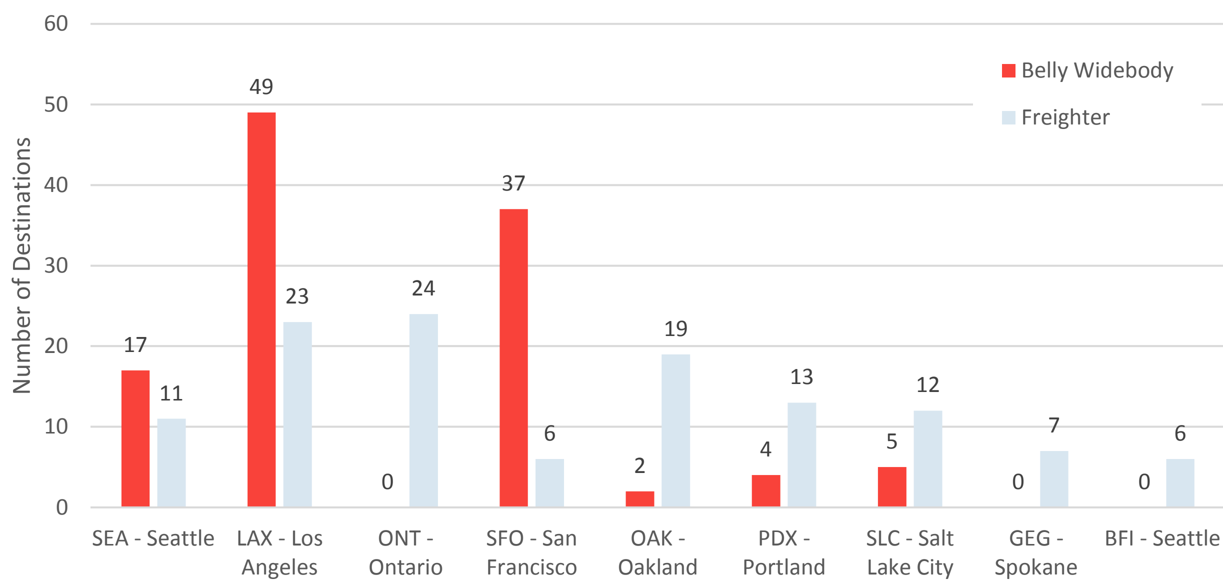
Source: Bureau of Transportation Statistics T-100 Segment Data

From Table 3-1, we can see that Sea-Tac originates 100 non-stop widebody belly flights per week to Asia, 41 to Europe, and 39 to other destination in North America. Sea-Tac currently does not offer non-stop belly service to South America. Relative to competing airports, more belly capacity is available at Sea-Tac than at OAK, PDX and SLC. This is particularly true for reaching markets in Asia or Europe. On the other hand, LAX and SFO offer substantially greater belly capacity to Asia, Europe, North America, and South America. Air cargo to and from South America is typically served from LAX; goods shipped to this market are either trucked down to LAX for carriage or placed on connecting flights to hubs that offer service to this market. Because of the limited domestic belly capacity in the U.S., it is likely that truck drays to LAX are preferred to connecting flights. Spokane International, BFI and ONT do not offer any widebody belly capacity.

Most of the freighter capacity at Sea-Tac, Spokane International, and BFI is domestic. Nonetheless, Sea-Tac offers 15 freighter flights per week to Asia and receives 3 flights per week from Europe. Spokane International and BFI offer significant numbers of domestic freighter flights, at 87 and 48 flights per week respectively; this compares to 94 domestic flights for Sea-Tac, although the sizes of aircraft can be different. While Sea-Tac offered more belly flights than OAK, PDX, and SLC, in freighters this finding is somewhat reversed. OAK (the FedEx hub) offers 66 percent more freighter flights than Sea-Tac; PDX offers 20 percent more freighter flights than Sea-Tac, although the tonnage it handles is much less. Almost all the freighter service at these three airports is domestic, although OAK competes with Sea-Tac in offering comparable levels of freighter service to Asia. Some of the freighter flights to North America head to Alaska for refueling and transferring onto planes heading to Asia, although the proportion is not high. This includes 9 flights per week at Sea-Tac, 8 flights per week at Spokane International, 5 flights per week at BFI, 2 flights per week at LAX, and 8 flights per week at ONT.

It is useful to define markets in greater detail because each of the four international markets spans a broad geography. Figure 3-2 defines destinations at the city level, showing the number of destinations receiving 4 or more belly flights or freighter flights per week. This threshold was selected because it guarantees that there is almost always a flight available within 48 hours of desired shipment. In terms of belly capacity, Sea-Tac serves 17 destinations with this flight frequency. This is smaller than LAX (49) and SFO (37), but significantly greater than OAK (2), PDX (4), and SLC (5). In terms of freighter flights, the advantage of LAX over Sea-Tac is reduced considerably, and ONT (the UPS hub) becomes the airport with better freighter service to a wider range of markets. Even though SFO provided more belly flights than Sea-Tac to more markets, Sea-Tac provides better freighter availability than SFO. The freighter comparisons can be somewhat misleading because they include the domestic flights of the integrators, who can reach anywhere in the country (and beyond) through their hubs. Spokane International and BFI serve 7 and 6 distinct destinations with frequent domestic freighter service from integrators.

Figure 3-2: Destinations with 4 Flights or More per Week (2016)



Source: Bureau of Transportation Statistics T-100 Segment Data

The air data analyzed in this section does not provide commodity information, which makes it difficult to infer precisely which commodities or industries are affected by the differing levels of air cargo capacity in regionally competitive airports. (Section 4.3 provides an overview of commodities handled using a different source of information.) Nonetheless, this data indicates the following:

- LAX and SFO offer exceptional belly capacity to Asia and Europe, competing strongly with Washington state airports for these markets.
- Of the regionally competitive airports, LAX provides the only direct service to South America. From Sea-Tac or other nearby airports, connecting flights or long truck drays to air hubs are required to serve this market.
- Spokane International and BFI offer a comparable level of domestic freighter flights as Sea-Tac, while Sea-Tac has significant belly and freighter capacity to Asia and Europe.
- Integrators provide most of the cargo capacity at ONT, BFI, and Spokane International. Sea-Tac, SFO, and LAX provide greater belly capacity for freight forwarders.
- The integrator hubs at ONT and OAK offer significant numbers of freighter flights, but these are accessible from Washington state airports and in that sense are not direct competitors.

3.1.2 Runways, Taxiways and Ramps

The capacity of airports is also determined by the configuration of runways, taxiways, and ramps. The availability of space and configuration of the airport can limit the number of aircraft that can be processed in any given period of time, particularly the larger aircraft that are the workhorses of freighter service. Passenger flights can compete with freighter flights for this available capacity. Volumes that exceed capacity will lead to delays and unreliability in airplane departures and arrivals, which can cause further delays and unreliability in other parts of the system. This section investigates these issues for Washington airports using data on the performance of airports.

The ASPM maintained by the FAA reports several key performance metrics for 77 large airports in the United States. In Washington, this only includes Sea-Tac. Abnormal delays or persistent issues in landing and takeoff procedure represent an indication that certain airport components are stressed and approaching their capacity. Section 4.2.4 of the *Market, Facilities and Forecast Technical Report* contains detailed information describing the runway, taxiway and ramp components at Sea-Tac and other key airports in the state.

ASPM data did not show current capacity constraints in this area at Sea-Tac. On-time performance and delays were significantly lower than other large competitive airports, such as LAX, SFO and OAK, showing that runway and taxiway systems are adequate to meet existing demand

Overall, the ASPM data did not show current capacity constraints in this area at Sea-Tac. On-time performance and delays were significantly lower than other large competitive airports, such as LAX, SFO and OAK, showing that runway and taxiway systems are adequate to meet existing demand. Sea-Tac did have worse on-time performance and delays than PDX and SLC, although not by a significant margin. Nationwide, airport performance has benefited from an overall decrease in airplane movements as airplane sizes have generally increased, relieving aircraft congestion at airports that were previously approaching capacity.

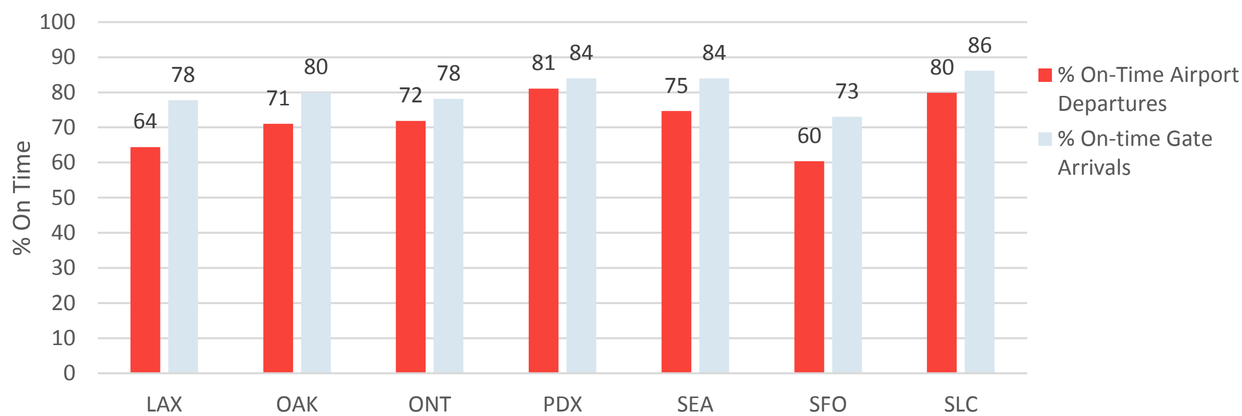
Section 6.2.1 of the *Market, Facilities and Forecast Technical Report* reached a similar conclusion by analyzing information from recent master plans. It concludes that no airport evaluated foresees a saturation of their runway system before 2026. In their master plan, Spokane International included a plan to build a new runway; however, this is not expected to be needed until after 2030. Sea-Tac has listed several planned airfield capacity improvements that will help it meet long-term demand without the addition of a new runway. Other airports have long-term plans for improving runways and taxiways along with passenger facilities.

Section 6.2.2 of the *Market, Facilities and Forecast Technical Report* also concluded that Sea-Tac will not lack aircraft ramps before 2026, although the continued expansion of passenger service has the potential to tighten ramp availability in the future. While BFI does appear to have a small deficit of ramp availability, its principal carrier UPS can manage this through its style of operations or expand into adjacent space. Spokane International currently has plans to construct two large ramps, which would suffice for foreseeable future.

ON-TIME PERFORMANCE

Figure 3-3 shows the percentage on-time for departures and arrivals at the competing airports included in the ASPM. An on-time departure is defined as having a "wheels off time" within 15 minutes of schedule. An on-time gate arrival is defined as arriving to the gate within 15 minutes of schedule. The data monitors FedEx and UPS as well as passenger airlines; cargo operations thus are substantially reflected, with the exception of charters and specialized freighters (such as Amazon Air). For both arrival and departure measures we observe that Sea-Tac ranks in the middle of the set of airports analyzed, with a 75 percent on-time departure and 84 percent on-time arrival. This is significantly better than LAX, which has a 64 percent on-time departure and 78 percent on-time arrival, and SFO, which has on-time departures 60 percent of flights and on-time arrivals 73 percent of flights. This metric indicates that SFO is currently operating close to capacity, affected in part by its chronic susceptibility to foggy conditions. OAK performs better than LAX and SFO, but not as well as Sea-Tac. PDX and SLC both have higher on-time departure and arrival rates than Sea-Tac, indicating greater runway and taxiway capacity to serve existing flight volumes; however, they offer fewer flights as demonstrated in the previous section.

Figure 3-3: Percentage of On-Time Departures and Arrivals (2017)

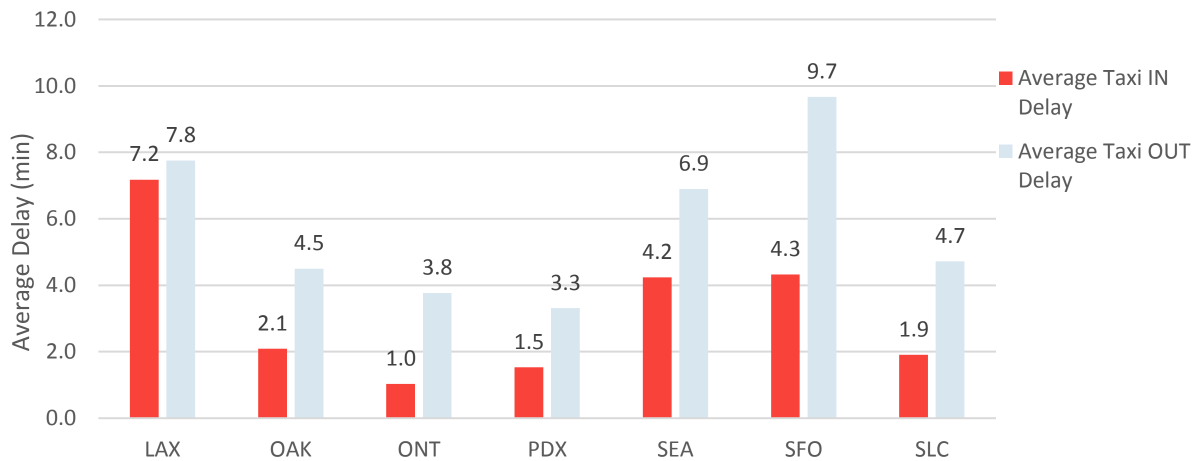


Source: FAA, Aviation System Performance Metrics (ASPM), From 01/2017 To 11/2017

TAXI DELAYS

Taxiway configuration can be an important factor causing these performance issues. Figure 3-4 shows the average taxi delay after landing (Taxi IN) and during departure (Taxi OUT). Delay in this figure is defined as the actual taxi time minus the unimpeded taxi time, in minutes. Here too, Sea-Tac places in the middle of the group, with taxi delays expected for an airport of its size and volume. The metrics show an average Taxi OUT delay of 6.9 minutes and average Taxi IN delay of 4.2 minutes. In contrast, SFO has almost 10 minutes of taxi delay during departure, contributing to it having the lowest on-time performance of the group. LAX has Taxi IN and Taxi OUT delays that are higher than Sea-Tac, although delays during arrival are considerably worse. The other airports considered, PDX, ONT, OAK and SLC have lower taxi delays corresponding to lower overall volumes.

Figure 3-4: Average Taxi Delay (2017)

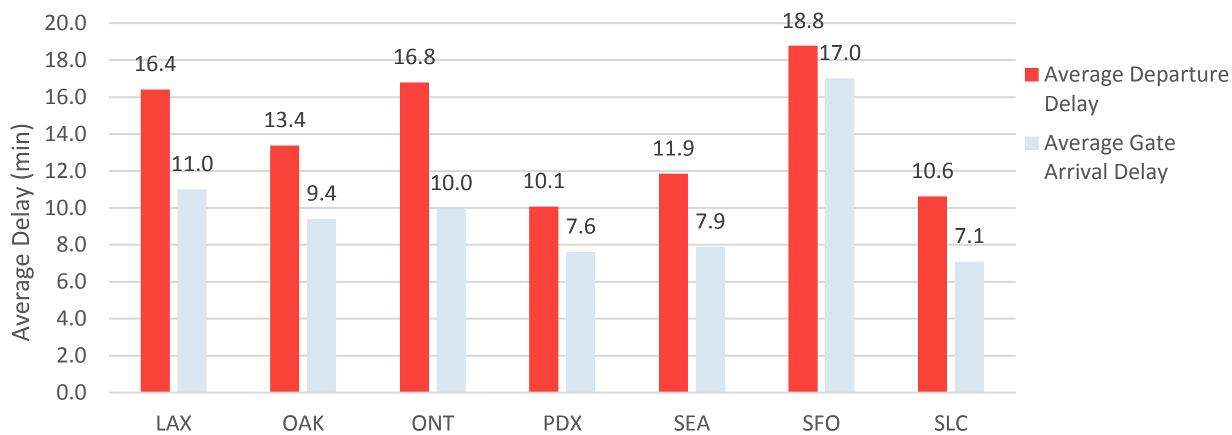


Source: FAA, Aviation System Performance Metrics (ASPM), From 01/2017 To 11/2017

DEPARTURE AND ARRIVAL DELAYS

One more way to analyze the ASPM data is to look at average departure and arrival delays in terms of minutes, as seen in Figure 3-5. Once again, Sea-Tac ranks better than LAX and SFO, and on par with the other airports. All this points to Sea-Tac's runways and taxiways working well to meet the demands being placed on the airport. LAX and SFO accrue substantially higher delays, and unreliability, pointing to these airports approaching their current capacity for their operating conditions. Based on this data, it does not appear that Sea-Tac has comparable capacity shortcoming in runways and taxiways.

Figure 3-5 Average Departure and Arrival Delay (2017)



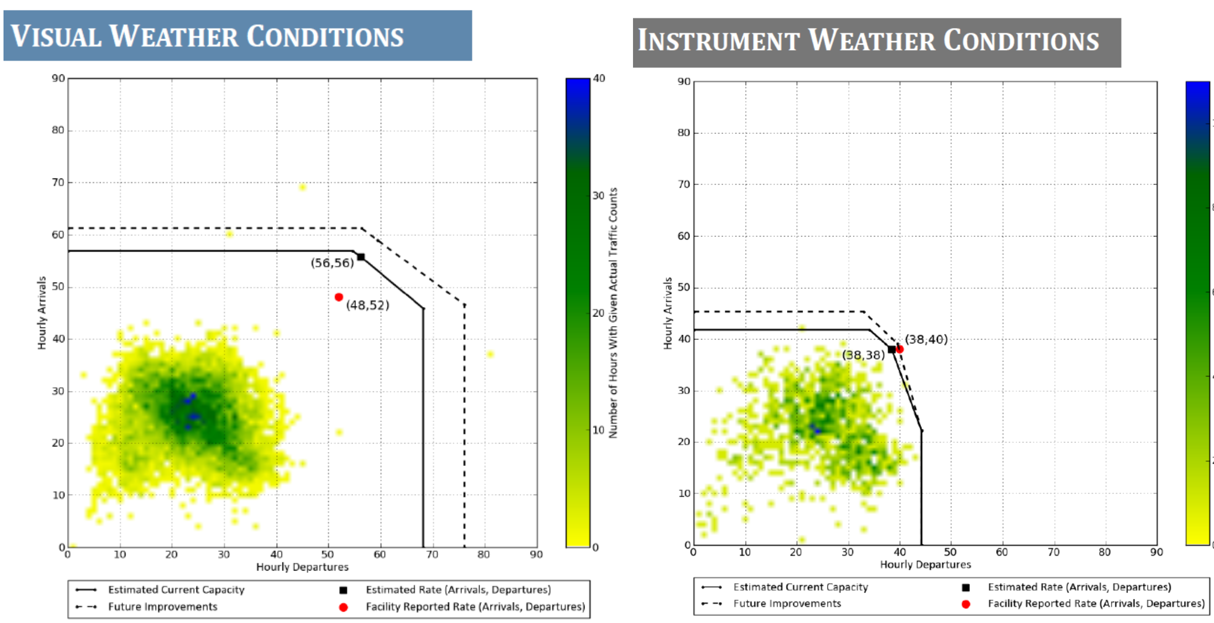
Source: FAA, Aviation System Performance Metrics (ASPM), From 01/2017 To 11/2017

FAA CAPACITY ANALYSIS

In 2014 the FAA performed a capacity analysis of major airports in the U.S.,[11] comparing planned improvements against forecasts to evaluate where delays are likely to get worse. This represents a different form of analysis of performance data to estimate the flight capacity of airports; however, it is only available in Washington state for Sea–Tac and is focused on weather conditions. Figure 3-6 shows the results of the analysis. The figure displays current (solid line) and future (dotted line) capacity for flight arrivals and departures under two classes of weather, and then charts the number of flights (the dots) and the amount of time (color coding of dots) the airport operated at that number. So long as the dots stay within the lines, the airport is within capacity for the conditions.

As can be seen, under visual (better) weather conditions[12] Sea-Tac operates well below the capacity estimated by the FAA. Under instrumented (worse) weather conditions[13] the flight capacity is lower and the airport occasionally operates near its limit, but not beyond. The FAA analysis concluded that there are no significant capacity shortfalls at Sea-Tac under different weather conditions. Comparisons to other major U.S. airports appear in Figure 3-7. Among Sea-Tac's west coast competitors, SFO is the only facility with capacity constraints through 2020 and 2030.

Figure 3-6: Results of Federal Aviation Administration Capacity Analysis for Seattle-Tacoma International Airport



Source: FAA Airport Capacity Profiles, 2014

[11] FAA, 2015, FACT3: Airport Capacity Needs in the National Airspace System, https://www.faa.gov/airports/planning_capacity/media/FACT3-Airport-Capacity-Needs-in-the-NAS.pdf
[12] Defined as having a ceiling and visibility that allow visual approaches, which is defined in this case as having a ceiling of at least 5,000 feet and visibility of 8 miles.
[13] Defined as having a ceiling and visibility that require instrumented flight, which is defined in this case as having a ceiling of 1,000 feet or below or a visibility of 3 miles or less.

Figure 3-7: Results of Federal Aviation Administration FACT3 Capacity Analysis

Airport	FACT3 2011	FACT3 2020	FACT3 2030
ABQ			
ATL	●	●	●
BDL			
BHM			
BOS			
BUR			
BWI			
CLT			●
CVG			
DCA			
DEN			
DFW			
DTW			
EWR	●	●	●
FLL			◑
HOU			
IAD			
IAH			●
ISP			
JFK	●	●	●
LAS			●
➡ LAX			
LGA	●	●	●
LGB			
MDW			
MEM			
MIA			
MSP			
OAK			
➡ ONT			
ORD			◑
PBI			
PHL	●	●	◑
PHX			●
PVD			
SAN			
SAT			
➡ SEA			
➡ SFO		◑	●
➡ SLC			
SNA			
STL			
TUS			

Comparative Summary Results Across all Three FACT Reports

Legend:

◑ Constrained in reference case, but unconstrained if planned improvements are implemented

● Constrained even after all planned improvements are implemented; additional capacity enhancement is needed; or constrained in base year.

No symbol indicates not capacity constrained

Note: *This table lists only the airports that were identified as capacity-constrained in one of the FACT reports. Other airports that were analyzed in the FACT reports, but not identified as capacity-constrained, are not included.*

3.2 LANDSIDE CAPACITY

No performance data was available for directly quantifying or tracking congestion of landside systems. This information is typically not reported by airports, and is confidential in the case of facilities operated by UPS or FedEx. Without this data it is difficult to assess from a performance point of view the adequacy of existing landside systems to meet future demand. To overcome this limitation, this study looked at several physical metrics of landside systems and compared then with industry benchmarks. This assesses whether airports in the state have the physical assets typically required to handle certain cargo volume. This analysis implicitly assumes that the productivity of these assets does not change considerably from airport to airport, or improve significantly over time. In recent history this is a reasonable simplification; however, the increasing automatization of distribution activity and improvements in optimization algorithms can conceivably lead to increases in productivity.

Chapter 6 in the *Market, Facilities and Forecast Technical Report* contains a detailed discussion of landside freight capacity in key freight airports in Washington state. As described above, landside capacity is a function of on-airport warehouses, on-airport office space, parking facilities, security procedures, etc. This analysis used factors from the U.S. Transportation Research Board's Airport Cooperative Research Program (ACRP) Report 143 on air cargo facility planning and development, to assess whether enough landside facilities were available to meet existing and future freight demand. The analysis focused on identifying constraints at Sea-Tac and BFI, while looking for underutilized capacity throughout the state.

3.2.1 On-Airport Freight Buildings

The planning analysis found that Sea-Tac will face a deficit of on-airport cargo buildings starting in 2021, and the deficit will continue to grow over time. In addition, the continuation of passenger demand growth will compete for space with freight, further amplifying this deficit. This analysis concluded that off-airport facilities will be required to bridge this deficit and reduce the stress on on-airport buildings. Without it, air cargo operations are expected to see substantial congestion and even limit the capacity of the airport. The deficit of freight buildings is estimated to reach 75,000 sq. ft. in 2026.

BFI was found to have a lower on-airport cargo building capacity than benchmark airports; however, UPS (its primary carrier) processes shipments in an off-airport building. Unless this changes, BFI has adequate on-airport buildings to accommodate future growth.

The planning analysis found that Spokane International operates with a small deficit of on-airport cargo buildings of about 4,600 sq. ft. However, this deficit is expected to grow to 20,300 sq. ft. by 2026, which left unchecked could constrain freight operations at the airport. However, the airport has vast land available on-airport, including with direct access to air cargo ramps. Additionally, given that about 90 percent of all tons at this airport are moved by an integrator, it is likely that they are monitoring cargo building requirements closely and would be in a position to quickly correct any deficit if it materialized.

Finally, the analysis concluded that additional truck and auto parking spaces are needed at all these airports given growth projections. This represents a greater challenge for Sea-Tac and BFI because of the availability and value of nearby land. Spokane International should not face major issues overcoming this challenge.

3.3 ACCESS CAPACITY

This section considers the ease with which freight can access airports, focusing on the roadway network and availability of off-site facilities. Congestion on access roads and important highways can lead airports to have difficult access to where freight is generated, consumed, or staged, which imposes costs to shippers. Off-site facilities are an important part of air cargo supply chains, particularly if on-airport facilities are limited, as is the case in Seattle.

Of all the airports in Washington state, access capacity is likely to be most limited at Sea-Tac and BFI. Other airports are in less populated cities with more adjacent space for off-site developments, if needed. Additionally, Seattle is significantly more congested than any other city in the state. This leads local traffic conditions to be an important factor that shippers and forwarders need to consider when making shipping decisions.

3.3.1 Roads

Roadway congestion creates constraints for shippers seeking to use airports. Slower speeds and increased unreliability forces trucks to depart earlier for outbound flights, enabling less of the days' production to make it on the flight. On inbound flights, delivery appointments become harder to make, such as the 10:30 AM schedule for express freight. Congestion makes meeting inbound and outbound flights more difficult, because usually it is not possible for inbound flights to arrive earlier and outbound flights to depart later. Trucking typically takes up the slack by using more trucks with fewer stops to fit the time schedule.

Persistent congestion and travel time unreliability thus represent higher direct costs to shippers and truckers. Decreasing speeds will elevate fuel consumption and air emissions and increase the number of drivers required. Increasing trip times reduce the productivity of trucks and drivers, forcing trucking companies to increase the size of the fleet and staff to meet the same shipper demand, raising operating costs, and subsequently trucking rates.

In addition to higher rates, shippers also face direct costs from roadway congestion. Unpredictability and increased travel time cause shippers to carry larger moving inventories (in truck) and stationary inventories (in warehouse). This represents a direct cost to shippers because valuable resources are being tied up in inventory that otherwise could be invested in their business. If stationary inventories become large enough this could increase warehousing needs, imposing additional costs for shippers. National Cooperative Highway Research Program Report 830[14] found that increasing stationary

[14] http://www.trb.org/Publications/Blurbs/174297.aspx

inventories is avoided by shippers as a response to congestion because it raises costs and capital requirements significantly.

Inventory costs are primarily a function of the value of the goods, so these types of costs can be large for many commodities typically shipped by air, such as pharmaceuticals, high-value electronics, or precision industrial parts. The inventory costs resulting from roadway congestion are also higher for perishable commodities or commodities that are time sensitive, such as products associated with retail marketing promotions. For these commodities, missing a scheduled flight could reduce significantly their value to customers.

Roadway congestion will tend to concentrate around peak commuting hours (except for accidents, which can happen at any time). Belly flights can be scheduled at any time of the day, although they do concentrate around peaks in the day that might coincide with roadway travel peaks. Integrator flights mainly depart in the evening and arrive in the morning, which requires trucks to operate during rush hours in order to meet them.

Roadway access can also be limited by the configuration of the roads. Truck restrictions, load restrictions, time-of-day restrictions, and antiquated roadway geometry can make it difficult for trucks to access airports. This is unlikely to be the case for airports that currently handle significant freight volumes, but this could be an issue for smaller airports without a history of cargo operations. At the large cargo airports such as Sea-Tac, trucks have specific roads to access cargo terminals.

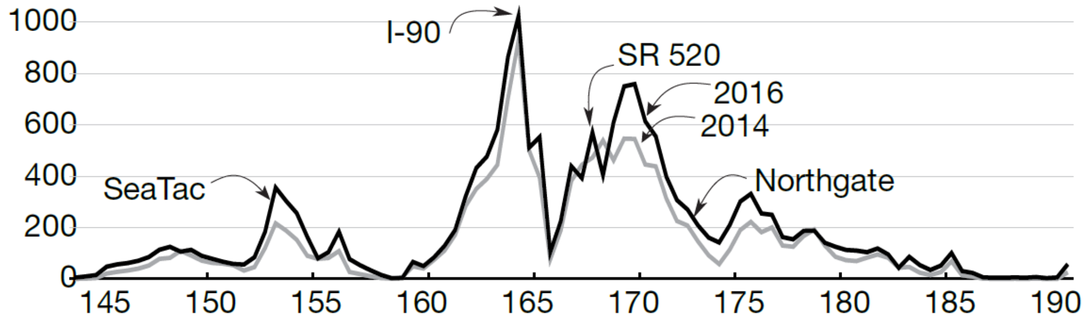
SEATTLE-TACOMA INTERNATIONAL AIRPORT

Sea-Tac is located near the interchange between I-5 and I-405. The main access roads to the airport are SR-518 and Airport Boulevard. Air cargo facilities are located off Air Cargo Road, which is separate from the main public access road. Air Cargo Road does not have direct access to SR-518 and requires driving through at least one signalized intersection.

The 2017 Corridor Capacity Report published by the Washington State Department of Transportation looked at congestion levels on I-5 adjacent to Sea-Tac.[15] This report found that southbound delays on I-5 at Sea-Tac occur predominantly in the afternoon rush hour, from 3PM to 7PM, while northbound delays occur predominantly in the morning rush, from 6AM to 9AM. From 2014 to 2016, southbound delays at Sea-Tac have increased by 62 percent from 2014 to 2016.As can be seen in Figure 3-8, volumes on I-5 peak considerably around Sea-Tac, and have increased substantially since 2014 (light grey). These higher volumes are caused by airport traffic, the interchange with I-405, and the large industrial development east of I-5 at Kent (described in more detail below).

15 http://www.wsdot.wa.gov/accountability/congestion/

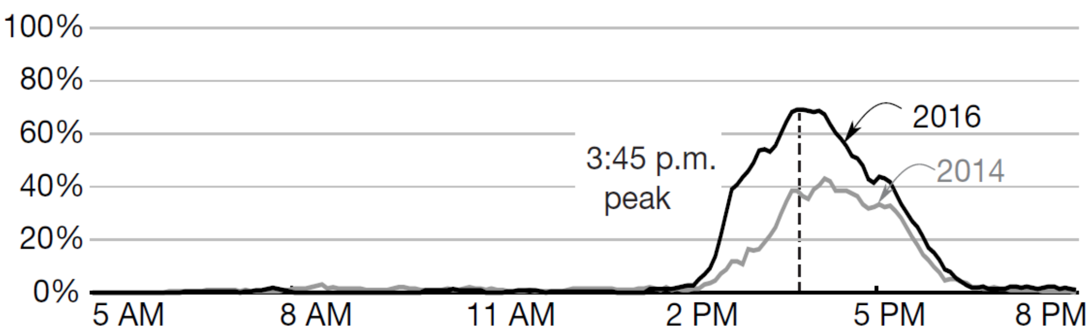
Figure 3-8: 2014 and 2016 Average Daily Vehicle Hours of Delay (by mileposts on I-5)



Source: The 2017 Corridor Capacity Report, Washington State Department of Transportation.

Persistent congestion on I-5 is reducing accessibility to Sea-Tac from Seattle, as can be seen in Figure 3-9. This figure shows the percent of days in which speeds at a particular time of the day decrease below 36mph, which is interpreted as represented congested conditions. By this measure, congestion on this critical road to access the airport has rapidly gotten worse over the past years. As the Corridor study points out, 39 percent of the days in 2014 saw speeds below 36 mph, but this had shot up to 69 percent in 2016.

Figure 3-9: Percentage of Days Seattle-to-Sea-Tac Commute Slower than 36mph (weekdays)

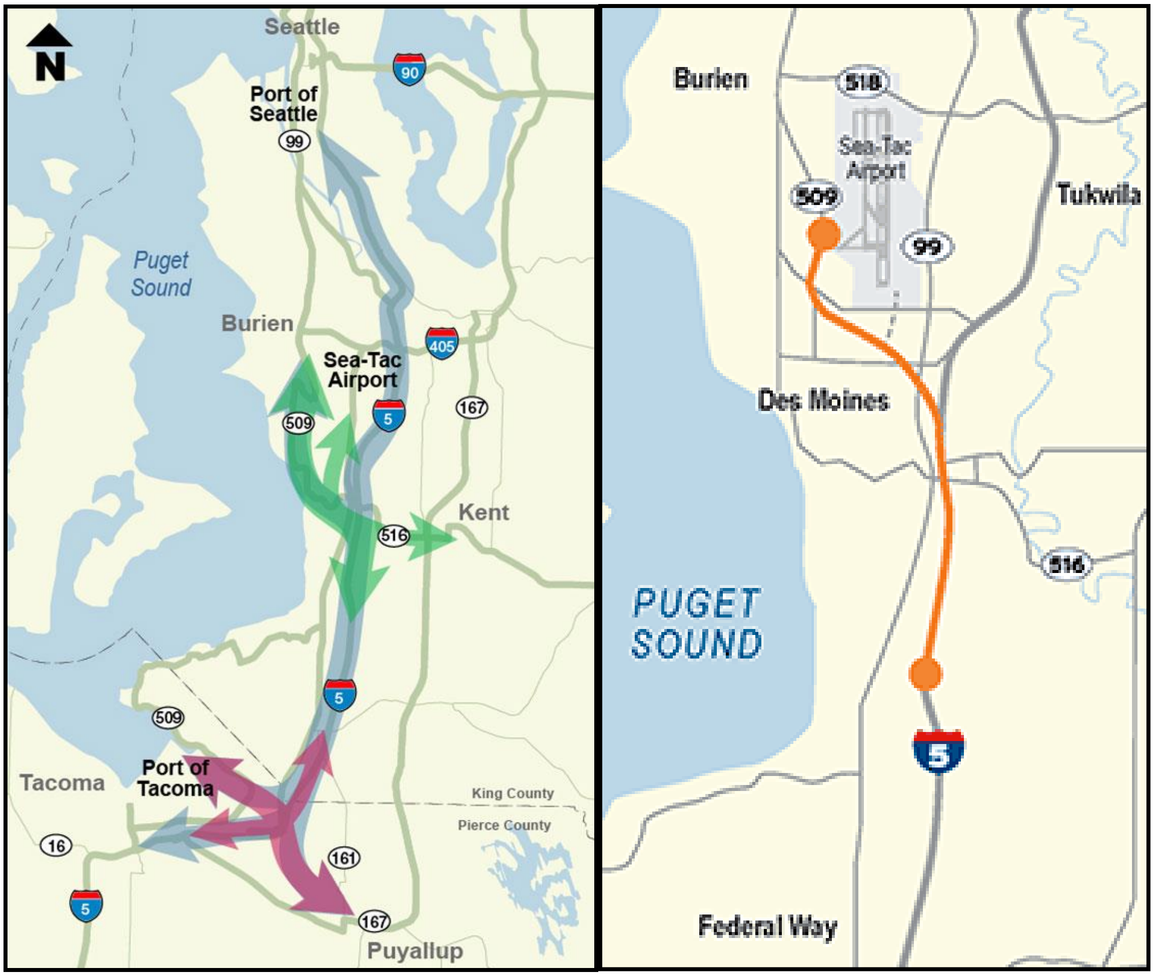


Source: The 2017 Corridor Capacity Report, Washington State Department of Transportation.

The roadway network also provides accessibility to nearby industrial sites and warehouses. Many facilities are close to the airport because they are involved in air cargo. The somewhat more distant Kent Valley is a distribution complex for the Seattle region (see Figure 3-13)and stages all varieties of freight, including air and marine cargo, which many forwarders also handle. Access to these facilities is provided by I-405, I-5, S 188th St, among other roads.

Washington DOT is currently implementing the Puget Sound Gateway Program, which includes several highway projects to improve access of the Port of Tacoma and Sea-Tac to I-5 and industrial and warehouse activity in Kent Valley, as shown in Figure 3-10. One of these projects includes the extension of SR-509, which will improve connection for trucks and passengers to Sea-Tac from I-5. The first phase of this project is expected to begin in 2022. This new airport access road will consist of 4 tolled lanes, alleviating congestion entering the airport considerably. The southward orientation of this road will provide a quicker route for trucks to reach Kent Valley.

Figure 3-10: Puget Sound Gateway Program



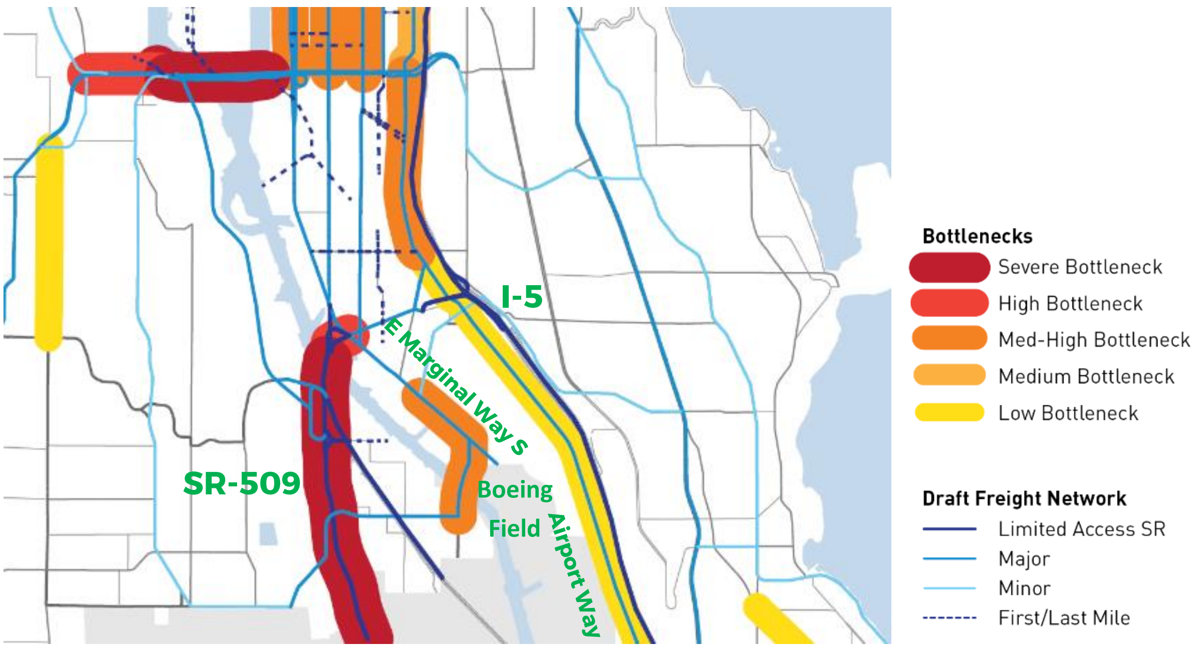
Source: https://www.wsdot.wa.gov/Projects/Gateway/map.htm

Just south of the airport on S 188th St there is another cluster of warehouses that focuses more intensely on air cargo. This is home to an Expeditors International facility and other freight forwarders with a large profile in the Seattle area.

BOEING FIELD INTERNATIONAL AIRPORT

Many roads provide access to this airport, but the primary roads are Airport Way S and E Marginal Way S, which were identified as truck bottlenecks in the City of Seattle Freight Master Plan (2016), as can be seen in Figure 3-11. This plan identified bottlenecks by considering the volume of trucks that use a given road per day and the volume-to-capacity ratio for that road. Using this methodology, the plan found that E Marginal Way S and Airport Way S are both "medium-high" bottlenecks. This means that the analysis found that both roads had daily truck volumes between 1,000 and 1,900 vehicles and a ratio of all traffic volume to capacity between 1.05 and 1.2. Values greater than 1 indicate that the road has exceeded theoretical capacity typical for that type of road. This analysis performed by the Seattle Freight Master Plan focused on local roads, not on interstates. The congestion on I-5 described by the Corridor Capacity Report (discussed above) also affects BFI, which is located approximately 10 miles north on I-5.

Figure 3-11: Truck Bottlenecks near Boeing Field International Airport

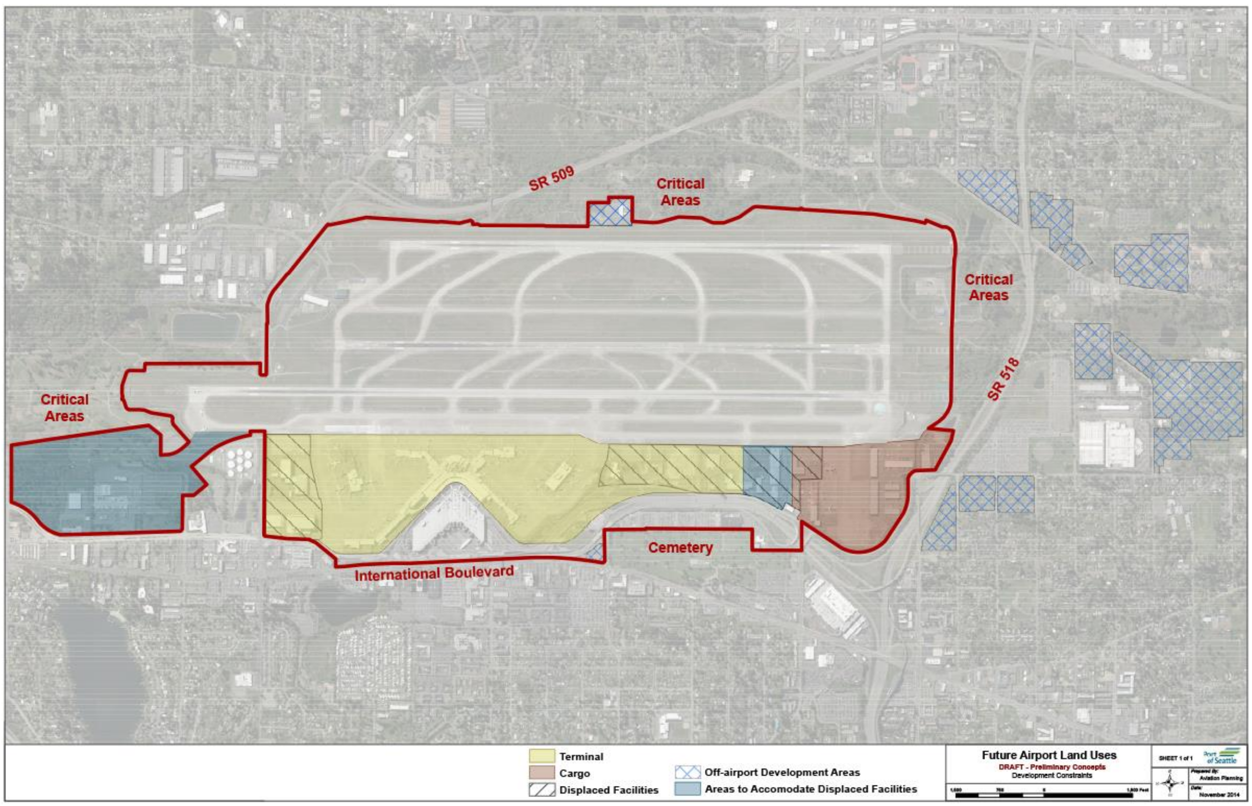


Source: City of Seattle Freight Master Plan, Appendix B: Existing and Future Truck Mobility and Access, September 2016.

3.3.2 Off-Airport Facilities

Given Sea-Tac's constrained on-airport freight buildings and potential trade-offs with passenger service in the coming years, off-site freight buildings represent an opportunity for dealing with existing constraints. Off-site warehouses and logistics centers play an important role in air cargo demand, as many forwarders and shippers, who rely on other parties to deliver the goods to the airport, do not need direct access to cargo ramps. Immediately north of Sea-Tac, on the other side of SR-518, there is space for off-airport buildings. Figure 3-12 shows off-site areas that have been identified by the ongoing master plan as potential for development. The area crosshatched in blue indicates land that is owned by the airport.

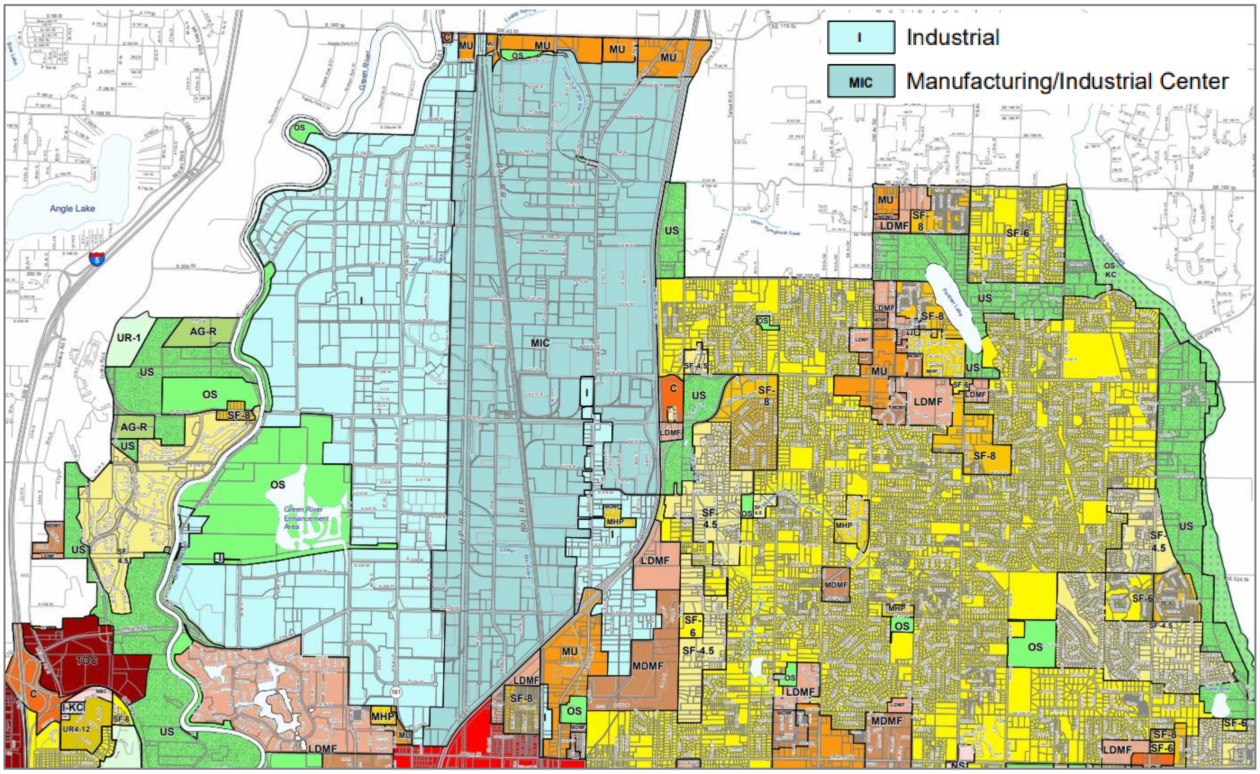
Figure 3-12: Adjacent Sea-Tac Land Use



Source: https://www.portseattle.org/About/Commission/Meetings/2015/2015_01_27_RM_7b_supp.pdf

In addition, the Kent Valley distribution complex located about seven miles southeast of Sea-Tac contains land zoned for industrial and manufacturing uses, as can be seen in Figure 3-13. The proximity of this area to Seattle and the interstate network make it an ideal location for serving local demand. Analysis of economic data shows that Kent Valley had in the third quarter of 2017 a vacancy rate of 4.2 percent, which is close to record lows.[16] From 2012 to 2017, asking rents increased from $5.5 per sq. ft. to over $7 per sq. ft. This economic analysis concludes that there currently is a shortage of industrial space in Kent Valley, primarily because of constrained availability of new land.

Figure 3-13: City of Kent Land Use Map



Source: https://www.kentwa.gov/government/public-works/maps

[16] http://www.cushmanwakefield.com/~/media/marketbeat/2017/10/Seattle_Americas_MarketBeat_Industrial_Q32017.pdf

3.4 SYNTHESIS

Table 3-3 summarizes the results of this congestion analysis. This table indicates whether airports have enough airside, landside, and airport access capacity to meet future demand over the coming 10 years. *Adequate* indicates that enough capacity is available so that the component is unlikely to cause significant air cargo congestion. When a component is judged not to be adequate, a brief explanation is provided of potential causes and solutions. While the analysis focused on Sea-Tac, BFI, and Spokane International, the data collected for other Washington airports showed adequate capacities for handling their forecasted air cargo growth.

The main conclusions are as follows:

- **Airside capacity** is adequate throughout the state to accommodate expected cargo volumes. Performance data shows that Sea-Tac operates better than regionally competing airports such as SFO and LAX, and on par with other regionally important airports such as PDX, OAK, and SLC. Other air cargo airports in the state likely have adequate airside capacity given this measure. Congestion costs from airside delay and unreliability are low relative to other nearby states. Planned infrastructure investments and improvements at airports throughout the state are expected to maintain adequate airside capacity.
- **Landside capacity** is inadequate to meet the cargo needs of the main air cargo airports in the state, particularly at Sea-Tac. Planning analysis shows that Sea-Tac will begin having a deficit in cargo buildings in 2021, which will reduce the efficiency of handling cargo at this airport and lead to system congestion. This deficit could be worsened by the rapid growth of passenger demand at this airport and increasing competition for on-airport space. As there are limited on-airport opportunities for expanding cargo building capacity, alternative strategies such as off-site facilities are required. This includes properties adjacent to the airport north of SR-518, as well as the warehousing district in Kent. While distribution center availability in Kent has very much tightened, air cargo volumes are relatively small compared to regional trucking and distribution, so that the real consequence of warehouse market conditions needs to be further explored.

  A similar situation is occurring at Spokane International Airport, although in this case there is ample on-airport land available for capacity enhancements. The planning analysis also showed that there is currently a truck and passenger parking deficit at Sea-Tac, BFI, and Spokane International. Reducing this deficit for Sea-Tac and BFI will be a challenge because of land availability.
- **Access capacity** is restricted in Seattle airports (Sea-Tac and BFI) because the main access interstate, I-5, is rapidly becoming congested. This increases costs to shippers and trucking companies, and affects the way shipments are dispatched and managed. Even so, roadway conditions may not be a material competitive disadvantage compared to the congestion surrounding the rival airports SFO and LAX. Washington DOT's Puget Sound Gateway Program includes several highway projects that will improve accessibility to Sea-Tac. Access capacity is adequate at other airports in the state.

Our analysis largely agrees with the 2006 PSRC Regional Air Cargo Strategy,[17] which covered Sea-Tac and BFI. That study indicated that the two most critical components limiting the capacity of air cargo at these airports were the roadway network and the space available to accommodate cargo facilities and aircraft parking.

17 http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=E5A781EA3BFDE6C3BB05EF460E5777FB?doi=10.1.1.115.8632&rep=rep1&type=pdf

Table 3-3: Adequacy of Existing Capacity to handle Forecasted Cargo Growth

	Airside Capacity			Landside Capacity		Access Capacity	
Airport	**Freight Service**	**Runways and Taxiways**	**Cargo Ramps**	**Freight Buildings**	**Parking**	**Roads**	**Off-site Freight Facilities**
Sea-Tac (SEA)	**Adequate:** Belly, Forwarder. and FedEx/UPS	**Adequate:** comparable or better on-time performance and delays than regional competition	**Adequate** according to performance data and MP; however, continuing growth in passenger service could restrict availability for freight	**Inadequate** according to planning analysis, deficit starting 2021. Continuing growth in passenger service could exacerbate deficit.	**Inadequate** according to planning analysis, limited land availability	**Restrictive** due to worsening congestion on I-5	**Potentially Adequate**
Boeing Field International (BFI)	**Adequate:** Mostly FedEx/UPS	**Adequate** according to MP; no performance data	**Small Restriction** according to planning analysis; however, UPS could adjust operations or make use of adjacent space	**Adequate**	**Inadequate** according to planning analysis, limited land availability	**Restrictive** due to worsening congestion on I-5	**Potentially Adequate**
Spokane International Airport (GEG)	**Adequate:** Mostly FedEx/UPS	**Adequate** according to MP; no performance data	**Adequate** after planned construction of large ramps	**Inadequate** according to planning analysis, although ample on-airport land available.	**Inadequate** according to planning analysis, ample land available	**Adequate**	**Adequate**
Paine Field	Not Analyzed	**Adequate** according to MP; no performance data	**Adequate:** private facility operated by Boeing with space to expand.	**Adequate**	**Adequate**	**Adequate**	**Adequate**
Bellingham International	Not Analyzed	**Adequate**	**Adequate**	**Adequate**	Not Analyzed	**Adequate**	**Adequate**
Yakima Air	Not Analyzed	**Adequate**	**Adequate**	**Adequate**	Not Analyzed	**Adequate**	**Adequate**
Pangborn Memorial	Not Analyzed	**Adequate**	**Adequate**	**Adequate**	Not Analyzed	**Adequate**	**Adequate**
Walla Walla Regional	Not Analyzed	**Adequate**	**Adequate**	**Adequate**	Not Analyzed	**Adequate**	**Adequate**
Grant County International Airport	Not Analyzed	**Adequate**	**Adequate:** inherited large cargo facilities from Larson Air Force Base	**Adequate**	Not Analyzed	**Adequate**	**Adequate**

4 Impact of Congestion

An analysis was conducted to assess the impacts of air cargo congestion on logistics. As indicated above, congestion occurs when any system component described in Figure 2-1 becomes stressed and introduces frictions, unpredictability, and costs to the movement of freight. The capacity assessment in the previous section concluded that Sea-Tac is likely to be the Washington airport facing the most congested conditions for air cargo in the coming decade. Congestion will be caused by the lack of space to expand freight buildings, some competition from increasing passenger volumes, and increasing roadway congestion on I-5. As such, this analysis focuses on Sea-Tac, to understand the likely impacts of facing congestion at this critical airport.

The question addressed in this section (and posed by the scope of work for this project) concerns businesses choosing to ship through airports outside of Washington as a consequence of congestion; the issue of how Washington airports can support one another to prevent departures is taken up later in the project. The factors that shape which rival airports would be chosen are complex, encompassing for example the availability of flights with affordable space, time windows, trucking costs, handling facilities, business relationships, and congestion at the alternative airport. The net delivered cost and performance from such a range of factors will shape decisions shipment by shipment and cannot be anticipated in a study such as this one.

Instead, the analysis in this section measures the value of preventing the shift of air cargo handling to out-of-state airports such as LAX and SFO. The analysis explores the magnitude of costs and impacts from several capacity shortfall scenarios at Sea-Tac. These scenarios were constructed by assuming hypothetically that Sea-Tac faces a 10 percent shortfall in air cargo capacity relative to demand. We are not asserting that Sea-Tac will encounter such a shortfall, and indeed there are responses to the challenges at Sea-Tac that may prevent any capacity limitation at all. Each scenario represents the extreme case of this unmet demand being handled by a different regionally competitive airport. In reality, a mix of airports would likely pick up this unmet demand; however, in this analysis we explore the boundary cases where all of the demand is picked up by a single airport, to develop an upper and lower bound to the impacts and costs that could be incurred, given a 10 percent shortfall.

The analysis in this section measures the value of preventing the shift of air cargo to out-of-state airports such as LAX and SFO.

As mentioned in Section 2.2, shippers also face costs well before an airport reaches capacity, as the system starts becoming saturated causing travel times to increase and reliability to decrease. We discuss some of the costs involved in Section 4.2, by reviewing the latest research on how shippers value travel time and reliability in air supply chains.

4.1 SCENARIO ANALYSIS: POTENTIAL IMPACTS OF SEA-TAC DIVERTED AIR CARGO

Currently there are many shippers in Seattle that truck their freight to airports in Los Angeles, the Bay Area, and other West Coast cities because they can find airports that meet their needs and budgets better for particular shipments or markets. In these cases, the value of having direct flights or more frequent service (thus waiting less time for the next outbound flight with available space) from these alternative airports outweighs the cost of long truck drays. These cases may involve higher value commodities in lean supply chains that do not carry significant inventories. Prices for cargo space to a specific destination also can vary by airport, depending on the local supply and demand on a given day.

The scenario considered in this section is that cargo capacity constraints at Sea-Tac would force more shippers to consider these alternative airports, if costs and delays at Sea-Tac grow significant enough. The costs we are considering in this section are the trucking costs to reach out-of-state airports that are the primary competitors to SeaTac. These represent the likely airports that air cargo would go to should SeaTac be unable to accommodate the cargo.

While there are many more factors and costs that determine the airports used for shipping freight, trucking costs represent a large proportion of overall costs for shipping through airports that are over 500 miles away. Measuring these is useful to assess the competitive landscape of airports in the state and considering some of the transportation realities that shippers weigh when making shipment decisions. Moreover, understanding these tradeoffs is useful in determining how freight users are likely to respond to strategies to improve air cargo capacity and efficiency.

Investigating trucking effects of diverting cargo to other airports is also important to describe the externalities generated by these changes. Increasing truck travel will increase fuel combustion, leading to additional emissions of criteria pollutants. These should be monetized as they impose a real and clear cost to society, especially when the emissions take place in urban centers. Additional trucks on the roads also imposes a marginal congestion cost on other vehicles, particularly when traveling through congested urban areas. These can be critical in the vicinity of airports. Having an accounting of these non-market costs is critical for developing comprehensive public policies and investments.

Table 4-1 describes the average truck costs that would be required for Seattle shippers to dray cargo to competing airports. These range from $240 for reaching nearby PDX to almost $1,700 for reaching LAX. It was assumed that trucks take the most direct route to these competing airports. Costs were estimated using the American Transportation Research Institute's (ATRI, an arm of the American Trucking Associations) latest estimate of average marginal truck costs nationwide, for 2016 (published in 2017); individual carrier cost profiles may differ from the average, but the ATRI figures are a reasonable baseline. It was conservatively assumed that truck trips to these airports represent backhauls (trucks returning from deliveries in Seattle), and therefore only variable costs were included (fuel costs, maintenance, insurance, permits, tolls, and driver wages). Fixed capital costs such as lease or purchase payments for the truck or trailer were not included. While truck pricing is based on market conditions instead of costs, carriers cannot price below marginal cost without losing money on every shipment. The costs presented here should thus represent the low end of the price range. Finally, because this is an estimate to establish the general size of impacts, we have not attempted to subtract out the drayage costs Seattle shippers already incur to travel to Sea-Tac.

Table 4-1: Truck Costs to Competing Airports

Competing Airport	Distance from Seattle (mi)	Cost/Truck Dray Haul
LAX - Los Angeles	1131	$1,629

OAK - Oakland	802	$1,155
ONT - Ontario	1165	$1,678
PDX - Portland	165	$238
SFO - San Francisco	810	$1,166
SLC - Salt Lake City	837	$1,205

Source: ATRI, 2017. An Analysis of the Operational Costs of Trucking: 2017 Update.
http://atri-online.org/wp-content/uploads/2017/10/ATRI-Operational-Costs-of-Trucking-2017-10-2017.pdf

Four scenarios were analyzed that represent the extreme cases of what would happen if 10 percent of the current cargo demand at Sea-Tac is diverted to competing airports because of a capacity constraint. Each scenario represents diversion to a different competing airport. Combined, these scenarios provide upper and lower bounds to the impacts and costs that would be generated by capacity constraints at Sea-Tac. This includes both trucking cargo to competing airports for outbound flights and trucking cargo from competing airports from inbound flights. The analysis assumes that there are no induced demand effects—shippers will have the same demand for air cargo before and after the capacity constraint.

Table 4-2 describes the estimated impacts of each diversion scenario. This includes increases in: truck vehicle miles traveled (VMT), truck costs, greenhouse gas (GHG) emissions, NOx emissions, particulate matter smaller than 10 microns (PM_{10}) emissions, and crashes. These impacts were estimated "nationwide" (meaning for all the states traversed en route to these airports) and within Washington state. Truck costs were estimated as described in Table 4-1, including only variable costs. GHG emissions were estimated by assuming an average fuel economy of 6 mpg. NOx and PM10 emissions were estimated by assuming emission rates from the EPA MOVES model. Crashes avoided were estimated using nationwide crash rates from the Federal Motor Carrier Safety Administration (including crashes that result in injuries, fatalities and property damage only).

Table 4-2: Impacts under Four Seattle-Tacoma International Airport Capacity Shortfall Scenarios

	Impacts	Scenario 1 - All Diversion to LAX	Scenario 2 - All Diversion to PDX	Scenario 3 - All Diversion to SFO	Scenario 4 - All Diversion to SLC
Nationwide Impacts	Truck VMT Increase (mi/yr)	3,580,226	531,811	2,564,087	2,649,557
	Truck Cost Increase (USD/yr)	$5,155,525	$765,807	$3,692,286	$3,815,362
	GHG Emissions ($MTCO_2$/yr)	6,057	900	4,338	4,483
	Emissions NO_x (Kg/yr)	18,911	2,809	13,544	13,995
	Emissions PM_{10} (Kg/yr)	616	91	441	456
	Crashes per Year	4.8	0.72	3.4	3.6
Washington State Impacts	Truck VMT Increase (mi/yr)	522,314	522,314	522,314	737,571
	Truck Cost Increase (USD/yr)	$752,132	$752,132	$752,132	$1,062,102
	GHG Emissions ($MTCO_2$)	884	884	884	1,248
	Emissions NO_x (Kg/yr)	2,759	2,759	2,759	3,896
	Emissions PM_{10} (Kg/yr)	89.8	89.8	89.8	126.9
	Crashes per year	0.70	0.70	0.70	0.99

Results show that serving the entire unmet demand from LAX would result in the largest VMT generation, at 3.6 million per year. This would add $5.2 million to shippers' logistic costs. The additional VMT would generate 6,057 metric tons of CO_2 per year, 16,911 kilograms of NO_x emissions, and 616 kilograms of PM_{10} emissions. Adding trucks on the roads also increases the probability of crashes, which are estimated at 4.8 per year. Table 4-2 shows the proportion of these impacts occurring in Washington state. VMT increases in Washington state represent 15 percent of the total, leading each of the State impacts to be 15 percent of the nationwide total. For the LAX diversion scenario, most of the impacts would accrue outside of the state. However, for the PDX diversion scenario almost all the impacts occur inside Washington state since PDX airport is directly across the border with Oregon. In the SLC diversion scenario, a different route would be taken by trucks to reach this airport, resulting in a larger VMT increase in Washington state.

Focusing on just Washington state impacts, a 10 percent diversion of cargo demand from Sea-Tac to competing airports would increase truck VMT on the highways by 522,000 to 737,000. This would result in 884 to 1,248 metric tons of CO_2 being emitting, 2,759 to 3,896 kilograms of NO_x being emitted, and 89.8 to 126.9 kilograms of PM_{10} being emitted. The additional truck VMT would also increase the frequency of crashes on the roads, which is estimated to range from 0.7 to 1.0 new crashes per year. These ranges are reasonable approximations whether all the freight is diverted to any of the airports considered or a mix of them.

Future papers will consider strategies that leverage alternative airports in Washington State to relieve congestion from SeaTac. Because freight service is limited at these other airports (with the exception of GIG and BFI), new developments would be required to entice shippers to consider these alternatives. The nature of these developments and strategies will be discussed in future papers.

4.2 CONGESTION COSTS

Congestion will create costs to shippers that do not change their supply chains just like it creates costs to shippers that do. As volumes approach capacity and the performance of the airport deteriorates, longer travel times, more delays and increased unreliability are the result. Deteriorating performance raises the costs for shippers, because it increases the risk of missed delivery windows and forces them to implement costly strategies to mitigate these risks.

A 2014 study in Europe conducted a survey of shippers to estimate their value of reliability and travel time for shipping by air.[18] Several studies have attempted to estimate these parameters for trucking, but to our knowledge only this study has directly asked about shipping by air. Air cargo in the United States is likely to have different performance requirements than in Europe; however, the 2014 European study is important to get an order-of-magnitude estimate on how critical travel times and reliability are for air shippers. The 2014 European study found that an hour of travel time for a freighter aircraft is worth approximately 13,000 Euros while an hour of travel time for a truck is worth 44 Euros. Assuming an average payload of 50 tons per freighter aircraft and 16 tons per average truck, this leads to the finding that each ton of cargo moving by air has a value of time that is 18 times greater

[18] de Jong, G., Kouwenhoven, M., Bates, J., Koster, P. R., Verhoef, E. T., Tavasszy, L. A., & Warffemius, P. (2014). "New SP-values of time and reliability for freight transport." *Transportation Research Part E: Logistics and Transportation Review, 64*(April), 71-87. DOI: 10.1016/j.tre.2014.01.008. While this valuation is affected by the cost of aircraft, which is considerably more expensive than truck equipment, the economic point is that shippers of cargo are willing to pay the difference.

than conventional trucking (as distinct from road feeder service). The 2014 European study also asked about reliability, as measured by the standard deviation of travel times. Here, the findings imply that one ton of cargo moving by air has a value of reliability that is 142 times greater than a ton moving by trucking. These results strongly indicate that shippers value performance and reliability much more highly for shipments by air than truck. Shippers put freight on air when they need the freight to be delivered quickly and on-time with a high degree of certainty.

A recent study in the United States conducted a survey of shippers and motor carriers in Florida to estimate their value of time and reliability.[19] This study found that the average truck trip has a value of time of $37 per hour and a value of reliability of $55 per hour (of standard deviation in actual travel time). Shipments of perishable commodities were found to have a lower value of time at $28 per hour, but higher value of reliability at $79 per hour. This study found that reliability ratios (defined as the ratio of the value of reliability to the value of time) ranged from 0.8 to 2.0 depending on the type of commodity and type of shipper. All this indicates that shippers value reliability more highly than travel time, in a wide range of circumstances. The European study suggests this relationship is even stronger for air cargo shipments. Therefore, the most costly aspect of air cargo congestion for shippers is the decrease in reliability of shipments. Although undesirable, shippers would be able to tolerate increases in travel times better than decreases in reliability.

The next section considers value from the industry-commodity perspective.

4.3 INDUSTRIES

The impact of infrastructure on the economy is related to the value of commodities passing through. Table 4-3 shows this information for airports in Washington state. The data source used was the federal 2015 Freight Analysis Framework (FAF, derived from a 2012 base year), which provides a comprehensive overview of freight flows throughout the U.S. As can be seen, the top commodity by value is Other Transportation Equipment, accounting for 31 percent of all value in 2015 ("other" means beyond motor vehicles and parts; it captures the Washington aircraft industry, as well as rail and marine equipment). This is followed by Electronic Equipment (29 percent), Machinery (13 percent), Precision Instruments (10 percent), and Miscellaneous Manufactured Products (4 percent).

This tells a clear story of the industries and sectors that depend on airports in the state, and their importance in the economy. The value of goods represents gross industry output and relates to state domestic product (GDP). Washington airports handle goods from outside the state, they do not handle 100 percent of Washington goods, and GDP is calculated by value added rather than gross value. Recognizing these caveats, it is nevertheless instructive to compare the $47.6 billion total value of Washington air freight to the $452 billion in 2015 state GDP. The size of the former points to substantial importance for the latter, and indicates that a heathy state economy requires a healthy air cargo capability.

[19] Jin, X. and Shams, K. (2016) *Examining the Value of Travel Time Reliability for Freight Transportation to Support Freight Planning and Decision-Making*, FDOT Project Number BDV29-977-15, Final Report.

Looking into the future, the value of Washington state air cargo is expected by FAF to grow at 4.4 percent per year in real terms out to 2045. The $47.6 billion of freight handled by airports in the state in 2015 is expected to grow to $173.6 billion by 2045. Air cargo value is forecasted to grow faster than the general economy, implying that air will play an ever more important function in the state's logistics. This trend is driven by the rapid growth of higher value commodities, which are more likely to be shipped by air. It is important to note that this forecast could be underestimating long-term air cargo demand because it does not consider continuing trends toward just-in-time supply chains and same-day home delivery that prioritize travel times and reliability, air's main advantages over other modes.

The commodities listed in Table 4-3 have high value-to-weight ratios, making them good candidates for shipping by air. These high-value commodities typically involve supply chains that minimize inventories. Because these commodities represent a high dollar value, maintaining large inventories is particularly expensive for the companies involved. Resources tied up in inventories cannot be reinvested in the company, incur carrying and storage costs, and lengthen the time until the cash spent on inventories is recovered. These industries are therefore particularly sensitive to delays or unreliability caused by congestion. Because of the lack of inventories, a delayed shipment could lead to a stoppage in production or a customer order not being fulfilled. This represents a worst-case scenario for most shippers, incurring high costs and disruptions that are intolerable to most.

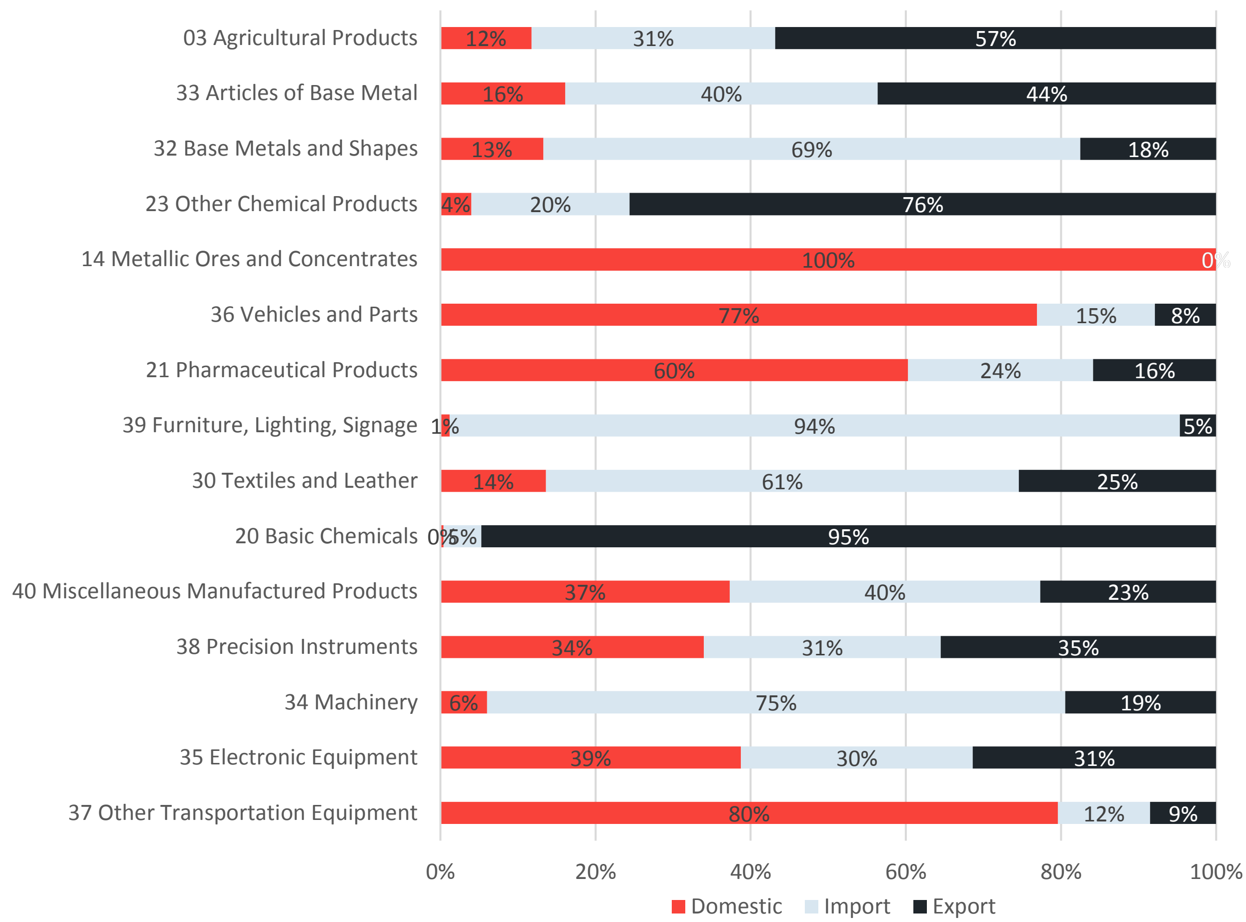
Table 4-3: Freight Value Handled by Washington State Airports, Exports, Imports, and Domestic

		2015		Value Forecast		
Rank	Commodity (2-SCTG2)	Value (M USD)	% of Total	Value 2045 ($M)	Incremental Value 2015 to 2045	Growth Rate 2015 - 2045
1	37 Other Transportation Equipment	14,966	31%	36,064	21,098	3.0%
2	35 Electronic Equipment	13,571	29%	55,741	42,170	4.8%
3	34 Machinery	5,952	13%	23,372	17,420	4.7%
4	38 Precision Instruments	4,842	10%	31,958	27,115	6.5%
5	40 Miscellaneous Manufactured Products	1,736	4%	6,183	4,447	4.3%
6	20 Basic Chemicals	1,719	4%	5,637	3,917	4.0%
7	30 Textiles and Leather	714	1%	2,174	1,461	3.8%
8	39 Furniture, Lighting, Signage	438	1%	2,638	2,199	6.2%
9	21 Pharmaceutical Products	413	1%	1,479	1,066	4.3%
10	36 Vehicles and Parts	385	1%	619	233	1.6%
11	23 Other Chemical Products	381	1%	1,333	952	4.3%
12	33 Articles of Base Metal	367	1%	1,128	761	3.8%
13	03 Agricultural Products	340	1%	1,203	863	4.3%
14	14 Metallic Ores and Concentrates	326	1%	58	-268	-5.6%
15	32 Base Metals and Shapes	304	1%	541	237	1.9%
	Other	1,138	2%	3,519	2,381	3.8%
	Total	**47,593**	**100%**	**173,647**	**126,053**	**4.4%**

Source: Bureau of Transportation Statistics and Federal Highway Administration, Freight Analysis Framework v4.3
*Arrivals and departures are counted as two separate records

Figure 4-1 shows the markets of the top commodities handled by Washington airports. The largest exported commodity is Basic Chemicals, with 95 percent of its $1.7 billion of value being exported outside of the U.S. A similar commodity group, Other Chemical Products, is the second highest exported commodity, with 76 percent of its $381 million exported. Agricultural Products is the other commodity of the group where more than 50 percent of value handled is to serve export markets. These represent industries where Washington state is globally competitive, which depend critically on air cargo to reach these global markets.

Figure 4-1. Top 15 Commodities (2-digit SCTG) handled by Washington State Airports by Market (2015)



Source: Bureau of Transportation Statistics and Federal Highway Administration, Freight Analysis Framework v4.3

Air cargo also allows consumers and companies to purchase goods from around the world. The main commodities imported are Furniture, Lighting, and Signage Products (94 percent of the 438 million USD handled), Machinery (75 percent of the 5.9 billion USD handled), Base Metals and Shapes (69 percent of the 304 million USD handled), and Textiles and Leather (61 percent of the 714 million USD handled). Having the ability to import needed products at competitive prices allows companies in the state to compete better with other regions of the U.S.

The commodity group that represents the largest value of air cargo in Washington state is Other Transportation Equipment, reflecting the activity of Boeing and others. This commodity group represents close to $15 billion in value per year, of which 80 percent is domestic, 12 percent is imported and 9 percent is exported. The second largest is Electronic Equipment, which amounts to $13.6 billion. Of this, 39 percent is domestic, 30 percent is imported, and 31 percent is exported.

4.4 SYNTHESIS

This section described the economic significance of air cargo performance and the impact of congestion affecting it. It reached the following findings:

- A capacity shortfall at Sea-Tac would not only reduce the performance of the airport and increase costs to shippers, but it would also force shippers to consider other regionally (West Coast) competitive airports. A 10 percent shift of demand from Sea-Tac to other airports is estimated to increase truck VMT in Washington state by 320,000 to 740,000 per year. This increase would generate significant emissions of pollutants and increase the accident risk on highways. Moreover, having to truck freight to regionally competitive airports would cost shippers from $760,000 to $5 million per year, depending on the distribution of the demand.

- The high-value just-in-time supply chains that typically rely on air cargo place a very high premium on travel times and reliability. Congestion that diminishes the performance of airports and causes delays and unreliability can be particularly costly for shippers that rely on air cargo. It is estimated that shippers value travel time by air 18 times higher than travel time by truck, and reliability 142 times higher by air than by truck. It is clear that reliability is the most important reason shippers use air freight service, and that risks to reliability from air cargo congestion impose a substantial economic penalty.

- Airports in Washington state handled $47.6 billion in freight in 2015, compared to state GDP of $452 billion. The top 3 commodity groups (Other Transportation Equipment, Electronic Equipment, and Machinery) combine for 73 percent of this freight value. Looking to the future, air cargo value in the state is anticipated to surge to $174 billion by 2045, representing an ever-growing share of the State's economy to which it is already vitally important.

5 Conclusion

This report produced a technical definition of air cargo congestion, and developed a set of performance indicators that can be used to assess whether airside, landside, and access system components are congested. The indicators are interrelated and can play out differently in different markets. For example, ramp capacity is not a major concern at BFI because its principal cargo carrier (UPS) performs most handling off-airport, a result of the carrier's multi-faceted, multimodal logistics system. This mixture of complex, interrelated factors and varying suitability to market segments leads us to use a wide range of indicators to identify the symptoms of air cargo congestion.

By combining this approach with the findings of the *Market, Facilities and Forecast Technical Report*, we concluded that congestion is a more pressing concern at Sea-Tac at than at other airports in the state, which do face some concerns although they can be readily managed. More specifically, we found the following:

- **Airside capacity** is adequate throughout the state to accommodate expected cargo volumes. Performance data shows that Sea-Tac operates better than regionally competing airports such as SFO and LAX, and on par with other regionally important airports such as PDX, OAK, and SLC. Other air cargo airports in the state likely have adequate airside capacity given this measure. Congestion costs from airside delay and unreliability are low relative to other nearby states. Planned infrastructure investments and improvements at airports throughout the state are expected to maintain adequate airside capacity.
- **Landside capacity** is inadequate to meet the cargo needs of the main air cargo airports in the state, particularly at Sea-Tac. Planning analysis shows that Sea-Tac will begin having a deficit in cargo buildings in 2021, which will reduce the efficiency of handling cargo at this airport and lead to system congestion. This deficit could be worsened by the rapid growth of passenger demand at this airport and increasing competition for on-airport space. As there are limited on-airport opportunities for expanding cargo building capacity, alternative strategies such as off-site facilities are required. Several properties in the immediate vicinity of the airport, north of SR-18, have been investigated previously and are being considered as part of the Sea-Tac master plan. In addition, air cargo related businesses have begun to locate in Kent. While distribution center availability in Kent has tightened considerably in the recent past, air cargo volumes are relatively small compared to regional trucking and distribution, so that the real consequence of warehouse market conditions needs to be further explored.

  A similar situation is occurring at Spokane International Airport, although in this case there is ample on-airport land available for capacity enhancements. The planning analysis also showed that there is currently a truck and passenger parking deficit at Sea-Tac, BFI, and Spokane International. Reducing this deficit for Sea-Tac and BFI will be a challenge because of land availability.
- **Access capacity** is restricted in Seattle airports (Sea-Tac and BFI) because the main access interstate, I-5, is rapidly becoming congested. This increases costs to shippers and trucking companies, and affects the way shipments are dispatched and managed. Even so, roadway conditions may not be a material competitive disadvantage compared to the congestion

surrounding the rival airports SFO and LAX. Washington DOT's Puget Sound Gateway Program includes several highway projects that will improve accessibility to Sea-Tac. Access capacity is adequate at other airports in the state.

Air cargo congestion at Sea-Tac would not only reduce the performance of the airport and increase costs to shippers, but it could possibly force shippers to consider other regionally (West Coast) competitive airports. An analysis was conducted to assess the impacts of a hypothetical shift of 10 percent of cargo demand at Sea-Tac to other airports. It was found that VMT in Washington State would increase by 320,000 to 740,000 per year. This increase would generate significant emissions of pollutants and increase the accident risk on highways. Moreover, having to truck freight to regionally competitive airports would cost shippers from $760,000 to $5 million per year, depending on which airports the demand would shift to.

Many industries stand to be affected by air cargo congestion. Airports in Washington state handled $47.6 billion in freight in 2015. The top 3 commodity groups (Other Transportation Equipment, Electronic Equipment, and Machinery) combine for 73 percent of this freight value. Looking to the future, air cargo value in the state is anticipated to surge to $174 billion by 2045, representing an ever-growing share of the state's economy.

The high-value just-in-time supply chains that typically rely on air cargo place a very high premium on travel times and reliability. Congestion that diminishes the performance of airports and causes delays and unreliability can be particularly costly for shippers that rely on air cargo. It is estimated that shippers value travel time by air 18 times more than travel time by truck, and reliability 142 times more by air than by truck. Reliability is the most important reason for shippers using air freight service, and risks to reliability from air cargo congestion impose a substantial economic penalty to these industries.