2013

Understanding the dynamic effects of flight patterns on land use

Matthew Paskus

Western Washington University

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UNDERSTANDING THE DYNAMIC EFFECTS OF FLIGHT PATTERNS ON LAND USE

By

Matthew Paskus

Accepted in Partial Completion
Of the Requirements for the Degree
Master of Science

Kathleen L. Kitto, Dean of the Graduate School

ADVISORY COMMITTEE

Chair, Dr. Patrick Buckley

Dr. Paul Stangl

Dr. Debnath Mockherjee

Dr. David Rossiter
MASTER’S THESIS

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Matt Paskus

May 1st, 2013
UNDERSTANDING THE DYNAMIC EFFECTS OF FLIGHT PATTERNS ON LAND USE

A Thesis Presented to the Faculty of Western Washington University

In Partial Fulfillment of the Requirements for the Degree Master of Science

by

Matthew Paskus

May 2013
ABSTRACT

In recent years, airlines have introduced a new business model, shifting to smaller regional airports in order to reduce costs, while at the same time offering convenience for air travelers. This shift, while easing demand constraints at larger airports, will increase the number of flight segments above Puget Sound altering the land uses below each new segment.

The airline industry is highly speculative, and the economic drivers associated with the airline industry are dynamic. It is projected that commercial jet traffic will increase annually between 2%-5% through 2050. The increase of jet aircraft traffic and recent residential growth are beginning to conflict. The cities of Everett, Seattle (Boeing Field) and Bremerton are interested in growing their aviation economies. This adds additional layers of complexity in land use mitigation in multiple regions without any one region requiring the consent of any bordering region.

This study will assess the land uses and property values which rest below the flight path of some of these new flight segments. The geographical focus for this study is centered in Whatcom County, Washington. BLI is one of the fastest growing airports in the United States with close proximity to the metropolitan areas of Seattle, Washington and Vancouver, Canada.

It is the researcher’s hypothesis that land use impact outside the airport boundaries is insufficiently accounted for in current use-models and will propose an expanded model to account for this.
ACKNOWLEDGEMENTS

I would like to give my utmost gratitude and appreciation to the Department of Geography.

I would like to thank my Committee Chair, Dr. Patrick Buckley for allowing me to tackle a highly contentious issue and for his patience in helping me achieve my goal at Western Washington University.

I would also like to thank my thesis committee for taking time away from their busy schedules to read my work. I am privileged to have Dr. Debnath Mookherjee, Dr. Paul Stangl, Dr. Patrick Buckley, and Dr. David Rossiter on my committee. There is a piece of their encouragement, enthusiasm, and inspiration in this work. This study is dedicated to them knowing that what they inspire in students has ignited a fire in me.

I want to also thank the staff and faculty for their technical and administrative support at Western Washington University.

I owe my family a great deal. They have allowed me to pursue a dream and sacrificed on my behalf. So Tamra, Elizabeth, and Alexandra, thank you for allowing me to complete my work.
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<td>ACRP</td>
<td>Airport Cooperative Research Program</td>
</tr>
<tr>
<td>BLI</td>
<td>Airport Code: Bellingham International Airport, WA USA</td>
</tr>
<tr>
<td>BTV</td>
<td>Airport Code: Burlington International Airport, VT USA</td>
</tr>
<tr>
<td>CAD</td>
<td>Canadian Dollar</td>
</tr>
<tr>
<td>CBD</td>
<td>Central Business District</td>
</tr>
<tr>
<td>DLH</td>
<td>Airport Code: Duluth International Airport, MN USA</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transportation</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>FAR</td>
<td>Federal Aviation Regulation</td>
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<td>FCA</td>
<td>Glacier Park International Airport, MT USA</td>
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<tr>
<td>GFK</td>
<td>Airport Code: Grand Forks International Airport, ND USA</td>
</tr>
<tr>
<td>HMMH</td>
<td>Harris Miller Miller &amp; Hanson Inc.</td>
</tr>
<tr>
<td>HSV</td>
<td>Hue, saturation &amp; value</td>
</tr>
<tr>
<td>IAG</td>
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<tr>
<td>IATA</td>
<td>International Air Transport Association</td>
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<td>INM</td>
<td>Integrated Noise Model</td>
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<td>POB</td>
<td>Port of Bellingham</td>
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<td>RGB</td>
<td>Red, green &amp; blue</td>
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<td>YXX</td>
<td>Airport Code: Abbotsford International Airport, Abbotsford, BC Canada</td>
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<td>WCC</td>
<td>Whatcom County Code</td>
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CHAPTER 1 INTRODUCTION

*The only true voyage of discovery, the only fountain of Eternal Youth, would be not to visit strange lands but to possess other eyes, to behold the universe through the eyes of another, of a hundred others, to behold the hundred universes that each of them beholds, that each of them is* (Proust, 1871-1922).

The United States has more airports than any other country in the world (Official Airline Guide, 2000). The aviation industry is part of America’s culture. Business and leisure travelers utilize aviation as a common mode of transportation. Dreams, discovery, and soaring (Dunbar, 2009) portray the images of flight and how aviation technology plays a vital role in American lives. The accomplishments of Wilbur and Orville Wright, Charles Lindbergh, and William Boeing fulfilled the ambitions and dreams imbedded in America’s aviation heritage (Petzinger, 1996). The commonality of the aviation industry, however, overshadows a looming question for tomorrow’s landscapes. Before Charles Lindbergh died, he acknowledged that the industry he helped pioneer, was flawed in respect to the environment (Morrow, 2001). The magnification of environmental and socioeconomics from the expansion of America’s aviation network raises concerns for land uses buffering both the airport and below the flight path. The patterns of flight are ever present in contrails that rest in the skies above Puget Sound.

Flight patterns change and this study offers the communities of Whatcom County, Washington (Figure 1.1) the opportunity to examine how the cause and effect of aviation demand alters the land uses and property values. The dynamics of a flight
paths buffering Whatcom County is relatively new. By examining the growth in Whatcom County population and the impacts of the aviation industry over the last twenty years (1990 through 2010), provides a unique perspective in what the impacts were and are today.

Figure 0.1 Whatcom County Washington, USA

**The Problem**

In recent years, airlines have introduced a new business model shifting to smaller regional airports in order to reduce costs while at the same time offering convenience for air travelers (Haley, 2006). This shift, while easing demand constraints at larger airports, will increase the number of flight segments above Puget Sound altering the land uses below each new segment. The aviation industry and the Federal Aviation Administration (FAA) recognize that there are constraints
and considerations in regard to land use compatibilities (Federal Aviation Administration, 2006).

The airline industry is highly speculative, and the economic drivers associated with the airline industry are dynamic (Petzinger, 1996). Over the last twenty years, Bellingham International Airport (BLI) has seen high turnover with six carriers ceasing operations. The Port of Bellingham has spent considerable investment on BLI and considers the number of flights and destinations beneficial for the communities of Whatcom County. It is projected that commercial jet traffic will annually increase between 2%-5% through 2050 (Penner, D.H., Griggs, & Dokken, 1999). The emergence of jet aircraft and residential growth, are beginning to conflict especially as Bellingham services more Canadian passengers. BLI not only impacts Whatcom County but the entire Puget Sound region. An aircraft descends into BLI well outside the Whatcom County region adding additional risks to other communities.

The cities of Everett, Seattle (Boeing Field) and Bremerton are interested in growing their local aviation economies. This adds additional layers into land use mitigation in multiple regions without the consent of that bordering region.

As regional aviation markets increase around Whatcom County (Figure 1.1.2), the patterns will become more dense adding complexity to land uses.
Airport privatization in other counties is also possible within the next twenty years. Smaller towns and cities outside Whatcom County or within could alter the demand
again shifting the flight pattern. Privatization offers quick airport operational start up and generates capital from investment dollars rather than from taxpayers within the region (Reed, 2009).

**Goal of Research**

This study will measure comparative land use changes examining how Bellingham growth and how BLI compares to other airports with projected enplanement (departing airline passengers) demand levels. The geographical focus for this study is centered in Whatcom County. BLI is one of the fastest growing airports in the United States (Port of Bellingham, 2008) with close proximity to the metropolitan areas of Seattle, Washington and Vancouver, Canada. BLI has three potential passenger catchment areas. The three catchment regions represented are Whatcom County, where BLI is located, a southern catchment and a northern catchment. Illustrated in Figure 1.1.3, the population of Whatcom County in 2010, was 201,140 and has grown by 21% since the year 2000 (United States Census Bureau, 2013). Over the same time period, airline passenger traffic has grown by 256%.
The southern catchment area covers the counties of Skagit and Snohomish counties with the potential to attract 300,000 passengers. The largest catchment is the northern catchment which represents 825,000 potential flyers from the lower Fraser Valley of British Columbia, Canada (Port of Bellingham, 2007). Canadians represent an estimated 80% of BLI’s traffic (Port of Bellingham, 2007). From the years, 1996 to 2006, BLI has seen a 31% increase in passenger enplanements from 190,000 to 270,000 (Port of Bellingham, 2007).
Figure 0.4: Regional Aviation Catchment (Port of Bellingham, 2007)

3 Million Residents
Within 50 Miles of BLI Live Nearly
Quality of Life

There are qualities of life issues for those who are subjected to the environmental risks and the impacts from jet aircraft activity (Witten, Zeigler, & Richie, 2011). The environmental impacts that are commonly associated with the aviation industry are air, water, noise, and soil. This affects both the local wildlife habitat and the communities within the flight pattern’s buffer.

Airport noise is most commonly associated with jet aircraft (Cidell, 2004). Over the last eight years, the area buffering the airport has seen dB levels rise and expand from the 60 dB to 65 dB range and increasing from 275 acres in 2000 to 591 acres in 2008 (Figure 1.5).

<table>
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<th>DNL (dB)</th>
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<th>2000</th>
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<td></td>
<td>Area (Acres)</td>
<td>Housing Units</td>
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<tr>
<td>60 dB to 65dB</td>
<td>591</td>
<td>73</td>
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<tr>
<td>65 dB to 70dB</td>
<td>218</td>
<td>11</td>
</tr>
<tr>
<td>70 dB to 75dB</td>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td>&gt; 75dB</td>
<td>95</td>
<td>0</td>
</tr>
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</table>

Figure 0. 5 Bellingham Area, Population and Housing Units at various Noise Levels (Harris Miller Miller Hanson Inc, 2009)

Housing units within this region increased from 7 to 39 units (Harris Miller Miller Hanson Inc, 2009). Homes that are under the flight path approximately five and one half miles away from BLI experienced the same 85 dB level from a commercial jet over flight when compared to a home 2,400 feet away from the end of the southern runway at BLI (Harris Miller Miller Hanson Inc, 2009). The center of Bellingham
experiences commercial aviation traffic over the Center Business District (CBD) (Figure 1.5). As airlines continue to add more destinations the volume of aircraft will increase in the flight path becoming more of an annoyance for homeowners. The issues related to health as a result of aircraft noise can include damage to the inner ear, introduce poor sleeping habits, and creates learning disabilities (Harris Miller Miller Hanson Inc, 2009). Schools subjected to aircraft noise intensity and unpredictability found more students with learning disabilities in aircraft buffered areas than those schools located away from aircraft operations zones (Clark C, 2012). Whatcom County has a number of schools within the flight corridor (Figure 1.5).
Figure 1.5 Flight Departure and Arrival patterns over Bellingham (Harris Miller Miller Hanson Inc, 2009).
Air quality from jet fuel exhaust contains water vapor, carbon dioxide, nitrogen oxides, hydrocarbons, carbon monoxide, sulfur gases, soot, and metal particles (Environmental Protection Agency, 2000). Extensive work has been done in regard to contrails and how they impact climate change. Contrails are artificial clouds produced from aircraft. A high concentration of cirrus clouds absorb and reflect solar and inferred radiation with the potential of impacting climate change as jet traffic increases within a region (Minnis, Ayers, & Nordeen, 2003).

Protecting the waters of Whatcom County is critical. Over the past ten years, considerable work has been done to preserve Bellingham’s reservoirs and the bay area. Elementary science dealing with the water cycle tells us that an air shed feeds the watershed. With an increase in jet traffic at BLI, it has introduced additional layers of risk in regard to air, water and soil. The Port of Bellingham has added containment systems to control leeching from deicing of aircraft. Even with newer technologies, the increased frequency has increased the amount of air pollutants in the Whatcom watershed. The EPA along with the FAA also noted that Bellingham had high concentrations of lead in aircraft engines (Environmenal Protection Agency, 2008).

Wildlife around BLI continues to be mitigated by filling in wetland areas in order to prevent bird strikes. BLI documented 21 strikes since 1997 with 56% of the strikes occurring while in flight (Fderal Aviation Administation, 2009). A strike represents a hazard to passengers, wildlife, and people living under the flight path. In some cases, depending on the type of strike, an aircraft returning to the airport will dump fuel to
reduce the risk of fire upon landing. Beavers, around the airport have also been removed in order to mitigate the threat of flooding the airport’s runway (McClurg, 2002).

The socioeconomic conditions underneath the pattern also change as demand for infrastructure and ancillary services supporting the airport’s operations increase around the airport. Traffic and congestion carries over to those neighborhoods around the airport.

The security and safety to a community is not just an environmental risk but presents the possibility of an airline crash within a residential area. Most aircraft related accidents happen within in the process of takeoff and landing.

**Previous Studies Illustrating Airport Noise Impacts on Communities**

There have been a number of studies at various locations around the world that have examined the sustainability or environmental costs associated with aircraft noise. Chapter four discusses this in further detail but to lay the ground work for this thesis the following studies represent a small sample of what has been captured in the past.

The “Reaction to aircraft noise in residential areas around Australian airports” (R.B. Bullen, 1996) highlights the impact from noise on residential communities.

Vancouver, Canada’s housing density and airport noise impact was examined in the work, “Density of Residential Land Use and the Impact of Airport Noise” (Uneyo & Hamilton, 1993). The study found that vacant land was more sensitive to pricing than residential homes and that further research was required.
Additional literature in regard to housing valuations was conducted around Chicago’s O’Hare in the work titled, “Airport expansions and property values: the case of Chicago O’Hare Airport” by Daniel McMillen (McMillen, 2004).

The study “Airport noise, location rent, and the market for residential amenities” by Jon Nelson, captures the valuations of several communities around airports (Nelson, 1979).

The “Impact of Airport Noise on Residential Real Estate” by Rendell Bell looks at housing valuation challenges facing many cities (Bell, 2001). The article was presented in the Appraisal Journal which includes an audience of real estate agents and assessors.

Another article, “The Impact of Airport Noise and Proximity on Residential Property Values” (Esprey & Lopez, 2000) examines the “negative relationship” between residential properties and airport noise.

The journal article, “Community Attitudes and Action in Response to Airport Noise” examines how the environmental impacts that were at one time ignored are becoming more important to communities around airports (Goodman & Clary, 1976) as their valuations decline.

Erwin Seago wrote a journal article in the Maryland Law Review titled, “The Airport Noise Problem and Airport Zoning” which examined cases involving litigation between airport operators and cities trying to mitigate noise and encroachment disputes (Seago, 2012).
Examining “Aircraft noise social cost and charge mechanisms – a case study of Amsterdam Airport Schiphol” (Morrell & Liu, 2000) illustrates that noise has a social cost which is not considered in the Integrated Noise Model (INM).

The work by Shingato Tsuru, noted the impacts from airport noise in Osaka, Japan in his work, “The Political Economy of the Environment: The Case of Japan” (Tsuru, 1999).

Another airport conflict in Japan captured by Roger Bowen highlighted “The Narita Conflict” (Bowen, 1975). This discussed the placement and selection process for a new airport that met opposition from farmers for the now Narita Airport.

Communities such as Lexington, Massachusetts, a small bedroom town outside Boston, was the setting for “Take Back the Sky, Protecting Communities in the Path of Aviation Expansion”, by Rae Andre (Andre, 2009), highlights the events surrounding the commercialization of Hanscom Field outside Boston. Dr. Andre, is a Professor of Organizational Behavior and Theory at Northeastern University. Her work described and compared her experience with other communities bordering an airport.

Deb Wagner’s account in, “Over my Head”, also acknowledged the Seattle area fight to stop the building of a third runway highlighting the environmental effects from additional flights at Seattle-Tacoma International Airport (Wagner, 2011).

This study will improve upon the previous work cited by providing a visual approach when dealing with airport issues. By observing and capturing multiple
locations experiencing growth adds additional support for increasing the reach of
the current INM.

**Methodology and Thesis Organization**

The patterns of flight above Bellingham and around an airport are dynamic. Weather conditions, fuel efficiency, air traffic, safety, and the destination are what determine a route. By capturing a specific time period from 1990 through 2010 and comparing the land uses in BLI along with other airports, will help plan Whatcom County’s future. The Integrated Noise Model (INM) will be compared with Whatcom County Assessor information. The INM is a model which assists politicians in order to help with noise mitigation techniques with the possibility for grant justifications from the FAA. One unique feature of BLI is its proximity to the Canadian border. This adds a unique criteria since Canadians can use BLI for travel. Since air travel is speculative and with the potential growth from other airports within an hour’s drive, planners, politicians, local businesses, and the community will have an opportunity to examine the risks and how the values of land share the same dynamics related to flight pattern change.

Studying the buffer surrounding the airport can determine the land use within the airport and set future framework for the flight paths situated in Whatcom County and eventually for Puget Sound. Questioning how many flights per day, what will be the airports anticipated future demand, what is the airport’s capacity, which directions will aircraft takeoff, hours of operation, what new destinations are being
marketed, what are the environmental risks, are all valid questions shaping the
dynamics of flight patterns over Whatcom County.

Understanding how historical patterns of flight impact the community is highlighted
in Chapter 2 setting the stage and flavor for the study. By examining the history of
aviation in the region and how demand influences policies and economics while
trying to balancing the environmental risks will also be covered in this chapter.
Previous works will also be contained in this chapter.

Chapter 3 examines the flight patterns or route and what the main drivers are for
making them dynamic. The commercial airline industry is what drives
enplanements at BLI. This chapter will also examine the risks associated with the
industry.

The primary reason communities across the country are annoyed by aircraft is from
noise. Chapter 4 examines the nuisance generated from aircraft and how noise is
measured. This chapter also examines how the Integrated Noise Model (INM) has
limitations when it comes to land uses outside the boundary of an airport.

Chapter 5, focuses in on a new methodology to help solve a problem facing many
communities. The analysis focuses in on enplanements and the volume within the
flight pattern over a twenty-year period and how land uses have changed
underneath the flight pattern and within the airport boundary. By examining other
airports that closely resemble Bellingham and with various snapshots in time adds
weight to this chapter. Bellingham has a unique geographical location being
classified as an edge city serving two larger metropolitan areas with one being in
Canada. The additional analysis will focus in on the cross border aviation relationships that both impact and influence the policies from the role of Canadian demand.

Chapter 6 contains the summary and conclusion for the first few and then covers summarizes the hypothesis and what the findings were.

The final chapter presents recommendations as well as offerings for further study. The intent of the application and the methodology behind it is to build a new way of looking at issues which fall into this same type of study.
Chapter 2 **HISTORICAL BACKGROUND**

In 1936, Whatcom County purchased land using funds from the Works Progress Administration, as part of the New Deal. Work stopped initially due to cost overruns on preliminary land prep work. The airport was situated in a wetlands area with uneven terrain. Work continued in 1940, just prior to World War II, Whatcom County politicians entertained the idea to not only foster job creation but to make the airport a port of entry prior to Seattle and Everett. After several months the airport runway was finally completed. The runway was 3,600 feet long and 150 feet wide. A scheduled landing by a United Airline’s Mainliner, was cancelled during the opening day ceremony due to the runway condition not being suitable for the weight of the aircraft.

As World War II approached, additional funding was received from the Corps of Engineers and the War Department. Two additional runways were constructed with the initial runway being lengthened an additional 1,600 feet. The airport opening was overshadowed by the bombing of Pearl Harbor on December 7th, 1941. A few days later the US Army began using the airport.

In 1946, after the war ended, the Army handed the airport over to Whatcom County. With costs rising and the inability to attract sustainable air service, the airport was sold for $1 to the Port of Bellingham in 1955. The Port of Bellingham was
established in 1920 to manage Port operations. Since that time, the Port operates and manages real estate, marinas, and the airport.

Costs

The Port saw operating expenses rising at the airport from upkeep and the lack of revenue from air service. To reduce resurfacing and maintenance costs, the Port shutdown runways leaving the main North-South runway open for resurfacing. Not until 1985, was the first jet service established by Pacific Southwest Airlines. The Port decides to invest $1 million for a new terminal to enhance the current facility and to attract addition air carriers. In 1987, Pacific Southwest became US Air. In that same year Horizon, a subsidiary of Alaska Airlines, started service. In 1989, both United Express and Alaska Airlines started service. From a marketing perspective, the Port decided to extend the runway and buy up homes to accommodate larger aircraft. Figure 2.0 illustrates the FAA grants applied for and received. From 2009 thru 2012, the Port received an estimated $37,525,089 from the FAA’s grant program (Federal Aviation Administration, 2013).
Figure 2.0 FAA Grants and Enplanements Statistics from the last twenty years (Federal Aviation Administration,
Present

BLI has experienced a tremendous increase in demand over the past eight years. The forecasted growth from the 2004 master plan was understated by the Federal Aviation Administration (FAA) and URS, the Port of Bellingham’s aviation consultant. The Port of Bellingham’s Aviation consultant missed the mark by 300%. In order to meet the unexpected demand, the Port of Bellingham voted to expand the terminal in order for the air carriers to expand service and grow. The Port decided to increase the baggage and ticketing areas, renovating the tarmac and adding wider taxiways for larger aircraft. Since 2004, enplanements have risen 526% (Department of Transportation, 1990-2012). Today, the current estimate is 62% of the enplanements are Canadian passengers (Port of Bellingham, 2007). In 2011, the airport had over a half-million enplanements setting a record with a 29.27% increase from the previous year. Figure 2.1, show just how fast BLI has grown since 2004. The illustration also lists the air carriers that have served BLI since 1990 along with the airline’s enplanement numbers for each year of service.
Figure 2.1: BLI Airline Passenger Enplanement History from 1990 to 2012 (Department of Transportation, 1990-2012)

Bellingham International Airport Enplanement History (1990-2012)
Geographical Location

BLI is located in Whatcom County, Washington located 80 miles north of Seattle, Washington, United States and 50 miles south of Vancouver, British Columbia, Canada. The Canadian border is 14 miles north of Bellingham International Airport. The airport site is just west of US Interstate 5, exit 258. The airport is three miles northwest of the City of Bellingham. The Airport owner is the Port of Bellingham. The height above mean sea level (AMSL) is 51.8 meters or 170 feet. The International Air Transport Association (IATA) airport code is BLI. The FAA Location Identifier (FAA LID) is BLI. The International Civil Aviation Organization (ICAO) airport code is KBLI. The runway runs north-south or in aviation terms, 16/34 which represents the compass headings of 160 and 340 degrees. The runway surface is asphalt with a length of 2,042 meters or 6,701 feet long and 45.7 meters or 150 feet wide. The geographical coordinates for Runway 16 are latitude 48°47’33”N and longitude of 122°32’15”W. The geographical coordinates for runway 36 are latitude 48°48’00”N and longitude of 122°32’14”W.

Geographical Size

The Port of Bellingham owns and operates the 309 acres Airport Operations Zone (AO) (Port of Bellingham, 2010). Figure 2.1.1, highlights the runway dimensions and specifics to pilots.
The airport is located in an Airport Operations Zone (AO) as defined by Whatcom County Code (WCC) and covers an estimated 2,190 acres. The land is made up of coniferous trees with extensive wetlands throughout the property.

**Weather Patterns**

Weather patterns determine the flight path. During the year winds in Bellingham, are predominantly from the south and in the spring, summer, and fall. Winds are
from the north in the winter months. Aircraft utilize the winds for both takeoffs and landings. Aircraft, in most cases, depart into the wind.

**Summary**

The history of BLI is not unlike other airports around the country. The placement, governance, and land use change as the demand change. In the case of BLI, the geographical location has not changed, but the CAD has. This leads us to the next chapter which discusses how flight patterns are derived and why they are dynamic.
Chapter 3 FLIGHT PATTERN DYNAMICS OF BLI

This chapter examines why flight patterns are dynamic in nature and why they are considered an “invisible-runway”. Weather, economics, volume, advancements in technology, security, policy, and safety all contribute to flight pattern dynamics.

The Business Model

The easiest way to become a millionaire is to start off a billionaire and go into the airline business.” – Richard Branson, Virgin Founder

Enplanements

Enplanements are the number of airline passengers that enter a departing aircraft. Each enplaned passenger in most cases has a seat on the aircraft. In some cases airlines can either over or under book (not by design) or by not having the demand to fill the seat. The Passenger Load Factor (PLF) is the number of enplanements (passengers) per number of seats. If an airline fails to meet a certain PLF, the air carrier may decide to terminate the route or increase their marketing. This is why the Port of Bellingham subsidizes the advertising and marketing for a given year knowing that the establishing the route is critical for the airline (Port of Bellingham, 2012).

When an airline establishes a new route, it takes considerable investment in establishing the new destination. The number of seats sold determines the success of a route. The PLF measures the total capacity of an aircraft based on the number
of seats sold per flight. An aircraft such as a 737 with 150 seats with 120 passengers has a PLF of 80.0% (120/150).

Figure 3.2 shows how an airline might use the PLF to drop or add routes. In the data provided by the Department of Transportation in Figure 3.2, is the 2012 Seat and Passenger counts for Hawaiian flights departing from BLI. The two airlines are Alaska Airlines (AS) and Allegiant Air (G4). The two destinations cities are Maui (OGG) and Honolulu (HNL).

Note that Allegiant Air started service to Hawaii November, 2012 while Alaska the previous year. Airline analysts and/or airport planners would use this data to either remove a route from the market or the carrier may elect to increase marketing efforts in order to increase the PLF.

<table>
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<tr>
<th>DEPARTURES</th>
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Figure 3.1 PLF for Hawaii Routes from Bellingham (Department of Transportation, 1990-2012).
Canadian Traffic

Bellingham is one of the fastest growing airports in the country. The Wall Street Journal (Nicas, 2012), Figure 3.2.1, noted that other cities like Bellingham, along the border are experiencing heavy growth from the disparity in airline tariffs.

Allegiant is aware as are other carriers that Bellingham is located just south of a major Canadian market and due to levies such as fuel and landing fees along with the Canadian dollar (CAD), the Canadian airlines cannot compete against American carriers just south of the border. Allegiant is so successful at this, that they are creating markets in small regional airports such as Plattsburg, NY servicing Montreal, Niagara Falls, NY serving Toronto, Grand Forks, ND serving Winnipeg, and Bellingham serving Vancouver, Canada. These small airports are seeing tremendous growth and are all within a sixty miles of a major airport in Canada.
**Marketing**

When an airline, such as Allegiant Air, markets to a specific area and is able to capture the market, it is known as a catchment. In most cases it is a geographical region. So if an airline successfully attracts lower BC catchment, such as Allegiant Air continues to do, it becomes a leakage for the Canadian air carriers such as WestJet and Air Canada. Allegiant Air is a no frills airline known for inexpensive fares. Allegiant also ties their ancillary businesses which draws income from linking their patrons with hotels and rental car packages.

Marketing and advertising is critical for the airlines in order to keep both catchment and to attract passengers. The Port of Bellingham (POB) hired the Gilmore Research Group a marketing firm based out of Seattle. The Bellingham Airport Survey (2011) Survey was put together with assistance from the FAA. The survey provided information to Port officials in order to gain an understanding on how people in Whatcom County felt about and airport and the continued expansion at BLI. The survey found that over all residents were satisfied (Gilmore Research Group, 2011).

There were three questions relating to the environmental impact on the community. The three quality of life impacts were noise, air pollution, and traffic flow with a one to ten level of impact where one having no effect and ten having a very large impact. The survey findings presented to the POB created three ranges from 8-10 having a large negative impact, 4-7, having a moderate impact, and 1-4 having little impact. There was also a category for do not know. The noise results yielded 17% indicating a large negative impact, 25% had moderate impact, and 57% and no
impact with 1% not knowing. In regard to air pollution, respondents had 9% felt largely impacted, 27% moderately impacted, 62% having no impact and 2% not knowing the impact of air pollution. Traffic results had 7% reporting they were largely impacted, 27% moderately impacted, and 66% felt no impact with no one not knowing. Figure 3.2 is a breakdown without specific ranges. The brightest color or more vivid red, represents those responses from residents that felt in their opinion, they were highly annoyed or felt their quality of life was negatively impacted. The sample size for the survey was 622 residents scattered in various areas in Whatcom County (Gilmore Research Group, 2011).

Figure 3.2 Bellingham Airport Survey 2011, (Gilmore Research Group, 2011)
Two recommendations for handling the negative impacts outlined in Figure 3.3 were provided to the POB in order to eliminate any community concerns.

1. **Use results of this survey to promote greater public awareness of (and increased public support for) expansion.** This is particularly important as development may begin to generate some opposition associated with growing pains (Gilmore Research Group, 2011).

2. **Counter negativity about expansion with key agreement statements stressing the greater travel convenience offered by the Bellingham Airport, the importance of the airport to the regional economy and the manageability of traffic into and out of the airport** (Gilmore Research Group, 2011).

Marketing as noted earlier, is critical for the operators of an airport and for an air carrier. There are various dependencies and agreements that are based on enplanement dollars supporting various businesses at the airport. Due to the number of airports seeking tenants from air carriers around the world, it is projected that marketing and advertising efforts will double over the next ten years (ICD Research, 2013).

**Risk**

In 2012, a report was released by the Airport Cooperative Research Program (ACRP), Report 76, titled, “Addressing Uncertainty about Future Airport Activity Levels in Airport Decision Making”. The ACRP is sponsored by the FAA. The study was conducted by Ian Kincaid, an economics professor who works for InterVISTAS, a consulting firm that specializes in solutions for the aviation, tourism, and transportation industry (InterVISTAS, 2013).

**This BLI example shows that upside risk can lead to a need for rapid airport expansion in order to keep airlines and passengers satisfied to ensure that airlines can continue to expand their services and to avoid congestion that**
may lead to a loss of passengers or the exit of a carrier (Kincaid & Tretheway, 2013).

In the report, Kincaid defined various impacts associated with BLI. The scatter diagram from Figure 4.2, highlights the risks and the Severity of Uncertainty at BLI. Kincaid recognized the threats and opportunities relating to BLI. Each risk was
assigned a percentage of probability (Y Value) and a measure of impact (X Value). The criteria was broken down into five separate categories which included macroeconomics, market, regulatory / policy, technology, and shock event.

**Macroeconomics:** a study of economics in terms of whole systems especially with reference to general levels of output and income and to the interrelations among sectors of the economy. (Merriam Webster, 2013)

The macroeconomics that Kincaid & Tretheway alludes to as a threat to the airline industry is the sensitivity to fuel prices, large decline in the CAD, and / or an economic recession.

As fuel prices rise, the airlines must charge back the cost on an airline ticket. Airlines will cut back on the number of operations. Fuel prices have a direct impact on operational costs for an airline. This is considered the primary macroeconomic threat facing airlines and as Kincaid noted and has the highest probability. This also has a correlation with aircraft technology in regard to the efficiency of newer engines and the ability to find cheaper fuels.

Fluctuations in the CAD determine ticket prices. If the CAD increases, this will attract lower BC residents to US airports since the cost of a ticket would be cheaper. A decline in the CAD will keep catchment in Canada.

Economic stability has an impact on the tourism industry. More people are willing to spend on luxuries, such as vacations when an economy is booming. In addition business travel would also increase. In a recession, there are is a drop in the number of passengers travelling.
When an airline enters the market, it leads to more opportunities to attract more enplaned passengers by having more destinations or options for the general public. Kincaid & Tretheway considered introducing more destinations as having the highest opportunity and probability for attracting more passengers. When a new airline enters the BLI market, the Port of Bellingham pays the airlines advertising and marketing costs for the year as an incentive to attract more destinations with the any new carrier entry or for a new destination (Port of Bellingham, 2012). With the close proximity to the Canadian border, advertising is paid for by the POB in Canada. As mentioned, the airline market is dynamic as more airlines can design or tailor their service around events or seasonal conditions.

Natural disasters, pandemics, and terrorist attacks are all considered shock events by Kincaid (Kincaid & Tretheway, 2013). Airports are considered an important part of a city’s economy and if an event would impede access to the airport.

Politics also plays a major role in deciding an airport’s future. Regulations and policy can drive airport initiatives and can control airport operations. Kincaid mentioned that security, open skies liberation, and an increase in either Canadian or American aviation taxes are all impacts. Incentive policies to attract air carriers is one type of policy.
Land use policies such as disclosures to curtail residential development sets the groundwork for setting airport land use policy. Acquiring property, noise mitigation, and creating berms are all political.

Illustrated in Figure 3.5 are the years in service by the total number of carriers between 1990-2010. The histogram was created from examining the number of US carriers in service between the years 1990 thru 2010. The query examined the air carrier’s destination records from the DOT measuring either the number of sequential or break in service by year.

![US Air Carrier Years in Service](image)

Figure 3.4, US Air Carrier Years in Service (Department of Transportation, 1990-2012)

It should be noted that there have been a number of mergers and bankruptcies in the last twenty years (Petzinger, 1996) that would impact the naming of an airline
and how they are recorded with the DOT over time. The average lifespan of an airline in the twenty year span was eight years (Appendix B).

Destinations

![Bellingham Destinations](image)

Figure 3.5 Bellingham Destinations. www.viatime.org/airdocs (Paskus, 2008)

In 1985 the first air passenger service began flying out of Bellingham. Pacific Southwest Airlines (PSA) offered service to Southern California. In 1987, PSA was
acquired by US Air. That same year Horizon Air, a subsidiary of Alaska Airlines, began commuter service to Seattle-Tacoma International Airport (SEA). Over the next two years, a few more airlines entered the market. United Express & San Juan Airlines known as West Isle Air started service. With a lack of passenger demand, US Air and Alaska Airlines left the Bellingham market in the early 1990’s. Leaving only Horizon Air, the Port aggressively looked to expand air service by offering incentives to various air carriers. Casino Express (XP), which later changed their name to Xtra Airways, began service to Las Vegas. Another airline called Sun Country started a chartered service out of Bellingham. Sun Country was founded by Braniff employees. Allegiant Air, started service in 2004 with flights to Las Vegas. Allegiant was interested in the Canadian market from British Columbia (BC). Western Air lasted one month after running into financial problems. The POB has attempted to attract carrier service in order to establish eastbound connections. SkyWest Airlines is a regional carrier which was contracted by Delta. The airline had the first eastern destination to Salt Lake City, one of Delta’s hubs. The service only lasted three years suffering from declining demand and the CRJ (smaller passenger jet) operating costs from inefficiencies in fuel consumption. Sky Bus Airlines in 2007 started service to Columbus, Ohio but ended service from a lack of demand and with bankruptcy looming. The airline folded shortly after leaving Bellingham.
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</tr>
<tr>
<td>PSP</td>
<td>114,602</td>
<td>817</td>
<td>140.27</td>
</tr>
<tr>
<td>AZA</td>
<td>103,390</td>
<td>713</td>
<td>145.01</td>
</tr>
<tr>
<td>OAK</td>
<td>73,125</td>
<td>511</td>
<td>143.10</td>
</tr>
<tr>
<td>HNL</td>
<td>70,064</td>
<td>507</td>
<td>138.19</td>
</tr>
<tr>
<td>SAN</td>
<td>68,859</td>
<td>494</td>
<td>139.39</td>
</tr>
<tr>
<td>LAX</td>
<td>65,563</td>
<td>459</td>
<td>142.84</td>
</tr>
<tr>
<td>SLC</td>
<td>41,561</td>
<td>1,097</td>
<td>35.89</td>
</tr>
<tr>
<td>RNO</td>
<td>41,074</td>
<td>344</td>
<td>119.40</td>
</tr>
<tr>
<td>ENV</td>
<td>25,945</td>
<td>181</td>
<td>143.34</td>
</tr>
<tr>
<td>CMH</td>
<td>23,866</td>
<td>221</td>
<td>105.99</td>
</tr>
<tr>
<td>LGB</td>
<td>20,498</td>
<td>151</td>
<td>135.75</td>
</tr>
<tr>
<td>EKO</td>
<td>19,632</td>
<td>181</td>
<td>108.46</td>
</tr>
<tr>
<td>IFP</td>
<td>17,837</td>
<td>134</td>
<td>133.11</td>
</tr>
<tr>
<td>SFO</td>
<td>12,361</td>
<td>91</td>
<td>135.84</td>
</tr>
<tr>
<td>ESD</td>
<td>10,450</td>
<td>17,844</td>
<td>0.59</td>
</tr>
<tr>
<td>FRD</td>
<td>7,244</td>
<td>11,304</td>
<td>0.64</td>
</tr>
<tr>
<td>PDX</td>
<td>4,752</td>
<td>144</td>
<td>33.00</td>
</tr>
<tr>
<td>DQF</td>
<td>2,908</td>
<td>32</td>
<td>90.88</td>
</tr>
<tr>
<td>ONT</td>
<td>1,059</td>
<td>16</td>
<td>66.19</td>
</tr>
<tr>
<td>DEN</td>
<td>933</td>
<td>9</td>
<td>103.67</td>
</tr>
<tr>
<td>YKM</td>
<td>389</td>
<td>23</td>
<td>16.91</td>
</tr>
<tr>
<td>CLM</td>
<td>387</td>
<td>16</td>
<td>24.19</td>
</tr>
<tr>
<td>SCK</td>
<td>306</td>
<td>2</td>
<td>153.00</td>
</tr>
<tr>
<td>PSC</td>
<td>303</td>
<td>12</td>
<td>25.25</td>
</tr>
<tr>
<td>EUG</td>
<td>290</td>
<td>5</td>
<td>58.00</td>
</tr>
<tr>
<td>TWF</td>
<td>163</td>
<td>2</td>
<td>81.50</td>
</tr>
<tr>
<td>BLI</td>
<td>157</td>
<td>11</td>
<td>14.27</td>
</tr>
<tr>
<td>PAE</td>
<td>152</td>
<td>1</td>
<td>152.00</td>
</tr>
</tbody>
</table>

Figure 3.6, BLI Destinations (Department of Transportation, 1990-2012)
In 2010, the BLI runway rehabilitation, was part of a FAA grant application. One stipulation of the grant was to not only rehabilitate the runway but to widen the taxiways. Widening the taxiways allowed for larger aircraft, like the 757. In the same article, it was reported that Allegiant would most likely offer flights to Hawaii from Bellingham (Port of Bellingham, 2010). Alaska, however, jumped in and started serving Hawaii service with 737-800 aircraft. Allegiant started service in the fall of 2012 starting almost a year later.

**Unpredicted Forecast**

When the 2004 BLI master plan forecast was released, Bellingham had an estimated 100K enplaned passengers. The URS forecast for BLI projected that the airport would have 270K passengers by the year 2050. By the end of 2012, BLI had just over 570K (Department of Transportation, 1990-2012) enplaned passengers. In less than 10 years, BLI experienced a 470% increase with a 111% increase over the projected estimate for the year 2050, this put BLI thirty-eight years ahead of the projected URS forecast (Figure 2.1) presented to the POB in 2004. Kincaid and Tretheway labeled Bellingham as an “Extreme Upside Scenario” (Kincaid & Tretheway, 2013).

In the case of BLI, airlines are attracting catchment from other markets placing a heavier environmental burden on the community (Environmental Protection Agency, 2000). In 2004, the primary catchment was considered to be Whatcom
County with lower British Columbia with both Skagit and Snohomish Counties considered as a secondary catchment (Figure 3.9). The Port of Bellingham recognized in 2010 that Canadian catchment was over 60% (Port of Bellingham, 2007) and even though Canadian's are the majority of passenger traffic, the catchment is still considered to be regional and a secondary catchment.

Summary

This chapter provided us with an understanding on how flight patterns are derived and how dynamic the aviation industry is. The chapter also noted that when a new business model is introduced, it can alter the volume of air traffic around an airport. This creates stresses on residential neighborhoods near the airport and under the
flight path. The most profound impact on communities is noise from jet aircraft.
This brings us to the next chapter which discusses how stakeholders measure the impacts from jet aircraft and what those tools are.
Chapter 4 THE IMPACT FROM NOISE AND THE INTEGRATED NOISE MODEL

*It’s not the airport, but the airplane*

(Ashford, Stanton, & Moore, 1997)

This chapter will cover the environmental impact of noise from an airport and how it is associated with aircraft. This chapter will also highlight the impacts on neighborhoods buffering the flight pattern and how the Integrated Noise Model (INM) is used by the Federal Aviation Administration (FAA) to mitigate noise.

Noise is a predominate cause of friction between homeowners and airport operators. This is a global issue and despite the best efforts, maintaining a balance between aviation and the surrounding communities is contentious.

The International Civil Aviation Organization (ICAO) Assembly in 1968, recognized as the aviation industry expands; noise impacts will also increase. In 1971, the Annex 16 document was introduced. The document established environmental protection guidelines within the industry.

The ICAO or *International Civil Aviation Organization* is the global forum for civil aviation. ICAO works to achieve its vision of safe, secure and sustainable development of civil aviation through the cooperation of its Member States (International Civil Aviation Organization, 2013).

ICAO revises the guidelines and set standards for ICAO members. The United States through the FAA, has their own set of standards but also serves as an ICAO member state and holds a council seat (International Civil Aviation Organization, 2013).
The FAA noise program is standardized on the SAE AIR 1845. To brake this down, the Society of Automotive Engineers (SAE), Air information Report (AIR), or the SAE-1845 is a document titled “Procedures for the Calculation of Airplane Noise in the Vicinity of Airports” (Society of Automotive Engineers, 2012). The standard is used to meet the Federal Aviation Regulation 150 or known as FAR 150 for environmental assessment under FAA Orders 1050 and 5050 which meets the National Environmental Policy Act (Federal Aviation Administration, 2006).

**F.A.R. Part 150 is a voluntary program that U.S. airports may undertake to seek a balance between their operational needs and the noise impacts their operations have on surrounding neighborhoods** (Federal Aviation Administration, 2006).

Aircraft create noise from their engines and from the flow of air traveling over the wings and body of the aircraft. As the sound waves travel through the air from the aircraft, “oscillations of pressure” (Harris Miller Miller Hanson Inc, 2009) strike our ear drum producing the sound we hear. The sound pressure level (SPL) is a measurement that takes the sound waves we interpret over the quietest sound level humans can hear. A bel (B) is a logarithmic unit which represents a single sound. Decibels (dB) are commonly used to measure sound and represent one tenth of a bel.

**Sound is the acoustical energy released into the atmosphere by vibrating or moving bodies** (Papcostas & Prevendouros, 2001).

Figure 4.1 illustrates dB sound levels and human response. As you move up the scale, a 3 dB increase is a doubling in sound (Environmental Protection Agency,
A dB value of 0 which climbs to 100 dB represents moving from $10^0$ to $10^{10}$ and equates to a range from where hearing begins to hearing the operations of a garbage truck noted on Figure 4.1.

<table>
<thead>
<tr>
<th>Common sounds</th>
<th>Noise level (dB)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier Deck</td>
<td>140</td>
<td>Painfully Loud</td>
</tr>
<tr>
<td>Jet Operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air raid system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet takeoff (200 ft.)</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Thunderclap</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discotheque</td>
<td>120</td>
<td>Maximum Vocal effort</td>
</tr>
<tr>
<td>Auto horn (3 ft.)</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Pile Drivers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garbage truck</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Heavy truck (50 ft.)</td>
<td>90</td>
<td>Very annoying</td>
</tr>
<tr>
<td>City traffic</td>
<td></td>
<td>Hearing damage (8 ft.)</td>
</tr>
<tr>
<td>Alarm Clock</td>
<td>80</td>
<td>Annoying</td>
</tr>
<tr>
<td>Hair dryer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noisy restaurant</td>
<td>70</td>
<td>Telephone use difficult</td>
</tr>
<tr>
<td>Freeway traffic</td>
<td></td>
<td>Beginning of ear damage</td>
</tr>
<tr>
<td>Man's voice (3 ft.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air-conditioning Unit (20 ft.)</td>
<td>60</td>
<td>Intrusive</td>
</tr>
<tr>
<td>Light auto traffic (100 ft.)</td>
<td>50</td>
<td>Quiet</td>
</tr>
<tr>
<td>Living room</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Bedroom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quiet office</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Library</td>
<td>30</td>
<td>Very quiet</td>
</tr>
<tr>
<td>Soft whisper (15 ft.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broadcasting studio</td>
<td>10</td>
<td>Just audible</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Hearing begins</td>
</tr>
</tbody>
</table>

*Figure 4.1. Sound levels and human responses. (Harris Harris Miller Hanson, 2013)*
Harris Miller Miller & Hanson (HMMH) is an engineering firm that specializes in acoustical engineering and consulting. HMMH represented the Port of Bellingham (POB) from 2008 through 2009 producing the Bellingham International Airport Noise Study which introduced six acoustical metrics to help the POB understand and evaluate different noise scenarios in the vicinity of the airport (Harris Miller Miller Hanson Inc, 2009). Within the same noise study, HMMH discussed the impacts on people, and introduced a noise model called the Integrated Noise Model (INM).

**HMMH solves complex problems affecting our environment. Our core values are to serve clients with excellence and honesty, to respect others, foster teamwork and seek growth opportunities** (Harris Harris Miller Hanson, 2013).

### Measuring Sound

Frequency is the rate of cycles per second which is measured in Hertz (Hz). Humans hear in the range of 20 Hz to 15,000 Hz. By applying weighting filters, provides acoustical engineers the ability to associate the sensitivity of our ears to our surroundings. This level is called “A” filtering and is abbreviated by dBA (Harris Miller Miller Hanson Inc, 2009). Figure 4.2, represents some of the terminology used by acoustical engineers.

<table>
<thead>
<tr>
<th>Acoustical Metrics</th>
<th>Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decibel</td>
<td>dB</td>
</tr>
<tr>
<td>A-Weighted-Decibel</td>
<td>dBA</td>
</tr>
<tr>
<td>Maximum A-Weighted Noise Level</td>
<td>$L_{\text{max}}$</td>
</tr>
<tr>
<td>Sound Exposure Level</td>
<td>SEL</td>
</tr>
<tr>
<td>Equivalent Sound Level</td>
<td>$L_{\text{eq}}$</td>
</tr>
<tr>
<td>Day-Night Average Sound Level</td>
<td>DNL</td>
</tr>
</tbody>
</table>

*Figure 4.2, Acoustic Metrics (Harris Miller Miller Hanson Inc, 2009)*
The Maximum A-Weighted Noise Level is abbreviated by $L_{\text{max}}$ and measures the maximum sound level from an event. The $L_{\text{max}}$ captures single events (Harris Miller Miller Hanson Inc, 2009).

The Sound Exposure Level (SEL) is the total noise level over time with a compressed duration of one second. When compared to $L_{\text{max}}$, the SEL will always be larger and captures single events. Noise models use the SEL and make up the FAR Part 150 study (Harris Miller Miller Hanson Inc, 2009).

The Equivalent Sound Level, $L_{\text{eq}}$ is the accumulation of sound over a specific period of time (Harris Miller Miller Hanson Inc, 2009).

The Day-Night Average Sound Level (DNL) measures the cumulative noise over an average annual day (Harris Miller Miller Hanson Inc, 2009). Federal agencies utilize the DNL extensively.

There are no new descriptors or metrics of sufficient scientific standing to substitute for the present DNL cumulative noise exposure metric (Federal Interagency Committee, 1992).

Researchers found that a common denominator in measuring noise impacts is how to understand and classify levels of annoyance and how noise annoyance impacts people. To help define what a noise annoyance is, social surveys have been and continue to be conducted in order to measure the impact. What drives the studies is that airports are a dynamic entity. Airport growth, flight pattern changes, and aircraft advancements keep the DNL dynamic. How stakeholders define the airport’s future and how it continues to co-exist with the community or region adds
an extra layer of impact for residual communities (Fidell, A first-principles model of aircraft annoyance, 2011).

*The rate of growth of community annoyance with aircraft noise exposure is closely related to the rate of growth of effective loudness of noise exposure* (Fidell, A first-principles model of aircraft annoyance, 2011).

Since the DNL is used as a determinate in mitigation, an applied dB value is applied in order to measure how much noise should be tolerable by a community. One method examined all the past surveys or “prevalence of annoyance” (Fidell & Silvati, Parsimonious alternative to regression analysis for characterizing prevalence rates of aircraft noise annoyance, 2004). This method examined forty three studies and how the Community Tolerance Level (CTL) represents a DNL where 50 percent of the community which felt “highly annoyed” and the other half did not.
Figure 4.3: Six surveys of communities exposed to aircraft noise (a) and the distribution (b). (Fidell, A first-principles model of aircraft annoyance, 2011)
Figure 4.3.a highlights six social surveys with the CTL value in different geographical settings. Illustrated in figure 4.3b, show the distribution of forty-three social surveys and their corresponding CTL values. The lowest CTL recording was 55.5 dB and the highest was 85.5 db which would be the equivalent from being in a quiet area to being awakened by an alarm clock (Fidell, A first-principles model of aircraft annoyance, 2011). The average CTL was 73.3 dB with a standard deviation of 7 dB with a sample size of 43 (Fidell, A first-principles model of aircraft annoyance, 2011).

Since the words “community” and “tolerance” are imbedded in the CTL, examining the definitions alone would explain the range differential noted in figure 4.3a and figure 4.3b. Airports have varying distances and geographical features which can naturally shield communities from noise.

Residents of the Bellingham area and Blaine/Birch Bay residents gave higher mean ratings for the negative effect of noise, than residents of the Lynden/Everson area (Gilmore Research Group, 2011).

The Port of Bellingham conducted, The Bellingham Airport Survey in 2011 in order to obtain public opinion and to gain and understanding from community residents about airport expansion. The survey noted that geographical region and distance from the airport influences annoyance levels (Gilmore Research Group, 2011).

The term “noise shadow” refers to the path of sound waves passing over the top of an area or object. Natural barriers such as trees or hills reflect sound energy over the top or away from an object. Manmade barriers such as berms or walls are used
along highways or at airports to reduce dB levels for communities (Papcostas & Prevendouros, 2001).

![Figure 4.4](image)

Figure 4.4, Relationships in social surveys Schultz (a) Ollerhead(b) (Papcostas & Prevendouros, 2001)

Tolerance or the level of annoyance is considered a social and subjective determination with a person's interpretation of how noise impacts them. For example, the occasional noise disturbance may not be considered an annoyance by one person but may be to another. As discussed, the social survey is an attempt to measure the tolerance of annoyance.

<table>
<thead>
<tr>
<th>Annoyance Category</th>
<th>Feelings About Aircraft Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Not annoyed. Practically unaware of aircraft noise.</td>
</tr>
<tr>
<td>B</td>
<td>A little annoyed, Occasionally disturbed.</td>
</tr>
<tr>
<td>C</td>
<td>Moderately annoyed, Disturbed by vibration; interference with conversation and TV/radio sound, may be awakened at night.</td>
</tr>
<tr>
<td>D</td>
<td>Very Annoyed. Considers area poor because of aircraft noise; is sometimes startled and awakened at night.</td>
</tr>
<tr>
<td>E</td>
<td>Severely Annoyed. Finds rest and relaxation distributed and is prevented from going to sleep; considers aircraft noise to be the major disadvantage to the area.</td>
</tr>
<tr>
<td>F</td>
<td>Finds noise difficult to tolerate. Suffers severe disturbance; feels like moving away because of aircraft noise and is likely to complain.</td>
</tr>
</tbody>
</table>

![Figure 4.5](image)

Figure 4.5, Degrees of annoyance illustrated in Figure 5.4b (Ashford, Stanton, & Moore, 1997).
Figure 4.5 was developed to help categorize and quantify based on the “Feelings about aircraft noise” (Ollerhead, 1973). With the associated illustration in Figure 4.4b. Ollerhead’s work, “Noise: How Can It Be Controlled?” examined the “human reaction” to noise. He noted the distribution between the populations and the annoyance noise level using the noise and number index (NNI).

\[
\text{NNI} = L_{pn} + 15 \log N - 80
\]

<table>
<thead>
<tr>
<th>( L_{pn} )</th>
<th>Average peaklevels</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N )</td>
<td>Number of operations exceeding 80 PNdB</td>
</tr>
</tbody>
</table>

*Figure 4.6, Noise and number index formula*

The NNI formula (Figure 4.6) was developed by the Wilson Committee on Noise (Wilson Committee, 1963). The committee was created in 1963 during the start of Europe’s jet age. The committee was established in order to gain an understanding on the problems facing residential communities being impacted by Heathrow Airport (LHR) located just outside London, England. The study measured noise levels in 85 locations and interviewed 1,731 people in a ten mile radius of LHR (Civil Aviation Authority, 1981).

The NNI was designed to measure the level of noise annoyances and reactions from the community surrounding Heathrow. In a report funded by the Department of Trade, the NNI was examined in order to assist with litigation. The report highlighted that several European and US airports had conducted surveys and were in line with the NNI. The report highlighted that “terms such as ‘annoyance’, ‘little’, ‘moderately’, etc..., are left to individual interpretation’ (Civil Aviation Authority,
1981). This report also highlighted that further investigation was needed and as noted that individuals have different sensitivity levels. The report mentioned that further studies should be conducted with different classifications such as “age, socio-economic group, etc” in order to aid measure the impact from noise (Civil Aviation Authority, 1981). The NNI formula represented in Figure 4.6, is used around the world for airport noise mitigation and tailored to meet the subjectivity for that region (Ashford, Stanton, & Moore, 1997).

Policy makers utilized the NNI as a “dose and response” mechanism which was used to create noise models creating contours around Heathrow. Community response desired a more efficient model. The NNI switched to the equivalent Sound level (L_{eq}) since noise exposure could be applied to a “period of interest” for a specific time. Residents had a concern that early morning and late night flights were not adequately captured in the current model. Residents wanted the studies to start addressing the time flights were operating. So the better fit was the L_{eq}.

The difference in finding that perfect noise contour fit can be observed in Figure 4.4b where Ollerhead’s “response and dose” highlighted the differences in the 55 L_{eq}, 55 L_{dn}, and 65 NNI. It was also noted that 10% of the population were not impacted (Ashford, Stanton, & Moore, 1997).

BLI is considered a small regional airport. As more flights are introduced, airports like BLI will observe a decline in the CTL indicating that smaller airports are more sensitive to noise than larger airports (Fidell, A first-principles model of aircraft annoyance, 2011). Small regionals had a CTL of 65.9 dB and a major airports, the
CTL was 75.2 dB (Ashford, Stanton, & Moore, 1997). This means that there was a higher tolerance for noise for communities closer to larger airports.

**Integrated Noise Model**

Currently the FAA uses the Integrated Noise Model (INM) to measure the impact of noise on communities located near an airport. The INM is a computer model designed to help airport operators understand airport aircraft noise impacts. The INM got its root from the initial studies done at Heathrow from the Wilson Committee. Each contour (Figure 4.7) represents a dB level difference. As suggested, the further you are away from an airport; the dB contours drawn will have diminishing dB levels and have the appearance of a topological map.
Figure 4.7 is an INM from a study conducted for the POB in 2009 with data from 2008. The study allowed the POB to review the existing 2008 conditions and
compare them with the 2000 dB levels in order to find those communities with the
greatest noise impacts. Figure 4.8 highlights the key designators for the INM.

<table>
<thead>
<tr>
<th>INM Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Assessing current aircraft noise impacts around a given airport or heliport</td>
</tr>
<tr>
<td>• Assessing changes in noise impact resulting from new or extended runways or runway configurations</td>
</tr>
<tr>
<td>• Assessing changes in noise impact resulting from new traffic demand and fleet mix</td>
</tr>
<tr>
<td>• Evaluating noise impacts from new operational procedures</td>
</tr>
<tr>
<td>• Evaluating noise impacts from aircraft operations in and around National Parks</td>
</tr>
</tbody>
</table>

Figure 4.8, What the INM is Designated to do (Federal Aviation Administration, 2013).

The INM is created from a software application sponsored and monitored by the FAA’s Office of Environment and Energy’s Noise Division. The performing organization is the ATAC Corporation and the Volpe National Transportation Systems Center (VNTSC) a subsidiary of the DOT. The ATAC Corporation is a California based software company specializing in simulation, modeling, and analysis for the aviation industry (ATAC, 2013).

**Limitations of the Integrated Noise Model**

Four limitations continue to follow the development of the INM. The first, is that INM is an average and does not consider single events which can range from 20-25 dB higher than the INM Contour. In the Noise Study conducted by HMMH, a location five and one half miles southwest of the center of the airport (Harris Miller Miller Hanson Inc, 2009). The recorded single event was 85 dB. An overflight. Noted earlier, 85 dB is slightly higher than the equivalent of an alarm clock (Figure 4.1).
The second, is the model only focuses in on the airport’s boundary. Sound is three dimensional, and the INM. As the aircraft departs, the sound even though spreads out, is still in the 85 dB range after leaving the boundary.

The third limitation is that the model even though considered the best available tool to measure an impact, is still under development evident by the software versioning over the course of a ten year period. Granted that the INM has evolved over time, but the INM is still a subjective measure.

The forth limitation is cost. The Bellingham Noise Study was $35,000. The software is limited in the ability to become automated for stakeholders. However, even with a lower costing allowing for more frequency, it would still not address the equity or property conflict with the present day model.

Other models such as the Noise Impact Model (NIM) utilizes the INM but adds census data to NASA released NASA/CR-1998-208952 (NASA, 1998). The NIM was developed to promote the aviation industry while taking into consideration abatement and airline efficiency. Within the document, they “recognized runway usage patterns or relocation aircraft flight patterns are technically and politically sensitive issues” (NASA, 1998).

The Local Policy of Noise

The operator or owner for BLI is the POB. The Aviation Director is an employee of the POB and manages the daily activities at the airport. Airlines lease space inside the terminal. When an aircraft departs, jurisdiction is passed over to FAA as the aircraft departs the AO Zone or outer boundary of the airport.
Funding sources stay within the Aviation Division. Such things as parking, leases, landing, and passenger enplanement fees are all revenue sources for POB Aviation. Another source of revenue is the grant funding from the FAA. When the POB applied for and received FAA grants, the POB became bound to FAA regulations. By accepting the grants, the City of Bellingham, Whatcom County, and the State of Washington lost jurisdiction or control over the airport. This means local governments cannot regulate the number of flights, noise levels, or hours of operation. Federal regulations prohibit the discrimination against an air carrier (Federal Aviation Administration, 2009). This means the cannot regulate the airline’s operations at the airport to conform to a communities concern.

In 2005, Whatcom County adopted an ordinance amending the airport/land use compatibility act as part of the Whatcom County Comprehensive Plan and Whatcom County Code. The adaptation addressed incompatible land uses around public airports in Whatcom County. As part of the ordinance, anyone living within a one mile radius of the runway must disclose this to a potential buyer (Whatcom County Council Agenda Bill, 2005).

Whatcom County Planners consulted the California Airport Land Use Planning Handbook (Shutt Moen Associates, 2002)(CALUSPH) which was recommended by the Washington State Department of Transportation’s (WSDOT) Aviation Division. The three areas addressed were noise, safety, and height hazards. The State Environmental Policy Act returned with a determination of non-significance. All
responses to the Whatcom County Policy Administration Environmental Checklist were returned with a “N/A Non-project proposal” response (Whatcom County, 2004). A public hearing was conducted in June 2004, and a presentation was made by Whatcom County Planning in which they introduced their findings from an Advisory Committee made up of aviation professionals and enthusiasts (PDS Whatcom County, 2004). The CALUSPH, the WSDOT Airport Land Use Compatibility Guidebook (Whatcom County Council Agenda Bill, 2005) and the POB 2004 Master Plan was utilized to help render their recommendation.

...there is not necessarily a correlation between complaints and noise exposure. At many airports, residential areas subjected to the highest noise levels produce relatively few complaints to originate from locations outside the defined noise contours... (Shutt Moen Associates, 2002)

...Total prohibition of certain type of land uses, especially residential land uses, consequently may not be necessary. More important is to give people who may be annoyed by airport noise timely information with which to assess how living in an airport vicinity would affect them. For these situations, buyer awareness measures can be effective strategies. (Shutt Moen Associates, 2002)

These two excerpts were presented to the Advisory Committee and were re-emphasized to the Planning Commission and to the Whatcom County Council by Whatcom County Planning.

Mead & Hunt, an aviation consultant (Mead & Hunt, 2013) was hired by WSDOT’s Aviation Division to evaluate their Airport Land Use Compatibility Program. A web based survey was created and sent to airport operators such as the POB. In regard to noise issues, the survey indicated that 26% felt that there was a low level of effectiveness with 9% stating that there was no effectiveness. 16% felt the program was highly effective. The POB fell with the majority with 49% of respondents
reporting that the guidebook had a medium level of effectiveness (Mead & Hunt, Inc., 2006).

*The intent is fine, but the process doesn't effectively garner comments from non-aviation agencies and the public* (Mead & Hunt, Inc., 2006)

The survey also collected comments on the overall plan. One of the comments (above) returned, was classified as a negative which indicated that there was not enough input from the general public.

**Whatcom County Assessor**

In order to see which homes were impacted from BLI, a request was presented to the Whatcom County Assessor's Office (Whatcom County Assessor's Office, 2012). There were approximately 60 homes impacted by aviation operations. Approximately 20 of the properties were located outside the INM (Figure 4.9). Figure 4.9, highlighted in red were residential properties impacted by the airport. The INM from Figure 4.7 was overlaid to help associate where the 2008 65 dB INM contour is related to the residential properties. If you refer back to Figure 4.7, you will note the expansion of the 2008 65 dB contour versus the 2000 65 dB (in yellow) noise contour.

The arrows indicate those properties outside the designated 2008 65 dB contour zone.
Summary

This chapter discussed how noise measurements have evolved to meet the requirements of politicians and planners in order to control noise related issues. The chapter also examined noise modeling and how it is used to abate and to conform land uses around an airport. The limitations of the INM was also discussed in order to support a new model that is less subjective and equity based. It is evident that as airport annoyances increase, equity conflicts will continue to persist. This is what brings us to the next chapter on how we can find solutions that focuses in on a new method for measuring land use change around airports.
Chapter 5 MODELING LAND USE UNDER THE FLIGHT PATTERN

This chapter will address the problem of land conflicts by using a new model in order to capture the land use changes around an airport. It will also show how the application can be utilized to capture land use changes under the flight path. The model uses a software application developed specifically to use ordinary images with varying qualities of resolution in order to analyze the impact. Later in this chapter is the hypothesis.

The first part of this chapter is background information that is essential for understanding how the application was design and how it works. The second part of this chapter focuses in on the methodology behind and overall steps taken to analyze an image.

The motivation for this chapter is to quantify what we see from images and compare them with other known areas. Color is the foundation in interpreting the landscape from satellite imagery.

Criteria

There were three preliminary pieces for this work that were part of the criteria before moving into the methodology. The first was to select a development platform and the tools to develop the application. The second piece was to develop an application to process the imagery, and the third was to process specific data within the imagery in order to find out how an airport impacts land use.
Software and Hardware

The software was written using the Python Programming Language. This allowed for faster coding and processing time. It is a formidable and popular language that makes it easy to create a job or batch environment in a short amount of time (Python, 2013). The application also uses the Python Image Library (PIL) for computer graphics. The PIL allows for reading and writing a variety of image files which is required in order to process and analyze data. All work was conducted on a Mac Mini from Apple Computer (Apple Computer, 2013). The operating system is ideal for bash shell scripting which was valuable for this work.

Methods

In order to proceed, understanding the basics about color and the varying color models was vital in the initial step into developing the application.

Color

Light is what allows us to see color. When light hits an object, an object can reflect and absorb various colors. What the human eye sees is the reflected colors from an object. If the object were to reflect back every color the color white would be observed. If an object were to absorb all the colors, black would be observed. By definition, color is what is emitted from an object as light hits the object, so black is not defined as a color (Morton, 2012).
The Color spectrum (Figure 5) was discovered by Sir Isaac Newton in 1666 who found that when light passed through a prism, colors are separated. Newton was the first to establish the color wheel by attaching the end of the spectrum together forming a circle (Figure 5.1).

![Color Spectrum](image)

**Figure 5.** Color Spectrum, Illustrated by M. Paskus

Color is the aspect of things that is caused by differing qualities of light being reflected or emitted by them (Crayola, 2013).

![Color Wheel](image)

**Figure 5.1,** Color Wheel (Jusko, 2012).
RGB Color Model

The colors that humans see are a combination of red, green, and blue light. The RGB color model is based on how humans interpret color. The RGB color model in today’s digital age, allows us to retrieve and send images between various types of devices (Gonzalez & P., 1987).

Within a computer program, the intensity of each primary color is used to generate over 16.7 million colors. The programming language used for this project, the instructions for placing the red color on the screen or within an image file might be constructed like the illustration in Figure 5.2.

<table>
<thead>
<tr>
<th>putpixel (100,100,(255,0,0))</th>
<th>red, green,blue=getpixel(100,100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR</td>
<td>OR</td>
</tr>
<tr>
<td>Pixel Coordinate Variables</td>
<td>Pixel Coordinate Variables</td>
</tr>
<tr>
<td>x=100</td>
<td>x=100</td>
</tr>
<tr>
<td>y=100</td>
<td>y=100</td>
</tr>
<tr>
<td>Color Variables</td>
<td></td>
</tr>
<tr>
<td>red=100</td>
<td></td>
</tr>
<tr>
<td>blue=0</td>
<td></td>
</tr>
<tr>
<td>green=0</td>
<td></td>
</tr>
<tr>
<td>putpixel(x,y),(red,blue,green)</td>
<td></td>
</tr>
</tbody>
</table>

a) Sending a specific RGB color to a device or image file.

b) Receiving a specific RGB color from a device or file.

Figure 5.2, An example of sending and receiving RGB color information to a specific file or device.

In the example, the image being referenced could be a pixel on a computer monitor or within an image file. The coordinate systems are the same between a display and an image file with the origin (0, 0) starting at the upper left corner. The values are
represented by red, green and blue and are in hexadecimal format. Valid values are
0 thru 255 for each primary color. In web applications, color is commonly noted in
hexadecimal format. The HTML color code for red is “#FF0000”. Since an RGB image
can have of $256^3$ or 16,777,216 possible colors within in an image. The problem is
how to associate the millions of colors with a specific theme or category. For
example, the color wheel image in Figure 5.1, has a total of 640,000 pixels with
17,639 unique colors when the file is in full resolution. In order to quantify the
number of colors, a method of sorting the colors and associating them into a various
categories was critical. This introduces us to the HSV color system.

**HSV Color System**

THE HSV color system is comprised of three variables (Figure 5.3). The hue (H)
represents the degree of colors in the color wheel. This is referred to as the true
color. The Saturation (S) determines the amount of color. The last dimension is the
value, which represents the amount of brightness (Smith, 2013).

![HSV Color Model](image)

*Figure 5.3 HSV Color Model, Illustrated by M.Paskus*
**Development**

The first development task was to synthesize the thousands of pixels into 360 manageable colors. This step involved converting a given pixel into the HSV Color system. What is unique about the developed application is that only one line of code was added in order to capture and associate the hue with a specific color index as described earlier. Each hue or degree on the color wheel is in floating-point notation when returned from the rgb2hsv (Equation 1). Each RGB pixel color is assigned a hue and is associated with that specific color. To normalize the color, the integer function was used (Equation 1).

\[
\text{rgb2hsv}(253,255,0) = (60.47058, 1.0, 1.0) \quad \text{(Equation 1)}
\]

\[
h, s, v = (60.47058, 1.0, 1.0) \\
h = \text{int}(h) \quad \# \text{ the int() function turns the h value of 60.47058 into 60.} \\
hsv2rgb(h, 1.0, 1.0) = (255, 255, 0)
\]

The returned HSV value in Equation 1, is slightly off the color of yellow and is interpreted to the human eye as yellow. Notice that the integer function lowers the h value to 60 and the pixel coordinate gets reclassified to RGB(255,255,0) or yellow.

To illustrate this process, Figure 5.4 has two images; the image on the left had a total of 647,200 pixels with 61,615 unique colors. The result is that the picture on the right, was squeezed down to 371 unique colors.
The shadow effect at the bottom can be selected out as part of the theme separation process which is later described in this chapter. Since a shadow and reflection can be represented as a yellow color, there is a noticeable difference in the yellow(s) and shadowed area making it easy to separate those colors from the orange during the theme selection process.

In most cases, there is an area of reference or buffer for grabbing the area of study. The next example shows how buffers or areas of study can be extracted and focused on a specific region or area of the image. In this case, an area in the center of the lemon with a radius of 50 pixels was selected using an onscreen digitizer. Figure 5.5 is a buffered area or section with a diameter of 100 pixels. The image on the left is the original image and the image on the right is the processed image. In this test, there were 7,404 pixels with 1,824 colors that were unique.
Additional tests were also conducted. The first test run was to evaluate the grey scale that is reference if Figure 5.6. Figure 5.6 was tested with an original image on the left and with the processed image on the right.

The next test was to evaluate the color wheel from Figure 5.1. The image on the left in Figure 5.7, contained in 640,000 pixels with 17,621 unique colors. The image on the right is the processed image. The subjective piece is in the value and the saturation as the colors slowly lose brightness and saturation from the center to the edge of the color wheel.
Figure 5.8 is a grey scale image of BLI the initial study area. The image was processed from a color image noted in Figure 5.99. The methodology noted that the grey scale colors are segmented off into selectable categories. The image had a total 111,748 pixels with 221 colors. At this point if we have less than 370 unique colors you can take a different path since grey scale images would be categorized with a set count of only 221 unique colors. Grey scale did have noticeable differences in defining urban, rural and green belt areas.
The image on the right, in Figure 5.9, is a processed image of Bellingham, WA. This was the first run on a colored image. Like Figure 5.8, there were 11,748 pixels with 24,756 unique colors. As the themes are selected black, red, yellow, magenta & white stand our as developed land or in this study will be considered urban.
**RGB to HSV Conversion**

In order to sort the RGB colors, converting the colors to the HSV color system provides the ability to quantify and consolidate pixels into a range of colors with the associated hue value between 0 and 360 degrees.

```python
def rgb2hsv(r, g, b):
    r, g, b = r / 255.0, g / 255.0, b / 255.0
    mx = max(r, g, b)
    mn = min(r, g, b)
    df = mx - mn
    if mx == mn:
        h = 0
    elif mx == r:
        h = (60 * ((g - b) / df) + 360) % 360
    elif mx == g:
        h = (60 * ((b - r) / df) + 120) % 360
    elif mx == b:
        h = (60 * ((r - g) / df) + 240) % 360
    else:
        s = df / mx
        v = mx
    return h, s, v

def hsv2rgb(h, s, v):
    h = float(h)
    s = float(s)
    v = float(v)
    h60 = h / 60.0
    h60f = math.floor(h60)
    hi = int(h60f) % 6
    f = h60 - h60f
    q = v * (1 - f * s)
    t = v * (1 - (1 - f) * s)
    r, g, b = 0, 0, 0
    if hi == 0:
        r, g, b = v, t, p
    elif hi == 1:
        r, g, b = q, v, p
    elif hi == 2:
        r, g, b = p, v, t
    elif hi == 3:
        r, g, b = p, q, v
    elif hi == 4:
        r, g, b = t, p, v
    elif hi == 5:
        r, g, b = v, p, q
    r, g, b = int(r * 255), int(g * 255), int(b * 255)
    return r, g, b
```

![Table for RGB to HSV and HSV to RGB conversion](image)

**Figure 5.10ab, Color Conversion Algorithms (Smith, 2013).**

Figure 5.10a is the routine that converts RGB to HSV. Alvy Ray Smith, a computer graphics pioneer, wrote the algorithms to covert the RGB Color model to the HSV model (Smith, 2013). In Figure 5.11, columns three and four illustrate how the RGB2HSV and HSV2RGB formatting works.
Equation 2, illustrates how the algorithm is called from an application or programming language.

\[
\text{rgb2hsv}(r,g,b) = (h,s,v) \quad \quad \text{(Equation 2)}
\]

\begin{align*}
    r &= \text{Red} \\
    b &= \text{blue} \\
    g &= \text{green}
\end{align*}

For example the RGB values will represent the color value of \( r=255, g=255, \text{ and } b=0 \).

The routine would then have the formula for the color yellow as.

\[
\text{rgb2hsv}(255,255,0) = (60.0,1.0,1.0).
\]

Another example would be taking a different value with a slightly lower red value. Changing the red value to 253 ( \( r=253 \)) provides a slightly higher hue value from the formula

\[
\text{rgb2hsv}(253,255,0) = (60.47058,1.0,1.0).
\]
**HSV to RGB Conversion**

The algorithm for converting the HSV values to RGB values is illustrated in Figure 5.10b.

If a manipulation is done within the HSV Color system and is required to be converted to an RGB format, so a pixel can be rendered, then the hsv2rgb function is used in Equation 3.

\[
\text{hsv2rgb}(h,s,v) = (r,g,b) \quad \text{(Equation 3)}
\]

Illustrated in the color conversion chart in Figure 5.11, the hue is represented in degrees of color from the color wheel (Figure 5.1). The example routine below accepts hue (h), saturation(s), and value (v). In this test case, h is represented as 240.0 degrees with both s and v having values of 100.0%. The result below for blue is,

\[
\text{hsv2rgb}(240,1,1) = (0,0,255)
\]

The color red has the following result,

\[
\text{hsv2rgb}(0,1,1) = (255,0,0).
\]

The color black has the following result,

\[
\text{hsv2rgb}(0,0,0) = (0,0,0).
\]

White has the following,
Notice that red, white and black have the same hue value of zero degrees. When we talked about white and black and these colors either absorb or reflect white light, this is how you determine gray scale values. What sets white and black apart from red is the saturation and value. Neither white nor black has a hue larger than 0 degrees or a saturation level higher than 0 %. If the hue is set to zero degrees and the saturation is set to 0 %, and if the value (v) is greater than zero and less than one percent, then the color will fall within the grey scale.

**Grey Scale**

The colors white, black, and the grey scale colors are not on the color wheel. How this is handled for the purpose of this research is to add a specific degree or enhanced color wheel where grey scale is captured. This was designed to capture grey scale pixels from every image. Figure 5.12, are the grey scale values (v) for the methods and results. The logic is if a value falls within a specific range, then it is assigned a specific grey color in the index.
The color index is used to first represent the 360 degrees or hues of color and can be expanded depending on the subjectivity during the imaging process. In this case, the twenty-one colors ranging from 361 through 381 are classified as the grey scale with black set to the color index of 361 and white set to the color index of 381. Since the color wheel starts at zero anything above 360 is not represented.

**Hypothesis**

In the airport master planning process, forecasts are used to help predict the number of enplanements. The airport master plan deals specifically with the airport property and not with the surrounding neighborhoods. Currently there is no method to measure the overall impact of increased enplanements outside of the airport boundary (AO) other than the INM. The following hypothesis will address the problem and acts as a building block for this work.
Hypothesis: If the number of enplaned passengers increases at a small regional airport, land uses inside the airport boundary and the immediately adjacent areas will shift towards urbanization therefore decreasing the grasslands and/or greenbelts.

The intent of the hypothesis is to emphasize the usefulness of the application that was described in the methodology. The application can compare land use changes over time and outside an airport boundary when compared to other airports over time.

Stated earlier in this study, the impact from an airport crosses multiple jurisdictional boundaries without concurrency. Meaning that local planners and politicians may not have the tools necessary to fully understand the impacts in a timely manner. Since airlines cannot be discriminated or controlled by local jurisdictions, this study will provide a method for stakeholders to assess the full impact on communities outside the AO boundary. How the study addresses various areas is through the use of buffers.

**Buffers**

In order to select various buffers or areas of study, routines or functions were developed in order to select specific criteria. The first buffer was a circle. The algorithm uses basic algebra to extrapolate the pixels from a given region. Digitized points of the center are captured along with the scale to help formulate the radius. Figure 5.13 had a radius of 25 pixels capturing 1,792 pixels with 1,394 unique colors.
Ring buffers can also be applied by providing the inner and outer radius. Figure 5.14 illustrates how a specific object can be analyzed with a ring buffer. The work in this thesis will utilize the ring buffer. The ring buffer offers the ability to focus in an area surrounding the area of interest.

Data

All the imagery for the project was collected from the USGS, the City of Bellingham, and the USDA. Google Maps was used to find airports and their associated agency maps (Google Inc, 2013). As part of this project, satellite imagery was the only element desired to find out what and / or how land use changes around specific
airports. As a reminder, the application was written for any type of study. The intent was to find a way to use ordinary imagery in order to analyze a problem.

For land use changes, eight airports were selected in order to capture the current trends associated with airports in proximity to the Canadian border. Figure 5.15, presents the airports with enplanement counts and the proximity to other airports.
Figure 5. Data Set (USGS, 2013; City of Bellingham, 2013; DOT, 2013).
The Latitude and longitude of every airport is available from either the FAA or by conducting searches from Google Maps. Over 1,550 points were digitized for this study. Software was developed specifically to digitize and capture the x-axis and y-axis coordinates associating a specific object for scaling. Each digitized point when captured, recorded the file name, x-axis, y-axis coordinate and scale factor.

For runway points, the application required two digitized points in order to record each end of the runway. Two points represent a single runway. For a single flight pattern or single track required also two points. The application recorded the digitized information and created a comma separated value (csv) file for further processing. Figure 5.16 is a sample of the csv file from the digitizing application. Field one is the airport image file. Field two is the scaling factor set to the number of pixels in two miles. So if a scale reflects a scale of 98 pixels. It means that 49 pixels represent a one mile. Field three is the x-axis, and field four represents the y-axis. The x and y axis points represent selected points of interest or study. In the case of this thesis, it is a point two miles resting off each runway.

```
SDF.png,98,213,128
SEA.png,114,254,72
SEA.png,114,240,72

# Track Example
SEA.png,114,240,409,140,201
SEA.png,114,222,389
SFB.png,98,426,250
SFB.png,98,412,262
```

Figure 5.16 Single point Digitized Airport Information File

Figure 5.17ab is a rendering of what one specific point with a specific radius defined. The image in Figure 5.17a has a radius of 25, and the image in Figure 5.17b
has a radius of seven. In most cases every airport has more than one egress and ingress and in most cases will have more than a single runway.

Figure 5.17ab Image radius adjustment example (Image Source: City of Bellingham)

Lines (Figure 5.18) can also be used to capture the land uses below any given area. In the case of Bellingham, there is one runway and flight patterns were applied over the tracks provided generally from Figure 1.5 with a 10 pixel width. The width can be tailored to address any issue defining the study area. For example, the width or thickness could be adjusted based on the volume of flight traffic.

Figure 5.18 Line Buffers over Bellingham (City of Bellingham, 2013)
Illustrated in Figure 5.19abc, are examples of how circle buffers could be represented at three major airports with multiple runways like Seattle’s Seattle-Tacoma Airport (SEA), Boston’s Logan Airport (BOS) and Chicago’s O’Hare (ORD). Each of these airports have multiple points. In the case of both Seattle and Boston’s airport, a new runway was added and even though not present in the original image, this provides additional analysis. In both cases, a radius of 20 pixels was used for rendering an area two miles ahead of every runway.

![Image of airports with circle buffers]

<table>
<thead>
<tr>
<th>Airport</th>
<th>Runways</th>
<th>Radius</th>
<th>Digitized Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOS</td>
<td>5</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>ORD</td>
<td>7</td>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>SEA</td>
<td>3</td>
<td>20</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 5.19abc Images with multiple runways (Source Images: USGS, 2013)

**Calculations**

At the end of every buffer run or pixel capture, a histogram and tally is rendered and associated with each degree in the color index.

Figure 5.20 illustrates the grand total of all the represented pixels in the color wheel associated with the buffered image.
Figure 5.21 is an enlarged rendering. There are four elements that make up the color index tally. The first column is the color represented by the degree in the color wheel. The second column is the degree or the color index number. The third column is the actually tally count with the forth column representing the average for the degree.
Each image is considered to be in a stack and the calculations are three-dimensional. Noted earlier, each color index or degree is stored in an array. Since not all the images may carry the same degree of color, the array will tally only those specified for a specific color index or degree. There are global and local arrays. The local arrays are initialized and set to zero with every new image, while the grand totals are established continue to tally throughout the project.

The formula for capturing each pixel within each of the color wheel degrees is noted in Equation 4.

**Total Number of Color Index Pixels**

\[
\text{Total Color Index}[i] = \sum_{x=0}^{X} \sum_{y=0}^{Y} \sum_{i=0}^{381} P_{x,y,i} \quad \text{(Equation 4)}
\]

\[5.24\]

P = Pixel

x = Maximum x value in the image or the width of the buffer or image.

Y = Maximum y value in the image or the height of the buffer or image.

I = Color Index or the degree in the color wheel plus the gray scale values.

\[
\text{Grand Total Color Index} = \sum_{i=0}^{381} \text{Total Color Index}[i] \quad \text{(Equation 5)}
\]

\[
\text{Average Color Index}[i] = \frac{\sum_{i=0}^{381} \text{Total Color Index}[i]}{\text{Grand Total Color Index}} \quad \text{(Equation 6)}
\]

Histograms use the local color index arrays for each image and utilize the logarithmic function in order to render the numerous points, Figure 5.22, provides a
simple example. In most cases a histogram is a fast way to get an idea for comparing images.

![Histogram](image)

Figure 5.22, Histogram.

The histogram is just one way to measure a comparison. The other method is to create themes. Even though created during the analysis phase, it is not used for this study.

**Themes**

Themes were built into the application at the start. Themes associate the colors with a specific category.

At the end of every process a theme tally is generated. It utilizes the same color index to associate a specific color with a specific theme. For simplicity, the theme file (Figure 5.23) is a “csv” file which can accept hundreds of theme types and ranges. When the application was designed it was critical to have the ability to quickly edit and capture specific tallies. Themes can also utilize the same color more than once for a number of different themes. In this study this is not used. Combining colors into multiple themes is an option since the application was written for more than one discipline. There are three fields associated in the themes file that allow you to associate the color index or degrees to a specific theme. A colon is used to separate each of the three fields. The first field is the theme name or legend reference. The second field represents a color associated with the selected theme. This is a
cosmetic feature and used to associate a color with the selected ranges. The third field is the color index assignment. There can be a number of separate ranges associated with each theme. A comma (,) separates each color and a hyphen (-) indicates a range. For example a range field with “17,22-34,10” will select the color index of 17, the range from 22 thru 34, and 10.

```
# Theme File: themes.csv
# Theme Name:Color:Range(s)
First Degree of Color:0:0
All of the Colors:371:0-371
Gray scale 361 thru 371 including Black and White:364:361-371
48 & 60:48:48,60
Lots of Red:0:300-359,0-30
Blues:195:160-270
Couple Greens:69:69,84-86,70,73,77,98
Lots of Green:135:90-150
Last Degree of Color:371:371
Urban:0:0-75,270-371
```

Figure 5.23 Theme File

Theme totals (Figure 5.24) are generated from the color index association. The render of every image calculates specific categories including the percentage of pixels associated to the themes (PoT) selected as well as the overall percentage compared to the number of pixels (PoP) captured by the buffer.

```
<table>
<thead>
<tr>
<th>Theme Totals</th>
<th>Theme Name</th>
<th>Theme Ranges</th>
<th>Total</th>
<th>PoT%</th>
<th>PoP%</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Degree of Color</td>
<td>0</td>
<td>217</td>
<td>0.19%</td>
<td>0.43%</td>
<td></td>
</tr>
<tr>
<td>All of the Colors</td>
<td>0-371</td>
<td>50258</td>
<td>43.99%</td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>Gray scale 361-371 including Black and White</td>
<td>364:361-371</td>
<td>469</td>
<td>0.48%</td>
<td>0.37%</td>
<td></td>
</tr>
<tr>
<td>48 &amp; 60</td>
<td>48</td>
<td>3011</td>
<td>2.65%</td>
<td>6.42%</td>
<td></td>
</tr>
<tr>
<td>Lots of Red</td>
<td>0-359,0-30</td>
<td>3971</td>
<td>0.74%</td>
<td>15.80%</td>
<td></td>
</tr>
<tr>
<td>Blues</td>
<td>160-270</td>
<td>3710</td>
<td>3.25%</td>
<td>7.23%</td>
<td></td>
</tr>
<tr>
<td>Couple Greens</td>
<td>69,64-66,70,73,77,98</td>
<td>3112</td>
<td>2.72%</td>
<td>6.18%</td>
<td></td>
</tr>
<tr>
<td>Lots of Green</td>
<td>90-150</td>
<td>5588</td>
<td>4.88%</td>
<td>11.16%</td>
<td></td>
</tr>
<tr>
<td>Last Degree of Color</td>
<td>371</td>
<td>488</td>
<td>0.46%</td>
<td>0.81%</td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>0-75,270-371</td>
<td>37581</td>
<td>32.83%</td>
<td>74.63%</td>
<td></td>
</tr>
</tbody>
</table>
```

Figure 5.24 Themes
Theme Elements

With images taken at different times and with different sensing equipment, calibration is required to help assimilate the data’s (pixels) likeness to the correct theme. This study and the application uses the supervised classification method which takes into account areas of interest or as Campbell (2002) suggests, “Training areas or fields”. In order to classify specific pixels, the application allows for either global or specific theme files. Images have varying levels of resolution. The method by which an image is captured along with the environmental conditions are what make image recognition. Cambell (2002) stated for example that using film versus remote sensors will make it harder to compare two objects. This is where themes come into this work. Theme files allow you to calibrate and capture totally different images for the same specific airport or region (Figure 5.25). The four themes that were selected for this study were classifications specified by the USGS Land Use and Land Cover Classification for remote sensing (Anderson, Hardy, & Roach, 1976). The color indexes which make up each theme were sorted by ocular selection. Since images can have different levels of quality, the themes classification file may contain different color index ranges.
<table>
<thead>
<tr>
<th>Theme Type</th>
<th>Image sample with rendering</th>
<th>Unique Colors</th>
<th>Color Index Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasslands/Dry lands</td>
<td><img src="image1.png" alt="Image" /></td>
<td>14,095</td>
<td>0-79</td>
</tr>
<tr>
<td>water</td>
<td><img src="image2.png" alt="Image" /></td>
<td>12,860</td>
<td>182-228</td>
</tr>
<tr>
<td>Green Belt</td>
<td><img src="image3.png" alt="Image" /></td>
<td>3,361</td>
<td>80-158</td>
</tr>
<tr>
<td>Urban</td>
<td><img src="image4.png" alt="Image" /></td>
<td>2,117</td>
<td>159-181,361-381</td>
</tr>
</tbody>
</table>

Figure 5.25 Theme Capture or training technique.
Review Application Steps

1. Categorize Images

Categorizing images for comparison is the starting point for every project. By dragging and dropping images into a specific folder allows the application to process a specific criteria.

Category Examples
- Population
- Economic
  - Cost
- Market
  - Enplanements
  - Catchment
  - Product
- Operations
  - Departures
  - Arrivals
- Location
- Historical Comparison
- Image Differencing

This is what is considered the stack of images to be processed.

2. Select Common Object

Selecting a common object for comparison is optional, depending on the image. When using a selected object, a rectangle is used to focus in on the area of interest or area of commonality which auto scales and rotates the image to a master object.
Buffers are used to gather the coverage area for the area of interest.

Buffer Types:
- **Rings** are used to circle a specific area and with two radius variables which control the thickness of the ring.
- **Circles** are points with a specific radius.
- **Rectangles or squares** have a length and width based on the upper left pixel coordinates to the lower right.
- **Random** points are used to help with calibration and gathering random sample of pixels over a specific rectangular region.
- **Lines** are used with an adjustable width allowing for paths to be analyzed.

Depending on common object and the buffering type, analysis is run against the specific criteria and the pixel data is collected on the stack of images producing a specific pixel count.
Each image, when processed, will have a specific pixel color count. This is based on a RGB conversion to HSV color. By converting the image from RGB to HSV allows for millions of colors to quantify in to a smaller set of colors that can be categorized for a specific project. This allows an individual image or the entire stack of images to be broken down into specific themes or categories. There is an option to select a specific color or a range of colors for processing. This step can also isolate specific categories or areas for additional study. This step is optional if a common set of themes was saved by a previous run. The color index is for specific projects which can be saved and exported and imported for another project. Each color can be associated for a specific theme using a delimited file (csv).

After colors are selected, the bottom of calculation is generated with the stack tally for a given buffer. File information is also provided. This tally includes the overall percentage over the total number of pixels and the total of selected colors over the selected coverage.

# Theme File: themes.csv
# Theme Name:Color:Range(s)
Water:180:165-240,183
Industrial Zone:60:15-40,345
Vegetation:135:135-150,78

6 Final Analysis
Results

Eight city airports were evaluated using satellite imagery supplied by the United States Geological Survey (USGS), the City of Bellingham, and the United States Department of Agriculture (USDA). Over the next several pages are the results from the image analysis which correspond to the graphs below (Figure 5.26).
The graphs represent each airport’s enplanement and urban pixel count. The graphs show enplanements (brown line) and urban (blue bar) land use totals from the application. The x-axis is the process image file. The y-axis on the left is the pixel count for urban land use and the y-axis on the right represents enplanements.

Figure 5.26 Result snapshot

Bellingham, Washington (BLI)
BLI Results and Discussion

BLI had five images that were processed (and appear on the following pages). The first image was a black and white image from 1998. Since the image was under 256 colors this could have been interpreted without consolidation. The results for the Infrared in 2004 were sharp. Infrared images work really well in capturing land use change. There were noticeable differences in urban registration between 2006 and 2012. Knowing the area in the more recent images, the parking lot expansions were captured by the application (Port of Bellingham, 2012) between the years 2006 and 2012. Both enplanements and urban trended upward.
Figure 5.29 BLI 1998 Results (City of Bellingham, 2013)
Figure 5.30 BLI 2004 Results (City of Bellingham, 2013)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Unique Colors</th>
<th>Total</th>
<th>PoF %</th>
<th>FuF %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Field</td>
<td>226-269</td>
<td>7056</td>
<td>27.07%</td>
<td>27.07%</td>
</tr>
<tr>
<td>Water</td>
<td>361</td>
<td>16</td>
<td>0.06%</td>
<td>0.06%</td>
</tr>
<tr>
<td>Greenbelt</td>
<td>381-337</td>
<td>3175</td>
<td>49.36%</td>
<td>49.36%</td>
</tr>
<tr>
<td>Urban</td>
<td>362-381,6-223</td>
<td>7537</td>
<td>22.82%</td>
<td>22.82%</td>
</tr>
<tr>
<td>Totals</td>
<td>282</td>
<td>23086</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
Figure 5.31 BLI 2006 Results (City of Bellingham, 2013)

<table>
<thead>
<tr>
<th>Theme Totals</th>
<th>Theme Name</th>
<th>Theme Range</th>
<th>Unique Colors</th>
<th>Total</th>
<th>Pop%</th>
<th>Pop%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Field</td>
<td>0-75</td>
<td>0-444</td>
<td>10402</td>
<td>21.52%</td>
<td>19.56%</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>267-270</td>
<td>4</td>
<td>4</td>
<td>0.01%</td>
<td>0.01%</td>
<td></td>
</tr>
<tr>
<td>Green Belt</td>
<td>39-103</td>
<td>229-6</td>
<td>34956</td>
<td>55.95%</td>
<td>56.95%</td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>104-266,279-391</td>
<td>60532</td>
<td>14971</td>
<td>29.42%</td>
<td>31.29%</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>399</td>
<td>43926</td>
<td>65490</td>
<td>100.00%</td>
<td>90.98%</td>
<td></td>
</tr>
</tbody>
</table>

Total Pixels: 63964
Unique Colors: 47820

Figure 5.31 BLI 2006 Results (City of Bellingham, 2013)
Figure 5.32 BLI 2008 Results (City of Bellingham, 2013)
Figure 5.33 BLI 2012 Results (City of Bellingham, 2013)
Burlington, Vermont (BTV)

BTV black and white images again could have been processed without placing each pixel into a color index. There were 165 shades of grey. Since image was very light, colors overlap the runway and dry grass. By using more shades of grey would have helped. Note that BTV had a decline in enplanements. This may be due to Canadians shifting to Plattsburg, New York which is closer to the Canadian border and Montreal. Plattsburg, is about 18 miles to the northwest across Lake Champlain. This shifting of passengers from one airport to another is recommended for further study. Burlington has also been actively purchasing homes around the airport.

The enplanements and urban are trending upward.
Figure 5.36 BTV 1999 Results (USGS, 2013)
Figure 5.37 BTV 2004 Results (USGS, 2013)
Figure 5.38 BTV 2009 Results (USGS, 2013)
Figure 5.39 BTV 2012 Results (USGS, 2013)
**Duluth, Minnesota (DLH)**

**Figure 5.40 DLH Results**

**DLH Results and Discussion**

DLH had a 1991 black and white image with 254 shades of grey and again to break this down the shades of grey would be able to help. The application picked up the new airport design between 1991 and 2003. The 2008 image was rather yellow and required a bit of work to interpret. Again it is all about the image quality. I limited my work to spending no more than 15 minutes per image in order to let the application do the work. Both Urban and Enplanements were upward trending.
Figure 5.42 DLH 1991 Results (USGS, 2013)

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Image Range</th>
<th>Unique Colors</th>
<th>Total</th>
<th>PoP4</th>
<th>PoP4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Field</td>
<td>368-379</td>
<td>36</td>
<td>21882</td>
<td>31.24%</td>
<td>31.24%</td>
</tr>
<tr>
<td>Water</td>
<td>52</td>
<td>13</td>
<td>279</td>
<td>0.40%</td>
<td>0.40%</td>
</tr>
<tr>
<td>Grass Fed</td>
<td>77</td>
<td>77</td>
<td>29358</td>
<td>42.77%</td>
<td>42.77%</td>
</tr>
<tr>
<td>Wohn</td>
<td>388-391</td>
<td>128</td>
<td>10385</td>
<td>15.05%</td>
<td>15.05%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31</strong></td>
<td><strong>254</strong></td>
<td><strong>65864</strong></td>
<td><strong>100.00%</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>
Figure 5.43 DLH 2003 Results (USGS, 2013)
Figure 5.44 DLH 2008 Results (USGS, 2013)
Grand Fork, North Dakota (GFK)

GFK Results and Discussion

GFK by was a great set of images to work with. The images were clear and were easy to process without any interpretation. The runway was clear and rendered really well and the expansion to the south was also captured. The themes were not altered for this set. Both the urban and enplanements had upward trends.
Figure 5.47 GFRK Step Results

Grand Forks North Dakota (GFRK)
Figure 5.48 GFK 1997 Results (USGS, 2013)
Figure 5.49 GFK 2004 Results (USGS, 2013)
Figure 5.50 GFK 2011 Results (USGS, 2013)
FCA Results and Discussion

FCA again had a black and white image which had lighter colors matching grass and the runway. The trouble spots here was simply the images having different shades of greens and blues. The application again did pretty well. Both urban and enplanements trended upward.
Figure 5.52 FCA Step Results

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage</th>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
<th>Step 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>32%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>32%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>32%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>32%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5.53 FCA 1990 Results (USGS, 2013)
Figure 5.54 FCA 2002 Results (USGS, 2002)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Theme Name</th>
<th>Unique Colors</th>
<th>Total</th>
<th>Not</th>
<th>Pop%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry Field</td>
<td>362,000-370</td>
<td>71</td>
<td>0.86%</td>
<td>0.86%</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>360</td>
<td>0</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td></td>
<td>Cropped Belt</td>
<td>362,371</td>
<td>24</td>
<td>7.86%</td>
<td>7.86%</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>361,344-365,275-381</td>
<td>82</td>
<td>10.09%</td>
<td>10.09%</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>59</td>
<td>170</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
Figure 5.55 FCA 2005 Results (USDA, 2005)
Figure 5.56 FCA 2012 Results (USGS, 2012)
Minot, North Dakota (MOT)

![Figure 5.57 MOT Results](image)

**MOT Results and Discussion**

MOT in 2006 had an image that was yellowed and was hard to interpret. With a better quality image this would have picked up more of the runway surface. There was an upward trend in enplanements with a slightly downward trend with urban.
Figure 5.38 MOT Step Results
Figure 5.59 MOT 1995 Results (USGS, 1995)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Theme Ranges</th>
<th>Unique Colors</th>
<th>Total</th>
<th>PoP%</th>
<th>PoF%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Field</td>
<td>262-267,265</td>
<td>39</td>
<td>21421</td>
<td>30.66%</td>
<td>30.66%</td>
</tr>
<tr>
<td>Water</td>
<td>261</td>
<td>12</td>
<td>230</td>
<td>0.34%</td>
<td>0.34%</td>
</tr>
<tr>
<td>Greens Delt</td>
<td>303-364,566</td>
<td>30</td>
<td>23353</td>
<td>41.70%</td>
<td>41.70%</td>
</tr>
<tr>
<td>Urban</td>
<td>368-361</td>
<td>166</td>
<td>15072</td>
<td>27.30%</td>
<td>27.30%</td>
</tr>
<tr>
<td>Totals</td>
<td>21</td>
<td>255</td>
<td>68964</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
Figure 5.60 MOT 2003 Results (USGS, 2003)
Figure 5.61 MOT 2006 Results (USDA, 2007)
Figure 5.62 MOT 2011 Results (USDA, 2012)
IAG Results and Discussion

IAG had by far the poorest quality images out of all the airports for this study. The 1995 had a poor quality black and white image of the airport. In 2003, the image was on the redder side. Again, the application is only as good as the image. The interpretation working in 1995 would was difficult since the image again was faded. If the pixels were not consolidated, then the image would have had a better result. The trend line for urban reflected the poor quality images.
Figure 5.64 IAG Step Results

(source image: 1323024723)

Steps 1 to 6

2011 2005 1995

Images from New York (USA)
Figure 5.65 IAG 1995 Results (USGS, 2013)
Figure 5.66 IAG 2005 Results (USGS, 2013)
Figure 5.67 IAG 2011 Results (USGS, 2013)
**PBG Results and Discussion**

PBG was an old military base that had very different types of images to process. The first two periods, the airport was strictly military and was closed to commercial activity. The long term of pattern has an increase in land use. For unknown reasons there is a dip in 2009. This could be due to resolution of the image or some other factor. The first black and white image of the airport runway was picked up easily. The 2012 image was a faint yellow. When this occurs there needs to be more interpretation in the lighter colors.

This airport has grown rapidly primarily from the Canadian market. This is taking Burlington, Vermont’s catchment. Allegiant Air decided against flying into BTV and
I chose PBG because of PBG's proximity to Canada. The graph shows an upward trend for both enplanements and urban.

Figure 5.69 PBG Step Results
**Figure 5.70 PBG 1995 Results (USGS, 2013)**

<table>
<thead>
<tr>
<th>Theme</th>
<th>Unique Colors</th>
<th>Total</th>
<th>PeX%</th>
<th>PePt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bay Field</td>
<td>364,367,385</td>
<td>55</td>
<td>28664</td>
<td>23.58%</td>
</tr>
<tr>
<td>Water</td>
<td>361</td>
<td>12</td>
<td>351</td>
<td>0.74%</td>
</tr>
<tr>
<td>Greens Belt</td>
<td>360,364,385</td>
<td>58</td>
<td>22865</td>
<td>46.12%</td>
</tr>
<tr>
<td>Urban</td>
<td>309-291</td>
<td>115</td>
<td>1313</td>
<td>22.40%</td>
</tr>
<tr>
<td>Totals</td>
<td>51</td>
<td>304</td>
<td>63664</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

*Total Pixels: 56,964*
Figure 5.71 PBG 2003 Results (USGS, 2013)
Figure 5.72 PBG 2009 Results (USGS, 2013)
## Captured Data

### File Ranges

<table>
<thead>
<tr>
<th>File</th>
<th>D Range</th>
<th>D Tally</th>
<th>W Range</th>
<th>W Tally</th>
<th>G Range</th>
<th>G Tally</th>
<th>U Range</th>
<th>U Tally</th>
<th>Enplanements</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLI2004</td>
<td>338-360</td>
<td>19539</td>
<td>330-337</td>
<td>34,838</td>
<td>362-381,0-329</td>
<td>15,800</td>
<td>82,353</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLI2006</td>
<td>0-75</td>
<td>13662</td>
<td>4-90-163</td>
<td>34,956</td>
<td>164-266,270-383</td>
<td>14,871</td>
<td>135,073</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLI2012</td>
<td>D-75</td>
<td>17933</td>
<td>61-90-185</td>
<td>27,592</td>
<td>186-266,271-383</td>
<td>21,019</td>
<td>574,601</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BTV1999</td>
<td>368-374</td>
<td>48487</td>
<td>139-362-367</td>
<td>13,845</td>
<td>367-375-381</td>
<td>7,393</td>
<td>258,903</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BTV2006</td>
<td>D-89</td>
<td>13171</td>
<td>21-90-185</td>
<td>38,875</td>
<td>186-266,271-383</td>
<td>19,797</td>
<td>648,613</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DLH2008</td>
<td>D-75</td>
<td>28217</td>
<td>134-90-185</td>
<td>17,470</td>
<td>186-266,271-383</td>
<td>13,564</td>
<td>150,224</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DLH2011</td>
<td>D-75</td>
<td>9051</td>
<td>400-90-185</td>
<td>23,998</td>
<td>186-266,271-383</td>
<td>33,525</td>
<td>131,018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCA2002</td>
<td>363,366-370</td>
<td>48809</td>
<td>360</td>
<td>7,046</td>
<td>361-364-365-372-381</td>
<td>14,009</td>
<td>165,017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCA2005</td>
<td>D-75</td>
<td>25389</td>
<td>404-90-185</td>
<td>22,477</td>
<td>186-266,271-383</td>
<td>18,249</td>
<td>190,909</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCA2012</td>
<td>D-75</td>
<td>26070</td>
<td>521-90-185</td>
<td>17,616</td>
<td>186-266,271-383</td>
<td>22,240</td>
<td>192,505</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GFK1997</td>
<td>368-374</td>
<td>18489</td>
<td>184-362-367</td>
<td>40,835</td>
<td>375-381</td>
<td>10,356</td>
<td>89,467</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GFK2011</td>
<td>D-75</td>
<td>24773</td>
<td>258-90-185</td>
<td>17,760</td>
<td>186-266,271-383</td>
<td>21,685</td>
<td>105,472</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAG2011</td>
<td>D-75</td>
<td>37577</td>
<td>12-90-185</td>
<td>7,056</td>
<td>186-266,271-383</td>
<td>10,636</td>
<td>73,438</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOT2003</td>
<td>D-89,164-266-271-360</td>
<td>46516</td>
<td>403-90-163</td>
<td>9,592</td>
<td>361-381</td>
<td>13,353</td>
<td>72,518</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOT2006</td>
<td>D-31,37,39,42-75</td>
<td>44789</td>
<td>-90-163</td>
<td>10,702</td>
<td>164-381,32-36,40,41</td>
<td>10,496</td>
<td>74,990</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOT2011</td>
<td>D-75</td>
<td>9127</td>
<td>151-90-185</td>
<td>38,404</td>
<td>186-266,271-383</td>
<td>19,828</td>
<td>127,628</td>
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<td></td>
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<td>PBG2003</td>
<td>D-75,186-266-271-380</td>
<td>15101</td>
<td>84-90-185</td>
<td>13,521</td>
<td>381</td>
<td>37,545</td>
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<td>D-75,186-266,271-380</td>
<td>26939</td>
<td>1322-90-185</td>
<td>10,564</td>
<td>381</td>
<td>30,960</td>
<td>41,489</td>
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<td>PBG2012</td>
<td>D-75</td>
<td>20570</td>
<td>216-90-185</td>
<td>2,871</td>
<td>186-266,271-381</td>
<td>45,444</td>
<td>129,184</td>
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</table>

**Figure 5.74 Captured Data**
Summary of Conclusion

Figure 5.75 DLH Trend Lines Results

Figure 5.76 FCA Trend Lines Results
Figure 5.77 GFK Trend Lines Results

Figure 5.78 MOT Trend Line Results
Figure 5.79 BTV Trend Line Results

Figure 5.80 PBG Trend Line Results
Figure 5.81 IAG Trend Line Results

Figure 5.82 Trend Graph Results
Airport Analysis Trending Results

Figure 5.76 is a tally of the upward (+) and downward (−) trends for enplanements and urbanization for each of the studied airports. All of the airports are trending upward in enplanements. The application found that 75% of the airports are trending upward in urbanization.

<table>
<thead>
<tr>
<th>Trend line Results</th>
<th>Airports</th>
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<tr>
<td></td>
<td>BLI</td>
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<tr>
<td>Urban</td>
<td>+</td>
</tr>
<tr>
<td>Enplanements</td>
<td>+</td>
</tr>
</tbody>
</table>

After reviewing the trend line results, the hypothesis was accepted and acknowledges that when there is an increase in enplanements over time, land uses around an airport, will urbanize.

As noted the quality of the imaging is critical for this work. Both MOT and IAG had images that were hard to distinguish or had yellowed. This makes interpretation resource intensive. The work in this study did not try and change the global themes for the airports. The study was to test an application’s ability to render a result easily and without too much interpretation.

The results also noted that airline enplanements can fluctuate by going up or down. This is why airports need to continue to market their airports.
Bellingham Flight Path

To generate the flight paths, eight points were digitized creating four tracks. The analysis used a generic theme which was also used in the BLI study. The lines were generated in proximity to departing and arriving aircraft presented earlier in Figure 1.5. The red represents urban. The arrows indicate in Figure 5.84 show where homes or businesses are located within the line, or in this case, the flight pattern. The arrows point out how the application can be used to decide who might be impacted. The middle lines are the final approach and takeoff path. The width can be determined by the stakeholder.

Figure 5.84 Flight Path Buffer
Chapter 6 SUMMARY & CONCLUSIONS

The problem presented in this thesis addresses land use changes around an airport. The motivation for this work was captured in the first four chapters introducing three distinct areas, equity, ecology, and economy. These three issues represent the principles of sustainability (Berke, Goldschalk, & Rodriguez, 2006).

![Basic Sustainability Triangle](image)

*Figure 6.1 Basic Sustainability Triangle (Berke, Goldschalk, & Rodriguez, 2006).*

Chapter five introduced a software technology for stakeholders so we can better understand our surroundings by quantifying what we see on a larger scale and how Whatcom County could benefit by observing the land use changes around airports.

This chapter will summarize each subject in the sustainability triangle (Figure 6.1) and associate them with the findings from this study. This chapter will also discuss
how technology was used to study land uses in order to avoid property conflicts in the future.

**Economy**

The thesis examined enplanement numbers and how the aviation industry is dynamic in nature. In order to comply with the State of Washington’s Growth Management Act, Whatcom County modified the WCC in order to protect airport land uses within the AO and created an ordinance to discouraged incompatible uses (Whatcom County Council Agenda Bill, 2005). The Advisory Committee used data made available to them at the time which was an underestimated forecast by URS or as Kincaid stated, had an “Extreme Upside Scenario” (Kincaid & Tretheway, 2013).

The thesis explored airport growth and how increased enplanements can and will impact a community. By serving a catchment primarily from outside Whatcom County, and the United States, Canadians are driven to BLI by cheaper flights. The POB understands that they need to continue to market air carriers in order to pay for the newer infrastructure (Port of Bellingham, 2008). This means that marketing Canadian travelers will be critical since the southern catchment will shift to Paine Field.

The Canadian populous is 20 times larger than Whatcom County. Building BLI to serve Vancouver International Airport (YVR) and Abbotsford International Airport (YXX) catchment defeats the Canadian aviation infrastructure while at the same time, places risks on local Whatcom County residents.
Figure 3.3, indicated that socioeconomic conditions were not addressed in Kincaid’s study. Kincaid and Tretheway are tourism and transportation consultants (Kincaid & Tretheway, 2013) and it is their business is to promote the aviation industry and stimulate growth at airports. Since their report was released, Everett’s Paine Field (PAE), which would be considered as an “increased airport diversion” by Kincaid, is scheduled to begin commercial flight next year.

YXX is 21 miles Northeast of Bellingham which is considered by Kincaid as an “increase airport diversion”, but it was not mentioned in the report.

Considerable investment has been made at YVR and YXX. There is considerable Canadian leakage which has prompted Canadian politicians to address the loss in aviation revenue and jobs (Nicas, 2012). If Canadian policy changes and tariffs are reduced, this would have a severe impact on BLI (Kincaid & Tretheway, 2013).

The study also noted that if the CAD were to drop, the airport would see a decrease in passengers. In turn, to make up the difference, fees would most likely rise at the airport and noted earlier, the shortfall would be placed on Whatcom County residents.

There is no doubt that airports are expensive to operate, airports need to attract passengers to feed airlines and to retain passengers. It was also noted that within a twenty year period the average lifespan for an airline is eight years.

The FAA’s recent announcement to close 149 control towers (Palmer, 2013) was an effort to control costs at rural airports.
All these factors have ignored the property conflicts as the WSDOT survey suggested (Mead & Hunt, Inc., 2006).

Layoffs and labor disputes have also played a role in showing just how dynamic the aviation industry especially for those airlines serving BLI (Petzinger, 1996).

Living wage jobs is also a prevalent in the airline industry. A flight attendant from Allegiant Airlines created a web site (Figure 6.2) which was sponsored by the Transport Workers Union (TWU). The intent of the site is to promote a better work place and to motivate Allegiant to negotiate for better working conditions (Transportation Workers Union, 2013). The map also shows how quickly and completely an airline can withdraw from a market.

![Figure 6.2, The Un-Route Map (Transportation Workers Union, 2013)](image)

The POB took a risk when they decided to expand the terminal (Port of Bellingham, 2008). This was done to accommodate for more passengers. Granted people from Whatcom County residents do use the airport, but the POB has made it clear that if it
were not for Canadians, the airport would lose air carriers (Port of Bellingham, 2012).

**Equity**

The thesis noted that the Whatcom County Assessor’s Office flagged homes impacted by airport operations well outside the airport boundary (Figure 4.7) showing firsthand how property conflicts persist outside the AO. Whatcom County in 2005, as part of the growth management act noted that properties within one mile of the runway would be required to disclose on the purchase and sale agreement that they live next to an airport. This devalued the properties on the spot.

The property conflicts caused by the inadequacies of the INM are apparent. The WSDOT survey (Mead & Hunt, Inc., 2006), highlighted that noise issues were not being addressed and there was a lack of representation from the public.

The last noise mitigation program was in 1990 and 1991 when homes were acquired to expand the runway. There has been no assistance to homeowners in the last twenty years and the Airport Survey (Figure 4.1) reflected that 30% of residents feel impacted by noise, air, and / or traffic.

On October 10, 2012, the POB held two separate meetings in regard to the master plan update (Appendix C) (Port of Bellingham, 2012). During the meeting, the FAA indicated that the POB was expanding the terminal but yet, wanted to inhibit growth in the future (Port of Bellingham, 2012). Since the airlines cannot be discriminated
against, the FAA has delayed the master plan forecast (Port of Bellingham, 2012). Depending on the outcome, the POB may not be able to have a small airport (Port of Bellingham, 2010) especially if the carriers continue to capture the Canadian market. This shows that local jurisdictions have no control over federal law making it hard for local politicians and planners to adjust or maintain compatible land uses around the airport. The INM noted that the dB contours are expanding (Harris Miller Miller Hanson Inc, 2009). The WCC placed a one mile disclosure on residential homes and noted by the Whatcom County valuations are not consistent. This means there is not a sustainable path since economics is the driving factor.

**Ecology**

How we define subjective in determining what an actual annoyance is rests at the heart of the noise problem. Airport INM models do suggest that there are areas impacted by noise, but the INM fails to address areas under the flight pattern. Even if the percentages are low, the study showed people are impacted. The continued theme is more research is required or the model needs to be refined in some way. This suggests that the INM should be replaced by equity valuations rather than actual noise studies.

It was also noted in the study that wildlife has been migrating away from the airport, The beaver population has declined and their habitat destroyed. Beavers have been found to be a keystone animal or indicator for measuring the environmental health of a region (Hood, 2011).
Wetlands have also been filled in with rocks to discourage birds that may interfere with aircraft. In the flight path diagram (Figure 1.5), aircraft fly near the Nooksack River frequented by eagles. There is consistent drive to mitigate wetlands and remove buffers that serve as a natural barrier for residents and refuge for wildlife.

**Technology**

The software application written for this study, demonstrated how technology can be used to solve a problem. With the ability to remotely sense land use coverage for both the airport and the flight pattern, allows stakeholders to measure the impacts by observing what is happening elsewhere. They also have the ability to adjust to a more sustainable air system. The developed application provides the ability to quickly analyze land use changes for stakeholders. The application can quantify what we see and be utilized as a predictive tool.

Applications like this will benefit agencies by offering an inexpensive way to aggregate data and find solutions quickly. As remote sensing advances, the area of image recognition will become a powerful tool especially as systems become more scalable. The current cost of an INM is over $35,000 and the INM software is dependent on other sources of data that can be hard to gather in a short amount of time.
Conclusion

With powerful business interests on one side and citizens with a personal stake but little to leverage on the other, success is surviving to fight the next battle.

Peter D. Enrich, activist and law professor (Andre, 2009)

The problem undertaken by this thesis remains an open question into how we want to develop our land uses so they are equitable, environmentally safe, while allowing our local economy to create a sustainable jobs for the future.

By having a tool that provides stakeholders with a predictive model by examining imagery with varying degrees of resolution can be an effective way for policy makers to move forward in a transparent manner.

The application developed for this thesis was designed for multiple disciplines offering an inexpensive way to capture and analyze image data. The application developed for this study was not designed to handle just eight airports but hundreds. As remote sensing becomes more accessible, we will be able to see things on a global scale rather than in a small vacuum. This work is a methodology for examining and analyzing problems on a large scale.

This study provided us with a different way of measuring and observing our surroundings through the use of imaging. If the POB had used this tool they would have been able to compare BLI with other cities. This work introduces us to resource, development, and property conflicts created by aviation. This work is
simply a reminder of how delicate our environment is especially for those people living under the flight pattern.
Chapter 7 RECOMMENDATIONS

Sustainability and transparency are vital for future generations. With the results from this thesis and by providing stakeholders with a graphical representation on how aviation can impact a community is a vital step in fostering and strengthening a sustainable future using tools that take into account other airports.

Techniques like this one, was developed to better understand the land uses around airports which the INM does not address. It is evident that with a projected 5-10% increase in air carrier service, over the next twenty years, will introduce additional conflicts as more airports start service. Regulating the size of airports to match the area may set a precedence diminishing conflicts in the future.

If a forecast predicts a specific number of enplanements, then examining the land use trends from a collection of other airports will provide better focus and scope on what the land use expectations will be based off the projected year’s enplanement total. In the case of Bellingham, economics as defined by the mission of the POB is to move forward and be proactive with airport growth. This however defeats the ability to focus on alternative transportation offerings to larger airports.

Examining the land use characteristics of airports that have moved, opened, shutdown, or transformed (military) will help airport operators understand the risks when apply for FAA grants. For each of these airport states, there would be an observed progression or pattern allowing stakeholders to make better decisions. This can be done through the same methodology that was followed in this thesis.
Further study to examine land use and economic activity after airline mergers, startups, hub migrations, or bankruptcies have occurred, would also benefit policymakers.

Examine FAA regulations and the FAR 150’s effectiveness as a program. Investigate what the economic vitality is at an airport.

Community comes before commerce especially when the volume of traffic is projected to increase. If a forecast under estimates, then land uses around the airport need to modified to reflect make sure no harm has been done and without equity loss for the homeowners.

Setup a reserve fund in order to mitigate in the future. This could come from airport user fees.

Additional investment in finding solutions for alternative transportation to larger airports is vital. SEA can handle millions of people where the once rural airport of Bellingham cannot without creating property and development conflicts (Berke, Goldschalk, & Rodriguez, 2006).

For instance, Alaska Airlines and Allegiant Air are interested in starting service at Everett’s Paine Field (PAE) leaving Bellingham serving a Canadian market (Sheets, 2013). PAE is 60 minutes from Bellingham and 30 minutes from Seattle. The projected offerings from Alaska Airlines and Allegiant Air will bring property conflict to Everett as it has in the cities of Seattle, Chicago, Boston, Los Angeles, and New York, just as it did and continues to do today at London’s Heathrow airport since 1963.
Granted if the mission of the POB is to grow, then they should accommodate those individuals since both the INM and the Whatcom County Assessors indicated that BLI is encroaching on residential communities.

Additional noise studies will not solve the problem of property conflict since the balance the POB cites (Port of Bellingham, 2012) has already exceeded the enplanement demands for the year 2050 (Port of Bellingham, 2004). Further research that involving equity analysis should be done by interviewing real estate brokers and families who have tried to sell their properties. Compensation should be granted since there were families living in homes prior to the 2005 WCC disclosure based off an underestimated 2004 forecast from the POB.
APPENDIX A VALUES OF CTL CALCULATED FOR A HALF-CENTURY OF AIRCRAFT NOISE SURVEY FINDINGS

(Fidell & Silvati, Parsimonious alternative to regression analysis for characterizing prevalence rates of aircraft noise annoyance, 2004)
<table>
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<tr>
<th>Study</th>
<th>Study year(s)</th>
<th>Primary authors</th>
<th>Report year</th>
<th>Number of interviews</th>
<th>Field catalog reference</th>
<th>Community tolerance level</th>
<th>rms error</th>
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<tr>
<td>First Heathrow</td>
<td>1961</td>
<td>McKennell—&quot;Wilson report&quot;</td>
<td>1963</td>
<td>1731</td>
<td>UKD-008</td>
<td>77.6</td>
<td>0.21 0.81</td>
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<td>French A/C</td>
<td>1965–66</td>
<td>Alexandre</td>
<td>1970</td>
<td>2000</td>
<td>FRA-016</td>
<td>79.6</td>
<td>0.04 0.99</td>
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<td>Second Heathrow</td>
<td>1967</td>
<td>MIL research, HMSG</td>
<td>1971</td>
<td>4699</td>
<td>UKD-024</td>
<td>84.0</td>
<td>0.17 0.96</td>
</tr>
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<td>Tracor, large cities</td>
<td>1967–69</td>
<td>Connor and Patterson</td>
<td>1976</td>
<td>3590</td>
<td>USA-022</td>
<td>74.3</td>
<td>0.67 0.62</td>
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<td>Tracor, small cities</td>
<td>1967–69</td>
<td>Connor and Patterson</td>
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<td>2912</td>
<td>USA-032</td>
<td>72.6</td>
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<td>1973</td>
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<td>Canadian A/C-street</td>
<td>1970–71</td>
<td>Connor and Patterson</td>
<td>1972</td>
<td>1960</td>
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<td>1973</td>
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<td>LAX</td>
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<td>1975</td>
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<td>Australian A/C</td>
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<td>Borsky</td>
<td>1983</td>
<td>874</td>
<td>USA-338</td>
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<td>1985</td>
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<td>Fidel</td>
<td>1983</td>
<td>140</td>
<td>PIT</td>
<td>83.0</td>
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<td>British ANS</td>
<td>1985</td>
<td>Brooker et al.</td>
<td>1985</td>
<td>2173</td>
<td>UKD-243</td>
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<td>French A/C-road</td>
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<td>Vallet et al.</td>
<td>1988</td>
<td>1032</td>
<td>FRA-239</td>
<td>74.6</td>
<td>0.12 0.93</td>
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<td>German A/C-road</td>
<td>1987</td>
<td>Kastka et al.</td>
<td>1996</td>
<td>516</td>
<td>GER-373</td>
<td>62.6</td>
<td>0.77 0.45</td>
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<td>Oslo A/C</td>
<td>1989</td>
<td>Gjestland et al.</td>
<td>1990</td>
<td>3337</td>
<td>NOR-311</td>
<td>74.3</td>
<td>0.18 0.88</td>
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<td>Long Beach</td>
<td>1989</td>
<td>Fidell and Silvati</td>
<td>1989</td>
<td>2505</td>
<td>LGB</td>
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<td>1994</td>
<td>1195</td>
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<td>1997</td>
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<td>Fidell et al.</td>
<td>2002</td>
<td>1000</td>
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<td>1999</td>
<td>644</td>
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<td>1998</td>
<td>Vallet et al.</td>
<td>2000</td>
<td>1334</td>
<td>FRA-395</td>
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<td>2002</td>
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<td>YVR</td>
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<td>0.44 0.17</td>
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<td>South San Francisco</td>
<td>1999</td>
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<td>1250</td>
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<td>2002</td>
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<td>2007</td>
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<td>Cincinnati</td>
<td>2005</td>
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APPENDIX B AIRLINE SERVICE YEARS
APPENDIX C BELLINGHAM INTERNATIONAL AIRPORT MASTER PLAN
UPDATE PUBLIC MEETING OCTOBER 10, 2012
Date: October 10, 2012
Time: 12:00 to 1:30 pm and 6:30 to 8:00 pm
In Attendance:
Daniel Zenk, Sylvia Goodwin, Carolyn Casey, Port of Bellingham; John Yarnish, Robert Osmanson, URS.

Summary
The following summary combines the comments received from two Public Meeting sessions that were held on October 10, 2012 at the Squalicum Boathouse (2600 Harbor Loop). The first meeting was held from 12:00 pm to 1:30 pm with approximately 55 members of the public attending. The second meeting was held that same evening, beginning at 6:30 pm and ending at 8:00 pm. This meeting was attended by approximately 90 members of the public. Both sessions began with a presentation of the Master Plan status that took about 20 minutes and contained the following information.
1. An update of the status of the master plan,
2. A discussion of the master plan’s objective, goals and process,
3. A presentation of the airport’s continued growth and development,
4. A presentation of the actions needed to address this growth, and
5. Opportunity for questions and comments from the public.

The presentation centered on the FAA’s review of the master plan to date and their desire to slow the process to assure that the complex issues being raised were fully and thoughtfully addressed. The FAA review concentrated on the following areas:
1. Review of the 20-year forecast to understand the full potential market for commercial service in Bellingham. FAA must approve the forecast that will serve as the basis for future Capital development planning.
2. FAA felt the alternatives that were developed were too limiting. Specific comments were;
   a. The Port must make an honest attempt to accommodate passenger growth.
   b. The concept of “managed growth” is inconsistent with FAA policies and may violate the Port’s Grant Assurances.
   c. The Port must maintain the option to accommodate the full range of future development options.
d. The decisions being made in the master plan are complex and the consequences are long-ranging. Therefore the master plan should be slowed down to accommodate full consideration of all decisions by the Port, FAA and the public.

The remainder of the presentation included a reiteration of the rapid growth in recent years that has led to the increases in service as well as the impacts on the neighbors. To respond to this growth, a series of needs were identified and presented to include the following.

**Immediate Actions**
1. Develop an Airport-Community Compatibility Plan.
2. Complete the terminal expansion project that is currently underway.
3. Relocate the Airport Traffic Control Tower (ATCT).
4. Rehabilitate and maintain all airport pavements.
5. Expand the fueling capacity.

**Near-Term Needs**
1. Complete Phase 2 of the wetland mitigation plan.
2. Prepare the Air National Guard site for general aviation development.
3. Complete the airports perimeter road.
4. Relocate the customs building away from the commercial terminal.
5. Expand GA capacity.

**Long-Term Options**
1. Expand the commercial terminal beyond the current capacity.
2. Mitigate additional wetlands.
3. Continue to add GA capacity.

The PowerPoint slide show used for this presentation is available for review on this site. Comments received are as follows.
Questions and Comments
Afternoon Meeting (12:00 to 1:30 pm – 55 attendees)

Question: Does FAA have say over what is final: can they veto the master plan direction?
Answer: They are the final approval. FAA has issues with managed growth because it sounds like the Port is not going to allow access to the airport which is inconsistent with their policies.

Question: Does FAA consider British Columbia to be part of the Region for BLI and why since it’s a different county.
Answer: It’s not their concern that BC is another country and they consider it to be a part of the region.

Question: How do you define Region?
Answer: There are classifications of airports defined by FAA. Bellingham is a Class 1 Commercial Airport based on funding levels; Seattle-Tacoma airport is a Category X. FAA does not look at catchment areas per se; they typically define an airport service area as any place within a 90 minute travel time.

Question: Pilot safety - What role does the tower play? There is no radar service and it is closed from 10 pm to 7 am; safety is needed 24 hours a day. Can this master plan process result in that?
Answer: Sure we can request that the FAA consider changes to the tower’s operating hours but ultimately that’s their call.

The Airport did make a request last September/October to increase tower hours. The FAA determined that there are not enough operations at BLI to justify extended hours so the request was denied.

Question: What is an ILS?
Answer: ILS = Instrument Landing System. It allows an airplane to find the end of the runway using instruments during times when they can’t see it.

Question: Seems that the increase in traffic is driven by one (inexpensive) airline. Most customers are Canadian and the airline is selling cheap flights at the community’s expense. The Port is keeping costs low for a low cost airline but the cost to the community is high and has a negative impact. How does the Port address that?
Answer: The Master Plan is tasked to identify the impacts of the airport and to strike a balance between impacts to the community and successful operations at the airport.

Question: Cheap never lasts and the Canadian market fluctuates. Why are we basing everything on the Canadians? Expanding for Canadians does not bring prosperity to everyone.
Answer: The Master Plan will address how to develop the airport in a responsible manner.

Question: When number crunching, does the master plan include the reality of property assessments going down? As a result, the county as a whole loses revenue with lower property tax?
Answer: The Master Plan will not look at property assessments. This requires more detail than a Master Plan can produce. The Port can elect to do a study later as a dedicated project.

Question: Additional destinations help local businesses and the economy. With Hawaii flights, there are tourists traveling to Bellingham. The Port should coordinate with Hawaii to cross promote the region.
Answer: The Port does work to promote the local area. There are already many passengers who stay at local hotels, eat at local restaurants and buy gas locally.

Question: There are conflicting goals of Whatcom County to keeping Aldridge Road pastoral but the airport noise is loud. Are there any options?
Answer: Preliminary noise contours indicate that noise is not going to get significantly worse. One way to resolve noise is to conduct a Part 150 Study. This will assess the impacts of different flight paths and procedures. A Part 150 looks at how to impact the fewest number of people.

Question: On the approach to the airport from the northwest we have planes making noise after hours. During good days they cut the approach short. It’s better if they go farther out.
Answer: A Part 150 Study can help quantify the impacts of actions like this.

Question: People can hear aircraft in the morning out by Lake Padden. It has increased in past four years. How many flights are there?
Answer: There are currently 65 departures/week.

Question: What is the limit to number of operations?
Answer: The number has not been determined by the master plan.

Question: When was the EIS on the 65 flights done? Is that covering an increase of next 5 years?
Answer: The last full EIS was completed in the late 80s for the project to extend the runway. It didn’t take into consideration the number of flights currently operating. As the Master Plan progressed through the 90s, a full EIS was not required.

Question: Does the Port have travel origin/destination data?
Answer: That is airline proprietary information. They do not give that out.

Question: Years ago, Vancouver was planning to add an extra runway. Are they still going to do that?
Answer: They did not, but are still taking about it.

Question: What is the Port going to do about the impact on the value of property?
Answer: This is a Master Plan study. If there are other studies that would be needed, it’s a Port decision as to whether such studies will be undertaken.

Question: How will the Port compensate people for reducing their property values? We are paying for your profit not ours.
Answer: There is likely a negative impact from airport operations and the Port is trying to understand the scope of these impacts. However this Master Plan will not give information regarding individual houses and properties.

Question: Will all environmental impacts be accounted for in the Master Plan. Will there be compensation for them?
Answer: The Master Plan sets a direction for development and approving it only indicates what direction the Port will take. Any specific development will be subjected to additional environmental analysis since each project has potential impacts.

Question: What about noise abatement for helicopters?
Answer: There are currently no abatement procedures. Helicopters stay 500 feet above ground and follow the same traffic patterns as airplanes.

Question: Would the Port consider making a business plan promote tourism?
Answer: The Port is setting aside funds for travel ambassadors to promote tourism.

Question: Since the Port took a grant for airport expansion, does this require the airport to keep growing?
Answer: The FAA does not require that an airport to grow. However, the airport does have to try to accommodate airplanes as best it can. The FAA requires that publicly funded airports provide equal access to all.

Question: People living farther from the airport question if the airplanes are at least 2,000 feet above the ground. They wonder why the planes don’t go down Northwest Street or over the Bay. There must be some approach to landing that would not impact them so negatively. It’s affecting thousands of people. What is the Port going to do?
Answer: Air traffic does not follow the roadway system, they follow flight patterns based on the runway centerline. There are procedures that can be done and FAA Flight Procedures are working on a new one that gives a constant rate of decent which will reduce likely noise and fuel consumption.

Planes arrive over bay 95% of the time coming from the south. Take off over the bay is also preferred by the airlines. However, for them to arrive over the bay, they must depart to the north which means more noise.

Allegiant is starting to phase out their use of MD-80 and replace them with A319s, which will also mean less noise. The airport is encouraging them to be used at BLI.

Question: Unlike Hawaii, Whatcom County Tourism does not have a $1 million budget. The Port has been a significant partner with the businesses which results in a $555 million impact to the country. The airport helps by delivering people from outside the county. Thanks to the Port for helping to make it successful. The Whatcom County Tourism CEO lives under a flight path and it does not bother her since it means jobs for the region.

Question: What is the budget of Master Plan?
Answer: This Master Plan is has a budget of $512,000. It is 95% funded by FAA.

Question: What is the effect of pollution on residences from exhaust?
Answer: Everything is done in accordance with the Clean Air Act. There have been some studies on leaded fuel but not specific to this airport and it is not a part of this study.

Question: What is the maximum amount of air traffic that can be accommodated?
Answer: The 20-year projection of takeoff and landings is every approximately 14,000 annual commercial operations.

Question: If the FAA is slowing the schedule down, why are you playing catch-up now? How did we get to this point? Not carefully planned?
Answer: Careful planning was done. It was done at a time when there were fewer than 50,000 people using BLI. A new airline came in and took the old assumptions and blew them out of the water. There is no way to plan for that. The Port is working to refocus with new data to try to find out what this means. The Port Commission said they want to wait a few years to see if Allegiant Air is here to stay.

Question: Expansion is feeding itself in a spiral. Everything leads to more expansion. Only push of Port is to expand and not serve the community that pays taxes to Port. What about the safety of the people on the ground; what is Port doing? The chance of an accident is higher now.
Answer: The Master Plan looks at land uses in the airport vicinity. The aviation system is designed to keep people safe. Whatcom County did an airport landing study and sets up zones where public facilities are not allowed. There are policies in place to limit exposure to risk.

Evening Meeting (6:30 to 8:00 pm – 90 Attendees)

Question: How would moving the customs building farther from terminal be efficient?
Answer: General Aviation is the primary user of the customs facility.

Question: The 76 Station area is being cleared for auto parking. What is DOT doing to deal with Bakerview congestion?
Answer: There is a cooperative program between the city/county/state to deal with this, but work will not start until next year. The Airport has no control over the parking lot as it is a private enterprise. The Bakerview interchange proposed design is on the portofbellingham.com website.

Question: Excavation is going on. The Port does not know about it?
Answer: Whatcom County deals with permitting, not the Port.

Question: What does the terminology General Aviation mean?
Answer: GA is anything that is not commercial flights.
Question: How much GA is there?
Answer: 75% of takeoffs and landings at Bellingham International are GA.

Question: Out at the elementary school the kids run for cover due to low aircraft. Allegiant flies lower but no one said it is.

Question: Where does the property tax the Port collects go?
Answer: 15 years ago the Port made the policy decision that all entities had to operate within their own budget. Tax money goes to parks/trails/environmental cleanups/economic development county-wide to assist small towns.

Question: Concern that the property taxes are paying for the Canadians.
Answer: The airport is funded by fees from the airlines and passengers. There are no property taxes being used to support the airport.

Question: The airport is affecting lives in negative ways. There is expansion of the runway as evident by the new structure off the southern part of the runway.
Answer: Planes land into the wind: 95% to the south, 5% to the north. The new Instrument Landing System (ILS) is an enhancement to safety; this will not increase landings only safety.

Question: Is the Master Plan going to include noise mitigation?
Answer: The Master Plan will not include that but a Part 150 study could. Nothing noise related can be adequately addressed without that. Regulations of FAA guide what can or cannot be done. The Port is going to request more study.

Question: When does growth start to slow down? What factors come into play?
Answer: The Master Plan looked at the market in terms of where people are coming from: B.C., Whatcom County, Skagit County, and North King County. It also looked at four other models and how BLI compared with other airports. A twenty-year forecast is an educated guess.

Question: Why is the Port investing for Canadians? What about the environmental issues and health of the children? Specifically, how is the Port studying economic inputs that are bad not just good. The Master Plan only shows the good. Property values are decreasing. Is that studied? Health impacts. Are these going to be studied on this Master Plan?
Answer: Increases in traffic are part of this work scope. Documenting negative impacts and health costs are not part of this Master Plan. Community comments are being shared with FAA and the Port Commission. The Commission is in charge of policies of the Port.

Question: What is the next step? If it’s not being studied, who do we go to get it done?
Answer: URS will be doing an additional update to the Commission and we will be sharing what we have heard. The Port understands that individuals are feeling an impact.

Question: If this does not address it, is there a possibility that more study will be done?
Answer: The Commission will be informed of positive and negative concerns from the community. Port Commission meeting agendas are available online. You can also submit comments at info@portofbellingham.com.

Question: There is an impression that the public has not been involved.
Answer: Before the Master Plan process the Port worked with a survey company to ask questions regarding the airport. After the Master Plan started we had a public meeting (day and night) at the cruise ship terminal. All meeting information has been available online.

Question: Why can’t the public vote on the commission’s design? We should have a public vote.
Answer: The Port Commissioners are elected to vote for us — democracy works that way.

Question: What does Alternatives mean?
Answer: Alternatives will give different approaches for the Port to take for future airport development. Each will be assessed. The early round of alternatives identified on the website.

Question: Concern that the public is not being heard.
**Answer:** The Commission is hearing everything.

**Question:** A large number of passengers are Canadians because the price of flights in Vancouver are sky high. What happens when YVR expansion is paid off and they stop coming to BLI?

**Answer:** The Commission has taken a conservative approach up to this point. With the Canadian market, taxes at Canadian airports are approximately 35% to 40%. Unless these are subsidized, it is unlikely that this will change.

**Question:** There is no attempt to enumerate the costs of the adverse effects; accumulated adverse effects. There is a desire for the Commission to look at the full range of impacts. The question is demand. Why are we looking to build a hotel on airport?

**Answer:** The hotel has been part of the plan for the past 10 years.

**Question:** There was concern that Doug Smith would prefer that the Port Commissioners be able to focus without being distracted by community concerns.

**Answer:** Mr. Smith is no longer a commissioner so his comments should not be considered.

**Question:** The Airport runs at a deficit according to the paper. Not in favor of subsidizing Canadians to fly to Las Vegas. There is a desire for a community vote.

**Answer:** It is highly unlikely that the airport operation would be put to a vote. That is why people elect the Commission, to make the vote. The Airport is a user-fee based airport. Property taxes do not pay for the Canadians.

**Question:** Clarify 800,000. It’s 35% to 40% increase over current volumes. The terminal building is designed to accommodate passenger levels of 700,000 to 800,000. Does this mean more flights?

**Answer:** The number of passengers does not equal the number of flights. It will probably result in a 5% to 7% increase in flights. The MD-80s are being phased out and they are already using new planes.

**Question:** Why doesn’t the Port restrict the use by Canadians?

**Answer:** The Port does not get to check ID at the door. The Port cannot completely control the airport. As we go through the Master Plan, it’s prepared under rules and regulations from FAA. The Port decides what they want. The FAA says the Port cannot discriminate since FAA is helping to pay for the airport. You have to give equal access. You cannot build the airport for only Whatcom County residents. FAA reviews Port decisions to make sure federal guidelines are followed.

**Question:** On noise mitigation, is it true that when FAA does noise studies the level of noise is 65 decibels average over a day.

**Answer:** The average is for a year. 65 Day/Night noise level.

**Question:** There is concern that an Allegiant executive told the Commissioners that if they don’t keep it inexpensive they’ll leave. The Allegiant plan is only to look at the Canadian dollar. Does the Port have control over what it charges airlines?

**Answer:** Yes, but there is no discrimination. The Port cannot show preferential treatment to Allegiant. The FAA grant assurances dictate that.

**Question:** FAA grants are only 90% to 95%.

**Answer:** The rest is paid by the Port through airport fees.
APPENDIX D FUTURE PROJECT
(Paskus, The Art of Donut Making)
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