2008

Comparing methodologies that correlate property values and airport noise

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Version 6.2 has an updated database that includes some newer aircraft, the ability to include run-ups and topography in the computations, and a provision to vary aircraft profiles in an automated fashion. It also includes more comprehensive and flexible contour plotting routines.

Operational data for input to the INM is gathered in a meticulous manner to assure its accuracy, and the data is arranged for input to the model. The INM program requires the input of the physical and operational characteristics of the airport. Physical characteristics include runway coordinates, airport altitude, temperature and, optionally, topographical data. Operational characteristics include aircraft types, flight tracks, departure procedures, arrival procedures and stage lengths (flight distance) that are specific to the operations at the airport. Aircraft data needed to generate noise contours include

- Number of aircraft operations by type
- Types of aircraft
- Day/Night time distribution by type
- Flight tracks
- Flight track utilization by type
- Flight profiles
- Typical operational procedures
- Average meteorological conditions

COMPARING METHODOLOGIES THAT CORRELATE PROPERTY VALUES AND AIRPORT NOISE

A Thesis

Presented to

The Faculty of the Department of Geography

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

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December 2008

SAN JOSE STATE UNIVERSTY

The Undersigned Thesis Committee Approves the Thesis Titled

COMPARING METHODOLOGIES THAT CORRELATE

PROPERTY VALUES AND AIRPORT NOISE

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ABSTRACT

COMPARING METHODOLOGIES THAT CORRELATE PROPERTY VALUES AND AIRPORT NOISE

by Christian Valdes

In order to compare the methodologies and results of studies that correlate airport noise and property value, this thesis introduces a methodology that spatially correlates property location and value to the magnitude of airport noise levels. The results of many studies conducted around airports in the United States and Canada show that airport noise tends to decrease property value. Contrary to the results of these studies, the Spatial Correlation results showed that an increase in airport noise levels do not decrease property values in a community adjacent to Oakland International Airport. In addition, the spatial correlation analysis showed positive and negative property value changes between 1 decibel (dB) airport noise level intervals and an overall appreciation of the average property value relative to increasing airport noise intervals.

There are many other factors influencing property values; isolating noise is difficult because other factors appear to have a larger effect on property values and appreciation rates. However, it is still important to study noise levels and fully understand all factors that influence property value.

ACKNOWLEDGEMENTS

This thesis is the culmination of converging academic and professional paths. Neither path can exist without several special contributors. Great appreciation goes to the San Jose State University professors for conveying the concepts and principles of Aviation and Geography. Thanks to my professional supervisors, Jaime, Carole, and Vince who extended their guidance beyond "the 9 to 5."

This thesis and the associated degree are dedicated to my mother Oriana, who is my biggest fan, my best teacher and enjoys my accomplishments as much as I do, at times, a little more.

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Chapter 1: Introduction

The jet-powered aircraft era revolutionized air transportation and enabled passengers and cargo to reach locations further and faster than previously known. In order to accommodate the development of air transportation, airports and the airline industry increased capacity and flights at a fast pace. The Airline Deregulation Act of 1978 changed air transportation into a highly competitive market that developed into a multi-billion dollar industry currently serving billions of passengers throughout the world. The positive growth and development of the air transportation industry did not occur without negative impacts, however. Communities near airports experienced the most impact from aircraft noise due to the proximity to flight paths and airport operations. Property owners in these communities continuously expressed their concerns that noise from airport operations decreased their property values. According to Bell (1999), "In researching real estate damage issues, the topic of airport noise and its impact on property market values are particularly well-documented and well-researched." (p. 1). Researchers conducted studies around the world that attempted to quantify the impact and relationship between property value and airport noise exposure; most concluded that property values tend to decrease as airport noise exposure increases.

In contrast to most results, Lipscomb conducted a study in the city of College Park, Georgia that revealed that noise did not significantly affect the values of residential properties. Unique conditions may have biased the results: "[the city] houses a high percentage of Hartsfield International Airport employees…Higher [property] sales prices due to being closer to the airport suggests that the benefits of being near a large air transportation hub outweigh the liabilities" (Lipscomb, 2003, pp. 264, 268). Furthermore, Tomkins *et al.* (1997) claimed that "the most significant findings of the study are that closeness to the airport appears to be a more important determinant of residential property prices than airport noise, and that it appears to be a positive rather than a negative attribute in terms of net impact" (p. 254). Distance from the airport (short work commute) earned greater importance to some homebuyers during the home purchasing process than noise from the airport. Therefore, a clear standard methodology had yet to be defined that would result in the same property value to aircraft noise ratio under all conditions.

Results from a survey of 200 realtors and 70 appraisers in 35 suburban communities near Chicago O'Hare International Airport show that noise-affected property owners could be categorized into two groups: "First, there are those who came to their locations when those locations were quiet, either because no airport yet existed or because the scope of its operations was limited, and who later became subject to aircraft noise. Second, there are those who purchased properties after the establishment of the airport and its current level of operations, acquiring those properties from previous owners or from the developers of new residential areas. It is the members of the first group who bear the true burden of airport noise" (Frankel, 1991, p. 110). If noise exposure decreased property value, one could have reasonably presumed that the second group was compensated for the existing noise exposure by willingly purchasing properties at a market-discounted price. This led to the description of aircraft noise as a one-time effect on property value.

Studies show the use of different methodologies that resulted in different conclusions. This thesis compared the methodologies of an original spatial correlation study conducted by the author to three previous studies performed by numerous researchers and agencies. The noise exposure data and property value data for the spatial correlation study were obtained from Oakland International Airport and the Bay Farm Island (BFI) district of Alameda, California, respectively. A study of this type had never been conducted on the communities surrounding the Oakland International Airport. This thesis showed that the conclusions of three previous studies regarding the correlation between property values and airport noise exposure did not apply to BFI homes and revealed that property values in BFI did not decrease as airport noise levels increased.

Although the primary analysis within this thesis was based on geographic principles, it was necessary to include a section on aircraft noise exposure principles. The Appendix described background information to aircraft noise and airport noise-exposure contours. In addition, the section described the reasoning behind the inherent human preference for quieter environments. The Federal Interagency Committee on Noise (FICON) found that "Annoyance is a summary measure of the general adverse reaction of people living in noisy environments that causes speech interference, sleep disturbance, desire for a tranquil environment; and the inability to use the telephone, radio or television satisfactorily" (FICON, 1992, p. 2).

Chapter 2 included a summary of three previously published studies and methodologies used to quantify property value to aircraft noise variables. The first study in Chapter 2, published by the Federal Aviation Administration (FAA), was entitled "The Effects of Airport Noise on Housing Values: A Summary Report." This document was an attempt by the FAA to analyze the impact of airport noise on property value. In order to avoid errors from the use of one technique over the other, the report combined quantitative and qualitative techniques described by previous studies.

The FAA applied an "Analytical Approach" to airports in three major metropolitan areas; it aimed to obtain consistent, repeatable results applied to a national determination regarding the impact of airport noise on property value. Additionally, the report included guidance on alternatives for further study.

The second study was entitled "Meta-Analysis of Airport Noise and Hedonic Property Values: Problems and Prospects," written by J.P. Nelson. Nelson, a well-known figure in the field of transportation noise and economic impacts, published dozens of papers and several books on the subject. One of his papers analyzed 20 hedonic property value studies that cover 23 airports in the U.S. and Canada. A common technique to estimate demand or pricing was the use of hedonic price models, which assigned values to numerous amenities of a residential property. Airport noise exposure was classified as an attribute in the model and, therefore, was assigned a monetary value. Most study calculations resulted in a common coefficient referred to as the Noise Depreciation Index (NDI), or noise discount, which was a decrease in property value per 1 dB Day-Night Noise Level (DNL) change.

The third study entitled "Spatial Hedonic Models of Airport Noise, Proximity, and Housing Prices," written by Jeffrey Cohen and Cletus Coughlin, was one of the first studies to apply spatial models to property value analysis. This study described how the values of surrounding properties, proximity to the airport and airport noise, influenced the value of an individual property by being spatially dependent. The spatial dependence magnified the noise impacts to a much greater degree than in the FAA (1994) and Nelson (2004) studies.

Although much of the research based on hedonic price modeling resulted in inverse relationships between property values and airport noise exposures, not all residential areas experienced this condition. An inconsistency of the hedonic price model relative to airport noise exposure was the inability to accurately and consistently control all other attributes and isolate the noise variable itself. In theory, property variables and buyer demand was controlled. However, in reality, hedonic modeling and other types of property value modeling revealed conclusions based on subjective variables and inaccurate assumptions. A further complication was the magnitude of the noise effect compared to real estate economic factors, e.g., identifying a change in price on the order of a fraction of a percent in a real estate market where property values doubled in a few years. A great number of buyer demand variables, which were nearly impossible to account for and control, drove real estate transactions. The buyer's participation in the real estate market was the most accurate indicator of the consumer's reaction to all property attributes, including airport noise.

Chapter 3 described an original spatial correlation analysis to achieve a property value to aircraft noise variable by implementing Geographic Information Science (GIS) principles. One of the most important criteria in the real estate market was property location, but even more important was the relationship between property location and any surrounding attribute that impacted property value. Another important criterion was the consumer reaction to external property attributes, especially over time.

The methodology of this thesis analyzed the locations and property resale data for 1,219 properties in BFI that sold twice between the years 1986 and 2006 relative to the location of the airport noise exposure contour as defined in the California Noise Standards. Results included a property value comparison to aircraft noise in 1 dB intervals, similar to previous studies. As a reference, local and state housing indices were included. To test the hypotheses, Chapter 3 showed the comparison between the results of the spatial correlation analysis and the results of the FAA (1994), Nelson (2004), and Cohen and Coughlin (2006) studies.

Chapter 2: Published Studies and Methodologies

2.1. The Federal Aviation Administration Approach

In 1994, the FAA published "The Effect of Airport Noise on Housing Values: A Summary Report" that attempted to define a standard a methodology to be used nationally to determine the impacts of airport noise on property value and assist in the creation of national policy or guidelines on the matter.

The FAA study claimed that many studies published prior to 1994 show inconsistencies in noise metrics, types of property values used (average census tract, average census block, actual sales), and single-airport and multiple-airport analyses. Therefore, definitive conclusions were not possible relative to the impacts of airport noise on property value. In light of this problem, the FAA combined quantitative and qualitative techniques that included extensive input from local realtors due to their knowledge of and familiarity with the real estate conditions within the study areas. This approach, called the "Analytical Approach", used a "neighborhood pair model" that compared sample houses in two neighborhoods of similar attributes (e.g., school quality, crime rate, property taxes). Airport noise levels were higher in one neighborhood and lower in the other. Once all attributes were normalized, the difference in property value was credited to airport noise.

The first step of three in the FAA's methodology was

Step 1. Identification of Neighborhoods

The National Board of Realtors suggests that the primary neighborhood attributes assessed by homebuyers were

- Property taxes
- Crime rate
- Quality of neighborhood residential units
- Racial/ethnic/social characteristics
- Local traffic conditions/congestion
- Nearness to commercial and shopping centers
- Quality of local schools
- Quality of municipal services
- Access to public transportation
- Commuting distance
- Quality and proximity of recreational facilities

Once a study airport was chosen, local realtors were surveyed to review and rate the above characteristics in order of importance to neighborhoods around the airport. A "norm" realtor was selected whose rating order was closest to the average surveyed rating order. The norm realtor then surveyed the social, ethnic, and economic conditions of neighborhoods around the airport and selected two similar neighborhoods located in areas with different noise exposure in terms of DNL.

Step 2: Selection of Sample Houses from Each Neighborhood

The criteria for selected homes were

- Sold recently (typically within the past 12 months)
- Similar housing characteristics and amenities, including age, number of rooms and bathrooms, square footage, garage, and pool.

Once the homes were selected, the recorded sales price of each home was found.

Step 3: Comparison of Housing Values in Each Neighborhood Pair

The effects of airport noise on the selected homes were evaluated by a combination of a subjective (qualitative) appraisal approach and a statistical (quantitative) regression modeling approach.

2.1.1. Appraisal Approach

A real estate appraiser was selected through an evaluation of education, background, professional qualifications and experience, understanding of the problem, recommended approach, response to a survey of factors that influenced homebuyers, and fees. The appraiser then selected two similar homes, one located in a noisy neighborhood, the other in a quiet neighborhood. Lastly, the property values were normalized and adjusted for any significant differences in attributes of each home (e.g., 1-car garage compared to a 2-car garage). The appraiser determined the dollar value of different attributes and tabulated the results for comparison. Any value difference between the property in the noisy neighborhood and the property in the quiet home was attributed to the impact of airport noise.

2.1.2. Modeling Approach

Property values were associated with property attributes and airport noise exposure by using multiple linear regression techniques. The dependent variable in the "Modeling Approach" was the property sale price. Numerous independent variables included age of the home, type of design, and appraised condition of home. Binary "dummy" variables were assigned to the noisy neighborhood (0) and to the quiet neighborhood (1). The "Modeling Approach" used the following mathematical equation

Housing Value = f (Housing characteristics, Noise)

The coefficient of the Noise variable established the monetary value of airport noise.

2.1.3. The Hybrid Analytical Approach

The qualitative "Appraisal Approach" yielded unsatisfactory results due to the emphasis on subjective input throughout the appraisal process. The quantitative "Modeling Approach" was deficient due to its statistical or mathematical emphasis. The "Analytical Approach" was created to enhance the conventional appraisal by normalizing the values of homes with significant differences in property attributes. Local realtors added qualitative value to the mathematical modeling process that isolated the effects of airport noise and balanced a subjective process and a statistical process.

2.1.4. Airport Studies

The "Analytical Approach" described above was applied to areas surrounding airports in three metropolitan areas: Baltimore/Washington International Airport (BWI), Los Angeles International Airport (LAX), and New York's John F. Kennedy Airport (JFK) and La Guardia Airport (LGA). The authors of the three studies concluded that airport noise had a negative impact on property value. However, the results of the "Appraisal Approach" were that the normalized property value reduction due to airport noise between the noisy neighborhood and quiet neighborhood ranged between 0.04% and 1.35% per 1 dB of increased airport noise exposure. The "Modeling Approach" revealed that property value reduction between neighborhoods ranged between 5% and 19% per 1 dB of increased airport noise exposure. The results of each approach were included at the end of this section.

Different ratios were attributed to the subjective input by the selected "norm" realtor during the appraisal process and the normalized property attributes. Additionally, the noise impact was more pronounced in higher priced neighborhoods. This study revealed that the "Analytical Approach" was relatively easy and economically feasible, that the procedures were repeatable and verifiable, and that the necessary data was readily available. Improvements to the "Analytical Approach" included analyzing the correct number of airports to study, classifying airports by size, assessing the economic status of each community, and examining airports as employment centers. Lastly, the impact of airport noise at the national level could not be calculated due to the wide range in study results, but further study was considered.

2.1.5. Analytical Approach Results

The BWI study was considered a pilot study due to the small size of the study area. Table 2-1 showed a 0.04% decrease in property value per 1 dB increase in noise exposure. Table 2-4 showed that the modeling approach assigned a $14,595, or 11.5%, reduction in property value attributed to the difference in noise exposure between the quiet neighborhood and the noisy neighborhood. The study area showed distinctive characteristics including second-generation ownership and homeowner's direct or indirect airport employment that may have revealed biased results.

The LAX study obtained more accurate results due to the large size of the study area. Table 2-2 showed that a 1 dB increase in airport noise exposure decreased property value by 0.7% and 1.12% in low priced neighborhoods and moderately priced neighborhoods, respectively. Table 2-5 showed that the modeling approach resulted in a $61,916, or 19%, reduction in property value to the difference between the quiet and noisy moderately priced neighborhoods.

The LGA/JFK study included low priced, moderately priced and high priced neighborhoods. Table 2-3 showed that a 1 dB increase in airport noise exposure decreased property value by 0.12% in low priced neighborhoods, 0.46% in moderately priced neighborhoods, and 1.35% in high priced neighborhoods. Table 2-6 showed that the "Modeling Approach" assigned the highest noise variable to the high priced neighborhoods at $20,224, or 5%, of the property.

2.1.6. Conclusions Regarding the FAA Methodology

The FAA report attempted to create a methodology that could be used nationwide to assess noise impacts on property value, but concluded, "the magnitude of this impact cannot be estimated at the national level, given the wide variation in the study results and the fact that only four airports were considered" (FAA, 1994). The study revealed that further analysis should be done by using the neighborhood pair mode and by selecting a sample of airports that would represent the impacted population nationwide. Noise impacts vary largely on communities and airport environments across the United States, but if researchers conducted enough studies, the local irregularities such as high property values or neighborhood features would average out.

The FAA recommended further analysis including

- Analysis based on airport size
- Analysis based on status of communities
- Analysis based on airport as employment centers, and
- Analysis of airport closures

Table 2-1 BWI Results

Summary of Appraisal Approach Implemented at BWI

Item	Neighborhood		Difference	% Difference	Difference per 1dB	% Difference per 1dB
	Noisy	Quiet				
DNL, dB	72	61	11	not applicable	not applicable	not applicable
Value (un-norm)	$120,538	$126,857	-$6,319	-5.0%	-$574	-0.45%
Value (norm)	$125,262	$125,879	-$617	-0.5%	-$56	-0.04%

Table 2-2 LAX Results

Summary of Appraisal Approach Implemented at LAX: Low Priced Neighborhoods

Item	Neighborhood		Difference	% Difference	Difference per 1dB	% Difference per 1dB
	Noisy	Quiet				
DNL, dB	72	60	12	not applicable	not applicable	not applicable
Value (un-norm)	$157,208	$171,333	-$14,125	-8.2%	-$1,177	-0.69%
Value (norm)	$157,641	$158,909	-$1,268	-0.8%	-$106	-0.07%

Summary of Appraisal Approach Implemented at LAX: Moderately Priced Neighborhoods

Item	Neighborhood		Difference	% Difference	Difference per 1dB	% Difference per 1dB
	Noisy	Quiet				
DNL, dB	69	55	14	not applicable	not applicable	not applicable
Value (un-norm)	$321,750	$380,375	-$58,625	-15.4%	-$4,188	-1.10%
Value (norm)	$326,692	$387,565	-$60,873	-15.7%	-$4,348	-1.12%

Table 2-3 JFK and LGA Results

Summary of Appraisal Approach Implemented at JFK: Low Priced Neighborhoods

Item	Neighborhood		Difference	% Difference	Difference per 1dB	% Difference per 1dB
	Noisy	Quiet				
DNL, dB	67	63	4	not applicable	not applicable	not applicable
Value (un-norm)	$158,500	$159,400	-$900	-0.6%	-$225	-0.14%
Value (norm)	$148,033	$148,767	-$734	-0.5%	-$184	-0.12%

Table 2-3 JFK and LGA Results (continued)

Summary of Appraisal Approach Implemented at LGA: Moderately Priced Neighborhoods

Item	Neighborhood		Difference	% Difference	Difference per 1dB	% Difference per 1dB
	Noisy	Quiet				
DNL, dB	73	63	10	not applicable	not applicable	not applicable
Value (un-norm)	$213,067	$232,000	-$18,933	-8.2%	-$1,893	-0.82%
Value (norm)	$220,400	$231,100	-$10,700	-4.6%	-$1,070	-0.46%

Summary of Appraisal Approach Implemented at JFK: High Priced Neighborhoods

Item	Neighborhood		Difference	% Difference	Difference per 1dB	% Difference per 1dB
	Noisy	Quiet				
DNL, dB	67	63	4	not applicable	not applicable	not applicable
Value (un-norm)	$385,500	$459,500	-$74,000	-16.1%	-$18,500	-4.03%
Value (norm)	$391,633	$414,000	-$22,367	-5.4%	-$5,592	-1.35%

Table 2-4 Linear Regression Models Developed for BWI

Y=41331+673X1+8065X2+6885X3+7726X4+2848X5+4718X6+8493X7+5706X8+4984X9+**14596X10**	
Y=	Appraised Value
X1=	Age of House
X2=	Overall Conditions of House (average, good)
X3=	Total Number of Rooms
X4=	Basement (Full, Partial, None)
X5=	Garage (2-car, 1-car, None)
X6=	Deck (Yes, No)
X7=	Pool (In-ground pool, None)
X8=	Patio (Yes, No)
X9=	Fireplace (Yes, No)
X10=	**Dummy Variable (Quiet, Noisy)**
r^2= .91 F-statistic < 0.0001 t-statistics for independent variables: all significant at 75% confidence level	

Table 2-5 Linear Regression Models Developed for LAX

Moderately Priced Neighborhoods	
Y=303858+15614X1+24909X2+22.28+44792X4+**61916X5**	
Y=	Sale Price
X1=	Design (traditional, bungalow, frame, rustic, mediterranean)
X2=	Condition (average, good)
X3=	Living area
X4=	Pool (Yes, No)
X5=	**Dummy Variable (Quiet, Noisy)**
r^2=0.83 F-statistic < 0.001 t-statistics for independent variables all significant at .85	

Low Priced Neighborhoods	
Y=141761+2842X1+6992X2+9680X3+9652X4+6146X5+**639X6**	
Y=	Sale Price
X1=	Design (traditional, bungalow, frame, rustic, mediterranean)
X2=	Condition (average, good)
X3=	Basement (Yes, No)
X4=	Garage (2-car, 1-car, None)
X5=	Fireplace (2 fireplaces, 1 fireplace, None)
X6=	**Dummy Variable (Quiet, Noisy)**
r^2=0.47 F-statistic < 0.066 t-statistics for independent variables varied	

Table 2-6 Linear Regression Models Developed for LGA and JFK

High Priced Neighborhoods	
Y=275866+1261X1+5.95X2+2757X3+130X4+**20224X5**	
Y=	Sale Price
X1=	Age of House
X2=	Lot Size
X3=	Total Number of Rooms
X4=	Type of Basement (Full, Partial, None)
X5=	**Dummy Variable (Quiet, Noisy)**
r^2=0.77 F-statistic < 0.001 t-statistics for independent variables varied	
Moderately Priced Neighborhoods	
Y=218118+967X1+6.82X2+2782X3+0.62X4+9413X5+**14918X6**	
Y=	Sale Price
X1=	Age of House
X2=	Lot Size
X3=	Total Number of Rooms
X4=	Living Area
X5=	Garage (Yes, No)
X6=	**Dummy Variable (Quiet, Noisy)**
r^2=0.57 F-statistic < 0.138 t-statistics for independent variables varied	
Low Priced Neighborhoods	
Y=106342-393X1+6399X2+34X3+8764X4+**724X5**	
Y=	Sale Price
X1=	Age of House

Table 2-6 Linear Regression Models Developed for LGA and JFK (continued)	
Low Priced Neighborhoods	
X2=	Number of Bedrooms
X3=	Living Area
X4=	Type of Basement (Full, Partial, Noise)
X5=	**Dummy Variable (Quiet, Noisy)**
r^2=0.73 F-statistic < 0.001 t-statistics for independent variables varied	

2.2. Analysis of Twenty Airport Studies

Jon P. Nelson, Department of Economics, Pennsylvania State University published several papers and books on the topic of transportation noise and economics. Nelson's paper titled, "Meta-analysis of Airport Noise and Hedonic Property Values: Problems and Prospects," summarized twenty hedonic property value studies that included 33 NDI estimates at 23 airports in the United States and Canada. The meta-analysis compared study results and assessed research consistency by reviewing systematic and random result variations. The primary objective of this meta-analysis was to establish a common NDI that could be compared to the results of alternative methodologies. Researchers used hedonic price models in all 33 studies. Nelson reviewed several other studies, but did not include them in the meta-analysis due to their inability to establish an NDI, used incorrect measurement of noise impacts, or calculations were unspecific to airport noise.

The first of four sections described the effects of airport noise on property values by referencing the effects on daily activities including sleep, speech, productivity, and outdoor activities. Although airport noise did not prevent most daily activities, people that heard the noise experienced levels of annoyance as an adverse psychological response. If two houses were identical in all attributes, but one was located in an area of high airport noise levels and the other was located in a quieter area, there would be a greater buyer demand for the house in the quieter area. The buyers' demand for the house located in the noisy area decreased due to the buyers' perceived cost of annoyance and other negative effects of noise exposure. Nelson (2004) claimed that "Consumers thus reveal the implicit value that they place on quietude by the explicit choices that they make in the housing market" (p. 4). No two houses were identical in all attributes and only vary in airport noise exposure. Therefore, attributes were controlled statistically to isolate the noise level attribute to achieve an NDI. He stated, "Given the differences in statistical methods, samples, time periods, and urban locations, empirical studies have not produced a singular value for the effects of airport noise on property values" (Nelson, 2003, p. 5).

Nelson described that the important characteristics of a meta-analysis were comparability, completeness, and transparency when comparing sample characteristics, locations, and variations in hedonic model methodologies. Nelson reviewed and compared three previous meta-analyses, Nelson (1980), Johnson and Button (1997), and Schipper et al. (1998), using the above meta-analysis characteristics. The latter two studies did not consider the effects of accessibility to the airport to calculate the NDI and the "statistical results were incompletely recorded" (Nelson, 2003, p. 14).

Nelson concluded that the airport noise reduced U.S. property value by the range of 0.5% to 0.6% per dB, and a weighted mean of 0.58% per dB. Meaning that a $1,000,000 house located in the 55 dB airport noise exposure level would sell for $942,000 if located in the 65 dB airport noise exposure level, given that all other property attributes were constant. Canadian legal rules and other economic differences contributed to a greater NDI on residential properties located in Canada ranging between 0.8% to 0.9% per dB.

Table 2-7 included the following variables

Sample Characteristics

- Airport and country (area if applicable)
- Sample time period
- Sample size
- Census data or individual sales
- Mean property value (2000 U.S. dollars)

Econometric Specification and Results

- NDI estimate (absolute value) and standard error (page no. for estimates)
- Logarithmic vs. linear functional form
- Coefficient of determination (r^2)
- Specification for airport accessibility ("no" means explicit adjustment is absent)

Table 2-7 Nelson Meta-analysis Results

Study (publication date & page no.)	Airport (& Area)	Study period (sample size)	Data type	Mean property value (2000 US $)	NDI %: absolute value (std err)	Dep. Variable (R-sq)	Access adjust?
BAH-FAA (1994, p18)	Baltimore	1990 (30)	individual sales	$123,698 ($170,703)	1.070 (0.823)	linear (0.91)	Yes
BAH-FAA (1994, p22)	Los Angeles	1991 (24)	individual sales	$351,062 ($449,359)	1.260 (0.788)	linear (0.83)	Yes
BAH-FAA (1994, p27)	New York (JFK)	1993 (30)	individual sales	$422,500 ($523,900)	1.200 (n.a.)	linear (0.77)	Yes
BAH-FAA (1994), p27)	New York (La Guardia)	1993 (30)	individual sales	$222,534 ($275,942)	0.670 (n.a.)	linear (0.57)	Yes
Blaylock (1977, p79)	Dallas	1970 (4,264)	census blocks	$25,000 ($136,250)	0.990 (0.330)	linear (0.82)	Yes
DeVany (1976, p213) NAS (1977, p139)	Dallas	1970 (1270)	census blocks	$22,000 ($119,900)	0.800 (0.267)	linear (0.82)	Yes
Dygert (1973, p105)	San Francisco (San Mateo)	1970 (82)	census tracts	$27,600 ($150,420)	0.500 (0.250)	log (0.66)	Yes
Dygert (1973, p113)	San Jose	1970 (98)	census tracts	$21,000 ($114,450)	0.700 (0.422)	log (0.67)	Yes
Emerson (1969, p68; 1972, p271)	Minneapolis	1967 (222)	individual sales	$19,683 ($132,270)	0.580 (0.366)	log (0.80)	Yes
Fromme (1978, p100)	Washington D.C. (National)	1970 (28)	census tracts	$30,068 ($163,871)	1.490 (0.753)	log (0.75)	Yes
Kaufman (1996, p33)	Reno	1991-95 (1596)	individual sales	$110,970 ($137,603)	0.280 (0.183)	log (0.85)	Yes
Lavesque (1994, p207)	Winnipeg	1985-86 (1635)	individual sales	$72,316 CN$ ($70,104)	1.300 (0.342)	log (0.80)	No
Mark (1980, p112)	St. Louis	1969-70 (6553)	individual sales	$15,015 ($81,832)	0.560 (0.240)	log (0.67)	No
Maser et al. (1977, p130); Quinlan (1970)	Rochester	1971	individual sales	$19,100	0.860	linear	No
	(urban)	(398)		($99,893)	(0.319)	(0.62)	

Table 2-7 Nelson Meta-analysis Results (continued)

Study (publication date & page no.)	Airport (& Area)	Study period (sample size)	Data type	Mean property value (2000 US $)	NDI %: absolute value (std err)	Dep. Variable (R-sq)	Access adjust?
Maser et al. (1977, p130); Quinlan (1970)	Rochester (suburban)	1971 (990)	individual sales	$21,800 ($114,014)	0.680 (0.279)	linear (0.84)	No
McMillian et al. (1980, p319); McMillian (1979)	Edmonton	1975-76 (352)	individual sales	$51,933 CN$ ($108,730)	0.510 (0.224)	log (0.71)	No
Mieszkowski & Saper (1978, p430)	Toronto (Mississauga)	1969-73 (509)	individual sales	$31,450 CN$ ($108,730)	0.870 (0.212)	log (0.90)	Yes
Mieszkowski & Saper (1978, p430)	Toronto (Etobicoke)	1969-73 (611)	individual sales	$37,770 CN$ ($108,063)	0.950 (0.187)	log (0.92)	Yes
Myles (1997, p21)	Reno	1991 (4332)	individual sales	$135,000 ($178,200)	0.370 (0.111)	log (0.74)	No
Nelson (1978, p98)	Washington D.C. (National)	1970 (52)	census tracts	$27,455 ($149,630)	1.060 (0.714)	log (0.86)	Yes
Nelson (1979, p325; 1980, p45)	Buffalo	1970 (126)	census blocks	$20,656 $112,575	0.520 0.200	log (0.61)	Yes
Nelson (1979, p325; 1980, p45)	Cleveland	1970 (185)	census blocks	$20,898 $113,894	0.290 (0.128)	log (0.89)	Yes
Nelson (1979, p325; 1980, p45)	New Orleans	1970 (143)	census blocks	$21,975 ($119,763)	0.400 (0.195)	log (0.75)	Yes
Nelson (1979, p325; 1980, p45)	St. Louis	1970 (113)	census blocks	$16,411 ($89,440)	0.510 (0.267)	log (0.74)	Yes
Nelson (1979, p325; 1980, p45)	San Diego	1970 (125)	census blocks	$32,241 ($175,713)	0.740 (0.233)	log (0.76)	Yes
Nelson (1979, p325; 1980, p45)	San Francisco	1970 (153)	census blocks	$29,686 ($161,789)	0.580 (0.184)	log (0.71)	Yes
Nelson (1979, p327; 1980, p69; 1981)	Six Airports	1970	census blocks	$23,713	0.550	log	Yes
		(845)		($129,236)	(0.200)	(0.84)	

Table 2-7 Nelson Meta-analysis Results (continued)

Study (publication date & page no.)	Airport (& Area)	Study period (sample size)	Data type	Mean property value (2000 US $)	NDI %: absolute value (std err)	Dep. Variable (R-sq)	Access adjust?
O'Byrne et al. (1985, p175)	Atlanta (blocks)	1970 (248)	census blocks	$18,964 ($103,354)	0.640 (0.200)	log (0.74)	No
O'Byrne et al. (1985, p173)	Atlanta (houses)	1979-80 (96)	individual sales	$28,889 ($81,178)	0.670 (0.300)	log (0.71)	Yes
Price (1974, p40 & 59)	Boston (rentals)	1970 (270)	census tracts	$103 per month (n.a.)	0.810 (0.238)	linear (0.50)	No
Trassoff (1993, p83)	Montreal	1989-90 (427)	individual sales	$148,525 CN$ ($118,985)	0.650 (0.325)	linear (0.64)	No
Uyeno et al. (1993, p9); Biggs (1990, p136)	Vancouver (houses)	1987-88 (645)	individual sales	$139100 CN$ ($124,076)	0.650 (0.164)	log (0.64)	Yes
Uyeno et al. (1993, p11)	Vancouver (condos)	1987-88 (907)	individual sales	not applicable	0.900 (0.323)	log (0.79)	Yes

2.3. A Spatial Hedonic Approach

In September 2006, Jeffery P. Cohen, Associate Professor of Economics at the University of Hartford and Cletus C. Coughlin, Vice President and Deputy Director of Research at the Federal Reserve Bank of St. Louis, published a working paper titled, "Spatial Hedonic Models of Airport Noise, Proximity, and Housing Prices." This paper was the first to apply spatial econometric models in a hedonic price framework, which examined 508 property values in neighborhoods around Atlanta's Hartsfield-Jackson International Airport. The data set included the airport noise contour map of 2003 and the single-family dwelling price data and characteristics for the year 2003 near the 65 DNL and 70 DNL airport noise contour. The average home sold for approximately $128,400, included 3 bedrooms and 1.78 bathrooms, in a lot of 0.37 acres. The price of a property near an airport was not only impacted by noise, but it was also dependent on location and spatial relationships.

Noise was only one proximity variable within all of the residential property attributes. To prevent incorrect estimates of the impact of noise as a proximity variable, the study included the spatial autocorrelation to one another and to the airport. This means that the value of individual properties was dependent and impacted by the values of surrounding homes and access to the airport. Testing for spatially-lagged dependent variables amongst homes near one another resulted in a parameter estimate of 0.536. That is, if nearby home sale prices decreased by 1% around a particular home, the sale price of that home would decrease by 0.54%. A 1% increase in the distance from the airport resulted in .15% decrease in property value indicating that proximity to the airport increased property value. By incorporating the spatially-dependent variable process to the standard hedonic model described in previous studies, the authors created a new general spatial econometric model. According to the model, properties in the 70 DNL sold for approximately 20.8% less than properties within the 65 DNL (a NDI per decibel was not given). The authors agreed with previous studies that concluded that noise reduced property value. Cohen and Coughlin emphasized the importance of spatial relationships by stating "the findings of this study imply that by ignoring spatial autocorrelation and spatially-lagged dependent variables in estimation of hedonic housing price models of airport noise, serious econometric problems may arise that can affect the policy implications of the model's parameter estimates" (2006, p. 24).

Chapter 3: Spatial Correlation Analysis of Airport Noise and Property Value

3.1. Introduction

The San Francisco Bay area was host to three major commercial airports including Oakland International Airport, built over 80 years ago. In 2006, the airport served over 15 million passengers and 700,000 tons of cargo. The flight paths of aircraft that used the airport crossed over many residential areas. However, certain residential areas were exposed to more aircraft noise than others. The residential area selected for this study was Bay Farm Island (BFI), Alameda, California, located adjacent to the Airport. See Figure 3-1, BFI Study Area Map.

Although most of the residential dwellings were built in BFI after 1976, residential developments continued to occur in close proximity to the airport boundaries due to ineffective local land use regulations. Residents living near the airport faced a 2% to 3% per year increase in flights prior to 2007. The airport received hundreds of noise complaints per month; many from BFI residents that claimed aircraft noise disturbed them and decreased the value of their homes.

The thesis author performed an original spatial correlation analysis on property values in BFI and the airport noise exposure and created the figures within this section. The results of this analysis based on GIS principles were then compared to the results of studies in Chapter 2.

3.2. Study Area

The Oakland Airport Noise Abatement Office provided airport noise exposure data and airport operations information. The residential area of BFI included approximately 5,800 residential properties. The Public Works Department of the City of Alameda provided the property value database for 1,219 properties that sold twice between 1986 and 2006. See Figure 3-2, Study Properties Map.

Bay Farm Island was considered an affluent neighborhood that was host to a municipal golf course, a high tech business park and shopping center, a chain of man-made lagoons, and the headquarters and practice field of the Oakland Raiders professional football team. Roughly one half of BFI's municipal boundaries were adjacent to Oakland Airport's property boundaries and the rest was surrounded by water. Two roads connected BFI with the main island of the City of Alameda and the southern areas of the City of Oakland.

3.3. Airport Operations and Noise Exposure

Approximately 90% of the year, flights departed from the airport towards the northwest. The closest point on the departure flight path from the airport's main runway (South Field), shown on Figure 3-2, was approximately 2,200 feet from the closest homes in BFI. Roughly 270 commercial daily departures (in year 2006) flew near the southwest perimeter of BFI. Flights operated 24 hours a day including a "Fed Ex launch" of approximately 8 departures between the hours of 2:00 a.m. and 5:00 a.m. Some business jets departed from the main runway on the same departure route as commercial aircraft.

Flights that operated on the North Field runways usually flew over the golf course before reaching the Oakland estuary as a form of noise abatement. Very few business jets departed from the North Field and flew over BFI, but such flights occurred occasionally. Noise exposure levels remained fairly constant throughout the past decade, but decreased slightly due to relatively more flights during by newer aircraft with quieter engines during recent years.

Airport staff prepared the airport noise contours by using the FAA's Integrated Noise Model (INM) version 6.2 to calculate noise exposure. Input to the model included type of aircraft, number of operations (arrivals and departures), flight paths, and times of operation. Airport staff also prepared noise exposure maps on a quarterly basis to comply with the State of California noise regulations. Figure 3-3, Airport Noise Contours Map showed the 2006 annual noise exposure map that included noise exposure levels from 54 dB Community Noise Equivalent Level (CNEL) (see appendix for CNEL definition) to 65 dB CNEL in 1 dB increments.

3.4. Spatial Correlation Analysis

In comparison to the FAA methodology, this spatial correlation analysis did not normalize property attributes of homes located at different airport noise exposure areas and assumed that the differences in property value were due to airport noise. This analysis calculated the annual growth rate of each property as a data layer attribute by comparing two transaction costs using the following compounding growth formula

$$\sqrt[(TY_2-TY_1)]{\frac{TC_2}{TC_1}}-1$$

where

TC_1 = Cost of 1st Transaction

TC_2 = Cost of 2nd Transaction

TY_1 = Year of 1st Transaction

TY_2 = Year of 2nd Transaction

(If both transactions occurred during the same year, $TY_2 - TY_1 = 1$)

Spatially joining the study property data layer and the airport noise exposure data layer correlated the annual growth rate of each property to airport noise exposure levels. Grouping the annual growth rates per property by CNEL interval led to the Average Annual Growth (AAΔ) per 1 dB CNEL. Table 3-2, BFI Average Annual Growth (AAΔ) in each noise contour showed the average annual growth in each noise contour of airport noise exposure. Figure 3-1, AAΔ Graph (Table 3-2 in bar graph format), showed a non-linear relationship amongst the AAΔ versus noise level and a slight increasing slope of .17% per dB as noise exposure increased throughout the study area.

As a reference, the City of Alameda and Alameda County annual average of real estate prices and growth rates over time from the California Association of Realtors, and the California and National Housing Price Index (HPI) prepared by the Office of Federal Housing Enterprise Oversight (OFHEO) were listed on Table 3-1, Housing Price Index. "The HPI is published on a quarterly basis and tracks average price changes in repeat sales or refinancings of the same single-family properties…based on analysis of data obtained from Fannie Mae and Freddie Mac from more than 32 million repeat transactions over the past 32 years" (OFHEO, 2007, p. 3).

3.5. Study Comparison

The FAA "neighborhood pair" model study revealed that property value decreased by values ranging from 0.04% to 1.35% per 1 dB increase. The Cohen and Coughlin spatial hedonic model discovered that the property value depreciation per decibel was approximately 4%. The Nelson Meta-analysis resulted in a property depreciation of 0.58% per an increase of 1 dB. To better compare the Nelson results to the spatial correlation analysis results, Figure 3-2, Nelson Noise Depreciation Index showed an average property depreciation of 6.74% between the study area noise levels of 53 dB and 65 dB, whereas Figure 3-1, AAΔ Graph showed an appreciation of 2.04%.

3.6. Conclusion

This chapter described the spatial correlation analysis that showed the average annual property value change on BFI ranged from -4.0% to +5.0% between 1 dB airport noise level interval. Figure 3-1 showed an overall appreciation of the average property value relative to increasing airport noise levels. Furthermore, overall BFI property values did not decrease with increasing airport noise exposure levels, contrary to the FAA (1994), Nelson (2004), Cohen and Coughlin (2006) results. Clearly, other factors had a much larger effect on property value than aircraft noise.

Table 3-1 Housing Price Index (HPI)

	City of Alameda				
Year	Single-Family HPI	Condominium HPI	Alameda County HPI	California HPI	National HPI
2000	23.0%	22.0%	27.40%	13.80%	8.10%
2001	10.5%	12.8%	6.40%	9.76%	6.92%
2002	11.4%	12.4%	10.70%	11.46%	6.89%
2003	5.5%	4.0%	5.40%	13.77%	7.97%
2004	15.5%	21.6%	17.80%	23.44%	11.17%
2005	16.1%	8.5%	17.50%	21.07%	12.95%
2006	not available	not available	1.20%	4.60%	5.87%

Table 3-2 BFI Average Annual Change (AAΔ) per Decibel

dB CNEL	AAΔ	AAΔ per 1dB increase	Number of homes per dB interval
53	10.9%		14
54	9.9%	-1.0%	156
55	8.1%	-1.8%	91
56	9.3%	1.2%	75
57	9.4%	0.1%	46
58	7.9%	-1.5%	98
59	12.9%	5.0%	118
60	8.9%	-4.0%	130
61	10.2%	1.3%	131
62	10.4%	0.2%	149
63	11.2%	0.8%	138
64	9.5%	-1.7%	64
65	13.3%	3.8%	9

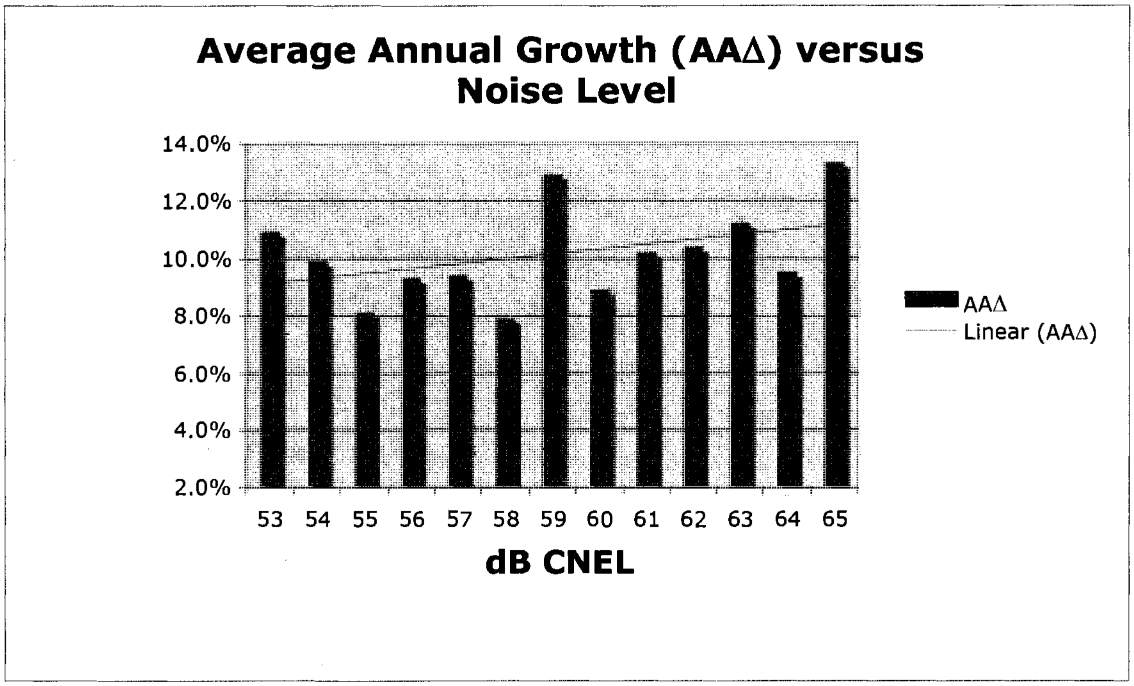

Figure 3-1 AAΔ Graph

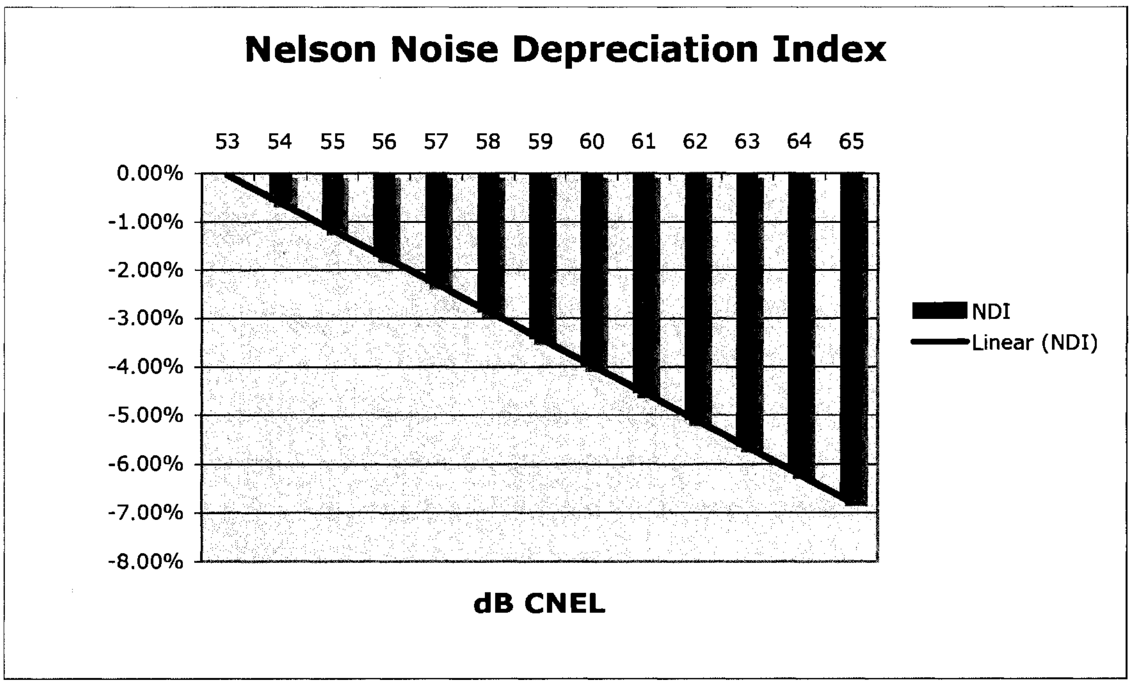

Figure 3-2 Nelson NDI Graph

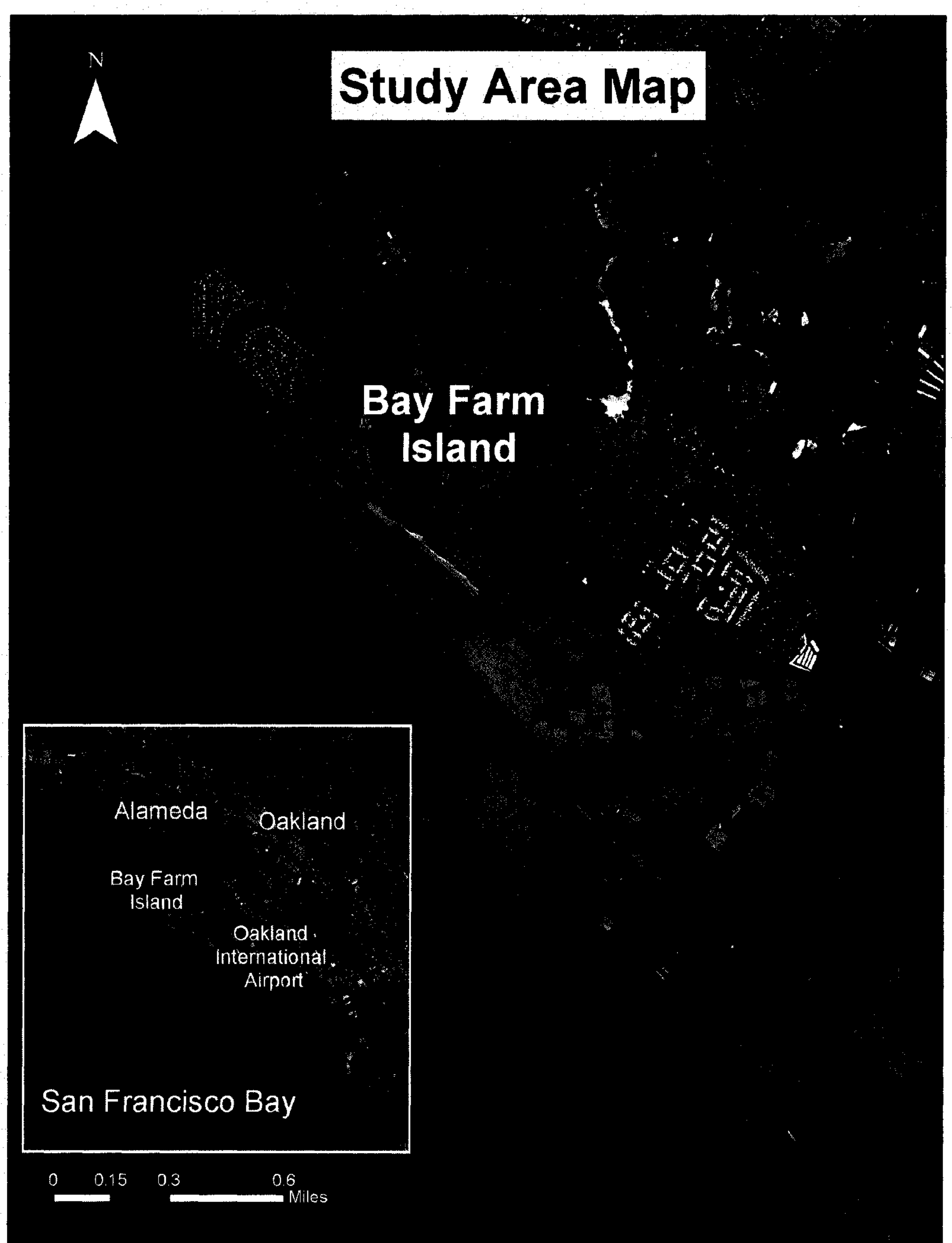

Figure 3-3 Study Area Map

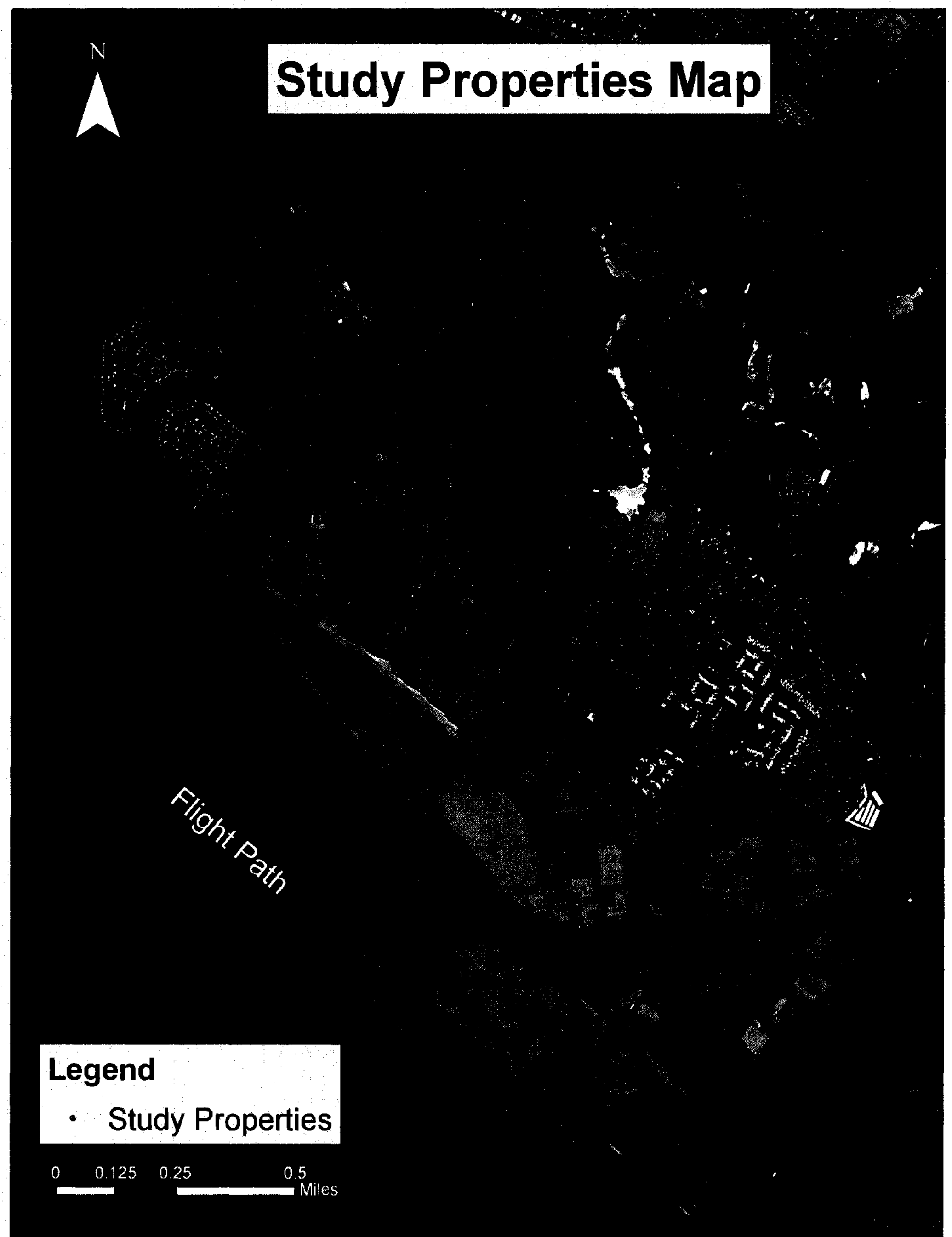

Figure 3-4 Study Properties Map

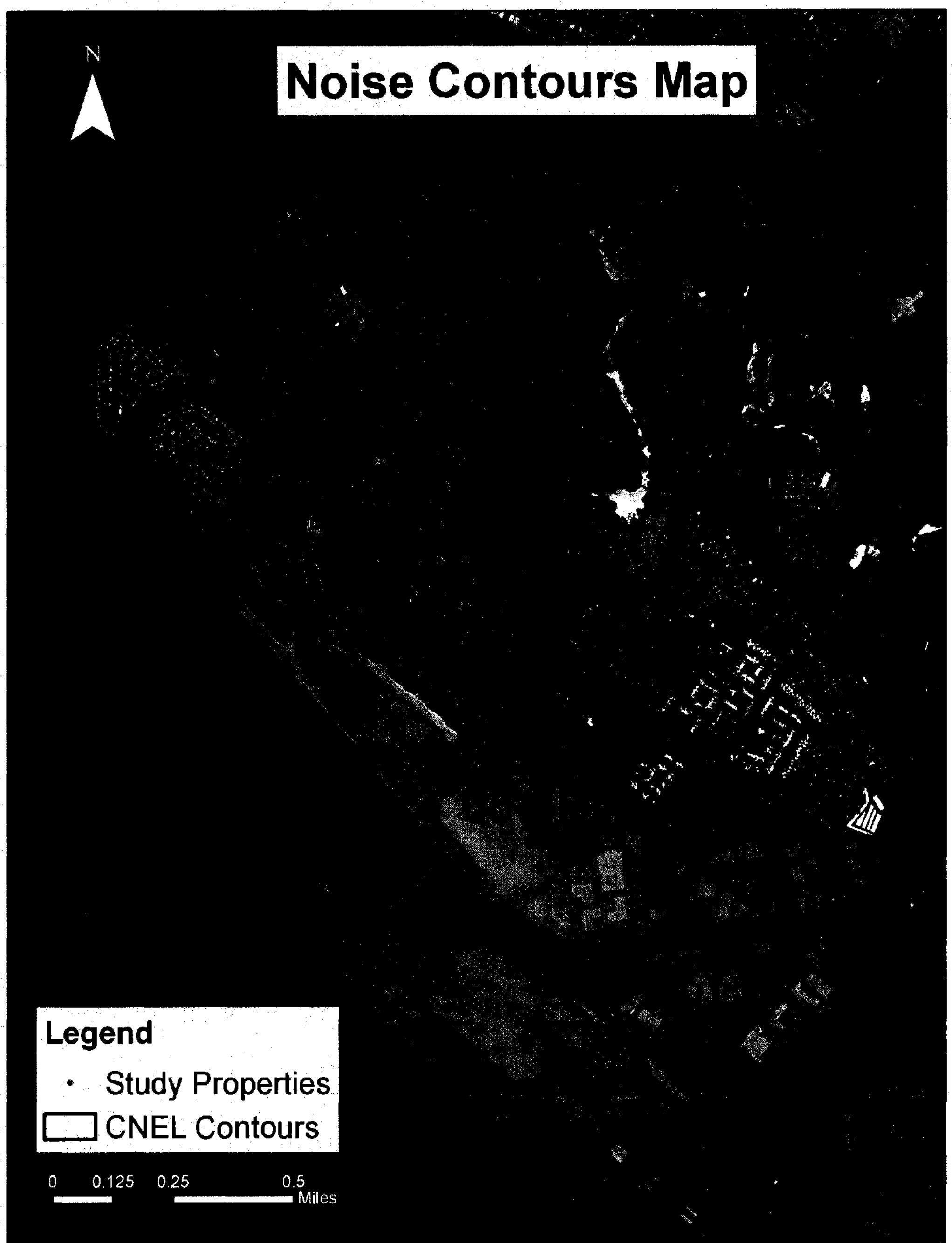

Figure 3-5 Noise Contours Map

Chapter 4: Summary and Conclusion

Air transportation served billions of passengers and tons of cargo every year. Unfortunately, many communities near airports experienced environmental impacts, especially noise. Many community residents believed that airport noise decreased the property value of their homes. Studies conducted at different airports and surrounding communities show that airport noise reduced property values by a range of 0.04% to 19% per 1dB of increased airport noise. "The similarity of results spanning several decades and several Western countries would seem to suggest a broad and long-lived consensus on the issue" (Uyeno *et al.,* 1993). However, this reduction in property value could be applied to all communities with surrounding airports.

The spatial correlation study of 1,219 properties that sold between 1986 and 2006 on Bay Farm Island, Alameda, CA, a community adjacent to Oakland International Airport, showed results contrary to previous studies. The Average Annual Growth in property value was spatially correlated to the airport noise exposure, and results showed an overall appreciation in property value as CNEL noise levels increased among homes located within the 53 and 65 dB CNEL.

The reasons Bay Farm Island property values did not decrease as noise levels increased in the same manner as shown in the results of many previous studies were unclear. Higher noise levels occurred near the water, and in general, coastline homes with views of the San Francisco Bay had greater purchase value. Other factors such as real estate market condition, attraction and location of a community, and buyer reaction or opinion towards airport noise may have had a large effect on the value of a home.

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Appendix: Airport Noise Background

This appendix presents background information on the characteristics of noise and summarizes the noise metrics and methodologies used to assess airport noise exposure. The effects of airport noise on people may in turn affect property values in neighborhoods around airports. This section is divided into the following sub-sections

A.1. Characteristics of Sound - Presents properties of sound that are important for technically describing noise in the airport setting.

A.2. Factors Influencing Human Response to Sound - Describes factors that influence what is audible to the human ear that can affect subjective perceptions and elicit a response.

A.3. Health Effects of Noise - Summarizes the potential disturbances and health effects of noise on humans.

A.4. Sound Rating Scales - Presents various sound rating scales and how they are applied to assessing aircraft operations.

A.5. Noise/Land Use Compatibility Guidelines - Summarizes current standards and regulations used to control the use of land in areas affected by aircraft noise.

A.6. Airport Noise Assessment Methodology - Describes computer modeling and on site noise measurement surveys used to measure aircraft and other noise in the vicinity of airports.

A.1. Characteristics of Sound

The standard unit of measurement of sound pressure is the Decibel (dB). One decibel is actually an exponent to the reference point of 20 micro Pascals or about .000000003 pounds per square inch. On the logarithmic scale, a sound level of 70 dB has 10 times as much acoustic energy as a level of 60 dB while a sound level of 80 has 100 times as much acoustic energy as 60 dB (This differs from the human perception to noise, which typically judges a sound 10 dB higher than another to be twice as loud, 20 dB higher four times as loud, and so forth).

The frequency of a sound is expressed as Hertz (Hz) or cycles per second. The normal audible frequency range for young adults is 20 Hz to 20,000 Hz. The human ear is not equally sensitive to all frequencies; some frequencies are judged to be louder for a given signal than others. As a result of this, various methods of frequency weighting have been developed. The most common weighting is the A-weighted decibel scale (dBA), which accounts for various frequencies in a manner approximating the sensitivity of the human ear. Most community noise analyses are based upon the A-weighted decibel scale, and everyday sounds normally range from 20 dBA (very quiet desert night) to 100 dBA (very loud jet flyover at 1,000 feet) (Beranek, 1994).

A.2. Factors Influencing Human Response to Sound

Many factors influence how a sound is perceived and whether or not it is considered annoying to the listener. This includes not only physical characteristics of the sound but also secondary influences such as sociological and external factors. Harris

(1979) describes human response to sound in terms of both acoustic and non-acoustic factors.

The primary factors are: sound level, frequency, and duration. The secondary acoustic factors are: spectral complexity, fluctuations in sound level, fluctuations in frequency, rise-time of the noise, localization of noise source. Non-acoustic factors are: physiology, adaptation and past experience, how the listener's activity affects annoyance, predictability of when a noise will occur, necessity of the noise, and individual differences and personality.

Sound rating scales have been developed to account for how humans respond to sound and how sounds are perceived in the community. Many non-acoustic parameters affect individual response to noise. Background sound, an additional acoustic factor not specifically listed, is important in describing sound in rural settings. Some research on the effects of personal and situational variables on noise annoyance identified a clear association of reported annoyance and fear of an accident. In particular, there is firm evidence that noise annoyance is associated with: (1) the fear of an aircraft crashing or of danger from nearby surface transportation; (2) the belief that aircraft noise could be prevented or reduced by designers, pilots or authorities related to airlines; and (3) an expressed sensitivity to noise generally. Thus, it is important to recognize that such non-acoustic factors as well as acoustic factors contribute to human response to noise.

A.3. Health Effects of Noise

Noise, often described as unwanted sound, is known to have several adverse effects on people. From these effects, criteria have been established to help protect public health and safety and prevent disruption of certain human activities. These criteria are based on effects of noise on people, such as hearing loss (not a factor with typical community noise), communication interference, sleep interference, physiological responses and annoyance. Each of these potential noise impacts are briefly discussed below

- Hearing loss is generally not a concern in community noise problems, even for people living close to a major airport or a freeway. The potential for noise induced hearing loss is more commonly associated with occupational noise exposures in heavy industry, very noisy work environments with long term exposure, or certain very loud recreational activities such as target shooting, motorcycle or car racing, etc. The Occupational Safety and Health Administration (OSHA) identifies a noise exposure limit of 90 dBA for 8 hours per day to protect from hearing loss (higher limits are allowed for shorter duration exposures). Noise levels in neighborhoods, even in very noisy neighborhoods, do not exceed this standard and are not sufficiently loud to cause hearing loss.

- Communication interference is one of the primary concerns in environmental noise problems. Communication interference includes speech interference and interference with activities such as watching television. Normal conversational speech is in the range of 60 to 65 dBA and any noise in this range or louder may interfere with speech.

- Sleep interference, particularly during nighttime hours, is a cause of annoyance due to community noise. Noise may make it difficult to fall asleep, create momentary disturbances of natural sleep patterns by causing shifts from deep to lighter stages and may cause awakenings.

- Physiological responses reflect measurable changes in pulse rate, blood pressure etc. Generally, physiological responses reflect a reaction to a loud short-term noise, such as a rifle shot or a very loud jet overflight. While such effects can be induced and observed, the extent to which these physiological responses may cause harm is not known.

- Annoyance is the most difficult of all noise responses to describe. Annoyance is an individual characteristic and can vary widely from person to person. What one person considers tolerable may be unbearable to another of equal hearing capability. The level of annoyance also depends on the characteristics of the noise (i.e., loudness, frequency, time, and duration), and how much activity interference (e.g., speech interference and sleep interference) results from the noise. However, the level of annoyance is also a function of the attitude of the receiver. Personal sensitivity to noise varies widely. It has been estimated that 2 to 10 percent of the population is highly susceptible to annoyance from noise not of their own making, while approximately 20 percent are unaffected by noise. Attitudes are affected by the relationship between the listener and the noise source, "Is it our dog barking or the neighbor's dog?" Whether we believe that someone is trying to abate the noise will also affect our level of annoyance.

A.4. Sound Rating Scales

The description, analysis, and reporting of community sound levels is made difficult by the complexity of human response to sound and the myriad of sound-rating scales and metrics that have been developed for describing acoustic effects. Various rating scales have been devised to approximate the human subjective assessment of "loudness" or "noisiness" of a sound.

Noise metrics can be categorized as single event metrics and cumulative metrics. Single event metrics describe the noise from individual events, such as an aircraft flyover. Cumulative metrics describe the noise in terms of the total noise exposure throughout the day, year or other time period. Airport noise exposure contours are measured by cumulative noise metrics.

A.4.1. Cumulative Metrics

Cumulative noise metrics have been developed to assess community response to noise. They are useful because these scales attempt to include the loudness and duration of the noise, the total number of noise events and the time of day these events occur into one single number rating scale. They are designed to account for the known health effects of noise on people. The Community Noise Equivalent Level (CNEL) index is a measure of the overall noise experienced during an entire (24-hour) day, which includes time-weighted energy average noise level based on the A-weighted decibel. Time-weighted refers to noise that occurs during certain sensitive time periods and is penalized for occurring at these times. In the CNEL scale, noise occurring between the hours of 10 p.m. to 7 a.m. is penalized by 10 dB, and between 7 p.m. and 10 p.m., it is penalized 5 dB. This penalty was selected to account for the higher sensitivity to noise in the evening and nighttime hours and the expected further decrease in background noise levels that typically occur at night. CNEL is specified by the FAA for community and airport noise assessment as well as the Environmental Protection Agency (EPA). Examples of various noise environments in terms of CNEL are presented in Table A, Typical Outdoors Noise Levels in CNEL. The CNEL index is used in the State of California. The remaining 49 states use a similar Day-Night Noise Level (DNL) index that excludes the noise penalty between 7 p.m. and 10 p.m.

Table A
Typical Outdoor Noise Levels in Terms of CNEL

CNEL (dB)	Typical Outdoor Location
90	
	Apartment Next to Freeway
	3/4 Mile From Touchdown at Major Airport
80	
	Downtown With Some Construction Activity
	Urban High Density Apartment
70	
	Urban Row Housing on Major Avenue
60	
	Old Urban Residential Area
	Wooded Area
50	
	Agricultural Crop Land
40	
	Rural Residential
	Wilderness Ambient
30	
Source: Environmental Protection Agency (1974)	

A.5. Noise/Land Use Compatibility Standards and Guidelines

Land use and development regulations often include compatibility standards for various levels of environmental noise. The most common noise/land use compatibility standard or criteria used is 65 dB DNL or CNEL for residential land use with outdoor activity areas. At 65 dB DNL, the Schultz curve predicts approximately 14% of the exposed population being highly annoyed. At 60 dB DNL this decreases to approximately 8% of the population highly annoyed. However, there is some uncertainty with the Schultz curve; even a higher percentage of residents within these contours may experience annoyance in some cases.

Several agencies utilize such research on the human response to aircraft noise and developed standards and guidelines for land use within certain areas exposed to aircraft noise. Such community standards also account for trade offs with the economic consequences of achieving noise and land use compatibility criteria. These laws and regulations provide the basis for local development of airport plans, analyses of airport impacts, and the enactment of compatibility policies. A summary of pertinent regulations and guidelines are presented below.

A.5.1 Federal Aviation Regulations, Part 36, "Noise Standards: Aircraft Type and Airworthiness Certification"

Originally adopted in 1960, FAR Part 36 prescribes noise standards for issuance of new aircraft type certificates; it also limited noise levels for certification of new types of propeller-driven, small airplanes as well as for transport category, large airplanes. Subsequent amendments extended the standards to certain newly produced aircraft of older type designs. Other amendments extended the required compliance dates. Aircraft may be certificated as Stage 1, Stage 2, or Stage 3 aircraft based on their noise level, weight, number of engines, and, in some cases, number of passengers. Stage 1 aircraft are no longer permitted to operate in the U.S. Stage 2 aircraft were phased out of the U.S. fleet as discussed below under Airport Noise and Capacity Act of 1990. Although aircraft meeting Part 36 standards are noticeably quieter than many of the older aircraft, the regulations make no determination that such aircraft are acceptably quiet for operation at any given airport.

A.5.2 Federal Aviation Regulations, Part 150, "Airport Noise Compatibility Planning"

As a means of implementing the Aviation Safety and Noise Abatement Act, the FAA adopted Federal Aviation Regulations Part 150 Airport Noise Compatibility Planning Programs which include a noise and land use compatibility chart to be used for land use planning with respect to aircraft noise. An expanded version of this chart appears in FAA Advisory Circular 150/5020-1 (dated August 5, 1983). These guidelines offer recommendations to local authorities for determining acceptability and compatibility of land uses. The guidelines specify the maximum amount of noise exposure (in terms of the cumulative noise metric DNL or CNEL) that is considered acceptable or compatible to people in living and working areas.

The State of California Department of Transportation Land Use Compatibility guidelines use noise exposure levels that reflect the use of CNEL.

A.5.3. Federal Aviation Administration Order 5050.4 and Directive 1050.1 for Environmental Analysis of Aircraft Noise Around Airports

The FAA issued Order 5050.4A containing guidelines for the environmental analysis of airports. Federal requirements now dictate that increases in noise levels over 1.5 dB CNEL within the 65 dB CNEL contour are considered significant (1050.1D Directive

12.21.83) and require additional analysis. The FAA is primarily concerned with the noise impacts that occur at the 65 dB CNEL or greater.

A.5.4. Airport Noise and Capacity Act of 1990

The Airport Noise and Capacity Act of 1990 (PL 101-508, 104 Stat. 1388), also known as ANCA or the Noise Act, established two broad directives for the FAA: (1) establish a method to review aircraft noise, and airport use or access restriction, imposed by airport proprietors, and (2) institute a program to phase-out Stage 2 aircraft over 75,000 pounds by December 31, 1999. Stage 2 aircraft are older, noisier aircraft (e.g., B-737-200, B-727 and DC-9); Stage 3 aircraft are newer, quieter aircraft (e.g., B-737-300, B-757, MD-80/90). To implement ANCA, FAA amended Part 91 to address the phase-out of large Stage 2 aircraft and the phase-in of Stage 3 aircraft. In addition, Part 91 states that all Stage 2 aircraft over 75,000 pounds, were to be removed from the domestic fleet by December 31, 1999. There are a few exceptions, otherwise, only Stage 3 aircraft greater than 75,000 pounds are now in the mainland domestic fleet. Hawaii is exempted from this rule and Stage 2 operations are permitted in this state.

FAR Part 161 was adopted to institute a more stringent review and approval process for implementing use or access restrictions by airport proprietors. Part 161 sets out the requirements and procedures for implementing new airport use and access restrictions by airport proprietors. The procedures use the CNEL metric to measure noise effects, and the Part 150 land use guideline table, which include 65 dB CNEL as the threshold contour to determine compatibility, unless there is a locally adopted standard that is more stringent.

Part 161 identifies three types of use restrictions and treats each one differently: negotiated restrictions, Stage 2 aircraft restrictions and Stage 3 aircraft restrictions. Generally speaking, any use restriction that affects the number or times of aircraft operations will be considered an access restriction. Even though the Part 91 phase-out does not apply to aircraft under 75,000 pounds, FAA has determined that Part 161 limitations on proprietors' authority also apply to smaller aircraft.

Negotiated restrictions are more favorable from the FAA's standpoint but still require complex procedures for approval and implementation. They must be agreed upon by all airlines, and public notice must be given.

Stage 2 restrictions are more difficult, as one of the major reasons for ANCA was to discourage local restrictions more stringent that the ANCA's 1999 phase-out. To comply with the regulation and institute a new Stage 2 restriction, the proprietor must prepare a cost/benefit analysis of the proposed restriction and give proper notice. The cost/benefit analysis is extensive and entails considerable evaluation. Stage 2 restrictions do not require approval by the FAA.

Stage 3 restrictions are especially difficult to implement. A Stage 3 restriction involves considerable additional analysis, justification, evaluation and economic discussion. In addition, a Stage 3 restriction must result in a decrease in noise exposure of the 65 dB CNEL to noise sensitive land uses (residences, schools, churches, parks). The regulation requires both public notice and FAA approval. ANCA applies to all local noise restrictions that are proposed after October 1990 and to amendments to existing restrictions proposed after October 1990.

A.5.5. *Federal Interagency Committee on Noise (FICON) Report of 1992*

The use of the CNEL or DNL metric and the 65 dB CNEL or DNL criteria has been criticized by various interest groups concerning its usefulness in assessing aircraft noise impacts. As a result, at the direction of the EPA and the FAA, FICON was formed to review specific elements of the assessment on airport noise impacts and to recommend procedures for potential improvements. FICON included representatives from the Departments of Transportation, Defense, Justice, Veterans Affairs, Housing and Urban Development, the Environmental Protection Agency, and the Council on Environmental Quality.

The FICON review focused primarily on the manner in which noise impacts are determined, including whether aircraft noise impacts are fundamentally different from other transportation noise impacts, how noise impacts are described, and whether impacts outside of CNEL or DNL 65 decibels (dB) should be reviewed in a National Environmental Policy Act (NEPA) document.

The committee determined there are no new descriptors or metrics of sufficient scientific standing to substitute for the present CNEL or DNL cumulative noise exposure metric. FICON determined that the CNEL or DNL method contains appropriate dose-response relationships to determine the noise impact and is properly used to assess noise impacts at both civil and military airports. The report does support agency discretion in the use of supplemental noise analysis and recommends public understanding of the CNEL or DNL and supplemental methodologies, as well as aircraft noise impacts.

FICON did, however, recommend that if screening analysis shows a 1.5 dB increase within a 65 CNEL or DNL or a 3.0 dB increase within a 60-65 CNEL or DNL, then additional analysis should be conducted.

A.5.6. Environmental Protection Agency Noise Assessment Guidelines

In March 1974 the EPA published "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety" (EPA 550/9-74-004). In this document, 55 DNL is described as the requisite level with an adequate margin of safety for areas with outdoor uses. This includes residences and recreational areas. This document does not constitute EPA regulations or standards. Rather, it is intended to "provide State and Local governments as well as the Federal Government and the private sector with an informational point of departure for the purpose of decision-making." Note that these levels were developed for suburban uses. In some urban settings, the noise levels will be significantly above this level, while in some wilderness settings, the noise levels will be well below this level. While this "levels document" does not constitute a standard specification or regulation, it does identify safe levels of environmental noise exposure without consideration for economic cost for achieving these levels.

A.6. Airport Noise Assessment Methodology

Existing and future aircraft noise environments for airports are typically determined through the use of a computer model. Once reliable computer generated contours are developed for existing conditions, the computer input files are altered to reflect future conditions based on forecasts of future operations and/or proposed noise abatement aircraft operational measures. New computer generated data and contours are then developed to assess those future conditions. The following section provides the details on this process.

A.6.1. Computer Noise Modeling

Computer noise modeling generates maps or tabular data of an airport's noise environment expressed in the various metrics described above, such as CNEL or DNL. Computer models are most useful in developing contours that depict, like elevation contours on a map, areas of equal noise exposure. Accurate noise contours are largely dependent on the use of a reliable, validated, and updated noise model and a collection of accurate aircraft operational data.

The FAA's Integrated Noise Model (INM) models civilian and military aviation operations. The original INM was released in 1977. The INM version 6.2a was released for use in May 2006 and is the state-of-the-art in airport noise modeling. The program includes standard aircraft noise and performance data for over 100 aircraft types, and can be tailored to the characteristics of the airport in question.