

Mitigating Transit Noise Through Urban Planning and Design

by

Michael L. Marrella

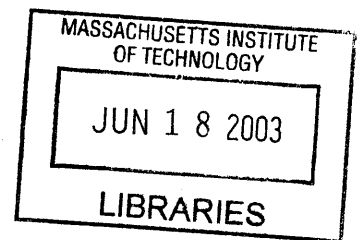
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Michael L. Marrella

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## Abstract

This thesis examines how urban design techniques can be used for path mitigation of transit noise. Noise problems from rail transit systems persist despite the existence of at-source noise reduction techniques for rail transit systems and substantial research on architectural acoustic solutions. Conventional planning literature suggests separating noise sources from residential parcels, a theory now seen as inadequate in dense urban environments. Because noise remains a problem, new techniques should be explored to find alternative means of reducing environmental noise.

By using computer software to model the promulgation of environmental noise from rail transit, the effectiveness of eight urban design techniques were examined. In addition to the preliminary modeling of the eight techniques, four neighborhoods were modeled to examine how noise promulgates through real environments. Additional urban design elements were then added to the model to determine how these urban design techniques can mitigate noise.

This thesis concludes that urban design techniques can be used to mitigate transit noise; however, noise should not be the only consideration when designing the urban environment. Furthermore, the thesis makes recommendations regarding land use policy and transit system management.

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## **Chapter 1. Introduction and Motivation**

The greater purpose of a transit system is to improve the lives of the residents of the metropolitan area. While increased transportation options likely increase the standard of living for local residents, the noise impacts of the system may significantly affect portions of the population living adjacent to the rail lines. Communities adjacent to on-grade or elevated train lines are often subjected to the annoyance of rumbling trains, chattering structures, squealing wheels, and squeaking brakes. In the past 100 years, the fields of noise control engineering and acoustics have found ways of reducing the impacts of noise. Despite this knowledge, noise remains a significant problem in many cities.

### **The Problem of Noise**

Although noise from rail transit may seem a mere annoyance to some residents, the impacts of noise go beyond just annoyance. In fact, noise has been found to influence human health, behavior, and productivity, as well as property values and urban form. Because of the significant detrimental impacts of noise, environmental noise pollution should not be dismissed as a mere annoyance. As William Strunk declared in 1930, “Noise costs money. It lowers efficiency. It causes waste. It shortens life.”<sup>1</sup>

#### *Health*

Although no studies directly examining transit noise and human health were found, the field of environmental health and the study of the impacts of noise are robust. Excessive noise has been found to cause significant health problems such as hearing impairment, interference with speech communication, sleep disturbances, negative impacts on the cardiovascular and other physiological systems, and negative influences on mental health. Yet, while these studies show conclusive evidence of the harmful effects of noise, noise remains a persistent and under-examined problem in many urban environments.

The body’s physiological susceptibility to the negative effects of noise, as with many environmental hazards, differs between long-term exposure and single-event exposure. Most protective noise level standards are derived from observations of general populations. However, several studies have found that several groups, in particular babies, young children and the elderly—are more vulnerable to the impacts of noise than the general population.<sup>2</sup>

#### *Behavior*

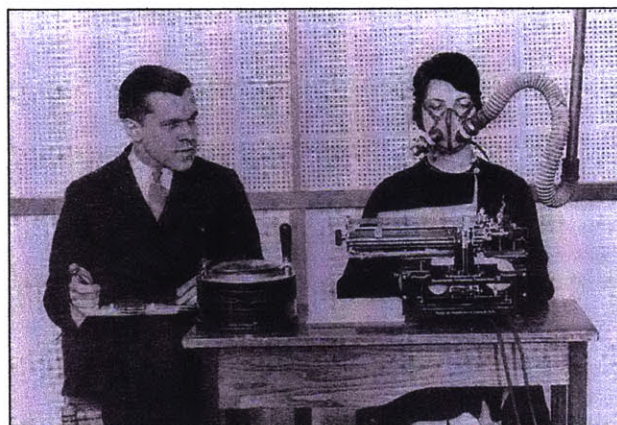
In addition to the health effects of noise, noise has also been found to influence daily behavior. According to the World Health organization report,

Noise can produce a number of social and behavioral effects in residents, besides annoyance. The social and behavioral effects are often complex, subtle and indirect. Many of the effects are assumed to be the result of interactions with a number of non-auditory variables. Social and behavioral effects include changes in overt everyday behavior patterns (e.g. closing windows, not using balconies, turning TV and radio to louder levels, writing petitions, complaining to authorities); adverse changes in social behavior (e.g. aggression, unfriendliness, disengagement, non-participation); adverse changes in social indicators (e.g. residential mobility, hospital admissions, drug consumption, accident rates); and changes in mood (e.g. less happy, more depressed).<sup>3</sup>

### *Productivity*

In addition to human health, excessive noise has been found to influence human productivity. In the late 1920's, a time when America became obsessed with productivity, industrial psychologists studied the effects of noise on workers' productivity. As seen in Figure 1.1, industrial psychologist Donald Laird studies the effects of noise on a clerical worker. In the study, a typist's performance was studied under both noisy and quiet conditions. The experiment found that caloric consumption increased under noisy conditions and the best typists worked about 7 percent faster in a quieter environment. Laird concluded, "noise does impair production."<sup>4</sup>

Many more recent studies have shown the connection between noise levels and human productivity. Noise has been found to adversely affect cognitive task performance, particularly among children. According to the World Health Organization report, "laboratory and workplace studies showed that noise can act as a distracting stimulus," causing decreased productivity.<sup>5</sup>



**Figure 1.1** Photograph of Donald Laird performing study of the influence of noise on human productivity. Image Source: *The Soundscape of Modernity*

### *Property Values*

Perhaps of greater interest to city officials is the relationship between transit noise and real estate values. This relationship has been well explored in many studies but the results are difficult to assess. Though there is clearly a relationship between property values and transportation systems that serve those properties, determining the exact relationship between the two is very difficult.

Numerous studies have shown that increased transportation options increases the value of those properties served by the transportation system.<sup>6</sup> However, few studies have conclusively found the financial impact of noise generated by these transportation systems. The lack of a

conclusive answer is due largely to combination of numerous factors that are difficult to parse. While proximity to transit increases property values due to increased mobility, rail transit may simultaneously lower property values because rail lines impose noise and other nuisances on neighborhoods.<sup>7</sup>

The relationship between noise and property values is difficult to explain. In Chicago, some of the most desirable neighborhoods are located on the north side of the city, such as Lincoln Park, a neighborhood served by the noisy elevated Red and Brown lines. The presence of multi-million dollar town homes adjacent to the rail line suggests that, in this location, noise does not significantly influence property values. In order to demonstrate that conclusively, one would have to show that similar properties located one block away from the rail line are not of greater value. Though noise can not explain why some neighborhoods are coveted while others are left abandoned, noise likely influenced real estate values within those neighborhoods.

### *Urban Form*

As real estate values are influenced by noise from transportation systems, the physical form of cities has been altered by the presence of noisy transportation systems. Chicago's downtown loop provides an interesting example of the connection between urban form and noise from the transit system.

As illustrated in Figure 1.2, twelve at-grade or above grade parking lots and structures exist on Wells Street, on which the "El" runs. As a result, blank garage walls dominate the street, as seen in Figure 1.3. Perhaps the clearest example of the El's influence on the urban form is the Sears Tower site. The Sears Tower, the tallest building in America was constructed one block away from the El. The block between the El and the Tower is consumed by an associated four story parking structure. The parking structure does little to contribute to street life, as seen in Figure 1.4. While it is unclear if the parking structures on Wells Street are a direct result of the noise or any number of other factors including the visible impact of the El, noise clearly plays into the form of the streetscape. Additionally, zoning regulations clearly influenced the design of the developments on Wells Street. However, zoning regulations (or city planners) that encouraged parking garages adjacent to the El do so because of the belief that the El is not a pleasant neighbor and that other uses do not belong adjacent to it. Ironically, the El was one of



**Figure 1.2** The influence of noise on urban design. The location of at-grade parking lots and parking structures are illustrated on this map with red marks. The dashed line represents the elevated rail line. Source: Author



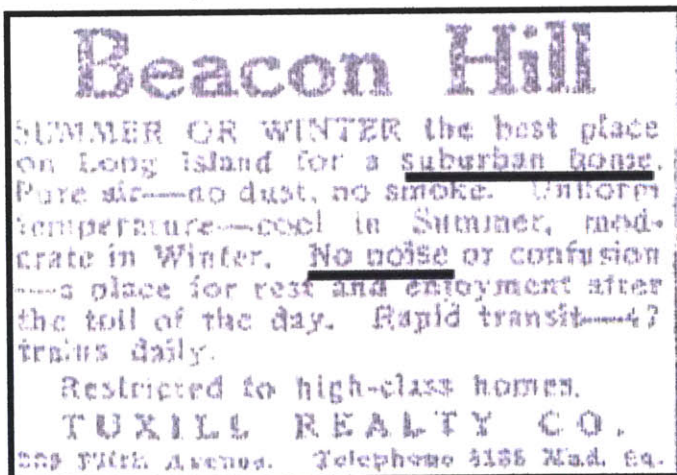
**Figure 1.3** Parking structures lining the street adjacent to the El. Source: Author



**Figure 1.4** The Sears Tower parking structure adjacent to the El.  
Source: Author



**Figure 1.5** Vacant land adjacent to the El.  
Source: Jordan Karp



**Figure 1.6** An advertisement of early suburban development citing “no noise”.  
Source: *The New York Times*

the reasons that Chicago’s downtown loop became the financial center of the Midwest in the early 1900’s and yet the El is also the reason why so much of the streetscape of Wells Street is now dominated by parking garages.

The El’s impact on property values can be seen on Chicago’s South Side, one of the poorest areas in the city. Though the north side of Chicago has become increasingly affluent, little investment has occurred in the south side. Today, large tracts of vacant land directly adjacent to the rail line remain undeveloped, as seen in Figure 1.5. The lack of development of the parcels adjacent to the El suggests that noise has influenced the physical form of the city.

In addition to the changing form of the city itself, the rise of the suburbs was, in part, a reaction to the noise of the city. In an attempt to escape the noisy city, residents who could afford it moved to the tranquility of the suburbs. In fact, as seen in Figure 1.6, advertisements for the early suburban communities invited city residents to enjoy the “peace and quiet” of the new developments. Of course, noise was not the only factor attributed the rise of the suburbs but noise was one factor that contributed to the rise of the suburbs, but it surely is one of the reasons for it. While it is not the topic of this paper, it is interesting to note that the rise of the suburbs directly contributed to another transportation noise nuisance, the U.S.



Interstate Highway System.

Despite all of the evidence on the harmful impacts of noise, many urban residents live and work under detrimental conditions.

### Noise Control History

The noise generated from trains rolling over at-grade or elevated rail lines has long been a thorny issue in urban history. In New York City, the first noise complaints were received in 1873, shortly after the transit system began operating.<sup>8</sup> A 1929 poll in New York reported that, according to residents, ten of the most troubling noises were products of the “machine-age inventions” including rail transit.<sup>9</sup> In 1930, the Noise Abatement Commission of New York City was formed to study the noises of the city and made recommendations to curb the excessive noise. The cover page of their report cited subway and elevated transit cars as one of the sources of noise in the city, as illustrated in Figure 1.7. The Commission efforts were noble but “without much success.”<sup>10</sup> In 1931, sound engineers from AT&T were hired to study the noise of the New York City subway system.

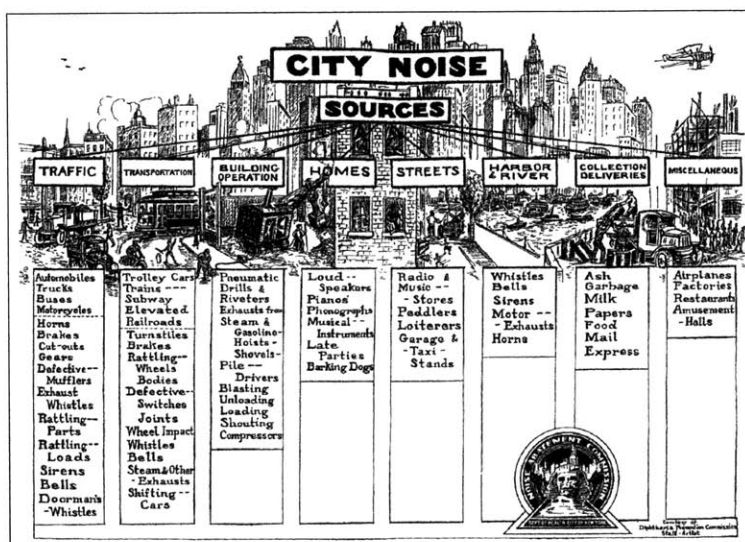


Figure 1.7 The cover image of the 1930 New York City Noise Commission Report identifying rail transit as a source of the noise problem. Source: *The Soundscape of Modernity*

As noise became a hot topic in the City, city planning, and the recently created tool of zoning, began to mature. The New York City zoning law was first established in 1916 and attempted to control development. The 1926 U.S. Supreme Court decision in *Euclid v. Ambler* upheld a municipality’s power to use zoning to control development, strengthening a city’s power over development.<sup>11</sup> This tool was used as a means of separating noisy uses from residents. As described by historian Emily Thompson:

Another strategy in the war against noise was to create special zones of quiet in particular areas of the city. Zoning in general was an attempt to legislate the landscape of urban life, to control not only its physical appearance but also the behavior of those who inhabited it. By geographically separating the different social functions that unplanned cities naturally superimposed—residential, commercial, industrials—city planners sought to rationalize the urban environment in a way that would improve the performance of each sector. The numerous “City Beautiful” movements of the late nineteenth and twentieth

centuries additionally sought to enhance the aesthetic appeal of the urban environment. By combining the morally improving qualities of art with the rationalizing order of science, proponents of these movements presented their work as a powerful ‘antidote to urban moral decay and social disorder.’<sup>12</sup>

In addition to the City’s efforts to control noise, the first half of the twentieth century marked a time when the science and technology of architectural acoustics transformed “the buildings themselves from problem to solution.”<sup>13</sup> Cass Gilbert’s New York Life Insurance Company Building constructed in 1929 on Madison Avenue in New York City was the first building to be designed with soundproofing as a design goal and used newly designed materials to control noise. Though the façade of the building evoked the Gothic past, as seen in Figure 1.8, the architectural acoustics were state-of-the-art. By 1930, dozens of architectural products were

manufactured with the express intention of reducing unwanted noise.<sup>14</sup>



**Figure 1.8** The New York Life Insurance Building, one of the first buildings to be designed with noise insulation as a goal.  
Source: *The Soundscape of Modernity*

Despite all of these efforts to control noise, little has changed since the early 1930s. The efforts of groups like the New York City Noise Commission, and today’s handful of non-profit groups dedicated to making the world quieter, remain unable to produce a quieter city. Zoning has proved effective in separating industrial uses from residents but has little control over other noise sources such as roads and rails. Architectural acoustics remains focused on protecting the interior spaces of a building and pays little attention to exterior spaces. Furthermore, architectural acoustics remain limited to those buildings that can afford improved acoustics.

## **Purpose of Research**

Despite all of these efforts to control urban noise, today’s city residents are forced to live with the daily annoyance of loud noises. The purpose of this research is to find new means of controlling noise in the city, particularly minimizing the impacts of noise from rail transit, and to explore the relationship between urban design and noise.

### *New Understanding of Noise and Urban Design*

The study of architectural acoustics has introduced the idea of aural aesthetics in a field once dominated by visual aesthetics. However, architectural acoustics remains focused on interior acoustics and fails to address the sounds of spaces between buildings. Far too often, the practice of urban design is dominated by visual aesthetics. When evaluating a site plan

or completed project, designers discuss the visual qualities, largely ignoring other sensory perceptions. In particular, urban designers rarely discuss issues concerning noise in the urban environment, yet acoustics greatly affect our perceptions of an environment and should be considered during the design process. Through computer-based modeling, noise impacts can be visualized. The visualization of noise provides urban designers with a useful tool to understand a sensory perception rarely considered during the design process. Such an approach provides an opportunity for improved design and ultimately an improved physical environment.

### *Provide Direction to the Chicago Transit Authority and Tren Urbano*

As part of an ongoing research project with the Chicago Transit Authority (CTA) and Tren Urbano in San Juan, Puerto Rico, this study was conducted to provide technical assistance to the two agencies, each faced with different problems related to noise.

In Chicago, the Chicago Transit Authority system provides daily transportation for 1.5 million residents. A large portion of the CTA rail rapid transit system operates on an old, lightweight steel elevated guideway, originally built over 100 years ago. In sharp contrast, the Tren Urbano system is still under construction and is expected to enter revenue service in September 2003. The first phase of the Tren Urbano system is approximately 12 miles in length and portions of the alignment are at-grade, open-cut, tunnel and on an elevated concrete guideway.

This thesis examines how these two transit agencies can use their resources to reduce the impacts of noise associated with their operations through at-source noise reduction techniques and through influencing the form of development that occurs adjacent to their alignments.

### **Motivation**

Noise remains a problem in many urban areas, despite knowledge of its harm and many efforts to control it. This thesis attempts to find new solutions and strategies to control noise from transit systems through the use of urban planning and design.

Transit system noise and the regulations that have attempted to mitigate the noise have fostered poor urban design and undesirable land use patterns. In many cities, through market forces or regulations, low-density industrial uses and parking lots have traditionally been placed adjacent to transit systems. Regulations placed on the transit systems themselves have resulted in little change. As a result, the impacts of transit noise are mitigated through other regulatory mechanisms, including zoning, building codes, and funding regulations. Often, zoning regulations attempted to fix the noise problem by keeping sensitive uses, such as residential and educational, far away from the source of the noise. Similarly, local and federal building codes often restrict maximum decibel levels within the home, forcing residences away from

transit systems, a goal now understood to be in contradiction to the idea of “transit-friendly” communities. Motivated by the poor urban design and land use patterns that resulted from transit noise and the fractured regulatory regime that attempted to mitigate the noise, this thesis attempts to show that transit noise impacts can be reduced through improved design of the urban landscape.

Transit-Oriented Development, often seen as an environmentally supportive solution, increases densities adjacent to transit, potentially subjecting a greater population to the adverse impacts associated with transit. Much has been written about the need to increase Transit-Oriented Development along Tren Urbano, yet little has been written about specifically addressing noise impacts on adjacent communities caused by the transit system. For Tren Urbano, the new developments should take advantage of the increased transportation options while limiting negative impacts of transit noise. In contrast, the CTA’s challenge is retrofitting the existing urban fabric to decrease transit noise impacts while improving the quality of life of those living and working near the transit system.

While much has been written about transit noise abatement through the maintenance of vehicles and tracks, few articles or books have been written since the 1960s about noise mitigation through planning techniques. The theories proposed prior to the 1960s suggest that “noise-sensitive land uses” such as residences and schools should be placed far from noise generating uses such as transit systems. This older approach to planning is far different from today’s planning ideology of Transit-Oriented Development that encourages higher densities clustered near transit stations. My research intends to reconcile the divergent goals of reducing the impact of transit noise and increasing densities near transit stations by proving that transit noise can be mitigated through landscape architecture, urban design, planning, and architecture.

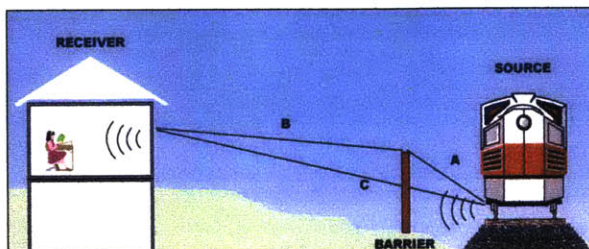
## **The Basics of Acoustics**

Prior to discussing the findings of this research, it is necessary to explain the fundamentals of acoustics. To aid in understanding the following chapters of this thesis, this section presents basic acoustical concepts. Though we all experience noise, many people are unfamiliar with the basic principles of the physics of acoustics.

While sound and noise are closely related and often incorrectly used interchangeably, their precise definitions are important. Sound is the energy produced by a vibrating object or surface and transmitted as a wave through an elastic medium. Noise is unwanted or annoying sound. Sound is typically measured in decibels, a measurement based on the logarithm of the sound pressure levels. Normal human hearing has a minimum threshold of 0 dB and a maximum threshold of pain of 130 dB. In addition to sound levels, frequency of sound is also an important component. Frequency is the time rate that a wave of sound repeats itself measured in cycles per

second or Hertz, abbreviated Hz. Human hearing can typically perceive sounds between 16 Hz and 20,000 Hz. Human speech ranges between 125 Hz and 8,000 Hz. Rail transit emits a vast range of noise from low frequency rumbles to high pitched wheel-rail squeals, a range beyond human perception.

With every noise problem, there are three components that must be considered when finding a solution: the source, the path, and the receiver. As illustrated in Figure 1.9, the source is the point at which the noise is generated. The path is the physical space between the source and the receiver. The receiver is the person or place by which the noise is heard or recorded. The impacts of noise generated by transit systems can be reduced through at-source mitigation, through path attenuation, or by receiver isolation.



**Figure 1.9** Illustration of Source-Path-Receiver Concept.  
Source: *City of Cleveland Home Sound Insulation and Noise Barrier Program*

### **Definitions<sup>15</sup>**

*A-weighted sound level, dB(A)*: a measure of sound pressure level designed to reflect the acuity of the human ear, which does not respond equally to all frequencies. The ear is less efficient at low and high frequencies than at medium or speech-range frequencies. Therefore, to describe a sound containing a wide range of frequencies in a manner representative of the ear's response, it is necessary to reduce the effects of the low and high frequencies with respect to the medium frequencies.

*Absorption coefficient*: the fraction of noise that not transmitted through a barrier.

*Barrier*: a solid obstruction placed between the source and receiver with the specific intent of reducing the noise levels at the receiver.

*Barrier insertion loss*: the difference in the sound level at a particular location with and without a noise barrier.

*Contour*: the physical area in an environment in which the noise level is the same.

*Decibel, dB*: a unit of measurement on a logarithmic scale that describes the magnitude of a particular quantity of sound pressure or power with respect to a standard reference value.

*Environmental Noise*: unwanted sound occurring outdoors.

*Façade treatment*: the improved architectural design of a building's exterior to insulate the interior of the building from environmental noise.

*Frequency*, (Hz): the number of times per second that the sine wave of sound repeats itself, or that the sine wave of a vibrating object repeats itself.

*Line source*: a noise source in which the entire length of the line simultaneously generates noise. The wheel-rail interface on a rail transit system is general considered a line source. A line source noise typically drops roughly 3 dB per every doubling of distance.

*Loudness*: the subjective judgment of intensity of a sound by human beings. Loudness depends upon the sound pressure and frequency of the stimulus. A threefold increase in sound pressure (a tenfold increase in acoustical energy, or, 10 dB) is said to produce a doubling of loudness.

*Noise*: any undesirable sound that interferes with speech and hearing, or is otherwise perceived as annoying.

*Noise attenuation*: the reduction of a noise level from a source by such means as distance, ground effects, or shielding.

*Noise levels*: the measurement of noise over a determined interval or location.

*Day-night noise level, L<sub>dn</sub>*: the A-weighted acoustical energy during a 24 hour period with the nighttime levels between 10 PM and 7AM weighted by 10 dB.

*Maximum noise level, L<sub>max</sub>*: the maximum single noise level emitted over a given period of time.

*Noise equivalent level, L<sub>eq</sub>*: the constant sound level that, in a given time period, would convey the same sound energy as the actual time-varying A-weighted sound level.

*Noise modeling*: the computer simulation of noise production and propagation in a given environment.

*Noise reduction coefficient*: a measure of the acoustical absorption performance of a material, calculated by averaging its sound absorption coefficients at 250, 500, 1000 and 2000 Hz, expressed to the nearest multiple of 0.05.

*Path*: the physical space noise waves travel through from the source to a receiver.

*Point source*: a sound source that generates and emits sound from a single, stationary point. The noise level from point sources drop 6 dB(A) per every doubling of distance from the source.

*Receiver*: the individual or location at which a noise source is heard or recorded.

*Shielding*: the attenuation of a sound by placing walls, buildings, or other barriers between a sound source and the receiver.

*Sound*: energy produced by a vibrating object or surface and transmitted as a wave through an elastic medium.

*Sound pressure*: the minute fluctuations in atmospheric pressure that accompany the passage of a sound wave.

*Sound shadow*: the area behind a barrier in which a receiver cannot see the sound source. Sound levels within a sound shadow are often only reduced and not completely eliminated because of diffraction effects over the top and sides of the barrier.

*Wayside noise levels*: The noise levels measured on the horizontal plane perpendicular to a rail track.

## **Organization of This Thesis**

The following chapters of this thesis are organized as follows:

### *Chapter 2. At-Source Noise Reduction Techniques*

This chapter will discuss the previous writing and research related to the sub-topics of transit-related noise and mitigation techniques, including previous studies of transit systems which successfully reduced noise impacts through at-source maintenance or design of the transit system.

### *Chapter 3. Previous Efforts to Reduce the Impacts of Noise through Planning and Urban Design Techniques*

This chapter will discuss the literature on noise mitigation through urban planning, urban design, landscape architecture, and architecture, making reference to studies showing the environmental impacts of such mitigation techniques.

### *Chapter 4. Analyzing Urban Design Techniques to Reduce the Impacts of Noise through the Use of Environmental Noise Modeling Software.*

In this chapter I discuss my research design including the methods I used to collect the data and the methods used to model the promulgation of noise using CADNA. These design techniques included the location, orientation, height, and scale of buildings, and the placement and design of streets, plazas, berms, and walls. This chapter discusses the results of the modeling and displays the various images produced by the modeling. In this chapter, I analyze the results of the modeling in terms of the effectiveness of each of the design techniques. This chapter also discusses the validity of the modeling technique used.

### *Chapter 5. Application of Urban Design Techniques to Specific Sites*

In this chapter, I examine how the techniques explored in Chapter 4 can be applied to specific sites along the Tren Urbano and Chicago Transit Authority systems. This analysis includes the computer modeling of the sites and noise reduction techniques and examines the implications of urban design at these specific sites.

### *Chapter 6. Conclusions and Recommendations*

This chapter provides a discussion of the problems of the single-minded goal of mitigating noise impacts. Modeling will not necessarily evaluate other objectives of urban design such as sense of scale, pedestrian-friendly design, aesthetics, and other matters of social importance. My conclusion addresses the need to consider noise as only one objective of design. In this chapter, I discuss how my findings could be applied to the Tren Urbano and Chicago Transit Authority for both new development and the rehabilitation or redevelopment of existing neighborhoods adjacent to the transit systems. These recommendations include new land use planning and urban design regulations to mitigate noise impacts and improved at-source techniques for reducing noise at the source.

#### **Endnotes**

<sup>1</sup> Emily Thompson, "The Soundscape of Modernity, Architectural Acoustics and the Culture of Listening in America, 1900-1933," MIT Press (2002) p. 157.

<sup>2</sup> World Health Organization, "Adverse Health Effects of Noise." p. 53

<sup>3</sup> World Health Organization, p. 53



<sup>4</sup> Thompson, 2002, p. 156.

<sup>5</sup> World Health Organization, p. 49.

<sup>6</sup> Parsons Brinkerhoff “The Effect of Rail Transit on Property Values: A Summary of Studies,” 2001

<sup>7</sup> Nelson, A.C., S.J. McCleskey, “Improving the Effects of Elevated Transit Stations on Neighborhoods,”  
Transportation Research Record, 1990 (1266) p. 173-180.

<sup>8</sup> Bronzaft, 1993

<sup>9</sup> Thompson, 2002, p. 117.

<sup>10</sup> Thompson, 2002, p. 170.

<sup>11</sup> Village of Euclid v. Ambler Realty Co. 272 U.S. 365 (1926).

<sup>12</sup> Thompson, 2002, p. 125.

<sup>13</sup> Thompson, 2002, p. 170.

<sup>14</sup> Thompson, 2002, p. 190.

<sup>15</sup> The definitions used in this glossary are a synthesis of several sources including class notes from Carl Rosenberg’s Architectural Acoustics class and several other sources cited through the paper.

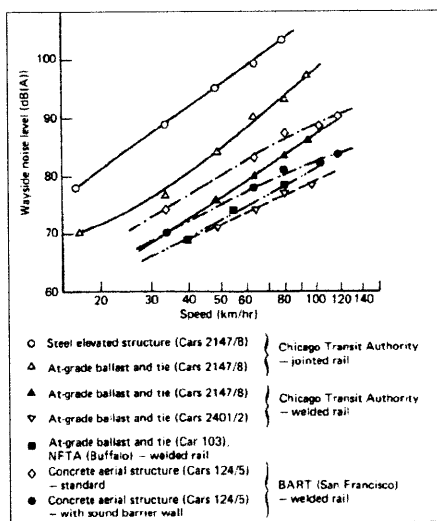
## Chapter 2. At-Source Noise Reduction Techniques

The impacts of rapid rail transit noise can be reduced by at-source reduction, path-mitigation, and receiver insulation. Prior to understanding the effectiveness of the path-mitigation techniques that will be the central focus of this thesis, it is necessary to understand the causes of noise associated with rail transit systems, as well as the effectiveness of reducing noise through at-source techniques and near-source barriers. This chapter examines previous literature on rapid rail transit noise generation and efforts undertaken to reduce the impacts of noise by reducing the production of noise at-source. Furthermore, this chapter will investigate near-source noise mitigation techniques.

### Sources of Noise

In the *Transportation Noise Reference Book*, a comprehensive source on transit related noise, the authors identify four sources of noise from rail operations:

1. Wheel and rail interface, the noise radiated directly from the vibrating wheels and rails,
2. The propulsion equipment, including the traction motors, cooling fans, and reduction gears,
3. The auxiliary equipment, including compressors, motor generators, brake, and ventilation systems, and
4. Noise generated by the vibration of the supporting structure, the “noise radiated by the vibration of the transit structure components that are excited by a train pass-by.”<sup>1</sup>



**Figure 2.1** The relationship between speed, noise level and system design  
Source: *Transportation Noise Reference Book*

System design—the various elements that comprise the design of the transit system—directly influences noise generated by the system. As apparent in Figure 2.1, noise levels are related to physical design of the system. Material of elevated structures, speed of the train, the presence of ballast, and type of rail joints all influence the noise level. However, it is important to note that this graph does not specifically address the relationship between noise levels and the maintenance of rail and wheel stock or the maintenance of the structure.

The authors of the *Transportation Reference Book* state how, under specific conditions, the different sources of noise can dominate noise levels. At low speeds, the auxiliary

equipment is predominant while at higher speeds the wheel rail noise, propulsion equipment, and elevated structure noise typically become more significant. In particular, “for older systems with light-weight steel elevated structures, the structure noise can predominate at all speeds above 15 km/h.”<sup>2</sup> Propulsion noise is “likely to be dominated by wheel/rail noise at speeds above about 30 km/h” for electric-powered rail systems.<sup>3</sup> but electric powered vehicles, like those used by Tren Urbano and the Chicago Transit Authority, do not have loud on-board propulsion equipment as compared to diesel locomotives.

### *Wheel/rail Interface*

Of the four sources of noise identified in the *Transportation Noise Reference Book*, noise generated by the wheel/rail interface has been among the most-studied phenomenon and yet remains problematic on many rail systems. According to the *Transportation Noise Reference Book*, of the multiple noise sources “wheel/rail noise is most common and most often dominant on the railway. It is also the source that is the most abiding problem in railway acoustics.”<sup>4</sup>

Wheel/rail interface noise is usually a result of deficiencies in the wheel, deficiencies in the track, and/or the rubbing of the steel wheel and rail. Each of these causes of noise can produce a different sound, in both pitch and loudness. It is important to note that this interface between the wheel and rail generates the vibration that exhibits itself in the noise from the structure and the vibration that is radiated through the ground to rattle secondary structures creating additional noise. As described in a study of noise on the Chicago Transit Authority system, researchers described deficiencies in the wheel as producing a “thump,” deficiencies in the track as a “roar,” and the rubbing of the wheel and rail as a “squeal.”<sup>5</sup>

The National Transit Institute at the Alan Voorhees Transportation Center at Rutgers University produced a report on the common causes of transit noise and identified three sources of noise and vibration caused by defects in the rail. Two common flaws in rail systems are related to the connections of rail segments. The flaws are gaps in the track joint and running surface misalignment. Gaps in the track joint are connections between two rails at which the adjacent tracks are separated by horizontal distance but are at equal running surface elevations. Similarly, running surface misalignment occurs where the track joints are not flush and one rail is elevated higher than the adjacent rail. Corrugations in the running surface are sections of rail in which the rail itself is ridged. These three track flaws are graphically illustrated in Figure 2.2. The study identifies wheel flats as a common deficiency in the wheel, as illustrated in Figure 2.3.

In 1997, under contract with the Transit Cooperative Research Board, acoustic consultants Wilson, Ihrig, and Associates, Inc. produced the *Wheel/Rail Noise Control Manual*, a report on the specific sources of noise generated at the wheel/rail interface and techniques to reduce the occurrence of wheel/rail interface noise. In this report, the components of wheel/rail

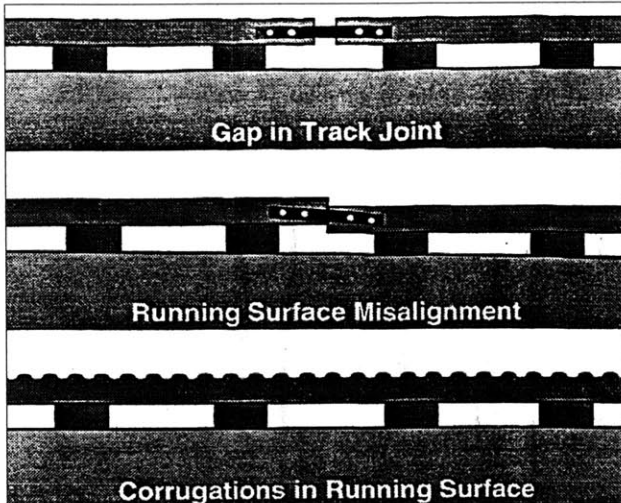


Figure 2.2 Illustration of common rail defects  
Source: *Transit Noise and Vibration Assessment*

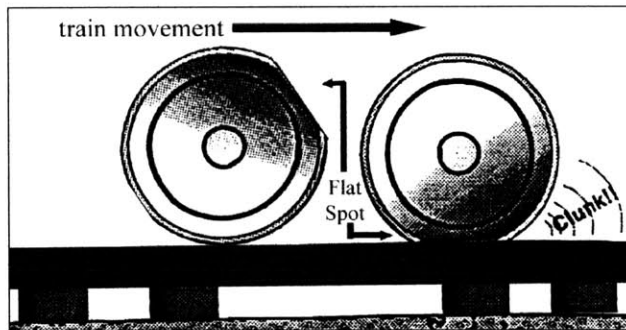


Figure 2.3 Illustration of wheel flat  
Source: *Transit Noise and Vibration Assessment*

interface noise are broken into two categories, tangent track noise and curving noise.

Tangent track noise, the noise generated when the train is traveling along a straightaway, can be caused by a number of different factors. According to the report, four generating mechanisms are sources of normal rolling noise: wheel and rail roughness, parameter variation, creep, and aerodynamic noise.

The report states “wheel/rail surface roughness is believed to be the most significant cause of wheel/rail noise.”<sup>6</sup> Wheel/rail surface roughness includes level and decreasing elevation rail joints, corrugated rail noise, and wheel flats, as illustrated in Figure 2.2 and Figure 2.3. The study provides mathematical equations to approximate the relationship between the size of defects and the corresponding change in amplitude and frequency. Though not discussed in the report, evidence suggests that rail switches, crossings,

and traction power block isolators all have gaps and are sources of misalignment of segments of rail, causing a thumping noise.<sup>7</sup>

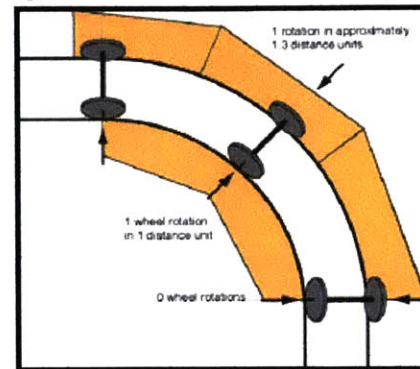
According to the study, “parameter variation refers to variation of rail and wheel steel moduli, rail support stiffness, and contact stiffness due to variation in the rail head transverse radius-of-curvature”—that is to say parameter variation is noise generated by the interaction of the wheel and rail caused by the differences in the shape of the wheel and the shape of the rail.<sup>8</sup> The study suggests several equations explaining the interaction between the shape of the rail and the shape of the wheel.

Dynamic creep occurs when the wheel slips on the rail. This can occur as longitudinal dynamic creep, lateral dynamic creep, roll-slip and spin-creep. Creep refers to any instance when the wheel slips on the rail.

Aerodynamic noise at the wheels, though largely considered insignificant at the speeds representative of most transit systems, is caused by the fluctuation of air between the wheel circumference and the under car components. This phenomenon differs from noise due to

air turbulence in the truck area, which may be significant at higher speeds. Noise generated by turbulence about the wheel in rail transit systems has been little studied but “has been anecdotally suggested as responsible for abnormally high noise levels after rail grinding at Tri-Met” when one would anticipate reduced noise levels.<sup>9</sup>

Curving noise—the noises caused as the train travels through a curved section of track, often a high-pitched squeal—is perceived to be among the most annoying of the sounds produced by a rail transit system. Similar to tangent track noise, dynamic creep is a significant source of noise along curved segments of rail alignments. Dynamic creep and wheel squeal are due to the difference in circumferences of outer and inner rails along a curve. On curves, the outer wheel has a greater distance to travel relative to the inner wheel. Unlike the drive wheels of trucks and automobiles which have differential axels, transit systems have fixed axels, causing the wheels to turn at the same rotational speed. When rounding the curve, the difference in distance traveled by the wheels causes one or both of a pair of wheels to slip along the rail, resulting a high-pitched squeal. Wheel squeal caused by curvature of the alignment is illustrated in Figure 2.4. As described by Wilson, Ihrig and Associates in a study of rail and wheel dampeners, “Wheel squeal is produced primarily by lateral slip of the steel tire across the rail head during curve negotiation.”<sup>10</sup>



**Figure 2.2** Diagram Illustrating the source of wheel squeal at a certain diameter. Source: *Noise Considerations on the Chicago Transit Authority's Elevated System*

### **Propulsion and Auxiliary Equipment**

Though propulsion noise is largely obscured by wheel/rail noise on rapid rail transit systems, the propulsion equipment can be a significant source of noise at slower speeds and when stopped at stations. Similar to noise generated by propulsion equipment, most noise generated by auxiliary equipment is often obscured by the noise generated by the wheel/rail interface. However, under certain circumstances, the noise generated by auxiliary equipment can be considered annoying. The auxiliary equipment includes braking mechanisms, ventilation and air conditioning equipment, announcement speaker systems, chimes, and warning and emergency bells and whistles. Train whistles used to notify oncoming automobile traffic at at-grade crossings is a significant issue along some rail transit systems, particularly commuter rail systems with frequent at-grade crossings. Along a small portion of the Chicago Transit Authority system, the trains run through several at-grade intersections and must use their whistle to alert on-coming cars. On the Tren Urbano alignment, no at-grade intersections are present and the whistle is likely to remain largely unused.

Though largely undocumented in transportation acoustics literature, announcement speaker systems are a source of complaints to transit agencies by abutters, according to anecdotal accounts. According to Jack Hruby of the Chicago Transit Authority, residents living near the stations have called the agency complaining about open-air platform station-stop announcements.<sup>11</sup> However, eliminating platform announcements is not possible because the Americans with Disabilities Act calls for platform announcements to be made to aid people with visual disabilities.

### **Elevated Structure Noise**

Older rail transit systems running on lightweight aerial structures are among the loudest of all rail systems, according to the *Transportation Noise Reference Book*. In an article on transit noise abatement in *Railway Track and Structure*, the author wrote, “The noise radiated from lightweight steel elevated structures is a major problem in many cities with older transit systems. The vibration of the rails transmits downward through the elevated structure, turning it into a large ‘sounding board.’”<sup>12</sup> According to the *Transportation Noise Reference Book*,

Aerial structures can be divided into two broad classes—lightweight steel elevated structures and those of higher mass construction. Train operation on lightweight steel structures creates one of the most severe environmental problems facing transit systems. The rail tie and support structure acts as a large sounding board with potentially very high noise levels radiated to the wayside community and into transit cars. The second category of aerial structures are constructed of higher mass materials such as concrete or concrete/steel composites. These structures typically have ballasted track beds or concrete decks with resilient rail fasteners. With appropriate noise control treatments, these structures can be placed even in noise-sensitive residential areas without adverse noise impact.<sup>13</sup>

Noise from an elevated structure is caused by the vibration induced as a train passes over the rail. The vibrations are passed from the wheel rail interface to the ties and finally to the elevated structure itself.

A 1974 study of the elevated transit lines in Boston, performed by the Acoustics and Vibration Laboratory at Massachusetts Institute of Technology, revealed that even among the lightweight steel elevated structures, variables in the construction of structures slightly influenced measured noise levels but the differences were generally less than what would be perceptible by the human ear. The authors state, “In comparing the various elevated structure types, the A-weighted values at comparable speeds are approximately equal for open girder, riveted plate and supported I-beam construction.”<sup>14</sup> The results from the study also report that trains traveling at 35 miles per hour over elevated structures were approximately 12 dBA louder than the same trains traveling the same speed at-grade.<sup>15</sup>

## **At-Source Reduction Techniques**

Given the incredible number of sources of noise along a rapid rail transit system, reducing the noise at-source is a difficult challenge. However, many techniques have been successfully devised to reduce the generation of noise. Because initial structural design of the rail system plays heavily into the noise levels produced by the rail system, significant noise reduction on older elevated systems often requires massive, expensive infrastructure improvements. However, several older systems have reduced noise levels through less expensive means.

As stated in the Transportation Noise Reference Book, the reduction of noise from transit systems “is achievable in two conceptually different ways: 1. By reducing the wheel-rail interaction forces. 2. By attenuating the propagation of vibrations” which decreases the production of structural noise.<sup>16</sup> Transit operators generally implement both concepts in an attempt to limit the production and impacts of noise. Rail transit operators have devised several means of reducing the production of noise. These techniques include:

1. The removal of wheel surface irregularities by wheel truing,
2. Reduction of the incidence of wheel surface irregularities by preventing or minimizing wheel flat generation through slip/slide breaking and acceleration control, lubrication, wheel mechanical properties, or composition treads brakes or disc brakes,
3. Detection of wheel surface irregularities through technical analysis that allows for more efficient maintenance practices,
4. Use of wheel or rail lubrication to reduce steel to steel contact—allowing slip without generating squeal,
5. Rail grinding to remove imperfections of rail surface,
6. Rail welding/rail alignment to reduce the severity of rail joint impacts,
7. Reduced primary suspension stiffness to limit the vibration-induced structural noise,
8. Resilient wheels to reduce the vibration passed from the vehicle to the rail,
9. Resiliently supported ties to absorb vibration passed through the rail,
10. Resilient rail fasteners to isolate the vibration induced from a passing train,
11. Floating slabs to absorb the vibration passed through the wheels, rails and ties,
12. Ballast mats to reduce groundborne noise and vibration, and
13. Reduced train speed.

### *Effectiveness of At-Source Reduction Techniques.*

In the Transportation Noise Reference Book, the authors examine several rail transit authorities to study the effectiveness of various noise reduction and mitigation techniques. In a follow-up report to the 1997 “Wheel Rail Noise Control Manual,” Wilson, Ihrig, and Associates, Inc. documented the effectiveness of new and emerging technologies to reduce wheel/rail noise

on the New Jersey Transit Corporation's subway system in Newark, New Jersey and the Tri-County Metropolitan Transportation District of Oregon (Tri-Met) Several transit authorities have conducted their own studies, as well. Below is a summary of the findings from those case studies.

#### *Southeastern Pennsylvania Transportation Authority (SEPTA)*

On tests on the rapid transit system of the Southeastern Pennsylvania Transportation Authority, truing of the wheels in normal service condition (without noticeable wheel flats) resulted in a decrease of 5-10 dB for frequencies above 100 Hz, but with little or no reduction for frequencies below 100 Hz.<sup>17</sup>

SEPTA has also explored special wheel treatments to reduce noise including testing of a number of different types of resilient wheels. Though the resilient wheels offered slight reduction of noise levels (0-2 dB) along tangent track, the wheels offered significant reduction along curved track (3-10 dB.) However, all three wheel types tested were damaged due to overheating, suggesting that resilient wheels may be too fragile for use on a rapid transit system with tread brakes.<sup>18</sup>

#### *New York City Transit Authority (NYC MTA)*

To retrofit existing vehicles with a simplified version of slip/slide control to prevent or minimize wheel flat generation, the NYC MTA employed a traction fault detector on some cars. The NYC MTA reported a 50% reduction in the number of wheel flat occurrences on cars equipped with the traction fault detector.<sup>19</sup>

In 1978, NYC MTA conducted a pilot study on the effectiveness of replacing the existing rail fastening system (steel tie plates spiked to wood ties) with resilient rail fasteners. Prior to the study, the existing elevated rail was generally 10 dB louder than comparable at-grade track. The study found that with the resilient rail fasteners, noise levels were lowered 3-6 dB at lower speeds. At speeds greater than 25 mph, the reductions achieved were negligible.<sup>20</sup>

Studies from NYC MTA on rail welding indicate that welded rails can offer a reduction of noise levels, but the extent of that reduction is largely dependent on the condition of the cars passing over the rail. For older cars, a welded rail provided a reduction of 1.5 dB(A) and newer cars averaged a noise reduction of nearly 3 db(A).<sup>21</sup>

In another study by NYC MTA, several models of dampened wheels were tested. The study found that the dampened wheels provided an average noise reduction of 5-8 dB(A)<sup>22</sup>

#### *Toronto Transit Commission (TTC)*

The Toronto Transit Commission developed a system to detect wheel flats and excessive roughness to aid in determining which wheels are in need of maintenance. "The TTC system



employs an accelerameter to measure the vibration on the subway tunnel invert as each train passes. The output from the accelerometer signal is transmitted via telephone lines to a carhouse where it is displayed on a graphic level recorder. Wheels, or at least trucks, that cause high vibration levels are clearly identified.”<sup>23</sup>

#### *Chicago Transit Authority (CTA)*

When designing a new series of cars, the 2400 series, the CTA introduced a softer primary suspension system that reduced ground vibration levels by 10-20 dB near at-grade track by compared to the older cars. Though this test was not conducted on the elevated track, it is presumable that the suspension system reduced vibration-induced elevated structure noise.<sup>24</sup>

#### *Metropolitan Atlanta Rapid Transit Authority (MARTA)*

Similar to the softer suspension system used by the CTA, MARTA reduced the stiffness of the primary suspension system, reducing groundborne vibration by 1-5 dB, primarily in the lower frequencies.<sup>25</sup>

MARTA has also used a resiliently supported tie system to reduce groundborne vibration. Tests results indicate a 0-10 dB level than the use of direct-fixation resilient fasteners, in the 10-125 Hz range.<sup>26</sup>

#### *Paris, France Metro (RATP)*

Similar to the resiliently supported tie system used by MARTA, the Paris metro system uses a resiliently supported tie system to reduce the groundborne vibration with similar success to that of MARTA.<sup>27</sup>

#### *Massachusetts Bay Transportation Authority (MBTA)*

As part of the Transportation Cooperative Research Project on wheel/rail noise mitigation, a test of rail vibration constrained layer dampers were conducted by the MBTA. The rail vibration dampers were marginally successful, reducing noise 4-8 dB in certain circumstances.

#### *Japan Railway, Shinkansen*

To reduce the noise radiated by the railway bridges of Shinkansen, ballast mats were installed where the noise from passing trains created a problem in the surrounding communities. The elastomer pad was approximately 1 inch thick and placed between the bridge deck and the ballast to prevent vibration passing through the ballast to the bridge deck. Test results from two rail bridges indicate a reduction of 8-14 dB due to the pad.<sup>28</sup>

*New Jersey Transit Corporation*

The New Jersey Transit Corporation’s rail rapid transit line in Newark, New Jersey was selected for the testing of wheel vibration absorbers for a study by Wilson, Ihrig, and Associates under contract with the Transportation Research Board, the Transportation Research Council and the Federal Transit Administration. The results of the study indicate that wheel vibration absorbers reduce wayside rolling noise along tangent track by less than 1 dB. However, along curved track segments, the probability of occurrence and decibel level of wheel squeal noise at curves was less with wheel vibration absorbers than without. However, wheel squeal was not eliminated completely. The Newark system was only tested for wheel vibration dampening.<sup>29</sup>

***Tri-County Metropolitan Transportation District of Oregon***

The Tri-County Metropolitan Transportation District of Oregon was the other site for the wheel and rail vibration study by Wilson, Ihrig, and Associates. In addition to the wheel dampeners tested with results similar to those found in Newark, rail vibration absorbers were also tested. The results of the study were surprising: the study indicates that wayside rolling noise levels were slightly higher with the rail vibration absorbers relative to without by 1-2 dB and there was no reduction of wayside rolling noise achieved by the combination of wheel and rail vibration absorbers. However, the rail vibration absorbers did eliminate the “singing rail” at tangent track test sections. According to the study, because of the ability to reduce the high-pitched tones, “the treated rail was considered to be quieter than the untreated rail, even though the maximum and single-event A-weighted noise levels were not reduced.”<sup>30</sup>

Though the Tri-Met study was conducted along at-grade segments, the groundborne vibration results may be applicable to the reduction of noise from elevated rail line structures. The study found that rail vibration levels at tangent track were significantly reduced with rail vibration absorbers. Moreover, rail vibration caused by stick-slip forces along curve track section was significantly reduced with the use of rail vibration absorbers.

The results of these case studies are summarized below<sup>31</sup>:

<b>Noise Reduction Technology:</b>	<b>Authority:</b>	<b>Effectiveness of noise and vibration reduction technology:</b>
Resilient Wheels	Southeastern Pennsylvania Transportation Authority	0-2 dB decrease along tangent track, 3-10 dB along curved track
	New Jersey Transit Subway Line	1 dB decrease along tangent track, “significant” reduction on curved track
	Tri-County Metropolitan Transportation District of Oregon	1 dB decrease along tangent track, “significant” reduction on curved track

Resilient Rail Fasteners	NYC Metropolitan Transportation Authority	3-6 dB reduction at speeds less than 25 mph
	Paris, France Metro	0-10 dB reduction of groundborne vibration.
	Metropolitan Atlanta Rapid Transit Authority	0-10 dB reduction of groundborne vibration.
	Massachusetts Bay Transportation Authority	4-8 dB reduction.
	Tri-County Metropolitan Transportation District of Oregon	Increase in rolling noise by 1-2 dB. Decrease in "singing rail" frequencies.
Soft Suspension Systems	Chicago Transit Authority	reduction of groundborne vibration of 10-20 dB
	Metropolitan Atlanta Rapid Transit Authority	reduction of groundborne vibration of 1-5 dB
Slip-slide control	NYC Metropolitan Transportation Authority	50% reduction in number of wheel flat occurrences
Welded Rail	NYC Metropolitan Transportation Authority	reduction of 1.5-3 dB(A)
Vibration Detection System	Toronto Transit Commission	does not directly lower noise levels but does notify workers of problematic equipment
Ballast Mats	Japan Railway Shinkansen	reduction of 8-14 dB
Wheel Truing	Southeastern Pennsylvania Transportation Authority	5-10 dB decrease for frequencies above 100 Hz

It should be noted that the reductions are, of course, dependent on the initial noise level and the other components of system design. Therefore, it is difficult to compare technologies and results across different systems. Moreover, it cannot be assumed that the results from one system can be duplicated on another.

### **Conclusion of At-Source Noise Reduction Techniques**

Despite all of the efforts of noise control engineers and the vast knowledge of the problems and the solutions, noise remains a problem on many rail transit systems, particularly older systems. The problem of noise is not a result of the lack of knowledge of the solutions, but a question of priorities. If given enough money, the technology is available to virtually eliminate the noise from rail transit. The solutions used by most transit systems only marginally improve the situation, typically reducing the noise by less than 10 dB. Fully addressing the problem of noise would typically require completely rebuilding much of the rail system, an expense far

beyond the budgets of any transit system. And so, the question remains: with noise problems a low priority, how should transit systems allocate their resources? The answer to this question is further examined in Chapter 6 of this thesis.

#### **Endnotes**

- <sup>1</sup> Transportation Noise Reference Book, sec. 13.2.2.1
- <sup>2</sup> Transportation Noise Reference Book, sec. 13.2.2.1
- <sup>3</sup> Transportation Noise Reference Book, sec. 14.2.8
- <sup>4</sup> Transportation Noise Reference Book, sec. 14.3
- <sup>5</sup> “Noise Considerations on the Chicago Transit Authority’s Elevated System” Presentation, Michael Shiffer et al.
- <sup>6</sup> TCRB Report 23, Wheel/Rail Noise Control Manual, p 37.
- <sup>7</sup> Interview with Jack Hruby, CTA VP of Rail Operations.
- <sup>8</sup> TCRB Report 23, Wheel/Rail Noise Control Manual, p 37.
- <sup>9</sup> TCRB Report 23, Wheel/Rail Noise Control Manual, p 38.
- <sup>10</sup> TCRP Report 67, Wheel and Rail Vibration Absorber Testing and Demonstation, Wilson, Ihrig and Associates, 2001. p. 3.
- <sup>11</sup> Interview with Jack Hruby, CTA VP of Rail Operations.
- <sup>12</sup> John Shearer, “Quieting Transit Track” in Rail Track and Structure, Nov. 1986
- <sup>13</sup> Transportation Noise Reference Book, sec. 13.2.2.1
- <sup>14</sup> Radiated Noise From Elevated Subway Systems in Boston, Acoustics and Vibration Laboratory, Massachusetts Institute of Technology, August, 1974, p. 25
- <sup>15</sup> Acoustics and Vibration Laboratory, Massachusetts Institute of Technology, August, 1974. p. 37
- <sup>16</sup> Transportation Noise Reference Book, Sec. 16.6
- <sup>17</sup> Transportation Noise Reference Book, sec 16.6.1.1.
- <sup>18</sup> Transportation Noise Reference Book, sec. 17.5.1
- <sup>19</sup> Transportation Noise Reference Book, sec. 16.6.1.2
- <sup>20</sup> Transportation Noise Reference Book, sec. 17.2.1
- <sup>21</sup> Transportation Noise Reference Book, sec. 17.4.1
- <sup>22</sup> Transportation Noise Reference Book, sec. 17.5.2
- <sup>23</sup> Transportation Noise Reference Book, sec. 16.6.1.5
- <sup>24</sup> Transportation Noise Reference Book, sec. 16.6.1.6
- <sup>25</sup> Transportation Noise Reference Book, sec. 16.6.1.6
- <sup>26</sup> Transportation Noise Reference Book, sec. 16.6.2.1
- <sup>27</sup> Transportation Noise Reference Book, sec. 16.6.2.1
- <sup>28</sup> Transportation Noise Reference Book, sec 17.2.2
- <sup>29</sup> TCRP Report 67, Wheel and Rail Vibration Absorber Testing and Demonstation, Wilson, Ihrig and Associates, 2001. p. 1.
- <sup>30</sup> TCRP Report 67, 2001. p. 1.
- <sup>31</sup> Table compiled from several sources. References cited in text

### **Chapter 3. Previous Efforts to Reduce the Impacts of Noise through Planning and Urban Design Techniques**

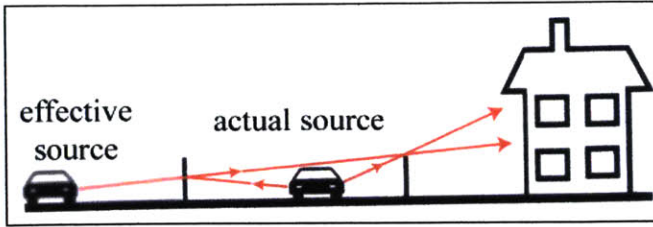
Though eliminating noise at-source is an effective means of reducing noise impacts, at-source reduction is often cost-prohibitive. Transit agencies and the municipal governments in which they operate have explored other means of reducing noise impacts, including the construction of noise walls and barriers, landscaping, land use policy, and noise-insulation of buildings. This chapter examines the various non-source techniques used to mitigate noise impacts caused by heavy rail transit systems.

#### *Path Mitigation Through Near Source Noise Barriers*

According to an article in *Planning*, the first noise walls in the United States were built along California interstates in 1968.<sup>1</sup> In the U.S., the majority of research on barrier design and effectiveness has centered on highway noise barriers—relatively few studies have been conducted on railway noise barriers. The number of studies on highway noise barriers may just be a reflection of their increasingly common use. By 2001, the Federal Highway Administration had funded the construction of more than 1,300 linear miles of noise walls along new freeways alone. This Figure does not count the miles of noise walls constructed by states, counties and municipalities along existing highways, ineligible for federal funding.<sup>2</sup> Although highway walls are increasingly common, few U.S. transit agencies have experience with noise barrier design. In contrast, noise barriers in Europe and Asia are widely used for rail systems and their acoustic and visual design elements have been well documented.

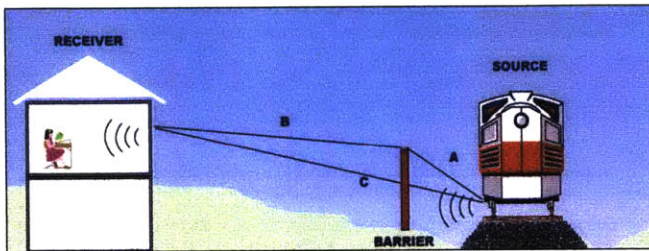
The purpose of noise barriers is to attenuate noise radiated from a train by either reflecting or absorbing the noise. Barriers, either reflective or absorptive or a combination of the two, typically reduce wayside railway noise between 7 and 15 dB(A).<sup>3</sup> According to the book *Time Saver Standards for Landscape Architecture*, the five main factors that influence the acoustic effectiveness of a barrier are: the distance between the barrier and the source, the height of the barrier, the continuity of the barrier, the length of the barrier, and the mass of the barrier.<sup>4</sup> A barrier should be placed as close as possible to the noise source to maximize the diffraction angle. The height of the barrier should be tall enough so that line of sight between the source and the receiver is interrupted. The barrier should be continuous with no gaps or holes. As a general guideline, at any given point along a line source, the length of the barrier should be at least 1 to 2 times the distance between the barrier and the receiver to minimize sound diffraction at the ends of the barrier. However, in the case of rail transit, the length should be that of the section of alignment needing noise mitigation.

Because diffraction over the top and sides of a barrier are an issue, its height and width



**Figure 3.1** Illustration of a common problem with parallel noise barriers. Though the actual noise source is the automobile inside the barriers, the reflection from the left wall reduces the angle of diffraction so that the noise source is effectively the automobile on the right.

Source: *Environmental Noise Barriers*



**Figure 3.2** Illustration of the path length difference. The path length difference is calculated by  $A+B-C$ .

Source: *City of Cleveland Home Sound Insulation and Noise Barrier Program*

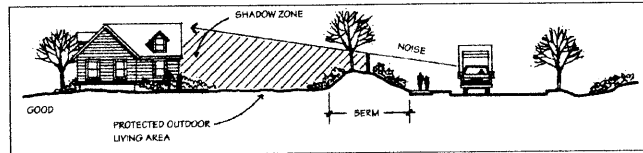
must be carefully considered. As illustrated in the schematic diagram in Figure 3.1, the effective path length is the distance from the source to the edge of the barrier plus the distance from the edge of the barrier to the source. The path length difference is the effective path length minus the direct distance from the source to the receiver. The path length difference is illustrated in Figure 3.1 as  $A+B-C$ . The greater the path length difference, the greater the noise reduction.

Many materials used in barriers have been tested for the amount of noise absorbed by the material, given a certain surface area. The percentage of noise absorbed at a given frequency is called the noise absorption coefficient (NAC). However, the amount of noise absorbed varies with frequency. For instance, the same material may have a 79%

NAC at 200 Hz and a 36% NAC at 2000 Hz. To understand how well a material performs over the spectrum of frequencies most associated with human hearing, the noise reduction coefficient (NRC) was created. The NRC is the arithmetic average of the sound absorptive coefficient of a material at 250, 500, 1000, and 2000 Hz. Though NRC and NAC is useful in choosing an noise barrier material, not all materials have been tested. According to an article written by engineers of the Florida Department of Transportation, “The most popular materials used to construct noise walls (concrete, metal, and wood) often lack NAC and NRC data.”<sup>5</sup> According to *Time Saver Standards for Landscape Architecture*, “to minimize sound passing through a barrier, it should have a surface weight, or mass, of at least 6 to 12 kg/m<sup>2</sup>. A noise level reduction of 10 to 15 dB(A) is possible with such a barrier; however, a reduction of 5 to 10 dB(A) is considered more cost-effective.”<sup>6</sup>

In transportation noise control literature, the diagrammatic representations of the physical properties of noise transmission and noise walls are problematic for two reasons. Almost always, the path of noise is indicated by an arrow, suggesting linear transmission. Though useful as a crude indicator for depicting the movement of noise, it is inaccurate to depict noise transmission linearly. In open air, noise will travel in all directions equally, not linearly. In transportation noise control literature, the area opposite the barrier from the source is often referred to as a

“shadow zone.” The shadow zone is often represented by a line-of-sight from the source to the top of the wall. While this generally illustrates the intention of a noise barrier, this does not truly represent the path of noise. The term “shadow zone” suggests that noise is completely eliminated from the area, which is untrue. Noise will diffract at the top of the noise barrier, and travel through the so-called shadow zone, though the diffracted noise levels are lower than would occur if no walls were present. The linear representation and shadow zone are illustrated in Figure 3.3. Furthermore, other objects, such as the trees in the Figure 3.3, reflect small amounts of noise in more complicated patterns than the simple line diagrams suggest. These reflections may further reduce the effectiveness of the barrier.



**Figure 3.3** An example of the depiction of linear noise path and the shadow zone from noise control and landscape architecture literature.

Source: *Time Saver Standards for Landscape Architecture*

### Parallel Wall Design

In an attempt to mitigate noise on both sides of a linear noise source, it is common to place noise barriers on either side of the line source. The placement of walls on opposing sides of a line source is called parallel walls. According to one study, “parallel walls, unless very far apart, cause sound to ricochet, dropping the effectiveness of each wall from a 10-decibel noise reduction to a barely discernable four decibels.”<sup>7</sup> Improper parallel wall design can lead to two problems:

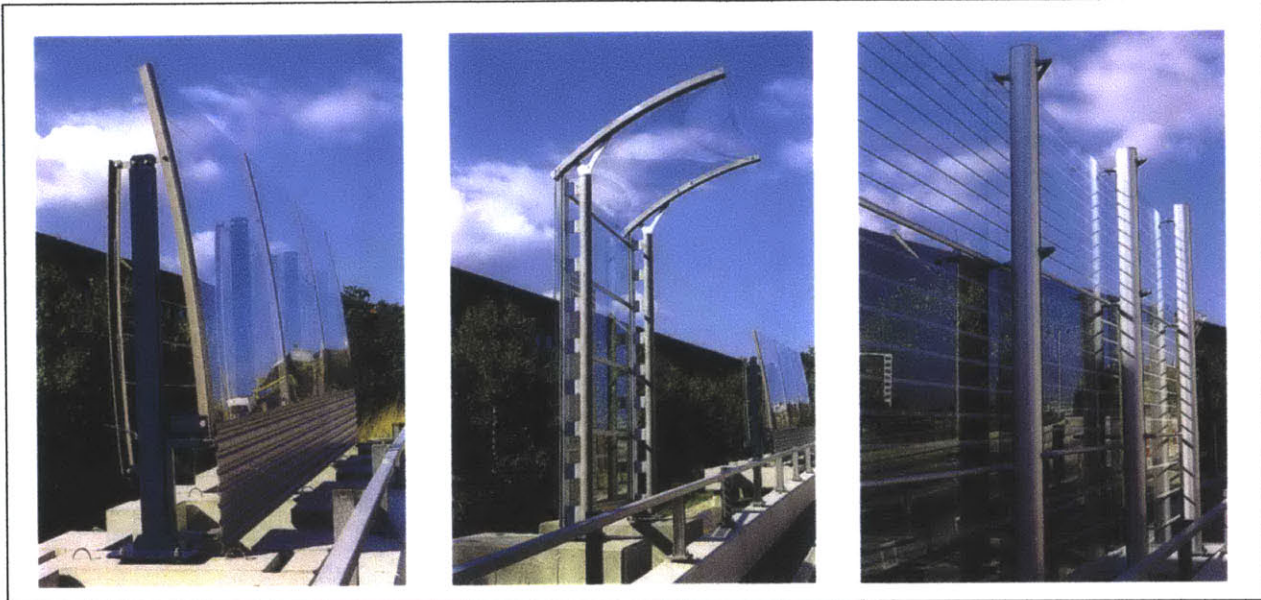
1. The placement of the walls too close together often leads to multiple reflections and the reverberation of sound between the two walls.<sup>8</sup>
2. Sound can reflect off one wall and above the other, reducing the effectiveness of barriers.

To solve these problems, two techniques are suggested:

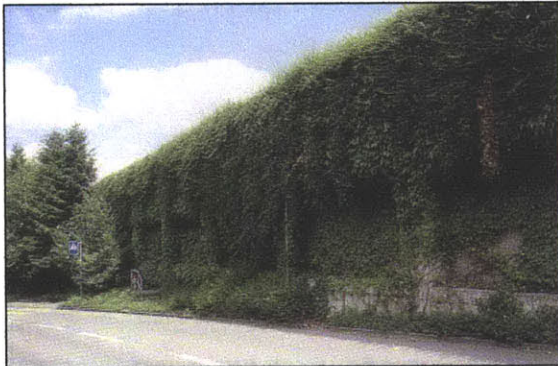
1. Construct barriers of highly absorptive material, to minimize the amount of noise reflected.
2. The distance between the walls should be more than 10 times the height of the wall to minimize the amount of sound reflected between the walls.

### Noise Barrier Aesthetics

Though often thought of as massive, unarticulated concrete walls, noise barriers can be designed using a variety of materials and finishes providing an interesting visual character. The large concrete noise barriers along highways are often thought of as unattractive. In an article in *Landscape Architecture*, the authors wrote, “Raw-concrete sound barriers often raise objections



**Figure 3.4** Three examples of glass, plastic and steel barriers from a design competition in Europe.  
 Source: *Environmental Noise Barriers*



**Figure 3.5** A brick and concrete wall covered with thick plantings.  
 Source: *Environmental Noise Barriers*



**Figure 3.6** A concrete noise barrier painted with the image of the sun and photovoltaic panels on top.  
 Source: *Environmental Noise Barriers*

from the very citizens they are erected to protect.”<sup>9</sup> In a response to public outcry over the ugliness of concrete noise barriers, alternative materials, colors, landscaping, and decorations have been adopted for the design of noise barriers, though are not as widely used in the United States as they are in Europe.<sup>10</sup> Figures 3.4, 3.5, and 3.6 are examples of the various materials, textures and colors used in noise barrier design. The aesthetic design of barriers is subjective but there are several aesthetic design considerations including context, location, scale, size, material, texture, color, shape, and pattern.

It is important to remember that every wall has two sides and the aesthetics of both sides of the wall should be well thought-out. Noise barrier aesthetics are rarely considered and when they are, it is typically from the abutters’ viewpoint. In instances where the barrier obscures the view of the rider through the train car window, the visual experience for those inside the train should also be considered. However, the perspective of a rider



inside a moving transit car is very different from that of an abutting resident. The view from inside the train changes as the train moves, typically at a rapid speed. In comparison, the view from an abutter's window is static. A pedestrian visual experience of the barrier also differs from the abutter and the passenger in that the view of the barrier changes slowly as the pedestrian walks through the space.

In addition to the aesthetic design, maintenance of the barrier must be considered when designing a barrier. Landscaped barriers such as the planting-covered wall in Figure 3.5 provide an alternative to the blank concrete face of many sound barriers but the plants must be maintained. Similarly, glass and steel barriers will quickly look dirty and worn by the elements without regular maintenance. With aesthetic improvements come the costs of maintenance.

Concrete walls do have the benefit that they are less affected by weather. However, blank concrete walls are often targets for graffiti, causing concern for many transit agencies. Though typically thought of as a sign of youth-gone-bad and often seen as an indication of a bad neighborhood, graffiti could improve the aesthetics of a noise barrier. Concrete noise barriers can be an opportunity to display public artwork. Similar to city-funded community murals on the sides of buildings, noise barriers could provide a new space to display local, public art.

Another option for altering the aesthetics of a noise barrier is to allow the façade of the barrier to be used as commercial advertising space, a modern-day equivalent to the farmer's barn or the municipal water tower that were once used to display advertisements. The locations of barriers that could display advertisements are likely limited. Advertisers would only want to place their products at locations where the advertisement is visible, such as intersections where an elevated transit line crosses a major street. Though this is an option to raise additional revenue, convincing a transit agency to turn their noise barriers into billboards may be difficult. This option is discussed in further detail in Chapter 6.

### **Design and Effectiveness of Barriers**

In recent years, an increasing number of transit agencies have begun replacing aging lightweight steel rail transit structures with more massive concrete guideways with sound barriers, significantly reducing wayside noise levels.<sup>11</sup> The "Renew the Blue" project on the Chicago Transit Authority Line replaces an older lightweight structure supporting the blue line with a concrete deck and expects significant reduction in wayside noise levels. The New York City Metropolitan Transportation Authority rebuilt significant portions of their elevated tracks, adding noise barriers along the guideway.

Metropolitan Atlanta Rapid Transit Authority (MARTA) and Dade County Metrorail have both used sound barriers on their elevated rail lines. The effectiveness of the noise barriers is assessed in the *Transportation Noise Reference Book*. A large portion of the MARTA rapid

rail transit system is comprised of an elevated structure of concrete slab deck, supported on a steel box beam. The rail is continuously welded and is fastened to the deck with resilient ties. The elevated guideway has a non-absorptive 5 foot high concrete acoustic barrier is affixed to the concrete deck, approximately 24 inches from the side of a passing transit car. The study measured noise 25 horizontal feet away from the track centerline. The study indicated that the barrier effectively reduced maximum wayside noise levels by 7 dB(A) at all tested speeds. Interestingly, additional tests confirmed that the 2-3 inch gaps that existed where adjacent spans come together had “no significant effect” on the performance of the barriers.<sup>12</sup>

In a similar design to that of the MARTA system, the Dade County Metrorail System’s elevated rapid rail consists of a concrete slab deck. The deck is cast as an integral part of the concrete double-tee girder. The rail is continuously welded and fastened to the deck with resilient ties. Unlike the MARTA noise barriers, the Dade County Metrorail uses 4 foot high 14 gauge sheet metal panels affixed to the edge of the deck at a distance of approximately 1 foot from passing transit cars. The trackside edge of the panel is covered with 4-inch thick mineral wool placed in plastic bags covered in a perforated metal facing, for protection. At each pier, a 1-inch gap is present between adjacent barrier panels. Additionally, a 1-inch gap exists between the guideway and the panel, when viewed from below. Noise levels were monitored at a distance of 25 horizontal feet from the track centerline. The tests examined noise level reductions with and without the sound absorptive mineral wool and with and without the gaps sealed. The unmodified barrier reduced maximum sound levels by 8.9 dB(A) whereas the barrier with no sound absorption reduced sound levels by only 7.8 dB(A). Researchers found a noise reduction of 10.9 dB(A) when the gaps were sealed and the sound absorptive mineral wool was present.<sup>13</sup>

### *Problems with Noise Barriers*

As previously mentioned, many studies of the performance of highway noise barriers have been conducted. The findings of some studies of the effectiveness of highway noise barriers are troubling. According to a study using before and after measurements along a highway noise barrier in Colorado Springs, researchers found that the barrier was only effective at reducing noise levels within 60 feet of the wall and that any reductions of noise level beyond 200 feet from the wall resulted primarily from distance, not the wall.<sup>14</sup>

Reflections from highway noise walls have also been identified as a significant problem. In Alameda, California a new residential development was sheltered from an adjacent highway by a noise wall constructed by the developer. Poor design of the wall resulted in the noise reflecting higher levels of noise towards an existing, poorer neighborhood on the opposite side of the highway.<sup>15</sup>

## Landscape Architectural Techniques

In addition to man-made walls, numerous landscape-architectural techniques have been devised to attenuate noise using natural materials. Though often thought of as an effective means of reducing noise, trees do little to reduce actual noise, even if they may completely obscure the view of the noise source. Only through very dense planting of trees and understory shrubs at a depth of 100 feet from the noise source can even minimal noise attenuation (3-5dB(A)) be observed on a noise meter. Interestingly, even though trees may not actually reduce the noise, trees may provide an important psychological benefit in the perception of noise: if a person is unable to see the noise source, they report being less bothered by the noise.<sup>16</sup> It is a widely held belief that plantings are an effective means of making barriers and walls more aesthetically attractive, though plantings at the top of a berm may actually reduce the effectiveness by diffracting the noise around the barrier.

Though plantings alone do little to attenuate noise, earth berms are an effective means of reducing noise from a surface road or railway. Berms, though generally requiring wider rights-of-way than man-made walls, “are slightly more effective than walls.”<sup>17</sup> Obviously, berms are difficult to use to attenuate noise from elevated or aerial structures, given the height at which they would be required. However, under the right circumstances—along an at-grade or open cut rail line, for instance—a berm can provide an aesthetically and acoustically pleasing means of reducing noise levels. The slope of a natural berm is largely dependent on the type of surface treatment and the maintenance required.

Because natural berms are subject to the slope of natural materials used, it is often difficult to attain the desired wall angle to aim reflections away from other receivers. In order to mitigate this problem, structurally reinforced earth covered walls have been used, often called bio-walls or green walls. Bio-walls were first introduced for noise attenuation in the 1970s in Western Europe. The walls typically consist of man-made blocks or screening material covered with earth material and plantings. The face of these walls can be constructed at such an angle to aim reflections.<sup>18</sup> Though increasingly used as noise barriers, little data is available discussing the effectiveness of berms or bio barriers at attenuating noise. A bio berm is illustrated in Figure 3.7.



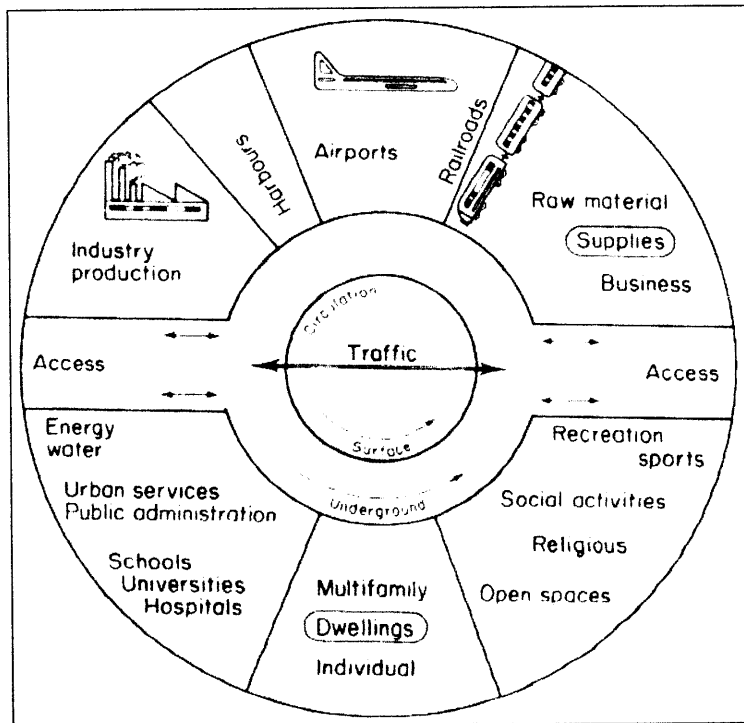
**Figure 3.7** A photograph of a structurally reinforced bio-barrier separating the rail line from a walking path.  
Source: *Environmental Noise Barriers*

## Path Mitigation Through the Design of the Urban Environment

Though largely absent from planning and urban design literature in the past 30 years, there are few examples that illustrate means of reducing the impacts of transit noise through planning and urban design methods. Interestingly, the documentation of such planning and urban design techniques was found in noise-control and noise-engineering publications, not in the literature traditionally associated with land-use planning or urban design.

### Zoning and Land Use Planning

The “purpose” section of many municipal zoning codes discusses protecting residents from unwanted noise. Although a noble goal, the resulting physical design of development



**Figure 3.8** Diagram illustrating a “model of urban zoning to minimize noise interference.”

Source: *Noise Pollution Control*

suffers as conventional zoning typically separates the various aspects of life. Conventional zoning typically uses two tools for dealing with noise impacts: separation of uses and building setbacks. The use of zoning to mitigate noise impacts has often meant separating “noise sensitive uses” from sources of noise. While protecting the residents from noise, the zoning code creates a less-than-ideal environment of fragmented land uses and under-utilized buffer lands.

Planning, noise control, and noise policy literature consistently speak of the separation of land uses from noise sources as the means of mitigating the impacts of noise

pollution. In *Noise Pollution Control*, G.L. Fuchs suggests that zoning is the most appropriate means of mitigating noise impacts. Fuch’s concept is illustrated in Figure 3.8. Fuchs writes, “Grouping of the various activities according to their noise generating capabilities is the simplest (though not always realizable) planning scheme. Partial improvements can be achieved through zoning or by moving noise sources away from residential areas.”<sup>19</sup>

Zoning does not always address noise directly, but rather associates the nuisance of noise with land use. For example, many zoning codes do not specifically address noise impacts

but will require a buffer between industrial and residential uses. Zoning utilizes generalized land uses as a surrogate for the actual nuisance. The broad strokes of a zoning district do not necessarily balance many other considerations. In protecting residents from noise, the tradeoffs are often significant. The buffer strips separating commercial uses from residential properties are often neglected, underused spaces and the distances prescribed decrease the likelihood that it is possible to walk from one to the other.

Several cities and towns have augmented zoning regulations with specific considerations for noise, most commonly for highway related noise. In an article in *Planning*, the author cites two cities in the United States that altered zoning codes to require noise issues to be addressed. In Aurora, Colorado, on developments where noise projections are high, “residential developers must agree to provide walls and berms or insulation and air conditioning to seal houses against noise.” Similarly, Fairfax, Virginia requires developers to do professional, onsite noise tests as part of the development-review process and construct noise barriers where necessary.<sup>20</sup> In both cities, noise walls, noise insulation of buildings, or distance separation were the means of mitigation.

While the U.S. has had little success integrating noise mitigation and urban design, other countries have lessened noise impacts through planning and design. In Canada, the Ottawa-Carleton Regional Municipality established noise control guidelines to specifically address the:

establishment of new noise sensitive developments adjacent to existing and future regional roads and transitways.... Four basic noise control measures are recommended which include site planning techniques, the use of acoustical barriers, the application of architectural design and construction techniques to buildings and structures.”<sup>21</sup>

The regulations require that all residential developments hire a professional engineer to prepare an acoustical report that analyzes and maps the noise impacts. Additionally, the regulations place design guidelines that limit the height and location of noise attenuation barriers. However, as a regional authority, the power of the Regional Municipality is limited and only directs other local municipalities to write noise-control policies. Even with limited authority, the comprehensiveness of the guidelines establishes a means of regulating both noise impacts and the physical design of development. No analysis of the resulting developments has occurred, so the success of the plan, in terms of visual and acoustical aesthetics, has yet to be determined.

In several U.S. communities where airport noise is a problem, special overlay zoning districts have been enacted where noise concerns are greatest. In these zoning districts, densities are typically reduced, noise sensitive uses are prohibited and special conditions to mitigate noise impacts are placed on development.<sup>22</sup> Such zoning districts are typically not enacted for heavy rail transit. With the increasing number of communities enacting “transit-friendly” overlay

districts to encourage higher densities, specific considerations for noise criteria could also be addressed in such zoning codes. However, I was unable to find any zoning codes in the United States that specifically address noise from rail transit systems.

In communities impacted by airport noise, Transferable Development Rights (TDR) programs have been enacted to move densities away by the most impacted areas. Under such programs, a property owner greatly impacted from airplane noise may sell the development rights of his or her property to another parcel located in less impacted neighborhood. In effect, TDR is land use regulation employed so that the municipality or transportation agency can continue benefiting from the airport without needing to compensate landowners impacted by the nuisance. While such a program is an effective means of reducing the number of homes impacted by noise, a TDR is only effective at reducing densities. As such, a TDR program may not be appropriate for mitigating noise from heavy rail rapid transit systems where densities along the alignment are desired. A further discussion of the use of a Transferable Development Rights programs is included in Chapter 6.

In contrast to the U.S. model of land use planning to reduce noise impacts, the European Union has begun to require municipalities to adopt Noise Abatement Plans. The EU initiative also regulates inter-country rail transport for both passenger and freight. The Noise Abatement Plans required by the EU are based on the German regulation that has been in effect since 1988. In Germany, the municipal Noise Abatement Plans focus on reducing roadway noise and generally do not focus on rail transit noise. Interestingly, the Noise Abatement Plans often call for reduced roadway speeds, traffic calming measures, improved pedestrian and biking infrastructure, land use regulations that decrease the dependence on the automobile, and improved public transportation. However, the plans do not specifically address noise from public transportation, specifically heavy rail rapid transit. Additionally, the European Union is encouraging municipalities to create noise maps to identify which locations are most susceptible to environmental noise. While an innovative approach to noise control policy, the EU policy does not specifically address rail transit noise.<sup>23</sup>



**Figure 3.9** The U.S. Department of Transportation’s published examples of “Noise Compatible Land Use Planning.” From right: open space buffering residential uses, retail setback from highway with large parking lot, the blank wall of a townhouse. Source: *Entering the Quiet Zone: Noise Compatible Land Use Planning*.

## Site Planning

In an attempt to move away from constructing costly noise walls along interstate highways, in 2002, the U.S. Department of Transportation published *Entering the Quiet Zone, Noise Compatible Land Use Planning*. The document calls for “land adjacent to highways (be developed) in a manner that reduce or eliminate noise problems.” To do so, the document suggests noise compatible land use planning should encourage the location of less noise-sensitive land uses next to highways and promote the use of open space or special building construction techniques to minimize noise impacts. The document states that commercial, industrial, and retail development should be placed along high-volume roadways to buffer traffic noise, a practice well established in many suburban areas. For residential development, DOT offers examples of townhouses built along highways that have no windows on the facade facing the arterials. Though effective at mitigating noise impacts, the DOT’s examples ignore many other urban design considerations including pedestrian access, visual aesthetics, utilization of land, and energy consumption.

### *Noise and Transit Oriented Development*

Although Euclidian zoning has been widely criticized in recent years for a multitude of reasons, these criticisms rarely consider Euclidian Zoning’s effectiveness in addressing noise impacts. New Urbanism points to the automobile as a source of urban noise pollution and suggests that decreased use of the automobile would reduce noise pollution. However, New Urbanism does not specifically address concerns of noise impacts from other sources. Transit-Oriented Development (TOD), often seen as an environmentally supportive solution, increases densities adjacent to transit, potentially subjecting a greater population to the adverse impacts associated with transit. Much has been written about the need to increase Transit-Oriented Development, yet little has been written about specifically addressing noise impacts caused by the transit system.

Peter Calthorpe, the creator of the TOD concept, and his firm, Calthorpe and Associates, have worked on numerous projects that sited medium to high density housing adjacent to rail lines. Calthorpe and Associates have used architectural treatments and building orientation to mitigate noise impacts. For the Richmond Transit Village project in Richmond, California, which called for high densities to be placed near the intermodal transit station, Calthorpe and Associates designed “single-aspect townhouses,” multifamily structures that have no windows on the rear of the structure, adjacent to the rail line, similar to the townhouses addressed by the Department of Transportation in *The Quiet Zone*. The “single-aspect townhouses” place bedrooms and other living spaces at the front of the unit nearest the street. The kitchen, laundry, bathrooms,

and other utility uses are placed at the rear of the units, buffering the bedrooms from the transit



Figure 3.10 Illustration of the use of the “building as barrier” technique.  
Source: *Noise Control: Handbook of Principles and Practices*.

noise. The buildings themselves are intended to provide a noise buffer to the rest of the community. However, such design does have its tradeoffs. Placing windowless facades adjacent to the rail line may reinforce the notion that the rail line is a psychological barrier between

two areas. Though thoughtfully designed, no actual noise analysis was performed to determine if the buildings adequately mitigate the impacts of transit noise. Furthermore, Calthorpe’s design focuses on reducing noise for residents inside their dwellings and does not pay much attention to reducing noise in the outdoors.

Within noise control literature, few references were found discussing the use of building orientation to block the noise for other areas. In *Time Saver Standards for Landscape Architecture*, a brief reference is made to “the use of existing or proposed buildings to shield others that are more sensitive” but no details are further explained. In *Noise Control: Handbook of Principles and Practices*, the authors discuss the use of site planning and building orientation as a means of reducing noise impacts. The authors write:

The noise coming to a complex of buildings or originating within the complex, should not be “trapped” in the area by bouncing to and back from surrounding walls.... For a cluster of buildings, a random layout is preferred. Parallel building arrangements should be avoided because repetitive sound reflections occur easily between them. For the same reason, U-shaped courtyards should not be oriented

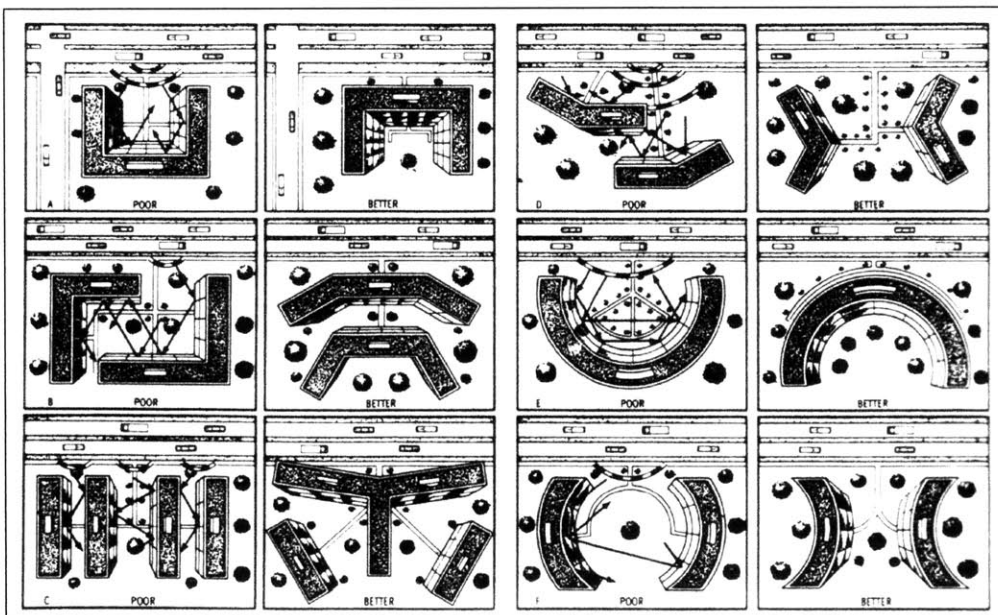


Figure 3.11 Illustration of building orientation and noise implications.  
Source: *Noise Control: Handbook of Principles and Practices*.



toward noise sources such as highways.<sup>24</sup>

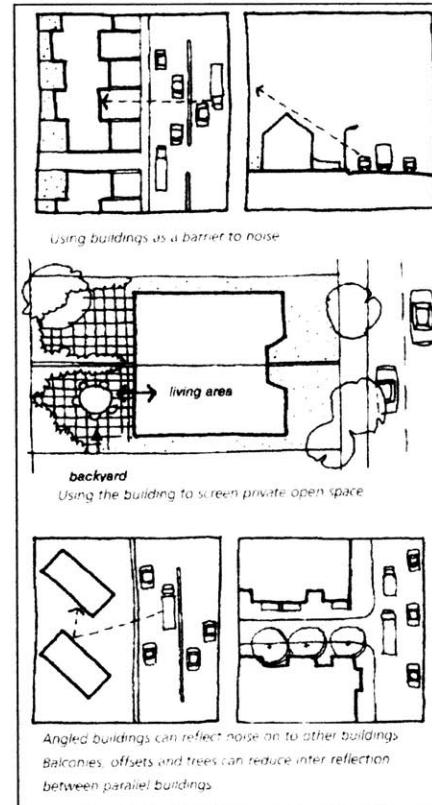
Though a seemingly reasonable argument, the authors provided no studies verifying their results. Without empirical evidence, the veracity of the claims is difficult to assess.

The Royal Australian Institute of Architects prepared a manual titled “Protection from Traffic Noise in Residential Areas” which discusses the need for sensitive site planning. In the report, the authors discuss the need to minimize the infiltration of noise into the buildings and lots, to provide an acoustic barrier for private and communal open space, and to reduce reflection of noise onto other buildings.<sup>25</sup> Similar to the techniques discussed in *Noise Control*, no case studies or empirical evidence is presented. However, the book addresses the need for an urban designer to consider factors other than noise. The authors write, “Housing located adjacent to busy roads should be designed and constructed in a manner that reduces the effect of noise and enhances streetscapes, functional roads, and comfortable living conditions.”<sup>26</sup>

In a paper presented at a conference in 1998, two Israeli researchers presented a paper entitled “The Use of Architectural Urban Elements as a Method for Noise Attenuation of the Sound Source in Residential Areas.” Though the authors use the term “architectural urban elements,” they are referring to what may usually be considered urban design—the width and layout of streets and buildings. In this paper, the authors attempt to quantify the amount of attenuation achieved in several different design scenarios including the layout of streets, paths and intersections. The authors write, “The rate of attenuation depends on the architectural layout and patterns of the suburbs, such as screening, the width of passages, and the types of architectural elements.... Four factors influence the extent of attenuation of noise, namely—the distance between the source and the receiver, screening, the width of a passageway, and its shape.”<sup>27</sup> The results of this study show how urban design can be used to mitigate noise in urban environments.

### Receiver Isolation Through Architectural Techniques

In addition to building orientation and floor plan designs that place non-sensitive uses closest to the noise source, noise-isolation or sound insulation of buildings is an feasible method of reducing the impacts of environmental noise. The use of noise-isolation is becoming



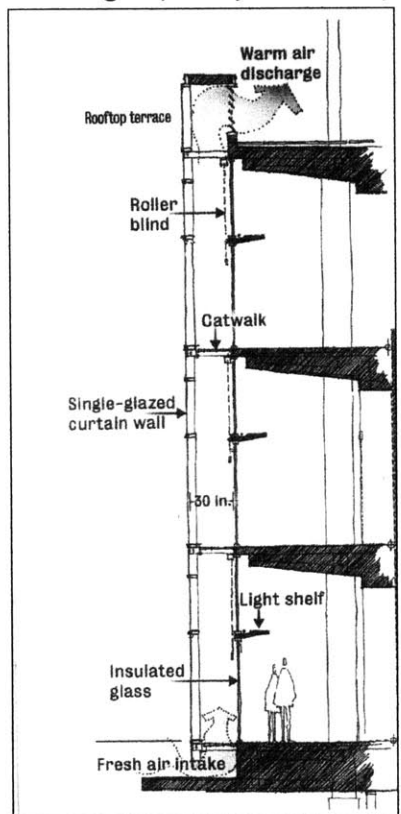
**Figure 3.12** Diagrams of site planning techniques to reduce noise impacts  
Source: *Protecting from Traffic Noise in Residential Areas*.

an increasingly popular means of noise control, particularly in areas where source control is difficult, such as neighborhoods under airport flight paths and urban neighborhoods where street noise from multiple sources is high.

Building sound insulation is used to improve the noise reduction characteristics of building facades. Typically, windows and doors are the weakest path into the building and therefore provide the greatest opportunity for noise reduction improvements. However, in older wood frame buildings, the walls may also be susceptible to noise transmission. Improvements to isolating a building's interior from outside noise are typically accomplished by the addition of mass, decoupling, and a large airspace. The additional mass in an exterior wall absorbs noise as it travels through the wall, reducing the amount of noise that travels into the building. Decoupling a wall prevents the flanking path in which the transmission of sound occurs not through the wall itself but through the transmission of energy from the wall to the floor or ceiling and into the interior of the house. The addition of a larger airspace in a cavity within the wall provides for greater noise reduction. These techniques can be very effective at reducing interior noise levels.

Isolating buildings from the noise of rail transit lines is particularly challenging due to the range of frequencies radiated from a rail system. As discussed in an article for the (Seattle, Washington) *Daily Journal of Commerce: Design 95*, an architectural researcher wrote,

“Railroad noise impacts present special challenges associated with high levels of low-frequency noise, pure-tone squeals, vibrations, and impulsive sounds that occur during impact when train cars are coupled.”<sup>28</sup>



In many cities and towns, municipal or state housing codes often requires the use of architectural elements for noise isolation if environmental noise levels exceed or are expected to exceed certain noise levels. Though these codes are laudable, enforcement is often difficult. Though an architect may draw construction plans for a noise-isolated building, the finer construction techniques required, such as resilient dampeners at the joists, are often overlooked during construction. In order for a building code to be effective, the construction site must be carefully monitored to ensure that the construction techniques follow the plans. A further discussion of building codes and construction techniques can be found in Chapter 6 of this thesis.

*Environmental Trade Offs of Noise Isolation*

Typically, noise isolation in buildings is achieved by fully sealing all windows and doors to prevent noise from entering

**Figure 3.13** Sketch of curtain wall technology.  
Source: *Engineering News Report*

the building. While this does provide for a quieter interior environment, architects typically rely on mechanical ventilation systems to circulate air. In newly constructed office buildings, particularly those taller than a few stories, windows are typically sealed, and so noise-isolating windows may not be considered a significant change. In residential buildings and tall residential towers, openable windows are common. And while many commercially available noise-isolating windows can be opened, they are only effective at keeping out the noise when closed. Noise isolation typically means that if noise reduction is to be achieved mechanical ventilation, heating and air conditioning is required.

Within recent years, architects have developed new ways of integrating noise isolation and passive ventilation systems. In an article in *Building and Environment*, researchers posed several strategies for noise control in naturally ventilated buildings. The authors found that “with careful design airflow rates adequate for assuring indoor air quality can be provided in buildings in combination with good noise insulation.”<sup>29</sup>

#### *Contemporary Architectural Design and Acoustics*

Perhaps the boldest step in recent architectural practice to address environmental noise is the new campus center at the Illinois Institute of Technology, designed by Rem Koolhaas. Rather than siting the building far from the CTA’s elevated Green Line or somehow hiding the city’s infrastructure, Koolhaas chose to celebrate the EI’s presence by incorporating the aerial structure into the design of the student center. Attached to the building is an elevated noise-dampening tunnel, constructed around the aerial structure. Koolhaas received much publicity for his competition-winning design, though most of it focused on his architectural response to a campus designed largely by Ludwig Mies Van der Rohe and relatively little attention was paid to the acoustical engineering required to dampen the noise of the EI.

Koolhaas’s design is perhaps emblematic of contemporary architecture: though the design is quite striking, its virtue is limited. Given the cost of construction of the IIT Campus Center, the noise-mitigating techniques developed for the building cannot



**Figure 3.14** Architectural rendering of the new Illinois Institute of Technology Campus Center. Source: *IIT.edu*

easily be duplicated in other areas. It would not be feasible to repeat the IIT noise tunnel for the entire length of the CTA's elevated alignment. This architectural showpiece well demonstrates that innovative, design-forward concepts can be applied to control noise; however, practical concerns such as financing will always play a role in the feasibility of such schemes.

#### Endnotes

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- <sup>11</sup> John C. Shearer, "Quieting Transit Track" in *Rail Track and Structure*, Nov. 1986
- <sup>12</sup> *Transportation Noise Reference Book*, sec 17.1.1
- <sup>13</sup> *Transportation Noise Reference Book*, sec 17.1.2
- <sup>14</sup> Sorvig, 2001.
- <sup>15</sup> Sorvig, 2001.
- <sup>16</sup> *Time Saver Standards for Landscape Architecture: Design and Construction Data.*, sec. 6.6.
- <sup>17</sup> Sorvig, 2001.
- <sup>18</sup> Crockett and Verkruijsen, 1991. p. 70.
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- <sup>25</sup> *Protection from Traffic Noise in Residential Areas*, Planning Notes, 1998. The Royal Australian Institute of Architects, p. 2
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## **Chapter 4. Analyzing Urban Design Techniques to Reduce the Impacts of Noise through the Use of Environmental Noise Modeling Software**

Although several sources in noise control and planning literature make reference to the use of building placement and orientation as a means of reducing noise impacts, only one reference attempted to quantify the effects of urban design acoustics. That source only examined the noise reduction through streets and passageways and did not consider larger site design elements. As such, I intend to test several urban design techniques to determine how well they can be used for mitigating the impacts of noise, specifically noise generated from a heavy rail transit system. Because it is impractical to measure the real-life implications of urban design techniques given the difficulty of limiting all other factors, other methods must be devised to examine the implications of elements of urban design on the transmission of noise. To examine the effectiveness, I have used computer-modeling software to test several urban design techniques in a virtual neighborhood.

### **Computer Modeling of Noise**

Computer modeling for environmental noise is increasingly common for proposed transportation routes or alterations of existing routes. When significant changes to rail transit systems are proposed, the Environmental Impact Statement must consider noise impacts. Typically, these noise impacts are studied through the use of computer modeled noise contours.

Computer modeling of environmental noise impacts was first used in the 1970s but its use was limited to only a few government and private professional offices that could afford the hardware required to run the modeling programs.<sup>1</sup> By the mid 1980s, as personal computers became increasingly common in professional offices, noise modeling software programs for personal computers became available. Today, several noise modeling software programs are available for personal computers.

In the United States, the Department of Transportation funded the development of several noise modeling programs, each designed for different modes of transportation. The Federal Aviation Administration and the Federal Highway Administration also funded the creation of noise analysis software packages designed for air and automobile travel, respectively. However, neither the Federal Railroad Administration nor the Federal Transit Administration has funded the development of a software package to model noise impacts from rail systems.<sup>2</sup>

In addition to those software packages produced by government agencies, there are several commercially available software packages used for environmental noise modeling, each with similar capabilities and interfaces. Few packages, however, can accurately model train noise, given the unique frequency spectra associated with wheel-rail noise. CADNA, a software

package produced by DataKustik, a German software company, allows for frequency spectra of line sources to be added by the user. Because of this capability, CADNA was chosen to model the community impacts of noise from a heavy rail rapid transit line. The CADNA computer noise program can be used to generate noise contours, assess impacts, and predict noise barrier insertion loss. CADNA is described as “a sophisticated environmental noise model that takes into account distance attenuation, reflections, ground absorption, barrier effects, and source directivity.”<sup>3</sup>

### **The Accuracy and Precision of Environmental Noise Modeling.**

Though CADNA is considered a useful tool in preparing Environmental Impact Statements, the accuracy of predicted noise levels are not fail-proof. The individual running the modeling program is largely responsible for the accuracy of the predicted noise levels. In a paper by two German researchers on the topic of the accuracy of noise prediction programs, the authors wrote:

With noise prediction programs the sound pressure levels at different locations are calculated using the sound power levels of sources and taking into account the attenuations on the propagation path.... [The accuracy of predicted noise levels] depend on the accuracy of the emission values used and the accuracy of the propagation calculation.<sup>4</sup>

In a study of environmental noise generated by a rail freight line in Cleveland, Ohio, CADNA was found to accurately predict noise pressure levels within 3 dBA of field measurements. Since the difference between measured and modeled noise levels was generally less than could be perceived by the human ear, the acoustic consultants considered the computer modeling software “reasonably accurate and could be relied upon.”<sup>5</sup>

Though modeling has been used for the environmental assessment process and for the prediction of mitigation techniques, CADNA is not typically considered an urban design tool. In fact, CADNA and other noise modeling programs are typically not used in the urban design process, unless an environmental impact statement is required. Because CADNA is typically not used for the type of modeling work I conducted for this thesis, the accuracy of the predicted noise levels is questionable. However, for the purpose of this thesis, the accuracy of predicted noise levels is not critical. In fact, more important are the general trends of noise levels in comparison to existing conditions and the results of other methods of noise reduction.

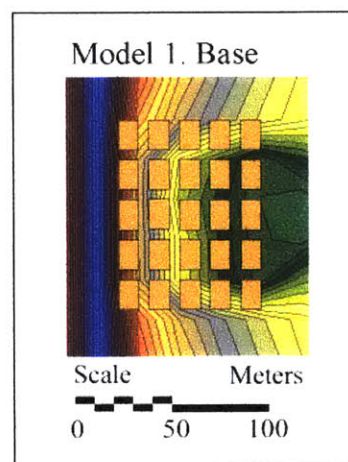
### **Modeling the Elements Urban Design**

Through the use of CADNA, noise dispersion can be visualized and the implications of different urban design elements can be isolated and understood. By examining the images

produced in CADNA, the effectiveness of each element can be seen. Several elements of urban design were modeled in CADNA to examine their effects on the transmission of noise through a neighborhood. This neighborhood is not a real place, but an abstract model created for testing purposes. The neighborhood is 100 meters wide by 100 meters deep. A line source, an at-grade rail line, is located on the west side of the neighborhood. In all models, the line source emitted the same noise pressure levels. The elements of urban design examined were walls, berms, building orientation, height, shape, width, and location impact.

### Baseline

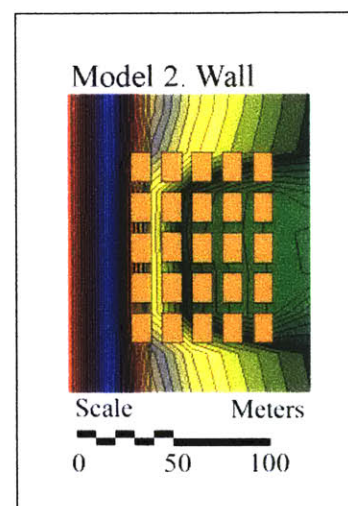
To begin, I modeled a baseline plan to examine how sound transmitted through the neighborhood, referred to as Model 1. This baseline plan is the control to which other elements are compared. This baseline plan simulates the preexisting conditions of a neighborhood in need of noise attenuation. The baseline plan contains 25 identical buildings placed in a grid across the entire site, with no specific sound reducing elements added to the site other than the buildings. By running the model of the baseline plan, it is clear that the buildings alone are capable of blocking some of the noise but the spaces between the buildings allow substantial amounts of noise into the neighborhood. This can be seen in Figure 4.1.



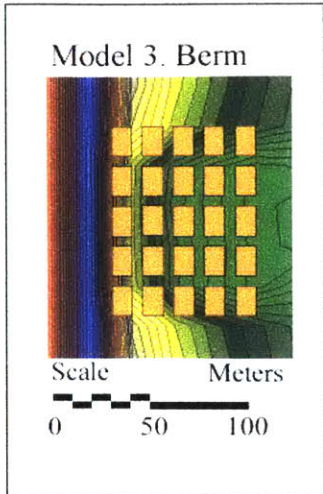
**Figure 4.1** Model 1 Baseplan  
Source: Author

### Walls and Berms

To examine how noise reduction elements can be added to the landscape to reduce the impacts of noise, I modeled how noise would be transmitted if berms or walls were constructed adjacent to the rail line, within the transit right-of-way. In Model 2, a six foot high wall was placed adjacent to the rail line. In Model 3, a six-foot berm replaced the wall from Model 2. In both Model 2 and Model 3, the buildings remain as in Model 1. It should be noted that additional modeling for cantilever walls was intended, however, CADNA is unable to model such configurations where two different points exist on the same vertical plane. From Models 2 and 3, we can begin to examine how well walls and berms attenuate the noise from an at-grade rail line and use those results for comparison with other urban design elements.



**Figure 4.2** Model 2 Wall  
Source: Author



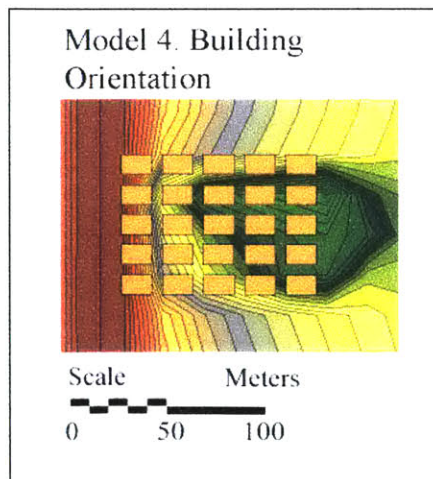
**Figure 4.3** Model 3 Berm  
Source: Author

In Model 2, in the wall was placed five meters from the rail line, it can be seen that the wall effectively reduces noise levels in the neighborhood. With the wall in place, the third row of houses was subjected to approximately 10 fewer decibels than without the wall. Similarly, the berm, 2 meters tall placed 5 meters from the rail line, at a slope of 1:1.5, also provided substantial relief from the rail noise. In fact, the berm was slightly more effective at reducing noise than the wall. The third row of houses found a 15-decibel relief with the berm compared to without the berm.

Although walls and berms are an effective means of reducing wayside noise levels, their use may have consequences on the urban landscape. Walls and berms may influence pedestrian routes and further divide neighborhoods. An at-grade wall, while preventing noise from entering a neighborhood, also reinforces the separation from one side of the tracks to another. The use of a berm is limited to locations where the right of way is wide enough to allow for the structure of the berm. In locations where a berm is physically feasible, an opportunity is available to integrate the natural and manmade landscapes. Berms require significant maintenance of the landscaping, which may make berms undesirable for transit agencies that do not wish to spend resources on landscaping.

### Building Orientation

In Model 4, the orientation of all buildings was shifted 90 degrees so that the narrow side of the building was parallel with the rail line, as seen in Figure 4.4. The spacing between the buildings remained constant but as a result of the shifted orientation, the rows of buildings



**Figure 4.4** Model 4 Building Orientation  
Source: Author

move further away from the rail source. As modeled, the shifted orientation had little effect on the noise passing into the neighborhood. However, as the shifted orientation moved the buildings further away from the rail line, those rows of buildings further away from the line source were less impacted by rail noise. The decreased noise levels are likely a product of distance and not caused by the buildings functioning as a noise barrier. It should be noted that in this model, the near-source noise levels appeared to be approximately 10 decibels less than in other models, even though the same source noise pressure levels were modeled. This may have been a result of less noise being reflected off



the buildings.

Though building orientation can influence noise levels in a neighborhood, it is important for an urban designer, planner, or architect to consider other factors when deciding building orientation. Natural sunlight, wind, street patterns, and surrounding conditions are integral to the overall design quality, and should be considered when determining the orientation of buildings on a site.

### Building Height

In Model 5, building height was considered. In this model, the heights of all buildings were increased from 3 stories to 6 stories. In plan view, the buildings are identical to that of Model 1. However, in cross section the difference is clearly seen, as illustrated in Figure 4.5

By running the simulation on Model 5, it was found that the increasing the height of all of the buildings had little impact on the noise levels predicted at ground level, as seen in Figure 4.6. It appears that in this scenario the ground level noise levels are not impacted by building height. It is likely, however, that the additional building height of a near-source building would reduce the noise levels of the higher floors of other buildings further away from the source. Additional modeling that examined the noise levels at upper floors of all buildings would be required to test this hypothesis.

Building height should not be determined solely based on its ability to block noise. Height should be decided by weighing a number of different factors including demand for space, location, surrounding building heights, and scale. Placing a tall building adjacent to the rail line may cast significant shadows onto a place already considered to be dark and scary; therefore, specific orientation, shape and distance between buildings will seriously affect both noise barrier effectiveness as well as the psychological comfort of the development's inhabitants.

### Building Shape

Models 6, 7, and 8 examine the impacts of building shape on noise propagation. In Model 6, the "U" shaped buildings were located adjacent to the rail line, with the top of the "U" oriented away from the rail line. In Model 7, a long building equal in length to the five of the previously used buildings was placed adjacent to the tracks. In Model 8, the

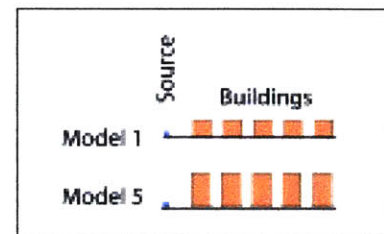


Figure 4.5 Cross Sections of Models 1 and 5 illustrating the difference in heights.  
Source: Author

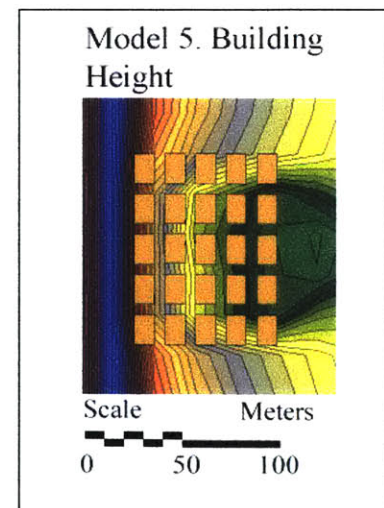
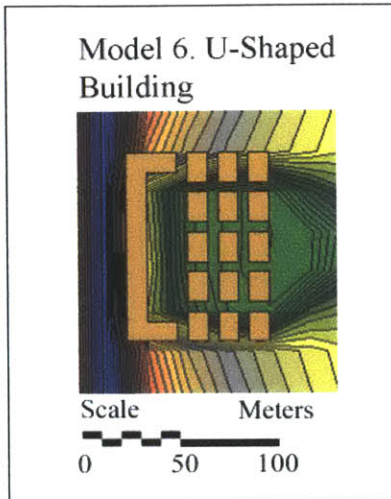
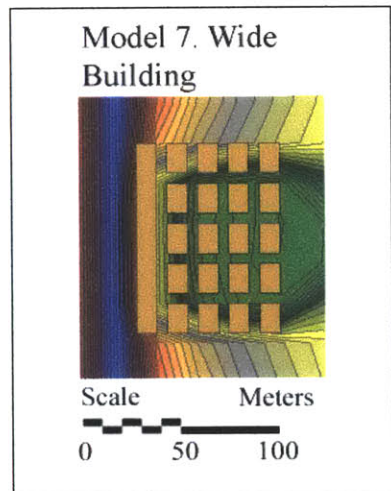


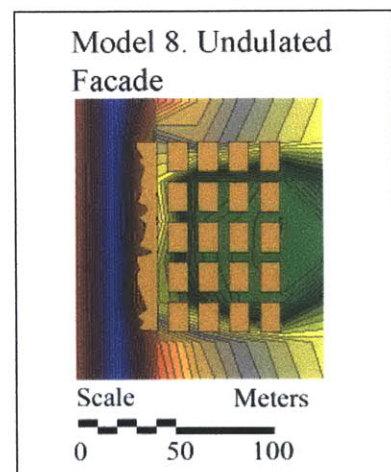
Figure 4.6 Model 5 Building Height  
Source: Author



**Figure 4.7** Model 6 U-Shaped Building  
Source: Author



**Figure 4.8** Model 7 Wide Building  
Source: Author



**Figure 4.9** Model 8 Undulated Facade  
Source: Author

facades of the buildings adjacent to the rail line were undulated. The results of the simulations of these models can be seen in Figure 4.7, 4.8, and 4.9.

In Model 6, it appears that the U-shaped building effectively blocked much of the sound from promulgating through the rest of the neighborhood. In fact, the U-shaped building was more effective at reducing noise levels inside the neighborhood than the berm or the wall.

In a similar scenario to that of the U-shaped building, a wide building was placed adjacent to the rail line in Model 7. Much like the U-shaped building, the wide building effectively reduced noise levels inside the neighborhood. However, the U-shaped building reduced noise levels at the north and south edges of the neighborhood more than the wide building. The wide building was approximately as effective at blocking noise as the wall.

In Model 8, a building with an undulated façade was placed adjacent to the rail line. The façade was irregular in shape. As a result of the undulations, the building was of less mass than the wide building in Model 7. The predicted noise levels resulting from the building with the undulating façade were greater than the wide building. It is unclear if the higher noise levels are a result of the undulating façade or the decreased building mass.

The shape of a building does influence noise levels but also has significant consequences on other objectives of urban design. As examined earlier, it is clear that urban design can reduce wayside noise levels. In particular, the “building as barrier” technique—the placement of one building adjacent to the noise source to block noise from propagating to other buildings further from the source, was found to be an effective method of reducing the impacts of noise. Though quite effective, the building as barrier technique does have consequences to the urban form. Noise, though very important, should not be the only factor influencing urban form. An urban designer must carefully balance the many factors that influence urban form and

should not simply design buildings and urban areas to reduce the impacts of noise.

In order to be effective, however, the “building as barrier” technique requires that the building be sufficiently wide to prevent noise from attenuating around the sides of the building. An argument can be made that on some sites wide buildings would be out of character with the surrounding buildings and therefore visually unattractive. To alter the visual impact of a large wall, the façade can be broken-up by a number of architectural techniques including altering façade materials or altering the façade setback. It is important to consider visual aesthetics in addition to the acoustical aesthetics.

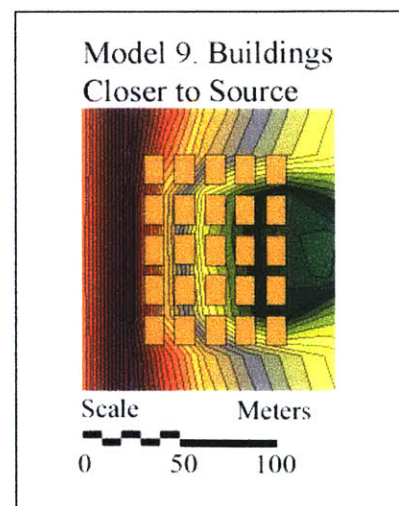
The building as barrier technique can only be used on sites that are large enough to allow for such a building to be constructed. In many urban areas, most redevelopment occurs in a piecemeal fashion as individual lots become available. The building as barrier technique is really only possible on large redevelopment sites such as the redevelopment of public housing sites or the adaptive reuse of industrial parcels.

### Building Locations

In Model 9, the implications of the neighborhood’s overall building placement were examined. The buildings adjacent to the rail line were placed closer to the rail line than the buildings in Model 1. By modeling these different scenarios, the fundamentals of urban design acoustics can be understood.

In Model 9, the buildings were placed five meters closer to the rail line. The row of buildings closest to the rail line was located five meters from the source. Interestingly, placing the buildings closer to the rail line had little impact on noise levels in the interior of the neighborhood. Additionally, the noise levels at the buildings adjacent to the rail line were not significantly higher. It should be noted, however, that the near source noise levels were less than predicted for Model 1. It is unclear why this occurred. A similar decrease in near-source noise levels occurred in Model 4, in which building orientation was examined. It is unclear why this phenomenon occurred.

Building location should be determined not only by the near-source building’s abilities to block noise, but by many other factors as well. It should be noted that in many urban areas, the existing lot lines and road patterns largely determine building location. In most cities, only on large redevelopment projects can new roads be significantly redesigned. That said, should the “building as barrier” technique be used, the buildings closest to the noise source should be placed far



**Figure 4.10** Model 9 Building closer to rail line.  
Source: Author

enough from the source so that architectural techniques can reduce interior noise levels to a comfortable range.

### **Conclusions on Urban Design Elements**

The balancing of multiple factors to create a single design is a fundamental element of the practice of planning and design. Noise is an important factor that influences the urban experience and so it must be considered when designing the urban environment. It is important to stress that the regulations must address the need for flexibility and provide some method for evaluating the balance of issues provided by potential design solutions. Further discussion of the design regulations can be found in Chapter 6 of this thesis.

### **Endnotes**

<sup>1</sup> Kenneth E. Nelson and Joseph L. Schofer, "Computer model for Highway Noise Reduction," *Journal of the Transportation Engineering Division*, vol. 100, no 2. May 1974, p. 325-334.

<sup>2</sup> Though both rail and road noise is typically characterized as line sources, the characteristics of the noise generated by cars traveling over a road are significantly different from train cars passing over rail. The frequency spectra of the wheel-rail interface is typically wider than that of tire-asphalt. As such, the FHWA noise modeling software is typically not used for assessing the impacts rail noise.

<sup>3</sup> City of Cleveland Home Sound Insulation and Noise Barrier Programs, Noise Analysis Technical Report, May 2000, Acentech Incorporated. p. 17

<sup>4</sup> Wolfgang Probst and Ulrich Donner, ACCON GmbH "The Uncertainty of Sound Pressure Levels Calculated with Noise Prediction Programs."

<sup>5</sup> City of Cleveland Home Sound Insulation and Noise Barrier Programs, Noise Analysis Technical Report, May 2000, Acentech Incorporated. p. 16

## **Chapter 5. Application of Urban Design Techniques to Specific Sites**

After general techniques of urban design were examined, these techniques were applied to specific neighborhoods. In Chicago, two sites were chosen that are fairly typical of development trends in Chicago. The two neighborhoods are both recent mid density redevelopment projects. The first site is the redevelopment of Henry Horner Housing on the west side of Chicago. The second site is Old Town Square and Village located north of Chicago's downtown Loop. In San Juan, two drastically different sites were chosen, one low density residential, the other a high-density central business district.

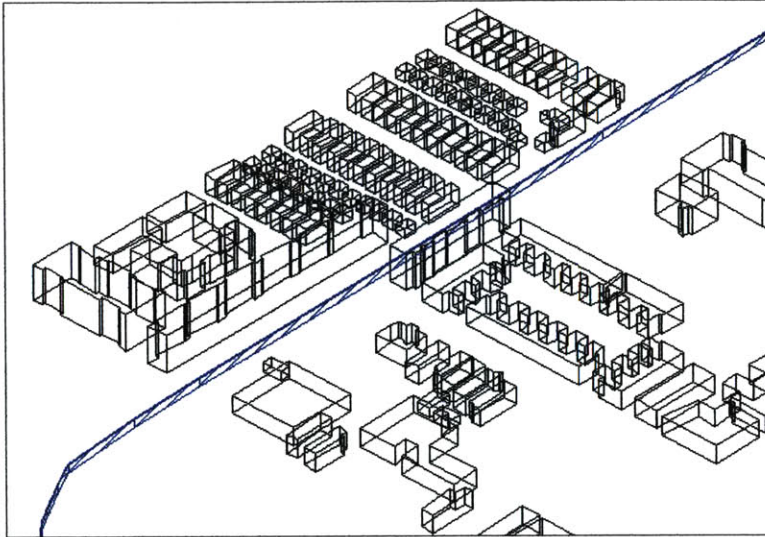
### **Information Sources**

In order to build the computer models, the base maps of each site was collected and entered into the model. To do so, several sources were necessary. Because Old Town Village and Square are such recent developments, the buildings do not yet appear on CTA or City of Chicago maps. For those sites, the site plans were obtained from the developer and entered into the GIS file of the neighborhood collected from the CTA. Similarly, on the Henry Horner site, the City of Chicago maps have yet to be updated since the redevelopment. As such, the site plan of the redevelopment was obtained from Peter Calthorpe and Associates. As building heights were not indicated on any of the plans, the building heights were estimated during field visits.

For the two sites in San Juan, the Tren Urbano office provided a AutoCAD file of all the neighborhoods adjacent to the Tren Urbano Alignment. The AutoCAD file was directly imported into CADNA. However, once again, building heights were not indicated in the AutoCAD file and building heights were estimated during field visits.

To accurately model the noise sources, several different techniques were used. To model noise radiating from the lightweight steel elevated structure in Chicago, two separate sources were used, a single line source and a vertical area source. The single line source represented the noise emitted from the wheel rail interface. The vertical area source represented the noise generated by the vibration of the lightweight aerial structure. Accentec, Inc., an acoustics-consulting firm in a study of the MBTA Charles-MGH Red Line T-stop, used this technique of representing elevated rail line noise with more than one source. At the Charles-MGH T-stop, transit cars travel over an older steel bridge causing noise to radiate from the wheel-rail interface and the steel structure, similar to the aerial structure in Chicago. Accentec represented the noise sources as both line sources and vertical area sources. The two sources are visible in the axonometric drawings of the Chicago sites, illustrated in Figure 5.1.

To model the noise generated by the Tren Urbano system, a single line source represented the noise created at the wheel rail interface. Because little noise is likely to be generated from



**Figure 5.1** An axonometric drawing of Old Town Village and Square. The two noise sources are visible in this drawing. The thick blue line represents the wheel rail interface. The hatched line represent the aerial structure.  
Source: Author

the concrete aerial structure, the aerial structure was not modeled as a source. However, the walls of the aerial structure were modeled as noise barriers. The modeling of the aerial structure was based on the cross section of the structure provided in the Environmental Impact Statement.

The source noise levels used for the modeling of the Chicago sites were estimated using noise pressure level readings taken in the field. The noise levels for the San Juan sites were based on the levels

presumed in the Environmental Impact Statement.

### **Henry Horner Housing, Chicago**

The history of the Henry Horner Housing development is typical of several development trends in Chicago. Originally constructed under an Urban Renewal grant, seven 13-story apartment buildings were placed on the site, adjacent to the CTA's elevated Green Line. The buildings typified the "tower in the park" designs of many Urban Renewal projects of the 1950's and 1960's. As with many Urban Renewal projects, the buildings suffered from disinvestments and in the late 1990s, the site was redeveloped under HUD's Hope IV program. Planner and Architect, Peter Calthorpe was selected to design the site. Calthorpe's plan called for mid-density townhomes along a reestablished grid. In his book *The Regional City*, Calthorpe described the redevelopment:

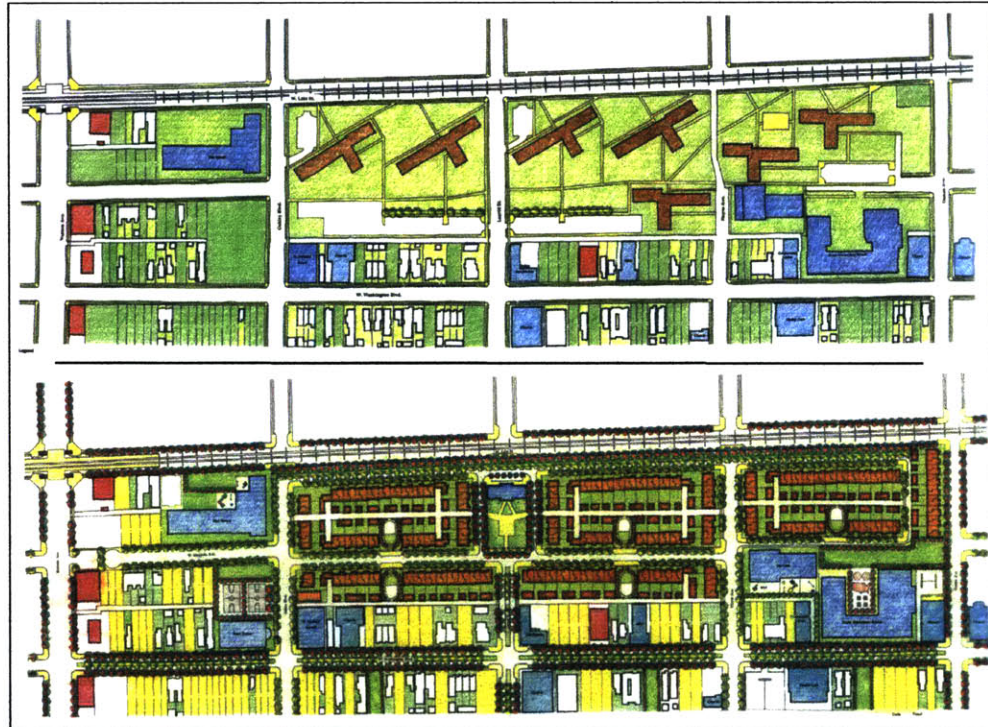
The old site plan for Henry Horner Housing clearly shows the discontinuity between the historic urban fabric and the isolated midrise apartments. The areas immediately surrounding the housing were very vulnerable to crime, as is the case in many public housing projects. Yet the assets of the site are plentiful: an abundance of schools, churches, and civic uses surround the housing, transit runs just to the north, and a commercial street is within walking distance. As the preliminary plan for replacement housing reestablished the tradition of street-front townhomes, stoops and private yards, the once-dangerous surroundings were eliminated and safe connections to the neighborhood were reestablished. As a result, there has been significant new private investment in housing and commercial development in an area that once was home to empty lots, burned-out houses, and failing stores.<sup>1</sup>

The site and building designs typify many of the principles of New Urbanism and Transit-Oriented Development. The brick townhomes have small front stoops or porches and are placed close to the street, setback from the sidewalks by only a few feet. The interior streets are narrow and are lined with trees. However, just east of the redeveloped site remain several abandoned apartment buildings

Though Calthorpe’s original plan oriented the buildings to front on Wells Street, facing the elevated CTA rail transit line, the plan was subsequently changed so that the buildings would front on interior streets. The rear facades of the buildings, facing Wells Street and the El, are almost entirely masonry with few windows. The façade is a concrete first floor and a brick second floor, a slight improvement to an entirely monotone wall but still rather dull and lifeless. The long, windowless facades fronting Wells Street provide a less-than-desirable pedestrian environment. Sparse landscaping at the rear of the building does little to break up the monotony of a largely blank wall. Perhaps more important than the visual aesthetics is that by orienting the buildings away from Wells Street, the street feels abandoned and utilitarian. The inward-facing buildings literally and figuratively turn their back on Wells Street, providing no interaction between the buildings and the streets. Jane Jacobs, in her well-renowned book, *The Death and Life of Great American Cities*, wrote of the importance of “eyes on the street” for pedestrians

to feel safe and for street life to flourish. Orienting the buildings to front on the interior street removes the eyes from the streets.

The redevelopment of the Henry Horner Housing project is similar to the redevelopment of several public housing projects in Chicago. As the “towers in



**Figure 5.2** Top: The site plan of the Henry Horner Housing Projects before redevelopment. Bottom: Calthorpe’s preliminary design for the redevelopment of the Henry Horner Site. The building orientation changed since the preliminary design.

Source: Calthorpe Associates



**Figure 5.3** The facades of the new buildings in the redeveloped Henry Horner site.  
Source: Author



**Figure 5.4** The view of the redeveloped Henry Horner Site from Wells Street, under the El.  
Source: Author

the park” are being torn down, lowrise, mid density projects are being built in their place, including the redevelopment of Cabrini-Green, located on Chicago’s north side, one of the largest public housing projects in the United States.

Prior to redevelopment, the site’s 13-story buildings were located in the middle of the site, with little apparent connection to the surrounding context. The tower-in-the-park design of the Henry Horner Public Housing project did little to mitigate the noise radiating from the elevated rail line. Small pockets of noise shadows were created south of the towers. However, most of the site’s the open space was subjected to high noise levels. The towers did provide a slight buffer to those buildings located directly south of the towers.

It is unclear exactly how the orientation of the towers affected noise levels. It appears that the offset building orientation may have influenced near source noise levels by limiting the amount of noise reflected off the buildings directly back towards the source. The orientation did, however,

allow noise to easily diffract around the buildings, creating smaller noise shadows and louder conditions on the south sides of the buildings.

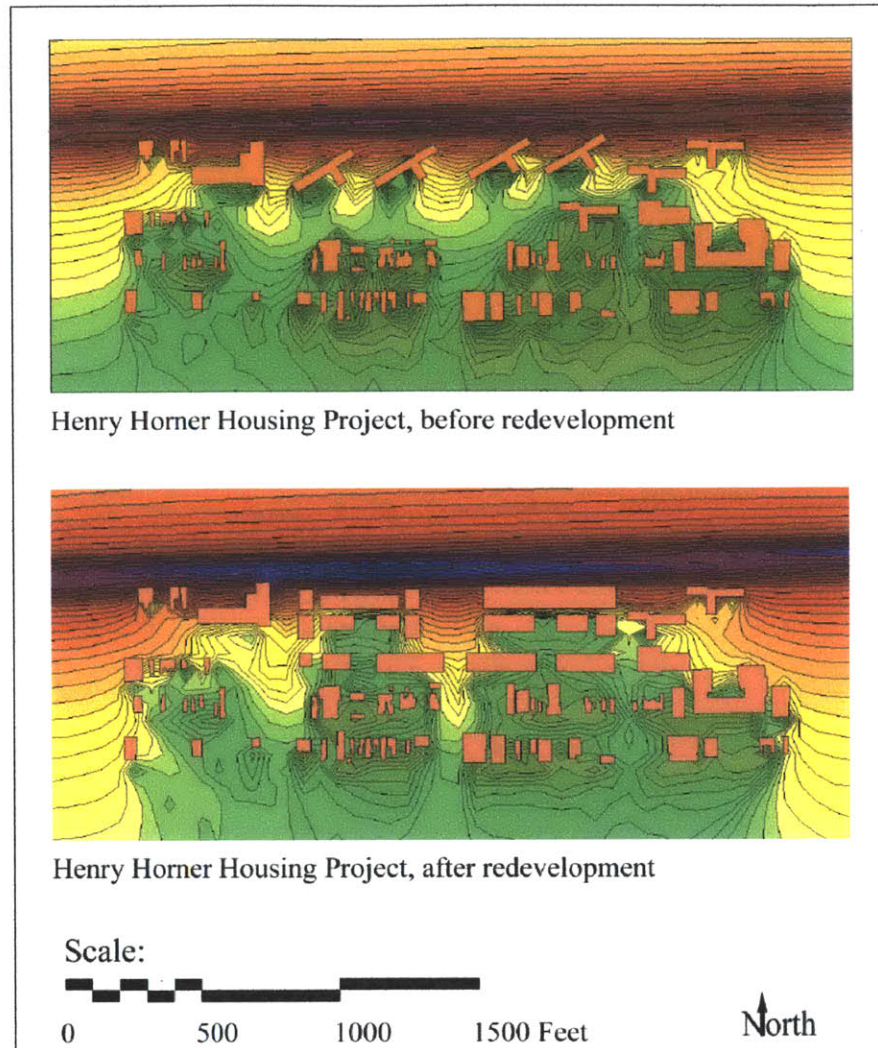
After the site was redeveloped and five of the towers removed, a number of 2½ story townhomes were placed on the site, re-establishing the street grid that existed prior to the public housing development. The redeveloped site provided small pockets of open-space on the interior of the site. As a result of the redevelopment the promulgation of noise through the neighborhood was altered. Much of the interior of the site was effectively shielded from the noise by the wide townhome buildings located adjacent to the elevated rail line. However, those buildings located



nearest the rail line were subjected to higher noise levels than the public housing towers.

Moreover, the placement of the buildings on the site and the wide spaces between the buildings allows noise to transmit into the site. A small grassy open space is placed in the middle of the redeveloped site, to serve as a focal point and entrance to the site. At this location no buildings block the view, and noise, of the elevated rail line. As a result, the noise from the elevated rail line is able to promulgate freely to the grassy open space. The noise levels at this open space are similar to the open spaces in the tower-in-the-park design.

Examining the results of the noise promulgation computer models of the pre-redeveloped and redeveloped Henry Horner Housing Project site provides an interesting perspective on the debate of the redevelopment of public housing sites and the Hope VI program which encourages low rise buildings and lower density site design. As was typical of urban renewal projects and the modern architecture of the 1950s and 1960s, the original mid-rise apartments were designed to provide light and air to enter cheap housing. The design of public housing was largely in response to the crowded conditions of tenement housing in older urban areas. However, as the public housing sites aged, problems with the tower in the park design became evident. Since the construction of public housing apartment towers on many urban renewal sites, views have changed about the design of public housing. HUD's Hope VI program marked a significant shift away from the view of public housing simply as a space of cheap living and instead took a wider



**Figure 5.3** The environmental noise modeling of the Henry Horner site, before and after redevelopment.  
Source: Author

view of the role of public housing. The intention of Hope VI is not just to create buildings for low-income residents but also to provide a physical and social environment in which they can better their lives. In doing so, Hope VI adopted many of the design elements of New Urbanism encouraging lower densities and smaller scale. However, in the redevelopment of many public housing towers to Hope VI neighborhoods, densities were decreased, resulting in fewer units total, and many fewer affordable units. While the towers did little to prevent noise from entering the neighborhood, they did provide more units than the redeveloped site.

### Old Town Village and Square, Chicago

Located on formerly industrial land adjacent to the CTA's Red Line, MCL Development Company recently completed one development and is constructing another on the other side of the El. The two developments are called Old Town Village East and Old Town Square. Though the projects both have Old Town in their names, neither of these developments is actually located



**Figure 5.7** The view of Old Town Square from the El.  
Source: Author

within the section of the city traditionally referred to as "Old Town." Similar to the redevelopment of the Henry Horner site, MCL's Old Town developments incorporate many elements of Transit-Oriented Development and New Urbanism. Both sites feature predominantly brick buildings with stoops or porches, echoing the older residential buildings of the city. Though the developer built these projects at

different times, the projects border one another and feature similar architectural styles, making the two projects function and appear as the same neighborhood.

Old Town Square was constructed in the late 1990s on the site of a former factory. The redevelopment included several apartment buildings, condominiums, and townhomes. The largest of the buildings, the four-story apartment building was placed on the west side of the site, adjacent to the El. The façade facing the El is almost entirely made of masonry, with a few glass brick windows. The impact of the windowless façade at Old Town Square is considerably

less than that of the redevelopment of the Henry Horner site, as the train runs on an elevated structure on its own right-of-way, not a public street. The right of way is currently used as a parking lot. While a parking lot may be a reasonable use under the EI, the security of those entering and exiting their cars may be a concern. The alleyway and elevated guideway behind large apartment buildings with windowless facades may be perceived as unsafe and unwelcoming.



**Figure 5.4** The rear facade of the apartment building at Old Town Square, adjacent to the EI.  
Source: Author

After the financial success of Old Town Square, the developer began construction of Old Town Village East, located adjacent to the EI, just west of Old Town Square. Old Town Village, with portions still under construction, feature similar site and architectural elements to that of Old Town Square. Almost identical to Old Town Square, a larger apartment building is located adjacent to the EI.

To examine the noise levels, the proposed site conditions were modeled. It can be seen from the model that the placement of large apartment buildings adjacent to the rail line provided quieter conditions in the neighborhood. In both Old Town Village and Old Town Square, the interior noise levels were reduced 10-15 decibels due to the placement of the buildings.

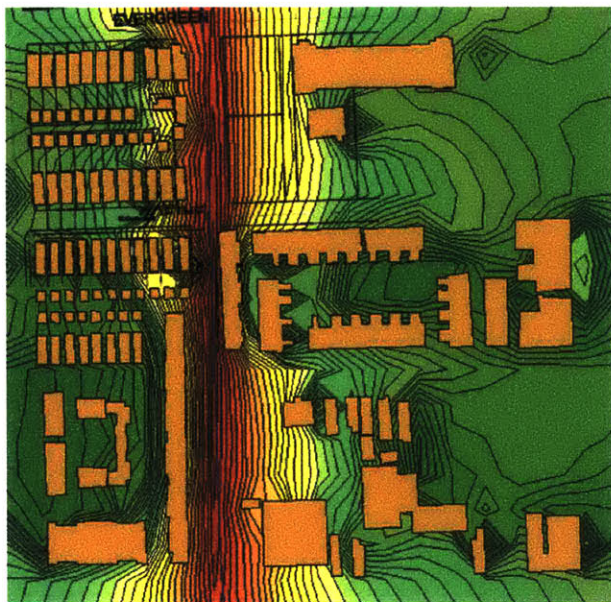
To examine how noise levels might be further improved, the impact of building height was considered. The heights of the two apartment buildings closest to the rail



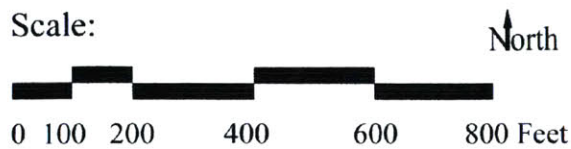
**Figure 5.4** The site plan of Old Town Village and Square..  
Source: Author



Old Town Village and Square, as proposed by developer



Old Town Village and Square, height of apartment buildings adjacent to El increased.



**Figure 5.9** The environmental noise modeling of the Old Town Village and Square Site. As evident from the models, building height made little difference on the groundplane noise levels.

Source: Author

line were increased. The relief caused by this increase in height was minimal. It confirms the assertion that building width is often times a more important consideration than building height, particularly for noise levels on the ground plane.

The site plan for Old Town Village and Square does raise several important issues regarding urban design. Siting large building adjacent to the rail line could influence pedestrian and automobile access. On the Old Town Village site, Scott Street was closed on the west side of the CTA right of way. The large apartment building was placed on the site, on the abandoned Scott Street right-of-way. Though effective at reducing the noise levels, transverse access at Goethe Street is no longer possible.

Though effective at reducing the impacts of noise, placing windowless facades adjacent to the rail line reinforces the notion that the rail line is a psychological barrier between two areas. If a resident is unable to see the other side of the tracks, the resident is likely to think of the other side of the tracks as a different neighborhood, supporting the notion of the “wrong side of the tracks.” However, the psychological impacts may be beneficial in some instances. Placing large buildings adjacent to the rail line may have important psychological effects on those living in, or considering living

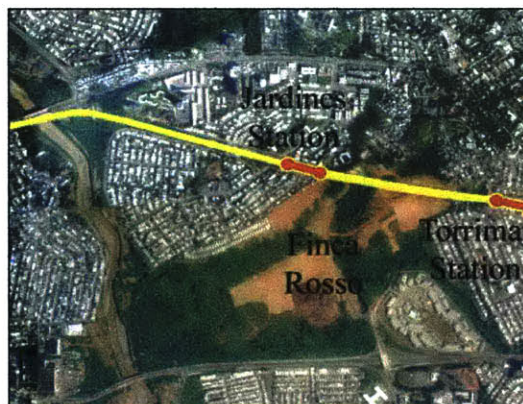
as in the case of potential condo owners on the Old Town Village site, the buildings further away from the source. In the Old Town Village Site, the large apartment building blocks the view of the El, potentially influencing the perception of noise for the rest of the site.

Though desirable in certain situations, placing large buildings adjacent to the rail line may not be feasible for any number of reasons. Placing large buildings on a site can be made difficult by the inherited land ownership and land use patterns. The lot lines, existing utility lines, and ownership patterns may hinder a developer from acquiring large tracts of land to construct wide buildings adjacent to the site. Moreover, finances always heavily influence the design of a development. Noise and the perception of noise will heavily influence the possibility of obtaining financing. In virtually all developments, a developer must be able to convince funding sources that the development will sell. Even with sophisticated noise insulation for the interior of the building, it may be difficult to obtain financing for the construction of a large building adjacent to the noise source for fears that no one will purchase the units in the building. Similarly, potential residents of the building may be less inclined to purchase a unit in the building, fearing that noise will be an annoyance, based not on the actual interior noise levels but simply on the proximity to the transit line and the fear of excessive noise.

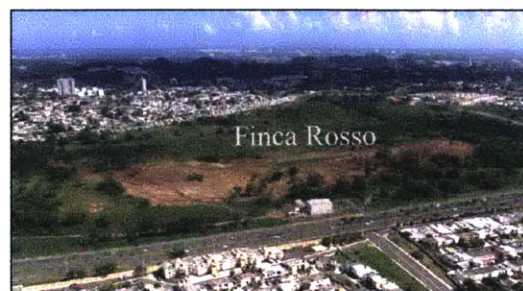
### **Finca Rosso Neighborhood, San Juan**

Located just south of the Tren Urbano alignment, between Jardines and Torrimar Stations, is an undeveloped, heavily wooded 300-acre parcel referred to as Finca Rosso. Since 1991, four plans have been proposed for the parcel, each a slight variation on the previous plan. Now, under the auspices of the Puerto Rico Department of Housing, a plan for Transit-Oriented Development is likely to move forward. The most recent plan calls for approximately 3500 housing units with some commercial and institutional uses. The highest densities are placed nearest the Jardines Station head house.

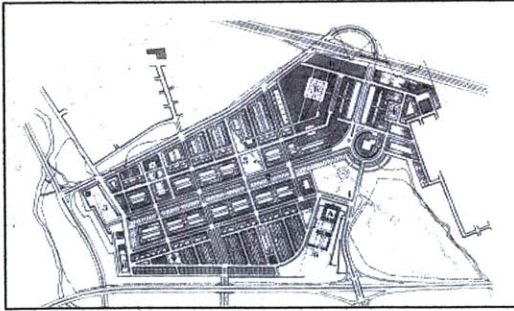
The Finca Rosso parcel is located between two very different neighborhoods. To the west is the Jardines residential neighborhood, a predominantly middle class area. To the east is the wealthy neighborhood of Torrimar, one of the wealthier



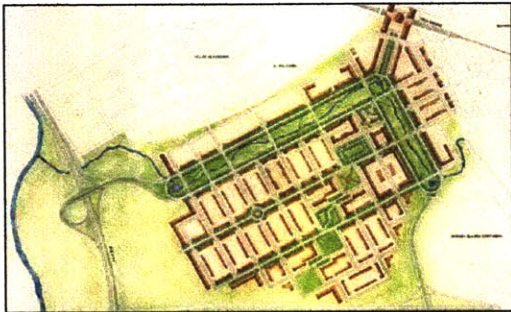
**Figure 5.10** Aerial view of the Finca Rosso parcel located between Jardines and Torrimar Stations.  
Source: Tren Urbano



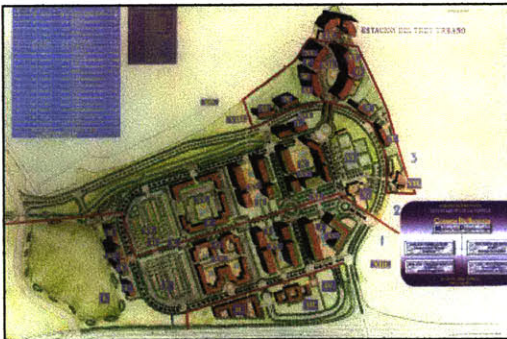
**Figure 5.10** Aerial perspective of the Finca Rosso site, looking north.  
Source: Tren Urbano



**Figure 5.12** The 1991 site plan for Finca Rosso. Significant densities of residential and commercial uses placed adjacent to the head house.  
Source: Tren Urbano



**Figure 5.13** The 1995 site plan for Finca Rosso. A greenbelt and drainage swale bisects much of the development from the head house.  
Source: Tren Urbano



**Figure 5.13** The 1996-1997 site plan for Finca Rosso. The blocks and greenbelt was altered.  
Source: Tren Urbano



**Figure 5.12** The 2001-2002 concept plan for Finca Rosso. Street hierarchy and land uses rearranged.  
Source: Tren Urbano

residential neighborhoods in San Juan. Both neighborhoods are comprised of one-story single-family houses on small plots of land. The Jardines neighborhood, Finca Rosso, and the Torrimar Neighborhood are located on a hillside, elevated several feet above the Tren Urbano Alignment. To examine how noise will promulgate through the proposed neighborhood, a section of the 2001-2002 plan was modeled. A consistent theme throughout all of the plans for the Finca Rosso site is a gateway into the site from the Tren Urbano head house located just north of the site. Though the building layout has varied with each new plan, the idea of a dense, mixed use development and small plaza at the north edge of the Finca Rosso site has remained consistent.

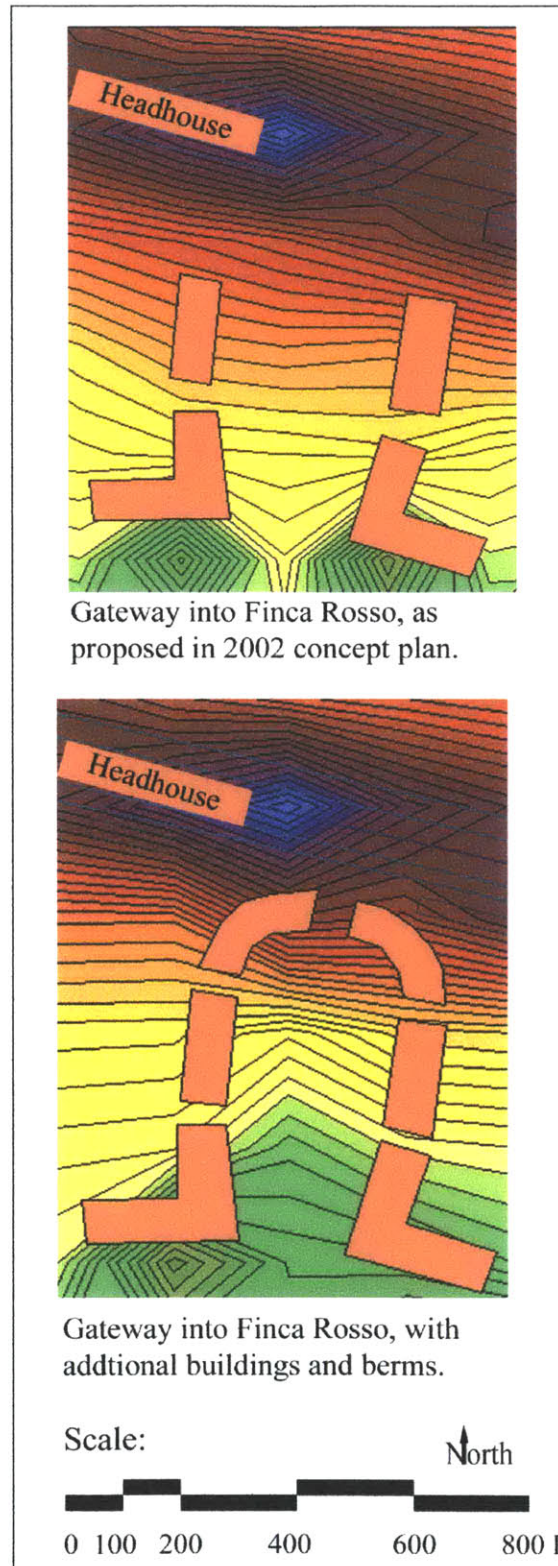
However, with placing higher densities and an open-air plaza near the rail line, noise may be an issue. To examine how noise might be best mitigated in the gateway area, the two designs were modeled to determine the noise impacts.

The first plan analyzed is based on the 2002 concept plan in which four buildings were placed along the edges of a public plaza. The buildings were several hundred feet from the Jardines head house. At this distance, the noise levels are high, but not unbearable. However, the location of the buildings and plaza creates a large portion of underutilized land between the plaza and the head house.

To examine how this land may be put to better use, two additional buildings were placed closer to the head house with the intention of using the buildings to shield some of the noise from entering the plaza. However, it is apparent from the computer models that placing the two crescent shaped buildings so close to the rail line does little to block the noise entering the plaza.

In addition to the two crescent-shaped buildings, a 6 foot high berm was placed between the buildings and rail line. However, the existing topography of the site makes the berm placement difficult. While the rail line is at-grade, this section of the alignment is in a slight valley, approximately 30 vertical feet below the adjacent properties. It should be noted, however, that the right of way is quite wide at this section of the alignment, and so the adjacent properties are approximately 100 feet from the rail line, allowing a rather gradual slope to the edge of the rail line. The berm was located at the top of the slope, near the crescent shaped buildings. Given its location, the berm did little to shield the noise from the rail line. The berm would likely have been more effective if located closer to the rail line.

The section between Jardines and Torrimar stations could provide an opportunity to create a linear park along the rail line. In this location, the Tren Urbano right-of-way is wide enough to allow for the construction of a landscaped berm and walking trail. In addition to providing an visually appealing edge to the at-grade rail line, the berm could block noise generated at the train. In this location, an at grade berm would likely not interfere with pedestrian and vehicular flows as the at-grade rail line already cuts off most transverse access. Moreover, the psychological impacts of a berm are likely to be minimal in that the rail line is in a valley, located at a lower elevation than the residences on either side of the right of way. As such, the visual connection between the two sides of the tracks would remain even if a berm were to be placed adjacent the rail line.



**Figure 5.16** Environmental noise modeling of Finca Rosso Site. The siting of the additional buildings did little to decrease noise levels. Source: Author



**Figure 5.17** Aerial perspective of Hato Rey's Golden Mile.  
Source: Tren Urbano



**Figure 5.18** View of Tren Urbano guideway and office towers near Roosevelt Station.  
Source: Author



**Figure 5.19** Typical homes near Roosevelt Station.  
Source: Author

### Hato Rey Business District, San Juan

Known as the “Golden Mile” for the many financial institutions located in the district. Clustered along Avenue Munoz Rivera and Avenue Ponce De Leon, are many 10-25 story office buildings. One short block from the main roads and office towers are residential neighborhoods comprised of one-story, single family homes.

Near Domenech Station, Tren Urbano's elevated guideway is within inches of the facades of several buildings. In fact, a portion of one building's entry canopy had to be removed for the guideway. Because these buildings are so close to the alignment, noise is a concern. The segment of alignment from Domenech Station to Roosevelt Station was modeled to examine how noise levels can be further reduced. Additional noise barriers were examined.

In Hato Rey, Tren Urbano will run on an elevated concrete guideway, weaving through some of the most valuable commercial real-estate in the metropolitan area. Although the guideway appears well-built and of solid construction, noise from the wheel-rail interface may remain a problem, particularly for those buildings located adjacent to the guideway, often within a few feet of the guideway. Located just one block beyond the office towers are smaller scale residential buildings, typically one-story concrete block structures on carefully manicured green lawns. The proximity of the residential properties to the rail line may cause concern of noise levels.

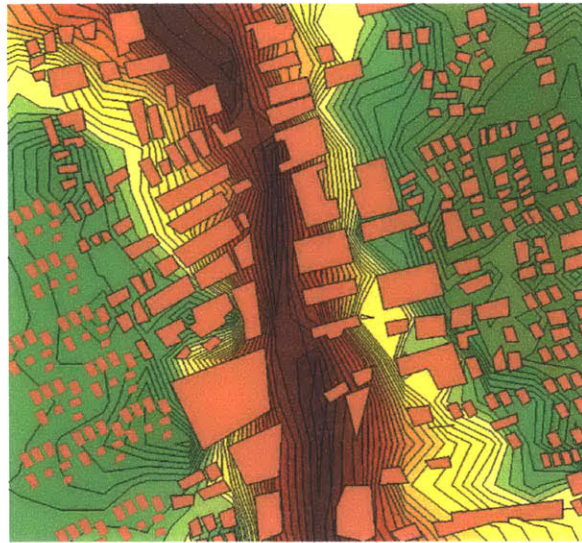


The section of the alignment from Domenech Station to Roosevelt Station was modeled to examine how the noise will promulgate through the neighborhood. From the modeling it can be seen that the noise levels at those buildings adjacent to the rail line will be quite high given the incredibly close proximity of the buildings to the rail line. However, under the current building arrangement, the large office buildings provide a sufficient buffer to the residential neighborhood. The residential neighborhoods are likely to experience little noise impacts, in large part due to the buffer created by the office and commercial buildings.

As demonstrated in the simulation, the addition of a three-foot noise barrier on the top of the existing parapet significantly reduced the noise levels at the abutting commercial and office buildings.

Though proven effective, additional noise barriers may not be necessary. Many of the existing mid and high rise office buildings adjacent to the elevated guideway are constructed so that the first few floors of the buildings are parking decks. Furthermore many of the office buildings were designed to limit the amount of noise entering the building. A portion of Hato Rey is beneath the path of airplanes landing at San Juan International Airport. As such, many of these buildings already feature noise-insulating windows.

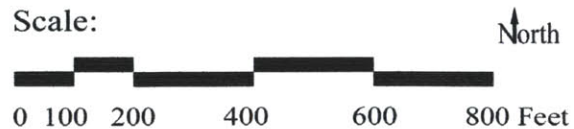
Though noise levels in the residential area are likely to be moderate,



Portion of the alignmnet, from Domenech Station to Roosevelt Station as built.



Portion of the alignmnet, from Domenech Station to Roosevelt Station with additional noise barriers on guideway.



**Figure 5.20** Environmental noise modeling of Hato Rey's Golden Mile. The additional noise barriers significantly reduces wayside noise levels.

Source: Author

the noise levels within the commercial buildings could be quite high depending upon building construction, windows and the specific uses within the building. As such, a possible solution would be to add additional noise barriers to the edges of the concrete guideway. In the second scenario, an additional 3-foot tall noise barrier was placed on top of the concrete parapet. As a result, the wayside noise levels dropped dramatically. Though the details of the barrier design were not examined, the barrier was modeled with a reflection loss coefficient of 20 dB, a standard reflection loss for barrier design. Adding an additional barrier to the parapet would alter the perceptions of riders on the train. Instead of gaining an interesting vantage point to see the city, riders would likely be viewing a blank barrier. However, if designed out of plastic and glass, the barrier could be transparent to view while opaque to sound, allowing views out of the train. Though much of the view from this section is only into the second and third floor windows of the office buildings, the views between the buildings could be an interesting perspective to view the city. In addition to blocking noise, the glass and steel design would fit in well with the modern design of the Hato Rey stations. It should be noted however that plastic and glass barrier, though less massive than concrete barriers, can effectively block noise transmission, typically through reflection, which may be a problem given the proximity of other buildings on the opposite side of the track.

Though these office buildings may already be well protected from the noise generated by the rail line, it does raise the question about appropriate uses adjacent to the elevated rail line. Though parking decks adjacent to the rail line may make sense when considering noise impacts, parking decks do little to contribute to street life.

However, the placement of office buildings adjacent to the rail line is a good use for a number of reasons. If mechanical ventilations systems are assumed for office buildings, the environmental consequences of noise-insulation are no worse as most office buildings are completely sealed. It should be noted, however, that new curtain wall technology can be used reduce interior noise levels while providing passive ventilation. Though many of the existing office buildings are noise-insulated, even without sufficient noise-insulation, the impacts of noise on office uses are likely to be less than the impacts on residential uses. While undoubtedly annoying, hearing train noise while typing in an office is not as bad as hearing that same noise when falling asleep.

However, just because a use is non-sensitive does not mean that it should be placed adjacent to the rail line. Ideally, the uses directly adjacent to the train rail line would be both tolerant of the noise and a use that encourages ridership. Placing office uses near transit stops should be encouraged because office uses are believed to be less sensitive to transit noise and offices are likely to be destinations for transit riders. In Hato Rey, the offices provide a buffer between the residences and the noise source, a buffer wide enough to prevent noise from

impacting the residences but small enough so that the residential neighborhood is within a comfortable walking distance to the Domenech and Roosevelt stations.

**Endnotes**

<sup>1</sup> Calthorpe, Peter and William Fulton, *The Regional City*, p. 264.

## Chapter 6. Conclusions

Though many techniques have been shown to reduce the impacts of noise from rail transit systems, rail noise remains a problem in many urban areas. Several questions remain: If noise reduction techniques are known, why does transit noise remain a problem? Moreover, how should transit agencies interested in noise mitigation approach the issue of transit noise? In this chapter these questions will be explored.

As discussed in previous chapters, the impacts of noise can successfully be reduced through at-source noise reduction, near source barriers, or through urban planning and design techniques. For future transit line extensions and new-starts, sensitive system design can minimize the production of noise. For existing systems, improving, maintaining, or retrofitting wheel, rail, and secondary equipment stock to minimize the production of noise can be effective. Furthermore, city planners, urban designers, and architects can use a number of techniques to insulate adjacent neighborhoods from wayside noise. And yet while these techniques are available, authorities have not exploited these methods and noise from transit systems remains a daily annoyance for many urban residents.

### *Public Agencies and Externalities*

Though the impacts of noise are intertwined with the urban design and planning of a city, the problem of noise cannot be fully addressed without examining the local, state, and federal policies that attempt to regulate the transit systems and the developments that occur adjacent to transit. The control of noise should not fall only on the shoulders of planners and designers but must also be addressed through public policy.

Fundamental to the problem of transit noise is the question of who should take responsibility for the impacts of noise. While many would quickly point to the transit agency as the party responsible for producing the noise, cash-strapped transit agencies can rarely afford the costs of significant infrastructure rebuilding necessary to fully eliminate the production of noise. Such projects usually require financial assistance from the federal Department of Transportation, through the Federal Transit Administration. Unlike transit line extensions or other large infrastructure projects, politicians will not get their names and photos in the newspapers when money is designated to noise mitigation. Frankly, noise mitigation is not sexy. And so, with limited budgets, transit agencies often make noise issues a low priority and as a result noise continues to be a persistent problem.

Transit agency officials likely see their agencies as providing a social service and any externalities that arise from providing the service pale in comparison to the benefits of the service. Furthermore, transit officials may not fully grasp the scope of the problem. Other than

complaints from abutters, they receive little feedback on the effects of transit noise. The best indicator of the importance of the noise problem is the lack of development adjacent some to the transit system, a problem that is rarely seen as the responsibility of the transit agency. It is this absence of a tangible result that influences the transit agencies understanding of the problem. Furthermore, transit agencies gain little by reducing noise levels. Even if property values adjacent to their rail lines were to soar as a result of decreased noise, the transit agency gains little, if anything.

A transit agency may see its sole responsibility as moving people from one point to another. Transit agencies must change their narrow focus and remember that they are part of a larger system whose goal is providing residents with a higher quality of life. But how can transit agencies respond to the need to reduce noise when they are constantly threatened with budget cuts, union strikes, and low ridership?

With that, there remains a public policy issue of how to respond when a public agency that provides a social service also harms the public. If a private company were to harm the public by releasing a pollutant into the air, government would quickly intervene. However, when a public agency creates the pollutant, we are less aggressive in our actions to correct the wrongdoing. While the public may agree that transit agencies should operate quieter trains, we don't want our service reduced as a tradeoff of funds going to noise mitigation instead of operations. And so the noise problem remains.

### **Agency Jurisdiction**

In addition to the transit agency responsible for operating the transit system that generates the noise, other public entities at different levels of government also enter the noise policy debate, including the Federal Transit Administration, the Department of Housing and Urban Development, state level transportation authorities and the local municipality. The discussion of the transit noise problem must address policy and not focus strictly on operations and design.

Though multiple agencies are involved in the regulation of noise, it remains a persistent problem. The division of responsibilities of regulating noise across jurisdictions has never been fully determined. In the United States, this fractured regulatory scheme to control noise has prompted poor urban design in many instances. The failure of American noise policy speaks to the difficulty of writing regulations that carefully balance the multitude of influences and potential consequences. In particular, no agency or entity is directly responsible monitoring and enforcing noise issues related to transit operations. This section examines how the various entities and authorities address the problem of transit noise.

### *National Noise Policy: The Failure of the National Noise Control Act*

In 1972, Congress passed the Noise Control Act, establishing a national noise policy to “promote an environment for all Americans free from noise that jeopardizes their health or welfare.”<sup>1</sup> The Noise Control Act intended to address all noise sources including transportation and industry. The regulations focused on at-source noise generation, not on noise levels experienced by the receiver. The scope of the act was quite broad, intending to address noise sources from lawnmowers and dishwashers to airplanes and automobiles. The Act did not set particular noise levels, but passed that responsibility to the Environmental Protection Agency and other administrative agencies.

Though well intentioned, the Act failed to adequately address the enforcement and “due to structural and procedural flaws, the legislation was doomed to failure from the day it was signed by the U.S. president,”<sup>2</sup> according to William Lang in an article in *Noise Control Engineering Journal*. Lang goes on to state:

Congress failed to assign responsibility for implementing the legislation to a single agency of the federal government. It divided the responsibility among the Environmental Protection Agency (EPA), the Federal Aviation Administration, and others. Jurisdictional disputes between federal agencies developed immediately over which agencies should regulate the ‘major’ sources of noise.... EPA retained regulatory authority over all [non-aircraft] sources of noise, but its efforts ended in total failure. It was not for lack of effort on EPA’s part, but primarily because the EPA was unable to get any cooperation from the manufacturers of the “major” sources of noise in America.... Manufacturers quickly learned that it was less expensive to fight the EPA’s jurisdiction in court than to implement noise control on their products.<sup>3</sup>

By the 1980s, the EPA’s failure to adequately address noise control resulted in the funds for noise control programs to be cut completely. Congress decided that the benefits of noise control are highly localized and therefore should be carried out by state and local authorities and that the EPA should remove itself from the noise regulation business. The failure of the Noise Control Act has limited the authority of the national government to regulate noise. Moreover, partly due to the failure of the Noise Control Act, noise remains a persistent problem in many urban and suburban locations.

### *Limited Scope: FTA’s Transit Noise and Vibration Impact Assessment*

The criteria for noise levels established by the Federal Transit Administration are only to used evaluate proposed new projects or expansion to existing facilities. As such, daily operations of long-standing rail transit lines, such as much of the CTA system, are unaffected by the criteria. As a new system, Tren Urbano was required to follow the assessment procedures and noise level criteria established in the FTA’s document. The FTA noise criteria are based on the increase in

sound levels cause by a transit project and range between 0 and 10 dB. If existing background levels are low, a 10 dB increase is permitted, whereas if background levels are high, no increase is allowed. In the event that projected noise levels exceed the criteria, noise abatement techniques must be considered.<sup>4</sup>

The limited scope of the FTA's criteria does little to improve the noise levels of existing rail transit lines. Even with the new protocol, future projects that are subject to the FTA's criteria during assessment will not necessarily be as quiet as desired by neighboring residents. A project's 10 dB increase allowed by the regulations when existing background levels are less than 40 dB will sound dramatic.

Furthermore, the FTA's regulations focus on existing land uses when determining the impacts of the noise. For instance, if a new rail transit line were to be proposed through an industrial neighborhood, the FTA's guidelines would allow for higher noise levels, never considering that one day the industrial properties may one day be converted to residential uses. No mechanism is in place to ensure that the rail transit system will be modified if the adjacent uses change. Establishing noise levels for existing land uses is shortsighted and suggests a lack of understanding of city growth patterns. Even when a transit line is sited to encourage redevelopment, the noise assessment does not need to consider the noise impacts on future land uses.

If a transit agency were found to be out of compliance with the FTA's criteria and the limits established during the environmental assessment, the procedure to force compliance is expensive and time consuming. No single agency is responsible for noise enforcement of transit systems. As such, a resident would need to file suit against the transit agency for failure of compliance, either individually or through a class-action lawsuit, a procedure most laypersons would be unwilling or unable to do. There is no government agency responsible for monitoring a transit system's compliance with FTA regulations. Given the lack of federal policy powers, federal agencies assume no responsibility in enforcing noise issues.

#### *The Need for Flexible Regulations: HUD Noise Abatement and Control Policy*

The Department of Housing and Urban Development (HUD) established its own Environmental Criteria and Standards, which included a section on noise abatement and control and set limits for the acceptability of funding for HUD-assisted residential projects. According to the regulations, "It is HUD's general policy to provide minimum national standards to HUD programs to protect citizens against excessive noise in their community and places of residence."<sup>5</sup> The regulations address new construction, support for existing construction, and rehabilitation. The regulations prohibited HUD funds from being distributed to projects where noise exceeds maximum allowable levels. Since the policy was first written, it has been revised

considerably to allow for flexibility to consider other goals. The history of the HUD regulations provides an important lesson the need for regulatory agencies to balance numerous factors rather than concentrating strictly on noise.

In 1972, the HUD regulations threatened to derail the construction of a low-income housing project that exceeded permissible noise levels, caused by a highway adjacent to the site. Located in New York City's Lower East Side between the Manhattan Bridge and Brooklyn Bridge, the Two Bridges project proposed a residential apartment building between Market Slip and Montgomery Street. The excessive noise was generated by traffic on the elevated section of Franklin Delano Roosevelt Drive, bordering the site, and the commercial and industrial uses in the neighborhood. To combat the noise, HUD suggested that the building be sited further from FDR Drive and be constructed with double glazed windows and central air conditioning. The developer feared these mitigation techniques would be too expensive, driving up the cost of the project and subsequently the rents. A proponent of the development stated, "If we incorporate these suggestions, the cost of the project will skyrocket. And catapulting costs would mean that rentals in the project will be placed beyond the financial reach of the area's low-income residents."<sup>6</sup>

Clara Fox, Executive Director of the Settlement Housing Fund and staff consultant to Two Bridges Settlement Houses, Inc., the developer of the site, wrote an article in the *New York Times*, addressing many of the developer's problems with the HUD policy. She wrote:

It seems incredible that a well-intentioned noise guideline is jeopardizing the construction of a low-income housing project that residents on the Lower East Side were on the verge of getting built after 14 years of planning and struggle.... The site of the Two Bridges project is on all counts one of the most desirable in Manhattan.... [The site has] a fine view of the river and ready access to transportation and commercial, educational, health, recreational and cultural facilities. Yet, despite all these desirable environmental factors—and they are all supposed to be taken into account under guidelines stemming from the Environmental Protection Act of 1969—the project is in danger of being scrapped on the issue of excessive noise levels alone.... What is so terribly frustrating about the situation is that the decibel count in HUD's guidelines are on a national basis, making little if any distinction between levels in a city like New York and those in a small Midwestern town. Granted that poor people deserve protection from adverse environmental factors in their housing, one must still ask whether noise alone outweighs the miserable conditions that now afflict most of the people who want to move into the Two Bridges project. Most of the thousands on the waiting list are housed in dark, dreary apartments in aging tenements, living with rats and roaches and, often enough, doing without heat and hot water in the winter... Even if the noise levels at the Two Bridges project are higher than they should be, the applicants would cheerfully choose them in preference to their present living conditions. One of the ironies of the situation is that the Two Bridges site is only a block from Gouverneur Gardens, a thriving middle-income co-op on East River Drive... It is only federally subsidized housing that has to meet the new noise guidelines. The affluent, who can afford nonsubsidized housing, can have their



noise and their view of the East River, too. The effect of the HUD ruling on the Two Bridges project is that poor people may not have that choice.... The issue is not just decibels, but decent housing for people who desperately need it.<sup>7</sup>

After much negotiation, HUD officials decided not to waive the noise requirements; instead, they increased HUD's financial support to the project and paid for the noise-mitigation by installing double-glazed windows and central air conditioning.

Since the Two Bridges project, the HUD noise policy has been significantly revised, offering greater flexibility and consideration of other HUD goals. In the policy, HUD established goals of maximum interior and exterior noise levels. The policy states:

It is a HUD goal that exterior noise levels do not exceed a day-night average sound level of 55 decibels. The level is recommended by the Environmental Protection Agency as a goal for outdoors in residential areas. The levels recommended by the EPA are not standards and do not take into account cost or feasibility. For the purposes of this regulation and to meet other program objectives, sites with a day-night average sound level of 65 and below are acceptable and are allowable.<sup>8</sup>

The HUD policy was changed after the EPA revised its recommendations given the mitigation costs of establishing a lower Ldn. The EPA's recommendations were largely based on an analysis of the number of people living inside the 55 dB noise contours near airports, a significant source of environmental noise. During the preparation of the Aviation Safety and Noise Abatement Act of 1979, federal agencies found that 20 million residents lived within the 55 dB noise contour and that the "mitigation cost estimates would have been staggering beyond all reason."<sup>9</sup>

Furthermore, the HUD policy was changed to allow other HUD objectives to be considered. The policy was revised to allow the consideration of "non-acoustic benefits." The policy states that "where it is determined that program objectives cannot be achieved on sites meeting the acceptability standard of 65 decibels, the Acceptable Zone may be shifted to 70 dB on a case-by-case basis" if certain criteria are met, including that noise is the only environmental issue, the project meets other program goals to provide housing in proximity to employment, public facilities, and transportation, and that the project is in conformance with local goals and maintains the character of the neighborhood. By altering the regulations and allowing additional considerations to outweigh noise requirements, HUD recognized the importance of flexibility in achieving an important goal.

### *The Limited Authority of State Transportation Authorities*

Under Federal Highway Administration regulations, state transportation authorities are able to determine their own criteria for acceptable noise levels. In contrast, the state transportation authorities have no jurisdiction over the noise issues related to transit systems, as

the Federal Transit Authority has never granted such power to state authorities. As such, state transportation authorities do not monitor or enforce noise levels from transit systems.

#### *Local Municipalities: Zoning, Building, and Noise Codes*

Though noise codes at the local municipal level are commonly used to ensure a quieter environment and have proven effective at limiting noise from diverse sources as construction and nightclubs, transit systems are exempt from local regulations. Local authorities can require that residents keep their dogs from barking after sunset, but local authorities cannot require transit operators to run a quieter train, as federal legislation has never been passed granted such authority to local jurisdictions.

However, local municipalities do have two important tools that can be used to control the impacts of transit noise: zoning and building codes. A local municipality, through their zoning and building codes, can require that proposed development in areas most impacted by transit noise be constructed in such a manner as to limit the impacts of noise. A further discussion of building and zoning codes can be found later in this chapter.

#### **Resident Choice and Deregulation**

In addition to the regulatory authorities, a city's residents also factor into the issue of noise pollution. As many economists would be quick to point out, the existing pattern of land uses and real estate values in a city is largely due to the combination of individual choices and government implemented land use control. The argument could be made that the vacant properties next to rail transit lines are simply the market's way of responding to the problem of a noisy transit system. If proximity to transit service were that important to residents, they would be willing to live next to the noisy transit line or find some means of mitigating the noise.

Market forces greatly influence the design of the environment. It is incredibly difficult to separate the influences of pure market forces from that of regulation on the design of the environment, as most every incorporated location in the United States has some form of regulation related to noise. Even in Houston, Texas, often upheld as an example of a city without zoning, a noise code exists,<sup>10</sup> suggesting that even Houstonians believe noise is an environmental problem that must be addressed through regulation and not left to market forces.

#### *Financial Institutions and Insurance Agencies*

In addition to resident choice, the financial institutions and insurance agencies backing development projects have a great impact on the design of development. Though not well documented in the United State mortgage companies often have minimum standards that must be met prior to granting a loan. Those standards include noise concerns. If a developer is unable

to meet the requirements of the lending institution, the project will not be built. In Canada, the Central Mortgage and Housing Corporation published several documents on noise abatement through architectural and site planning techniques.

In addition to funding sources, many insurance companies require that buildings be constructed of higher-grade materials; these requirements go above and beyond local building codes. For instance, in San Juan, local building codes do allow for wood frame construction in certain locations but insurance companies typically require concrete and masonry construction to protect against hurricanes.<sup>11</sup> As a result, almost all new houses in the San Juan area are constructed out of concrete and masonry. In areas effected by noise, insurance companies may require improved building standards, even if government regulations do not require it.

### *Market Solutions and Equity*

Given the examples of how the market reacts to urban noise, some suggest that deregulation of noise emission sources is appropriate and necessary. Such an argument would suggest that the market would determine what levels of noise are tolerable and what land uses should be placed adjacent to noise sources. Furthermore, an argument could be made that noise provides for affordable housing because houses subject to noise are often less expensive than similar houses without noise impacts. Furthermore, noise from transit systems does, at least in theory, provide cheap real estate, which is necessary for a diversity of uses and users, such as bars and nightclubs. Additionally, the land impacted by transit noise could be used for other utilitarian purposes such as the storage of maintenance vehicles and other manufacturing uses.

However, such arguments are flawed and, in fact, rather dangerous. For one, a transit system impacts too large a geographic area to suggest that bars and nightclubs should be placed along the entire alignment. Second, the land uses adjacent to transit systems should not be placed there simply because they are less sensitive to high noise levels. The purpose of a transit system is to provide mobility to people; therefore, the land uses adjacent to the transit system should ideally be both tolerant of the noise and a use that encourages ridership. Furthermore, proposing that depressed residential land values near the source of noise is a good thing suggests that those who cannot afford better housing should be subjected to the ill-health effects associated with exposure to high noise levels. Regardless of income, individuals should be granted a safe and comfortable place to live and work.

The problem of deregulation is that urban design is the cumulative effect of individual choices and when left to their own devices, individuals are likely to make choices that best suit their own needs, regardless of the impacts on others. With time, it is possible that the market will establish buffers around noise sources as residents move away from the source. However, buffers are not necessarily the best solution, particularly in an urban environment where land is scarce.

Noise pollution is very much a dilemma of the tragedy of the commons. A single property owner does not control the acoustics of an environment. Noise transmits across property lines and political boundaries.

### **Cost Benefit Analysis**

In considering the best solution for reducing externalities, a cost-benefit analysis could be employed. A cost-benefit analysis may be a useful means of convincing some stakeholders that a noise-reduction project is worthwhile; however, cost benefit analyses can be flawed and lead to misguided or misinformed decisions. Placing a monetary figure on the acoustics of a city is not a precise science and the costs and benefits are not distributed equally throughout society. Land use and transportation are complex systems and decisions regarding them cannot easily, and accurately, be reduced to monetary terms. Furthermore, cost-benefit analyses rarely consider the implications of alternatives solutions. For example, if a noisy transit line were removed from a city and the all passengers were expected to travel by private automobile, the cumulative noise impacts from the resulting automobile traffic, though more disperse, may in fact be worse than the noise created by the transit line.

In a cost-benefit analysis, a precise definition of the end goal is critical. In performing a cost-benefit analysis of transit noise, defining the “tolerable” level of noise is necessary. Furthermore, it is necessary to determine the location of the “tolerable” level. Determining the tolerable noise level inside a residence instead of at the edge of the right of way will significantly alter the cost-benefit analysis. Cost-benefit analyses have been used to determine the most cost effective solution for reducing the impacts of noise generated by airplanes. No cost-benefit studies were found regarding noise from transit systems. Studies on aircraft noise have shown that noise-isolation of those homes within the flight path is the most cost-effective solution, as path mitigation from an airplane is not a feasible option. Though noise-isolation of all houses within a given decibel contour may prove to be the most cost-effective method of reducing the impacts of noise, such a solution says nothing about the impacts of noise on the use of outdoor space. If the cost-benefit analysis were to consider the use of public open space, the most-cost effective solution may prove to be at-source noise reduction and not noise-insulation of homes.

The trouble with the cost-benefit analysis is that it assumes a concentration of wealth and that all participants appreciate the costs and benefits equally, which is clearly not the situation. A cost benefit analysis may show that the most cost effective means of reducing noise would be to rebuild the entire system. However, if a transit agency cannot afford to rebuild the system and cannot obtain money from federal sources, the cost benefit analysis was of little use. Cost-effective and politically effective are not always synonymous. Furthermore, while abutters may rejoice in their newfound silence, a transit agency gains little and loses a lot if it diverts money

away from operations to be used on noise mitigation projects. If there were a very large pool of money to be divided by an unbiased entity, a cost-benefit analysis would be useful. However, given the divided nature of public and private interests, a cost benefit analysis is of little help.

### *The “We Were Here First” Argument*

If a cost benefit analysis were to show that the best use of funding would be for the transit agency to pay for improved noise insulation of residences impacted by the noise, questions remain over the legal and ethical necessity of a transit agency to pay for the improvements. In Chicago, the transit system and noise associated with it was established before many, if not all, of the residents who now live in the neighborhoods adjacent to the tracks. In San Juan, with few exceptions, the track has been constructed through existing neighborhoods. This distinction has important legal and policy implications in that the notion of “moving to the nuisance” has long been debated in land use law and policy, predating formal zoning law.

Residential sound insulation programs funded by the Federal Aviation Administration were largely a result of lawsuits filed by communities impacted by airport take-offs and landings. However, airport operators are quick to point out that many of the residents of those communities moved to those neighborhoods long after the airport began operating, claiming that many of the residents purchased their homes at significantly reduced rates given the noise issue. As such, the airport operators feel that they should not be required to compensate these landowners who chose to move into a residence knowing full well that the residence was in the airport landing-path. Airport officials suggest that if the airport were to pay for the noise insulation of the residences, those residents who recently bought into the community would be getting a great deal—the resident bought the property at a reduced rate, someone else pays for the improvements, greatly increasing the value of the home.<sup>12</sup>

However, the U.S. legal system views the matter of “coming to the nuisance” differently. In the 1972 landmark decision in *Spur Industries, Inc. v. Del E. Webb Development Co.*,<sup>13</sup> the Arizona Supreme Court found that when a new development was constructed next to an existing cattle farm, the cattle farm became a public nuisance but the developer must indemnify the cattle farm owner for a reasonable amount of moving or shutting down the business. Even though the operation of the cattle farm was a public nuisance, the fact that the cattle farm predated the development was reason for the developer to pay for the remedy.

Should such logic be extended to noise from public transit systems, the court may determine that the noise from the transit system is a public nuisance, but new developments should pay for mitigation themselves. In the event that a new system was installed or existing service extended, the courts may not be so lenient, citing that the neighborhood existed prior to the transit service. Parsing the fine line between new and existing is difficult in constantly

changing urban areas.

Though the noise from a transit system may be considered a public nuisance, matters are further complicated by the fact that transit systems also provide a public service. No case law has tested the boundaries between public nuisance and public service, a problem difficult to navigate. Even without the legal repercussions, a transit agency should accept the fact that a noisy system hurts the city as a whole and decreases the quality of life of the city's residents.

### **Transit Agency Responsibility**

Given the complex legal and political framework in which a transit agency operates, how should a transit agency respond to the problem of noise? What should the agency's noise policy address? Who should be responsible for overseeing that the policy is adhered to? This section examines those questions.

For a transit agency to fully address the issue of noise, the agency must change its attitude about its mission. Transit agencies must see themselves as part of a larger system that provides a better quality of life for residents of the city. They cannot view their mission simply as providing transportation and mobility. Furthermore, transit agencies must acknowledge that there are no simple solutions to the complex problem of transit noise. That said, they must adopt policies and practices that make noise reduction a priority.

Because there are no easy solutions, transit agencies must use a multi-pronged approach to reduce the impacts of noise. Transit agencies should consider using as many noise reduction techniques as feasible, including capital projects, at-source reduction, near source path barriers, and receiver isolation. Furthermore, transit agencies should partner with other institutions and agencies to assist in the fight against noise.

#### *Capital Projects to Rebuild Existing Alignment*

Rebuilding entire rail transit systems just to reduce noise impacts is not politically or economically feasible, even though such projects could largely eliminate the noise problem, given today's wheel, rail, and structural technology. However, capital projects to rebuild segments of the alignment that are particularly noisy should not be dismissed. For instance, the Chicago Transit Authority's Harrison Curve Realignment Project, a dramatic s-curve just south of the downtown Loop, was an instance where capital improvement dollars went to redesigning and rebuilding a segment of the alignment, largely in response to the problem of noise. The project received funding from the Federal Transit Administration, Illinois Department of Transportation, and the Regional Transportation Authority.

In many instances, even if noise is a problem, noise alone may not be considered a significant enough problem to convince funding sources that a segment of alignment should

be rebuilt. Finding additional reasons other than noise to rebuild aging, noisy structures may be necessary. It is important to note that many of the noisiest structures are also those that are structurally decaying and may be structurally unsound. Noise is often a signal of other, potentially more serious, problems.

The Chicago Transit Authority's \$482 million "Renew the Blue" project, currently ongoing, is rebuilding a large segment of the elevated Blue line west of the Loop. The project reconstructs a portion of the alignment originally built between 1895 and 1912. The CTA's website cites speed as the major reason for the reconstruction. The CTA states,

The Cermak (Douglas) branch deteriorated to the point that nearly half of its 6.6-mile length (35,000 feet) is in "slow zones" that require trains to operate at 15 m.p.h. instead of the normal 55 m.p.h. The slow zones can make a trip from the terminal at 54<sup>th</sup>/Cermak to downtown take up to 35 minutes. When the line is reconstructed, this trip will take only 28 minutes.<sup>14</sup>

In addition to speed, the CTA states that many of the stations needed to be rebuilt to comply with ADA regulations and that the power supply system was obsolete. Though not officially stated by the CTA in the "Renew the Blue" literature, noise from the old lightweight steel structure was a consideration when deciding to rebuild the alignment, according to CTA's Jack Hruby.<sup>15</sup> The "Renew the Blue" campaign is a good example of addressing noise through major reconstruction.

But as sum of nearly half a billion dollars spent on rebuilding approximately 5 miles of alignment is difficult to justify simply for noise concerns. As such, the transit authority should attempt to build coalitions with other institutions to gain political and economic power to make change. In many cities, the rail transit serves powerful institutions such as hospitals, colleges, and universities. The transit authorities should partner with these institutions to lobby for increased funding for noise attenuation projections.

In addition to the huge sums of money required for these capital projects, they only solve the problem of noise for the segments that rebuilt and do not address the noise at a system-wide level. However, this piecemeal approach to noise mitigation should not be dismissed just because its scale is limited. Every portion of rebuilt alignment that effectively reduces noise is a benefit to the neighborhoods affected.

### *At-Source Reduction*

Short of large capital projects to rebuild segments of the alignment, transit agencies should study how to use their resources to minimize the impacts of noise of their existing systems, particularly focusing on at-source reduction. To do so, however, is quite difficult given the complex causes of noise on a rail transit system.

Transit agencies should hire noise consultants to study the sources of noise. Although

many transit agencies may have staffers with knowledge of noise, an outside expert may be necessary for several reasons. A consultant will likely have greater knowledge of noise and analysis capabilities than in-house staff. For instance, a consultant could perform Fourier analysis of system noise to isolate the various sources of noise, a task not easily performed without expensive equipment and technical knowledge. Further, there are many misconceptions about noise sources and solutions among laypersons, including in-house staff. Additionally, an outside consultant would be less susceptible to in-house politics regarding the noise problem. Often, one division within a transit agency may feel that the noise problem is caused by another division. For instance, the track designers may blame the maintenance folks and the maintenance folks blame the train operators. A consultant should be able to find the problems and solutions and avoid the battle between agency divisions.

Such consulting work could lay the groundwork for finding cost-effective means of reducing noise levels. Once the sources of noise are clearly identified, solutions can be devised. Using a cost-benefit analysis solely to study at-source solutions could be one means of finding solutions on the cheap. A cost-benefit analysis could estimate the decibel reduction for each mitigation technique and the cost associated with it. Such an analysis could show the cost-per-decibel reduction. It should be noted, however, that certain techniques are only effective under certain circumstances. For instance, rail lubrication effectively cuts down on wheel squeal during curve negotiation, but does little on segments of tangent track. Finding the cost-per-decibel-per-linear-foot of alignment is more complex.

In addition to new physical solutions, transit agencies must examine their operations and maintenance practices to determine how noise problems can be minimized through daily practice. Wheel truing, rail grinding, braking mechanisms and operator habits all significantly influence noise levels and must be addressed. For instance, the Chicago Transit Authority's rail grinding system should be reconsidered. According to the *Transportation Noise Reference Book*, the CTA's abrasive block grinding train requires 110 passes over a rail section to smooth the surface fully whereas a rotating grinding stone can accomplish the same goal in two to three passes.<sup>16</sup> The CTA's rail grinding process causes sparking and requires fire protection during the process. Clearly, the CTA's rail grinding is cumbersome and time consuming. As a result, rail grinding typically only occurs once a year per alignment.<sup>17</sup> Such changes to maintenance practices must be examined.

Another item for transit agencies to consider is the use of new technology to monitor noise levels that can provide feedback on maintenance practices and operator performance. The Toronto Transit Commission's wheel-rail monitoring system, discussed in Chapter 2, is such a system. By digitally recording the vibration levels and car numbers of each passing train, the Commission can isolate which cars are particularly problematic and require maintenance. Such



a system can also be used to test new maintenance and operations practices. Combining today's sophisticated Intelligent Transportation technology that monitors precise locations of transit cars with noise and vibration recordings can help monitor particular maintenance problems such as wheel flat and rail irregularities.

In addition to technological solutions, transit agencies should keep better tracking of the noise problems reported by abutters and riders. If the agency receives a noise complaint about a particular location, car, or line the agency should take the complaint seriously, find the source of the problem and work towards a solution. Such a response to complaints is part of acknowledging that the agency is part of a system meant to improve the lives of residents.

### *Path Mitigation*

In addition to at-source solutions, a transit agency should consider the use of near-source barriers and berms to reduce wayside noise levels. Berms and barriers can be very effective at limiting the impacts of noise but only under certain circumstances. Berms and barriers are particularly useful when the wheel-rail interface, typically higher frequencies, is the major source of noise.<sup>18</sup> Rail-side noise barriers do little to mitigate noise from aerial structures.

Wayside barriers are an effective option for rail segments that are at-grade or open cut, as well as for newer, massive aerial structures, such as the concrete guideway structure used on portions of the Tren Urbano system and the CTA's Blue line reconstruction. The design of the barriers should be in harmony with the surrounding conditions. For instance, glass and steel barriers may be in context in Hato Rey, surrounded by new office buildings. In Chicago's residential neighborhoods, the glass and steel barriers may look out of place and other materials should be considered. On the elevated portion of the Tren Urbano alignment, glass and steel barriers may be in character with the modern architecture of many of the area's stations. Such details as the tensile structures at Pinero Station, as seen in Figure 6.1, though purely for decoration and not actually for structural support, can be mimicked



**Figure 6.1** The tensile supports at Pinero Station evoke a modern feel.  
Source: Author



**Figure 6.2** Superimposed image of Tren Urbano guideway near Domenech Station with additional noise barrier constructed on existing guideway. The glass noise barrier has tensile supports, mimicking the architecture of Pinero Station.

Source: Author

in the design of the noise barriers, as sketched in Figure 6.2.

Though effective, barriers do cost money to build and install, though often less than other methods of noise mitigation. To pay for the installation of barriers, a transit agency may wish to consider using a portion of the barrier for advertising space. Transit agencies are well accustomed to providing advertising

space inside their transit cars, buses and stations, so thinking of barriers as billboards may be the next step. A glass and steel barrier can be adapted to allow digital images to be projected on it, providing a high-tech image to both the transit system and the advertiser. Furthermore, the transit agencies may wish to market such space to targeted advertisers, such as products in which noise and sound are relevant to the product. Advertising Bose noise-reduction headphones on a noise barrier could be clever and effective product placement and generate money for the transit agency.

In addition to walls, shields, and other hard barriers, transit agencies should consider using berms and biobarriers when possible, in locations such as at-grade and open cut rail alignments. Berms and biobarriers provide an opportunity to add green into urban areas, which is usually seen as a welcome addition. In places where the right of way is wide enough to allow it, transit agencies should consider placing a berm or biobarrier next to the track to create a linear park and walking trail. To create such plans, transit agencies should consider partnering with parks commissions to design, fund, and build such projects. Such a solution would provide many benefits including the creation of new open space in the city, adapting underutilized land for recreational uses, find new constituents to support such endeavors and reduce wayside noise levels. A sketch for such a proposal is seen in Figure 6.3.

### ***Planning, Urban Design and Architectural Regulations***

A transit agency should take advantage of all noise reduction techniques, including land use planning, urban design, and architectural solutions, typically considered beyond the jurisdiction of a transit agency. A transit agency should take several steps to ensure that such techniques are used,

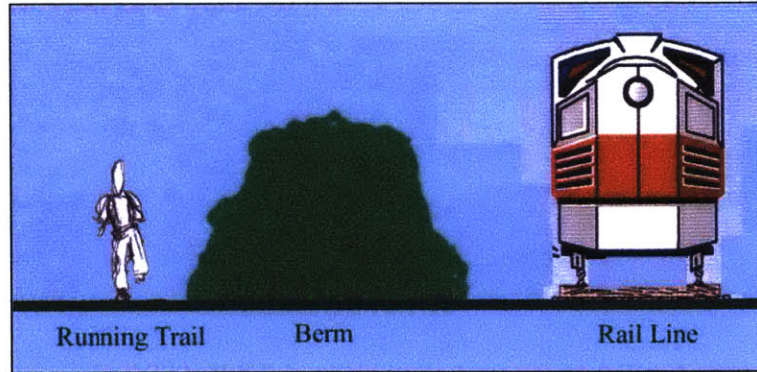
including working with other agencies that are more directly connected to the land development and provide education about the techniques.

In many cities, transit agencies are working closely with land use planning agencies to adopt new regulations that encourage transit ridership, as is occurring in Chicago. Such partnerships can be exploited to influence land use regulations to require noise considerations. A fundamental question such regulations must address is what should the area directly adjacent to the tracks be like? This question is difficult to answer, particularly near elevated transit lines where the structure's visual presence is also an issue. The transit agency should work with the regulatory agency and the community to decide such issues.

Several options are available for consideration of the areas under and directly adjacent to the track. Such areas can be designed as alleyways where utilities are clustered and other less-than-desirable uses such as storage and car parking occur. In every urban setting uses such as parking are needed but nobody wants them displayed in prominent locations. Directly adjacent to transit lines might be an appropriate place for such uses. However, if such uses are allowed there, those spaces are likely to be perceived as unsafe and unwelcoming.

Another option is to create landscaped open space under and adjacent to the rail line, as discussed above. However, even if the area is nicely landscaped, will the visual presence of the rail line prevent people from using the park? If a transit agency were to allow a portion of their right of way to be landscaped, the agency should be concerned about ownership and maintenance issues of the landscaped area. Without regular users, the park may quickly become under-maintained and undesirable.

New regulations that include noise considerations should address the use of urban design techniques discussed in Chapters 4 and 5 of this thesis. On parcels large enough to allow for such construction, the regulations should encourage the “building as barrier” technique. The regulations should make sure that the buildings close to the source are also designed to



**Figure 6.3** Cross section diagram of using berm to create running path adjacent to at-grade rail line.  
Source: Author

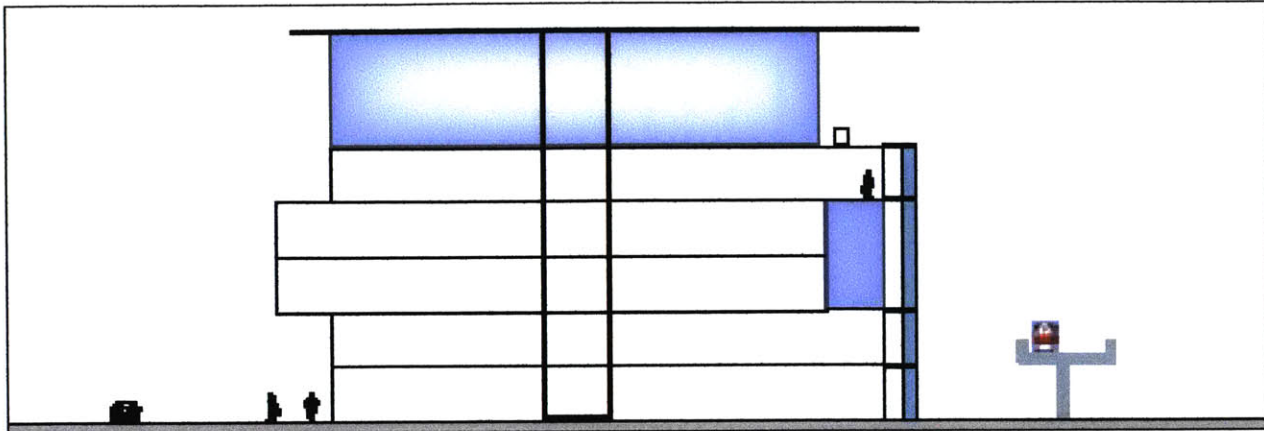
sufficiently reduce interior noise levels. The “building as barrier” technique should specify that the barrier building be located far enough from the rail source to allow light and air to the rail right of way. The buildings should not be constructed directly adjacent to the rail line as the rail right of way could result in a dark, canyon-like setting if large buildings were placed directly adjacent to the rail line. Sunlight patterns should be studied to examine the shadows that would be cast from the proposed buildings. However, another option would be to place the buildings directly adjacent to the transit line, using the space adjacent to the transit line only for service access. However, placing the buildings so close to the rail line makes noise insulation of the building increasingly difficult. The larger the distance between the source and the building, the less noise the building façade must block.

Though the design goal of noise reduction is laudable, the regulations address the financial realities of the development industry. In order to ensure that these guidelines will be used, development incentives should be considered. The incentives could be higher densities and a quicker approval process for those projects that meet established goals and objectives. Placing density bonuses on good design can also increase potential transit ridership, as is the intention of many Transit-Oriented Development regulations and projects.

In addition to density bonuses, planning officials may wish to consider using a transferable development rights (TDR) programs to transfer densities away from one area to others. Such a program could remove density from areas not served by transit and encourage higher densities to areas well served by transit. Though used in the past to mitigate noise problems by removing density near the noise source, cities should consider using TDR to increase densities near transit and taking advantage of economies of scale. As part of the TDR program, noise guidelines can be included for the receiving areas. By increasing densities in the receiving areas, the cost of noise solutions can be more easily absorbed.

Planning agencies should also consider increased benefits through bonuses for using green design and noise proofing. Density bonuses should be considered for those developments willing to use glass curtain wall technology and passive ventilation systems to reduce noise levels. A curtain wall could be used at the rear of a building adjacent to the rail line, providing noise reduction while still allowing residents to peer out onto the tracks, as illustrated in figure 6.4. Though quite radical, such design could mitigate noise, provide passive ventilation and create a safer feeling for the area directly under and adjacent to rail lines.

The regulatory mechanism by which development adjacent to the rail transit corridor will be reviewed should be a special permit for all development in the transit-corridor overlay district. Though a fast-track approval process may be desired to expedite and encourage particular design goals, the agency may wish to consider that noise studies be required of all development in district. Such a requirement could become a barrier to development, since such



**Figure 6.4** A cross section of building which uses curtain wall at the rear of the building to block noise from the adjacent rail line. Source: Author

studies cost developers time and money. The regulatory agency may wish to set benchmarks for a streamlined process if certain conditions are met.

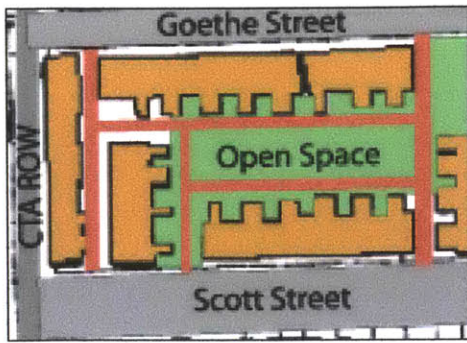
Another planning and design tool a planning agency should consider is encouraging commercial, retail, and office uses directly adjacent to transit systems. Such uses are less sensitive to transit noise than residential uses and do encourage transit ridership. Planning agencies should encourage commercial and retail uses where pedestrian and/or automobile traffic is high enough to support such uses. Placing these uses directly adjacent to the rail line can buffer more sensitive uses.

### *Architectural Review*

In addition to planning and zoning agencies, transit agencies should work with building and architectural review agencies to improve their regulations regarding noise-proofing structures. Transit agencies should encourage building regulations to allow for new materials and new construction techniques to reduce interior noise levels. In addition, building codes should be revised to consider floor plan layout as an option to reduce the impacts of noise in addition to façade treatments. Finally, building regulations should be revised to require inspections of noise levels after construction, rather than just plan inspection. Improper construction can severely reduce the effectiveness of noise-mitigation techniques and must be carefully monitored.

### *Joint Development Possibilities*

In addition to working with regulatory agencies, transit agencies may wish to consider using joint development as a means of trying new design solutions for mitigating noise. Joint development, the practice in which transit agencies and developers partner to construct buildings on property owned by the transit agency, can be an opportunity for the transit agency to display cutting-edge noise mitigation technology, architecture, and design. A project featuring green



**Figure 6.5** A portion of the site plan of Old Town Square. Though the buildings block noise from entering the open space, the open spaces feel very private.  
Source: Author



**Figure 6.6** The gated entrance to the open space at Old Town Square, reinforcing the privateness of the open space.  
Source: Author

design and glass curtain wall technology could be a bold statement for a transit agency to prove their commitment to sustainable practices of all types.

Transit agencies should work with developers and city officials to plan open spaces in appropriate areas. The building as barrier technique can be used to provide shielding for open space areas. Open spaces near transit stops are often the most highly visited open spaces in a city. Protecting such an open space from transit noise helps ensure that people will use the space. However, shielding open space with large buildings may create the feeling that the open space is private, as intentionally created at Old Town Village in Chicago, as seen in Figure 6.5 and 6.6. The specific design and landscaping of the open space must be carefully considered to ensure the notion of public open space, if that is, in fact, the intention. To further reduce the impacts of transit noise, adding a masking noise to the open space, such as a small waterfall or fountain, may provide enough background noise to obscure the surrounding urban noises.

### *Planning, Design, and Architectural Education*

In addition to influencing regulatory agencies, transit agencies should take it upon themselves to educate developers and homeowners about techniques that can be used to reduce noise impacts. Producing a pamphlet that educates the public of the architectural, urban design, and planning techniques discussed in Chapters 3, 4, and 5 of this thesis, could help alleviate the problem of noise without costing much money or resources. However, if a transit agency were to produce such a document, it may appear as if the agency is passing the responsibility of noise reduction to the general public. However, if such a pamphlet were to be produced as part of a larger campaign on appropriate forms of development adjacent to the transit line, the noise-mitigation techniques will be in context of the larger issue surrounding Transit Oriented Development.

In addition to educating the public about noise mitigation options, noise control and acoustics should be introduced into the planning and urban design curriculum of accredited professional programs. Many architectural schools require students to take at least one semester of architectural acoustics so that their students are aware of the many issues related to the aural

environment. Similarly, planning and urban design programs should consider introducing courses and lectures specifically addressing environmental noise and acoustics.

### **Recommendations for Further Research**

Much is still unknown and likely misunderstood about urban design and acoustics. There are five main focus areas in which further research should be pursued to gain:

1. A more robust understanding of the acoustics of urban design and how elements of urban design can be used to mitigate noise impacts, including the use of street furniture, façade materials, and architectural detailing.
2. A further understanding of the impacts of noise on property values. The economic impact of noise may be an effective tool to convince policy makers that noise issues must be addressed.
3. A further understanding of how environmentally sensitive architecture can be integrated with noise reduction, such as the previous efforts to use curtain walls as noise barriers. Ecologically sensitive design is increasingly becoming standard practice and noise control should be included in such designs.
4. A means of integrating design and analysis into one process to introduce the consideration of acoustics into site planning and urban design. This can be accomplished through the integration of software packages such as CADNA and AutoCAD, in which the designer could run simulations during the design process rather than exporting the design into a separate program for analysis. Similarly, acoustics could be an added element into the Illuminating Clay project, a collaboration between the Department of Urban Studies and Planning and the Media Lab, in which design and analysis is integrated into one process through the use of physical models and computer simulations. Thus far, the Illuminating Clay project has been used to analyze stormwater runoff and wind, based on pre-programmed algorithms. A similar algorithm could be used to introduce acoustics into the project, allowing designers to consider the noise impacts
5. A further analysis of costs of noise reduction techniques and their effectiveness. Convincing transit authorities to spend resources on noise reduction is difficult given the current demands on their budgets. As such, show cost-effective methods of reducing the impacts of noise could be greatly useful for a transit authority.

### **Conclusion**

As stated previously in this thesis, many techniques are known to reduce noise levels. Due to a multitude of reasons, transit noise remains a problem. If at-source noise reduction is not able to reduce noise to acceptable levels, planners and urban designers must consider noise-

reduction as a goal of their work. Planners and urban designers are well suited for such tasks since balancing multiple factors to create a single design is a fundamental element of the practice of planning and design. Noise influences the urban experience and must be considered when designing the urban environment. However, it is not the only consideration and the regulations must address the need for flexibility. Planners and urban designers must become as familiar with decibels, emissions, and attenuation as they are with building setbacks, façade materials, and variances.

It is the duty of all planners and urban designers to consider the greater social impact of any project they work on. Because noise affects the lives of many urban residents, planners and urban designers must consider on noise an imperative. Traditionally planners and urban designers have misunderstood and under appreciated the impacts of noise. It is now time for planners and urban designers to work to providing a quieter environment and a better quality of life for all.

#### **Endnotes**

<sup>1</sup> Noise Control Act of 1972.

<sup>2</sup> William Lang “Is noise policy a global issue, or is it a local issue?” in *Noise Control Engineering Journal*, Vol. 49, No. 4, July-August 2001.

<sup>3</sup> Lang, 2001.

<sup>4</sup> *Transit Noise and Vibration Impact Assessment*, US DOT report number DOT-T-95-16.

<sup>5</sup> Department of Housing and Urban Development, *Environmental Criteria and Standard*

<sup>6</sup> “Noise Survey is Planned At Projected Housing Site,” *The New York Times* Oct 2, 1972; pg. 41

<sup>7</sup> Clara Fox, “Noise Issue Must Not Halt Project,” *The New York Times*. November 5, 1972, Sec. 8, p.1.

<sup>8</sup> Department of Housing and Urban Development, *Environmental Criteria and Standard* revised as of April 1, 2001.

<sup>9</sup> William Albee, *Why We Must Supplement DNL Noise Analysis*, May 2002.

<sup>10</sup> Houston City Ordinance, Chapter 30, “Noise and Sound Level Regulation.”

<sup>11</sup> Interview with Professor Esteban Sennay

<sup>12</sup> Interview with Stephen Lukachko, MIT Aero-Environmental Research Laboratory

<sup>13</sup> 108 Ariz. 178, 494 P.2d 700 (1972)

<sup>14</sup> CTA Website, [www.transitchicago.com](http://www.transitchicago.com), 1/20/03

<sup>15</sup> Interview with Jack Hruby, VP of Rail Operations

<sup>16</sup> *Transportation Noise Reference Book*, sec. 16.6.1.4

<sup>17</sup> Interview with Jack Hruby, VP of Rail Operations

<sup>18</sup> *City of Cleveland Home Sound Insulation and Noise Barrier Programs, Noise Analysis Technical Report*, Acentech Incorporated, 2000, p. 10



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