UCLA Luskin School of Public Affairs

Luskin Center for Innovation

Passenger Exposure To Noise At Transit Platforms In Los Angeles

By:

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About the Report

In Los Angeles County, 16 transit stations, on the Green and Gold Light Rail Lines and on the Harbor Transitway, are located in highway medians. Passengers on the platforms of these transit stations are subjected to elevated noise levels produced by cars passing these stations. Exposure to these high sound volumes makes waiting for a bus or train unpleasant at best, and potentially harmful to passengers' health. This study examines the noise levels at these stations with a goal of finding which stations are the loudest, identifying reasons why noise levels vary at the stations, and suggesting ways to reduce noise levels.

At the stations in the study area, average decibel readings ranged from the high 70's to high 80's, the equivalent of standing close to a passing truck or a kitchen blender. Stations on the Green Line tend to be the loudest, with five of the noisiest stations found on that line. Several factors contribute to the high noise levels at these stations:

- The high speed of traffic on the freeway.
- The short distance between station platforms and freeway travel lanes.
- The presence of structures above the platforms such as canopies and roadways that reflect noise back onto the platform.

Several design elements at stations may reduce the amount of noise that reaches passengers on the platforms. With one exception, Metro has not employed these devices, which include:

- Large objects, such a high-backed benches, that block noise from the freeway lanes. Stations on the Harbor Transitway do contain these benches, which can reduce noise levels by 3 to 4 decibels.
- Enclosed shelters that would block some freeway noise from reaching passengers waiting in them. Installation of such shelters can reduce noise levels by 7 or 8 decibels.
- Sound walls along the outside border of the station. These would be the most effective at reducing noise, achieving reductions of up to 13 decibels.

In light of these findings, Metro should consider installing sound walls and shelters at stations in highways median. In particular, it should focus on stations along the Green Line since those are generally the loudest.

In addition, the results of this study should serve as a warning to Metro and other agencies that may wish to build new transit lines or stations in highway medians. While locating stations along highways may initially be cheaper and easier than building them on or near surface streets, the experience for passengers waiting at these stations is unpleasant and may drive away potential transit users. The apparent cost savings in construction costs may be offset by the loss of passengers and the hidden costs of health problems suffered by those who do use the stations. Transit agencies must take noise problems into consideration when deciding on the routing of new lines.

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Neither the University of California nor the School of Public Affairs either supports or disavows the findings in any project, report, paper, or research listed herein. University affiliations are for identification only; the University is not involved in or responsible for the project.

About the Author

Alexander Schaffer is a 2012 graduate of the UCLA Luskin School of Public Affairs master's degree program in Urban Planning.

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1. Introduction

1.1 Research Question

In the Los Angeles area, three transit lines, the Green and Gold light rail lines and the Harbor Transitway bus lanes, include stations located in highway medians. While placing transit lines and stations in the center of freeways instead of on, above or below surface streets can allow for faster operations, lower construction costs and reduced opposition from nearby residents and businesses, these station locations may not be ideal from the point of view of the riders who use them. Many freeways are not located near dense residential or commercial areas, and thus many passengers must travel long distances to reach the stations. Since the stations are often located near freeway exits, passengers walking or cycling to the station may also have to navigate fast-moving traffic coming off of the exit ramps onto surface streets. Once at the stations, passengers waiting for their bus or train may be exposed to higher than average levels of air pollution from vehicles on the highway passing by the station. The most immediately noticeable problem, however, is that passengers at these highway-centered stations are subjected to elevated noise levels created by these passing vehicles.

Exposure to high levels of noise has negative effects in the short- and long-term. Long term effects include damage to human health: it is possible that repeated exposure to high noise levels at these highway-centered stations may result in damage to transit riders' hearing and circulatory systems. As will be discussed in this study's literature review, researchers have shown a conclusive link between hearing loss and exposure to high ambient noise levels, and daily commuters who use stations in noisy highway medians over the course of many years may suffer from hearing loss (WHO 1999). Other studies have linked cardiovascular problems, particularly hypertension, to long-term exposure to high noise levels (Passchier-Vermeer and Passchier 2000; Chepesiuk 2005). Increased risk of ischemic heart disease has also been found in those who are exposed to elevated noise levels (Babisch 2005). While research has not specifically studied health problems in transit passengers, the possibility of passengers who use highway-centered stations experiencing long-term health problems is a substantial risk.

In the short-term, the high levels of noise on station platforms create an unpleasant environment for passengers waiting for their bus or train. Riders have difficulty holding conversations with fellow passengers or on their phones. Research into annoyance caused by noise shows that people exposed to high noise levels have difficulty concentrating, making even silent activities, such as reading, problematic (Garcia 2001). In addition, the high noise levels can prevent the effective use of loudspeakers in the station to provide information to riders, especially important in emergency situations. Some passengers may find the environment unpleasant enough that they choose not to use these stations, thus reducing ridership on the lines. Because the cost to construct these lines runs to the hundreds of millions of dollars, Metro should be concerned that the unpleasant station environment is deterring potential riders from using the stations and so reducing the value of its investment in these lines.

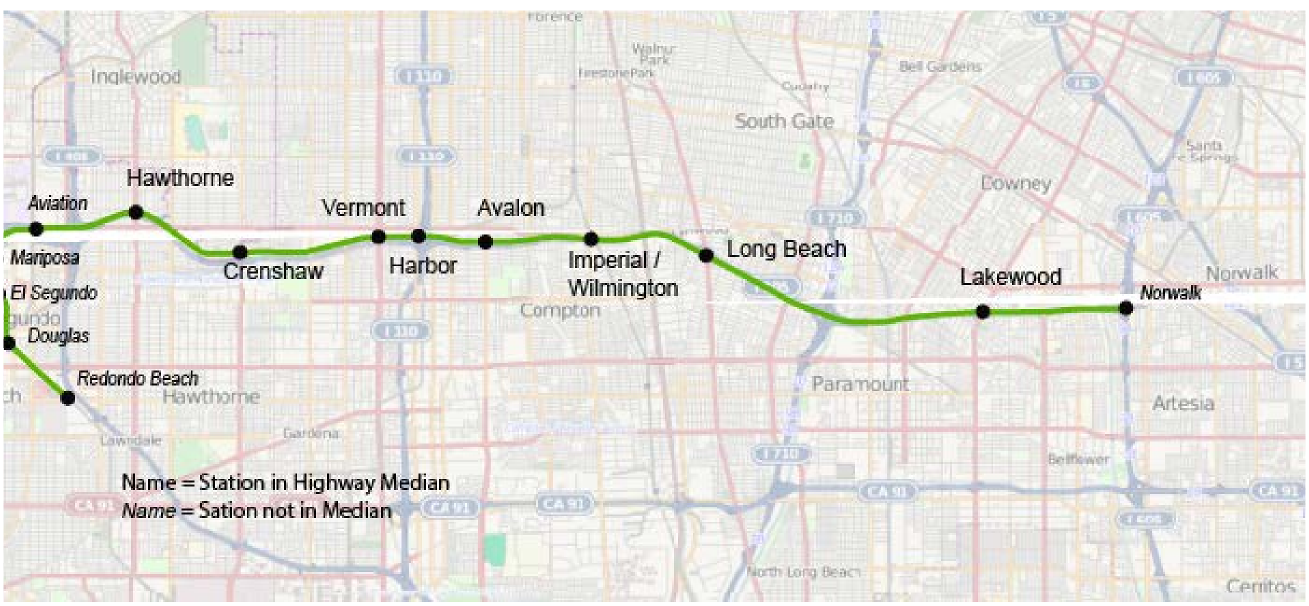
In this study I examine the noise levels at all sixteen highway-centered transit stations in the Los Angeles area. Based on the recorded levels at the stations, I identify those stations with the highest average noise levels. This identification of the louder stations may serve as a guide for prioritizing which stations Metro should retrofit with features such as sound walls or enclosures that can reduce passengers' exposure to noise. In 2009, Metro commissioned ATS Consulting to study noise at the 37th Street station on the Harbor Transitway. ATS suggested possible methods of reducing freeway noise and estimated the decibel reduction associated with each method. Since the most effective noise-reducing measure, complete sound walls, is very expensive, identification of stations where noise levels are not loud enough to warrant the most costly interventions may be useful for planning the best way to reduce the noise to which passengers are exposed.

In addition to comparing the noise levels of different stations, I attempt to determine station design elements that affect noise levels. Within stations, noise levels can vary significantly depending on where on the station platform a passenger stands. Elements such as overhead structures that reflect sound from passing vehicles back onto the platforms, large vertical objects such as high-backed benches that obstruct some vehicle noise, and the distance between the roadway and the station platform may account for some of this variation. Identifying the features that reduce or increase noise may help both to plan for the retrofitting of existing stations and to assist with the design of new stations located in highway medians. Metro has proposed new rail lines in its Long-Range Transportation Plan that may include stations on freeways. While placing stations in the median of freeways is not ideal, if the engineers who design the stations are aware of features that increase or decrease the noise from passing vehicles that reaches the station platform, they may be able to locate and build stations in a way that minimizes the noise.

1.2 The Study Area

The stations in this study are located on three freeways across a wide area of Los Angeles County. The Green Line, a light rail line stretching from Norwalk to Redondo Beach, has eight stations in the middle of Interstate105: Lakewood, Long Beach, Imperial/Wilmington, Avalon, Harbor Freeway, Vermont, Crenshaw and Hawthorne (see Map 1). Lakewood Station is located in the city of Downey, Hawthorne and Crenshaw stations are in Hawthorne, just south of the city's border with Inglewood, Long Beach station is in the Lynwood, and the

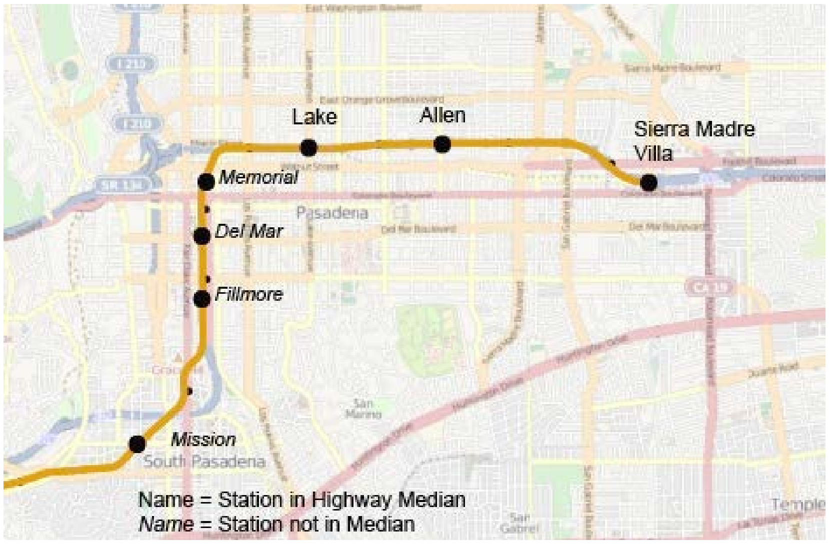
Map 1: Green Line Stations



remaining stations are located in the city or county of Los Angeles.

Three stations along the Gold Line, a light rail line that travels from Pasadena to downtown Los Angeles and further into East Los Angeles, are in the middle of Interstate 210. These three stations, Lake, Allen and Sierra Madre Villa are all located in Pasadena.

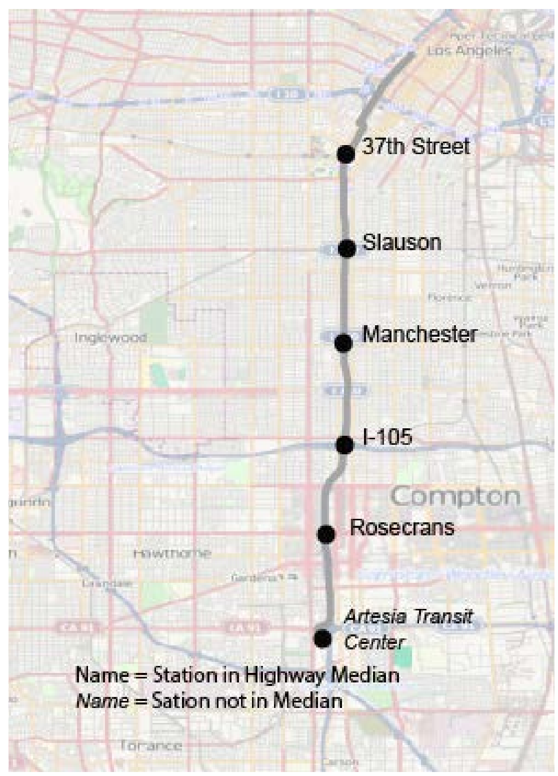
Map 3: Harbor Transitway Stations



Finally, the Harbor Transitway, which carries several bus lines in exclusive lanes along Interstate 110 between downtown Los Angeles and the Harbor Gateway area, has five stations located in the middle of the highway: 37th Street, Slauson, Manchester, I-105, and Rosecrans. These stations are all located in the city of Los Angeles.

Most of freeway-centered stations on the Harbor Transitway and Green Line are in low-income neighborhoods with predominantly Latino and African-American residents. Residents of these areas already experience higher pollution than the average resident of Los Angeles County. While the presence of fast transit service on the Green Line and the bus lines that use the Harbor Transitway is a benefit to those who live in these areas, the location of stations in the freeway median may contribute to the unhealthy environment in which many passengers live.

Map 3: Harbor Transitway Stations



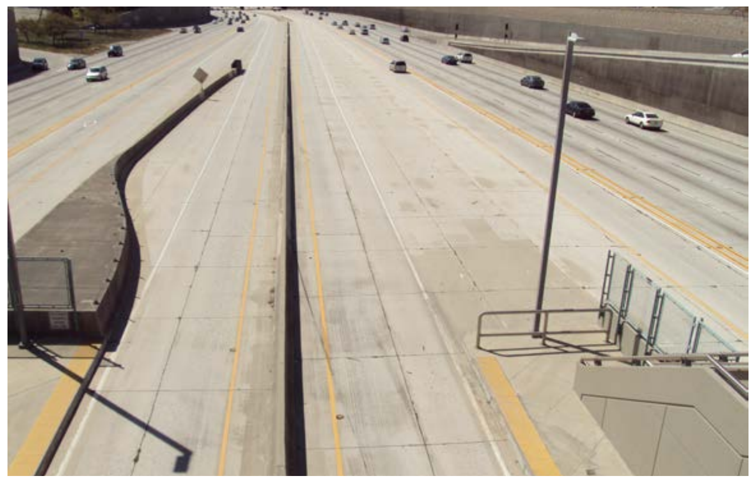
1.3 Station Design

The stations in this study are of two basic design styles. All stations on the Green and Gold Light rail lines, as well as the I-105 Station on the Harbor Transitway, have single platforms with tracks on both sides of the platform and the freeway lanes beyond the tracks (see figure 1). Passengers heading in either direction on the line will stand on the same platform. The distance between the platform and the closest freeway lanes is usually about 20 feet.

Figure 1: Single Platform Configuration at Lake Avenue Station.

The second type of station, found at the 37th Street, Slauson and Manchester Stations on the Harbor Transitway, has two platforms separated by the roadway used by the bus in the center of the station. The freeway lanes are immediately adjacent to the platforms (see figure 2). Passengers waiting for northbound buses wait on the east side platform, and southbound passengers wait on the west side. The distance between the platform and the freeway lanes is 10 feet or less. A low concrete wall topped with chain-link fencing separates the platform from the freeway lanes.

Figure 2: Double Platform Configuration at Rosecrans Station.



1.4 Sound and Sound Measurement

Sound is created by vibrations in the air that strike the human ear. Sound, which travels through the air in the form of a wave, is louder when the magnitude of the wave is greater. The most common unit for measuring sound is the decibel (dB), a unit that expresses the intensity of a sound relative to a baseline of 0 decibels. The decibel scale is logarithmic, meaning that a 10 point increase in decibel level represents a doubling of sound intensity: 110 dB is twice as loud as 100 dB. Although a one unit rise in decibel level is the smallest increase detectable by human hearing, in most situations a three dB increase or decrease is required for people to notice a change in noise level (Peterson and Gross 1967).

In addition to magnitude, sound is characterized by frequency, or the number of times the sound wave goes up and down. Frequency is denoted by hertz (Hz). The human ear generally detects sounds between 20 and 20,000 Hz, and many people will not perceive sounds even at the higher and lower end of this range (Peterson and Gross 1967). As a result, when studying human exposure to noise, researchers have developed a modified decibel scale that assigns less weight to noises with low or high frequencies since the human ear will not recognize these sounds as readily as sounds in the middle of the frequency range. This weighting is known as A-weighting and sound measurements recorded with this scale are denoted dBA. All readings in this study were taken with a device using A-weighted scale, which is the usual standard when measuring environmental noise's effect on people because it more closely captures the actual sound levels that the human ear registers (Peterson and Gross 1967).

2. Literature Review

While a developing literature focuses on air pollution exposure along transit station platforms or at neighborhoods adjacent to freeways and major arterials, studies have not so far examined passenger exposure to freeway noise on transit platforms. Some parts of the available literature on noise, however, pertain to certain aspects of my study.

i) Health problems associated with noise exposure;
ii) Standards and regulations governing noise exposure;
iii) Studies of transit passengers' exposure to noise;
iv) Methods of reducing highway noise levels or transit passengers' exposure to noise.

By examining these areas, I hope first to determine whether passengers at transit stations in highway medians are at risk of health problems from noise, and second to investigate whether methods of noise abatement are available to protect these passengers from harmful noise levels. In addition, by reviewing previous research on noise exposure, I am able to examine methods for carrying out my own research for this study.

2.1 Health Problems Associated With Exposure to Elevated Noise Levels

A great deal of research has documented the physical and psychological damage that excessive noise causes to humans. Studies focus either on long-term exposure to elevated ambient noise levels (e.g. Passchier-Vermeer and Passchier 2000) or the effects of exposure to brief, extremely loud sounds such a gunshots, known as "impulsive" or "impact" noise (Muhr and Rosenhall 2011). This research has identified hearing loss, hypertension, cardiovascular disease and sleep deprivation, immune system disorders and birth defects among the effects of noise exposure (Passchier-Vermeer and Passchier 2000; Chepesiuk 2005).

Hearing loss is the most obvious and well-understood effect of prolonged exposure to high noise levels. Referred to as Noise Induced Hearing Loss (NIHL), this hearing damage can occur immediately in those exposed to extremely high noise levels (140 dB and above), but at lower decibel levels it takes daily exposure over the course of many years for damage to occur (WHO 1999). At 75 dB, it would take 40 years of exposure over 8 hours each day for the average person to suffer hearing loss. Although noise levels at transit stations in highway medians are usually higher than 75 dB (ATS Consulting 2009), a relatively high amount, these levels may not be high enough to cause hearing damage even to those who use the stations daily over the course of many years because passengers spend relatively short periods of time on the platforms.

While the effects of noise on hearing loss are well established, other effects are not as well studied, understood or proven. Many, including Chang et al. (2009), de Kluizenaar et al. (2007) and Ndrepepa and Twardella (2011), find a relationship between high noise levels and hypertension, but other studies do not find a strong enough connection to directly connect elevated blood pressure to noise exposure. Researchers in Switzerland, for example, found a correlation between hypertension and exposure to noise from trains, but no correlation with exposure to highway noise, except in diabetics (Dratva 2011). Researchers have also examined the relationship between noise annoyance and ischemic heart disease. Studies by Babisch (2005) and Belojevic and Saric-Tanaskovic (2002) show a positive correlation between high noise levels (> 70 dB) and heart disease in men but not women. Others, however, argue that the correlation, while positive, is not statistically significant (Nderepepa and Twardella 2011). At this stage, the research, while generally pointing towards an association between noise and cardiovascular problems, is not sufficiently advanced to make a direct connection between the two.

Annoyance, the feeling of discomfort or displeasure that noise causes when it interrupts an activity, is a major effect of exposure to elevated noise levels. For passengers on noisy transit platforms, annoyance is the most common effect of noise exposure. Although noise annoyance studies depend on subjective responses from those surveyed, researchers have been able to make generalizations about the levels of sound at which people become annoyed. The level of annoyance is determined in part by the context in which respondents are exposed to this noise: workers in an office may report annoyance at levels as low as 55 dB, while factory workers may not report annoyance until 85 dB (Passchier-Vermeer and Passchier 2000). Schultz (1978) used previous studies of annoyance to graph a curve that indicates the percentage of people reporting themselves to be "highly annoyed" at particular levels of noise exposure. This curve indicates that about 50% of respondents report being highly annoyed when exposed to sound at 80 dB, and 30-40% report becoming highly annoyed at 70 db. While Schultz's work on annoyance set the standard for subsequent studies and regulation of noise, later researchers have proposed updates to his annoyance curve, and have noted that the source of noise (highway, airplane or train) changes the levels at which people begin to experience annoyance (Miedema and Vos 1998; Fidell 2003; Kryter 2007). These studies find that respondents generally rank airplane noise as the most annoying, highway noise second most, and train noise the least annoying.

A common thread in these studies of noise and health is that research focuses on long-term exposure, usually eight hours per day or more at noise levels between 55 and 75 dB. Consequently, detailed study would be necessary to accurately estimate the health damage to passengers waiting for relatively short periods on highway centered transit platforms with high noise levels. In any case, the correlations between exposure to noise and health problems are not yet firmly proven in the most rigorous studies. However, the feeling of annoyance from noise exposure, which is significant at levels as low as 70 dB, is sufficiently well established and warrants study of noise on transit platforms.

2.2 Noise Standards and Regulations

Various government agencies have set standards for acceptable noise levels. These standards depend largely on the context of where the listener is exposed to noise and the duration of the exposure. Following the passage of the Noise Control Act in 1972, the Environmental Protection Agency created guidelines for exposure to and measurement of noise in occupational and environmental settings (EPA 1974). Other government agencies have provided more specific guidelines. In occupational situations, for example, the Occupational Safety and Health Administration requires that employers attempt to abate noise at levels of 85 dB and above, depending on the length of time workers must be exposed to it (NIOSH 1998).

Outside of occupational situations, federal aid for state highway projects is contingent on highway construction agencies reducing nearby residents' exposure to noise from new or rebuilt highways (Caltrans 2011). Depending on the land uses that exist adjacent to a highway under construction, agencies building it must attempt to reduce noise levels to as low as 52 dB (measured inside buildings with sensitive uses, such as hospitals, schools, and recording studios), to 67 dB measured outside residential building, and as high 72 dB (measured outside offices, restaurants, and similar buildings). The table below indicates Caltrans' noise limits associated with various land uses.

Table 1: Caltrans noise limits for land uses adjacent to highways.

Land Use	Measurement Location	Decibel Limit
Hospitals, Day Care Centers, Recording studios and similar sensitive uses	Indoors	52 dB
Outdoor locations in which quiet and serenity are vital	Outdoors	57 dB
Residential	Outdoors	67 dB
Hotels, Office Buildings, Restaurants and similar non-sensitive uses	Outdoors	72 dB
Agricultural, industrial and similar non-sensitive uses	n/a	n/a

Source: Caltrans Traffic Noise Analysis Protocol 2011

Significantly, these maximum levels are for the equivalent of one hour of exposure. This makes the standard much higher than that required in occupational noise regulations, which govern exposure over an eight hour period, and are closer to what passengers on a transit platform are likely to experience. However, Caltrans does not explain why they choose these numbers as the limits for acceptable sound levels, and so cannot offer guidance for whether the specified noise levels are dangerous to listeners, and in what way.

The Federal Transit Administration publishes guidelines on noise for agencies building new transit projects (FTA 2006). Depending on existing noise levels in the area, the FTA allows projects to increase these noise levels anywhere from 1 to 7 dB before classifying the project as having "moderate impact" on affected areas. Despite the care taken to keep noise levels low for those near the proposed projects, no standards are in place to govern the noise exposure of passengers using these projects.

2.3 Noise and Transit

As described above, most research on transportation noise focuses on the exposure of people living, working or going to school near noise sources such as highways, airports and rail lines. Much less research is available on the problems suffered by those who use transit, whether they are exposed to noise while riding a transit vehicle or waiting for a vehicle on a noisy street or platform. In this section I review studies that examine passenger noise exposure and attempt to determine the problems that excessive noise causes for transit passengers.

In 2009 Los Angeles County Metropolitan Transportation Agency hired the firm ATS Consulting to examine noise levels at the 37th Street Station along the Harbor Transitway, just South of Downtown Los Angeles. Taking measurements at various locations on the platform, which is located in the center of the I-110 Freeway, ATS found that noise levels ranged from 78 to 87 dB (ATS 2009). ATS determined that these levels are not high enough to cause hearing damage even with long term exposure, but are sufficiently high to impede most conversation and cause annoyance. The study concludes by listing methods for reducing passengers' exposure to noise. Possible abatement methods include the construction of sound barriers along the side of the station to block highway noise, which could reduce the noise level by 13 dB, and the use of enclosed shelters on the platform, which would reduce exposure by 7 to 8 dB.

Besides ATS Consulting's study, only one other researcher has undertaken a study of noise problems at transit stations located in the middle of freeways in the Los Angeles area. In a paper at the 1996 Rapid Transit Conference of the American Public Transit Association, Wolf (1996) investigated noise at stations on the Green Line in Los Angeles, located in the median of the I-105 freeway, and analyzed or predicted the noise reduction capability of on-platform shelters, sound absorptive materials on the canopies and other overhead structures on the platforms, and sound barriers between the highway and the platform. Wolf took measurements at the Crenshaw and Lakewood Stations, finding that noise levels ranged from 80 dB, at the open-air ends of the Lakewood Station, to 88 dB at locations in the Lakewood Station underneath the roadway that passes above the platform.

Wolf determined that a 14' high sound wall along the entire length of the station platform would reduce noise levels by as much as 15 dB, provided that sound-dampening material is also used on the underside of the station platform and other overhead structures. Barriers that are lower or not as long would have significantly less effect in reducing noise levels. Table 2 below reproduces Wolf's estimates of the noise reduction offered by sound walls of various heights and lengths.

Table 2: Estimated Noise Reduction Provided By Sound Walls

Sound Wall Height	Ends of Platform	Middle of Platform
No Mitigation	81-82 dBA	85-86 dBA, 81-82 dBA
14' Continuous Sound Wall	74-76 dBA	71 dBA
12' Continuous Sound Wall	75-76 dBA	73 dBA
10' Continuous Sound all	76-77 dBA	75 dBA
8' Continuous Sound Wall	77-78 dBA	77 dBA
12' Middle Sound Wall, 8' End Sound Walls	76-77 dBA	73 dBA
12' Middle Sound Wall, 6' End Sound Walls	76-78 dBA	73 dBA
10' Middle Sound Wall, 6' End Sound Walls	77-78 dBA	75 dBA

Source: Wolf 1996[1]

In addition to estimating the effects of a barrier, Wolf reports on the noise reduction offered by a shelter that Metro built (apparently on a temporary basis since it is no longer there) on the platform at the Lakewood Station. Because the shelter had a 4' wide opening to meet Americans with Disabilities Act requirements, sound from vehicles was able to enter easily and the shelter offered only minimal protection from noise, with an average reduction of 1 dB. Wolf indicates that greater reduction would be possible if the shelter were configured in such a way that the entrance was not in the direct line of sight of the freeway travel lanes. Configured in this way, noise would not be able to enter the shelter directly.

1 The two figures 81-82 in row one represent the average sound level measurements at locations under an overhead structure (the higher decibel level) and in open air locations (the lower decibel level).

Wolf notes that at the time he carried out the study, Metro's station design guidelines called for a maximum noise level of 70 dB on platforms. Because the study indicated that the costs of reducing noise to that level would be so high, the agency increased the limit to 75 dB. Based on the ATS Consulting study, it appears that the agency has not been able to meet even this relaxed standard.

One other study examined noise at Los Angeles-area stations in highway medians, albeit briefly. METRANS, in a study of design elements at stations along Los Angeles' Harbor Transitway, found that riders surveyed about the stations expressed displeasure with the noise to which they were exposed on the platforms (Bannerjee 2005). The study did not measure the sound, however, nor did it attempt to learn the extent to which the passengers felt that noise, as opposed to other factors they disliked about the platforms, was a major problem as they waited for their bus. A similar study of transit stations along SR-520, a highway near Seattle, also found that passengers at these stations cited noise as a problem when waiting for their buses (Transportation Issues, Inc. 2005). The SR-520 stations are along the side of the highway rather than in the median, however, and researchers did not measure the actual sound levels from passing vehicles.

A handful of studies have examined passengers' exposure to noise at heavy rail stations and on the rail vehicles themselves and attempted to determine potential health problems. Gershon et al. (2006) measured noise at subway stations in New York City, as well as on the subways themselves and at bus stops on major streets. The researchers found an average of 86 dB, although on some subway cars and platforms the maximum sound level exceeded 100 dB and a maximum reading of 89 dB was taken at a curbside bus stop. Although the study does not bear directly on the research for this project because it measures noise in enclosed spaces (the subway platforms and cars), and at curbside stops on city streets rather than in a highway median, it does provide a comparison point for the sound levels found in the Los Angeles area. The authors also describe in detail their methodology for taking sound readings with a handheld noise dosimeter, which provides a good starting point for creating a plan for taking noise readings in this study.

In a similar study, Dinno (2011) measured the sound levels found on BART trains in the San Francisco Bay Area. The author found that the levels were elevated enough to cause physical health problems for riders who frequently use the trains for long commutes. Again, this study is not directly relevant to the questions of this paper, but, as in Gershon's study, the authors provide good descriptions of their research methodology, including the use of the dosimeter to measure both peak and average sound levels, and placing the dosimeter's microphone to best capture noise levels.

Two other studies have measured noise problems for passengers on transit platforms, although not those located in highway medians. Koushki (2002) examined passengers' exposure to high noise levels in Kuwaiti bus terminals. Chang and Herman (1974) examined noise effects on rail transit passengers in Chicago and determined that, despite noise levels that occasionally reached 115dB and frequently impeded conversation, the likelihood of hearing loss was remote.

2.4 Noise Abatement Methods

Two methods of reducing noise from highway sources are most commonly implemented: noise barriers and noise reducing pavement. Sound barriers block sound waves from any source, while certain pavement types are able to reduce the noise created by tires rolling on the road. Researchers have examined both methods extensively, although not in relation to attempts to protect passengers of highway-centered transit stations from noise.

i) Noise barriers are common along highways to protect nearby residences and businesses from the noise of passing vehicles. The Federal Highway Administration provides basic guidance for the design and construction of noise barriers (FHWA 2001). FHWA's guidebook, Keeping the Noise Down: Highway Traffic Noise Barriers, indicates that a sound barrier can decrease noise levels by 5 dB as long as the barrier blocks the noise receptor's line of sight to the source of noise. An additional 1.5 dB of noise reduction is possible for each additional meter of height added to the barrier. For the sound barrier to work most effectively, however, it should extend at least eight times the distance between the wall and the person exposed to the noise (i.e. if one stands 20 feet from the sound barrier, the barrier must extend 80 feet to the left and 80 feet to the right to provide maximum protection from the noise).

Besides size, several other factors influence the appropriateness of noise barriers on transit platforms. Noise can reflect back from barriers located on opposite sides, causing the barrier to lose some of its noise blocking ability (Li, Kwok and Law 2008). Consequently, barriers to protect platforms in highway medians may be less effective if the opposite side of the freeway has barriers to protect homes and businesses from noise as sound can bounce back from these barriers and reach passengers on the platform. In addition, security concerns require that noise barriers be constructed out of a clear material such as glass or plastic so that the view of the transit platform is not obstructed. Most noise barriers are made of concrete, brick, wood or metal, and plastics and glass are less common (FHWA 2007). The FHWA notes that glass necessarily shatters when struck, which is a major concern if the barrier is placed close to the transit platform. Consequently, plastics are the only acceptable material for barrier construction. However, the cost of constructing a full barrier from plastic materials may be prohibitive: ATS (2009) estimates that enclosing the 37th Street Station on Metro's Harbor Transitway would cost approximately $200,000.

ii) Pavement materials can increase or reduce the amount of noise generated by passing traffic. A booklet from the Federal Highway Administration provides a simple introduction to noise generated from highways, and notes that, for passenger vehicles traveling at speeds greater than approximately 30 mph, the greatest source of noise is the sound of tires rolling on pavement (FHWA 2007b). Both the sound of the revolving tire striking the pavement and the air that escapes from between the roadway and the grooves of the tire contribute to the noise. When measured in close proximity, the sound of a tire traveling at high speed can be in excess of 90 dB.

Researchers have found that numerous types of asphalt and paving material are capable of reducing the noise level by several decibels (FHWA 2007b). The noise reduction ability of these pavements depends on the presence of gaps in the pavement surface that allow air to escape quietly from between to tire and the road. Ahammed and Tighe (2011) examined Portland Concrete Cement (PCC) with multiple surface textures, and several mixes of asphalt pavement, finding that the PCC can reduce noise 5% to 6% over standard pavement, and the asphalt mixtures can provide between 6% and 8.5% noise reduction. These findings seem significant enough to warrant investigating the use of these pavements on highway sections next to transit stations in the median, assuming that these sections are not already paved with noise reducing pavement.

Although these pavement types provide a measure of noise reduction, they are prone to problems. First, the more porous forms of pavement, which provide the best sound absorption, tend to wear out more quickly than denser pavement types (FHWA 2007). Second, the noise reducing qualities of these pavements decline over time, losing as much as 0.5 dB of noise reduction each year as the pores in the pavement become clogged with dirt and other debris (Bendtsen 2009b). Finally, in lower temperatures when both the pavement and tires become more stiff because of the cold, noise from the pavement increases by as much a 1 dB for each 10 degree decline in temperature (Bendtsen 2009a; Rasmussen 2011). While cold weather is generally not a problem in the Los Angeles area, it may cause enough of an increase in noise that it can negate some benefits of using a quieter pavement type.

2.5 Analysis

Research on the subject of transportation noise is generally lacking when it comes to the effects of noise on transit passengers. In particular, literature on the effects of highway noise on transit passengers waiting at highway-centered stations is extremely scarce. From the little that exists, as well as related studies, it appears that passengers at these stations are not at immediate risk for health problems caused by excessive noise, but are prone to high levels of annoyance. The primary methods for reducing the noise at these stations are sound barriers, shelters and quieter pavement. In the later sections of this study I will examine the applicability of these methods to highway-centered stations in the Los Angeles area.

3. Methodology and Data Collection

3.1 Data Collection

To measure noise levels on the 16 transit platforms in the study area, my research assistant I and used a Quest NoisePro DLX dosimeter, a device similar to that used by Dinno in her study of noise on the BART system (Dinno 2011). The dosimeter's microphone clips onto the shirt collar, just below the ear, so that sound picked up by the device approximates the same sound levels that the ear would receive. The dosimeter settings were: 3dB exchange rate, 70 dB threshold, 70-140 dB range, and slow response rate.[2] After every third measurement session, I used a Quest QC-10 calibrator to ensure the dosimeter's accuracy.

Time of measurements: In order to capture the expected variations in sound levels at different times of day and days of the week, we took at least four readings at each station: one during the morning rush hour period (7 a.m. to 9 a.m.), one at evening rush hour (5 p.m. to 7 p.m.), one in the middle portion of the day (9 a.m. to 5 p.m.) on weekday, and one during the middle of the day (10 a.m. to 3 p.m.) on a weekend day. The rush hour times roughly approximate when traffic is heaviest and traffic speeds are lowest on freeways. As time permit-

2 The exchange rate is the conversion factor that determines how many decibels a doubling in sound energy will create in an averaged weighting of noise exposure over time. For example, under a 3dB exchange rate, exposure to 85 dB for 4 hours is equivalent to exposure to 88 dB for 2 hours. A 3 dB exchange rate is most common, although OSHA uses a 5 dB standard. The threshold is the sound level at which the dosimeter will record data for the purpose of calculating the average over time. At a 70 dB threshold, a reading of 68 dB will not be calculated as part of the average. The range indicates the lowest and highest points at which the dosimeter will record sound levels. The NoisePro DLX can be set with either a 70-140 dB or 40-110 dB range. I set the machine up at the higher range based on the assumption that some readings taken during the study would come close to exceeding the 110 dB and would not fall below 70 dB. The latter proved to be true, but the highest level recorded was just slightly over 100 dB. Response rate indicates the length of time required for the dosimeter to respond to changes in the sound level. Slow response rate, which is most common for environmental noise studies, measures at 1-second intervals. At this setting, the noise level of sounds that stop abruptly will decay at a rate of 4.35 dB per second, and a burst of sound must last longer than 2 seconds to register at its full sound level. The slow response rate is appropriate for this study since noise produced by vehicles passing on the freeway does not change abruptly in most cases.

ted, we took additional readings at several stations, most during the morning rush hour or mid-day periods.[3]

Location of Measurements: To take account of variations in the noise levels within each station platform, we took measurements at different locations on each platform. Depending on the layout of the station, I chose six, seven, or eight spots on the platform at which to stand when taking the measurements. The following station design elements determined the locations on the platforms where we took readings:

- Locations with no obstruction in the line of sight to the freeway
- Locations next to walls, large map boxes, large benches, or other tall, solid structures that block line of sight to the freeway
- Locations at the ends of platforms, as well as in the middle portions
- Locations under canopies or other structures above the platform that reflect noise from the freeway back onto the platform.

Appendix 1 lists the exact reading locations on the individual platforms.

Noise Measurements: At each of the locations on the station platforms we took readings with the dosimeter for two minutes. During these two minutes, the dosimeter recorded the average ambient sound level as well as maximum and minimum sound levels during that period. Although it would have been ideal to take readings over a longer period in order to capture more variation in the noise levels at the stations, time constraints made it impossible to obtain a sufficient number of readings while staying at the same location and measuring sound levels over the course of 10 minutes or more. Readings of two minutes should nevertheless be sufficient to account for normal variations in sound levels and to provide a good representation of the average sound levels at each location.

While recording the sound measurements at each station, I noted the following information in addition to obtaining noise levels:

- The time measurements began
- The approximate speed of vehicles traveling in each direction on the adjacent freeway
- The approximate percentage of cars (as opposed to trucks or buses) on the freeway
- The approximate temperature.

Speed, traffic mix and temperature all may affect the noise levels that passengers experience on the platforms. Although in stop and go traffic cars make noise braking and accelerating, at faster speeds vehicles create more noise as engines work harder and tires strike the pavement with more force. Large vehicles create more noise than cars because of their larger engines and tires, so a higher percentage of buses and trucks on the road may increase the average noise levels. Lower temperatures may create more noise since tires become harder in cooler weather, and so create more noise as they strike the pavement. In addition to the data recorded at the stations, I obtained from Caltrans the average daily traffic volumes for the freeway segments adjacent to the station. These levels may serve as a rough proxy for the number of cars passing by each station. Finally, I used the measurement tool on Google Earth to calculate the approximate distance from the platform to the nearest travel lane of the freeway in order to capture any variation in noise levels that may be due to greater or less distance between the vehicles on the roadway and the spots on the platform where we stood to obtain the readings.

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3 We obtained readings at six different times for the Avalon, Harbor, Imperial / Wilmington and Long Beach stations, five different times at 37th Street, Hawthorne, I-105, Lakewood, Manchester, Slauson and Vermont stations, and four times at Allen, Crenshaw, Lake, Rosecrans and Sierra Madre Villa stations.

3.2 Expected Results

Previous studies of noise levels at the 37th Street station on the Harbor Transitway and the Lakewood and Crenshaw stations on the Green Line found sound levels ranging from 78-90 dBA, with much of the variation due to the presence or absence of overhead structures that reflect sound (Wolf 1996, ATS 2009). Some variation also appears to be due to objects such as benches and walls in the station that obstruct noise from the passing vehicles. Consequently, I expected that the loudest stations would be Lakewood, Rosecrans and Vermont stations, all of which have a roadway passing above most of the platform. The roadway creates a large area from which sound from passing vehicles reflects back towards the station platform. Within individual stations, I expected that sound would be louder in those areas under canopies and those that do not have objects such as benches or walls blocking the line of sight to the freeway. In addition, I anticipated that noise levels would be lower when traffic was moving slowly rather than at full speed since noise generated by vehicles increases at higher speeds. Finally, I expected that noise levels would be higher when the traffic mix contained a higher percentage of trucks and buses since their engines are louder than car engines.

3.3 Limitations to Study

The data collected for this study is not comprehensive. The readings do not capture a full range of variation in traffic speeds at many stations, so it was not possible to determine the effects of traffic speeds on noise at each station. Also, although I attempt to use the yearly average of daily traffic volumes as a proxy, the actual traffic volume at the time the readings were taken is not known. Another problem, as noted above, is the inability to record noise levels continuously over the course of several days at stations, so I am unable to determine if the sound levels recorded at the times of day when I took measurements are typical. Finally, the noise levels recorded in this study may skew higher than typical levels because traffic at the time I took the readings may have been moving faster than it does normally. Readings were taken between December 14, 2011 and January 7, 2012, and, at most stations, traffic moved quickly even at rush hour periods. The low traffic levels and higher speeds may be due to the fact that numerous people were taking time off from work for the Christmas holiday. As a result, the readings of this study may not reflect the usual noise levels at many stations since free-flowing traffic is louder than heavy, slow traffic. On the other hand, traffic speeds and sound measurements recorded after January 3rd, when fewer workers were on vacation, were generally comparable to those taken before the New Year.

Despite these limitations, with at least four readings taken at each station, and varying traffic speeds at several locations, the measurements capture enough variation to allow me to make several comparisons of noise levels both between stations and at different locations within the same stations.

4. Data Analysis

Over the three weeks of data collection, we recorded 560 individual readings. Because stations on the light rail lines and Harbor Transitway stations have different configurations (see section 1-3), the following analysis examines the stations in the study by type: those with a single platform in the middle of the station and the tracks or roadway running on either side of the platform, and those in which the roadway runs through the middle of the station with two platforms, one for passengers heading in each direction, on either side of the roadway. In the first section of this analysis I compare the average noise levels at different platforms and attempt to explain the variation between them. In the next section I examine noise levels at different parts of the same stations in order to determine if certain station design features or other factors explain variations in the noise levels.

4.1 Inter-station measurements

Among all stations at all times of day, the station with the loudest platform was Avalon Station, followed by Vermont, Lakewood, Crenshaw and Harbor Stations, all of which are on the Green Line. The average of all readings taken at Avalon is 88.1 dBA. At Lakewood the average is 88.0 and at Vermont 87.7. The stations with the lowest noise levels are 37th Street, with an average of 80.8 dBA, Lake at 81.7 dBA, and Slauson at 82.0 dBA. Table 1 lists the average decibel levels for all stations, as well as the maximum and minimum, averaged over all visits to the stations.

Table 3: Average Noise Levels at All Stations in Study Area

Station	Avg.	Max.	Min.
Avalon	88.1	92.0	83.8
Lakewood	88.0	92.9	83.1
Vermont	87.7	91.9	83.7
Crenshaw	87.1	90.8	82.4
Harbor	86.7	90.4	82.0
Rosecrans	86.2	90.5	82.5
Imperial/Wilmington	86.1	90.6	81.3
Allen	85.7	90.5	81.2
Hawthorne	85.5	89.8	81.6
I-105	85.2	90.1	81.6
Manchester	83.9	89.7	78.7
Long Beach	83.5	88.5	78.8
Sierra Madre Villa	83.1	87.4	78.7
Slauson	82.0	86.8	77.9
Lake	81.7	87.3	78.1
37th Street	80.8	85.4	76.1

The approximately 7 decibel difference between the loudest and quietest stations, while not extremely large, is significant: a 3 dB increase in sound is immediately noticeable to most people, and an increase of 10 dB is a doubling of the noise level. Though exact comparisons are difficult to make, 80 dB is similar to the noise of normal city traffic, while decibel levels in the high 80's are comparable to noise from trucks or motorcycles passing nearby. Several factors may explain the difference in the noise levels: overhead structures, speed of traffic on surrounding roads, and distance from the station platform to the adjacent roadway.

4.1.1 Overhead Roadways

While all stations have canopies covering part of the platform to protect riders from rain and sun, three stations, Vermont and Lakewood on the Green Line and Rosecrans on the Harbor Transitway, have roadways passing directly over the station platform. These three are among the loudest stations, having the 2nd, 3rd and 6th highest average decibel levels in the study. Sound from vehicles on the freeway reflects off of the bottom of the roadway back onto the platform rather than moving up and away from the station, and so increases the amount of noise that reaches passengers. Rosecrans Station, where the average noise level is slightly lower than at Lakewood or Vermont, may be quieter because the roadway above covers only about half of the platform. The roadways above Lakewood and Vermont stations cover nearly the entire platform, making more of the platform subject to the reflected noise. In addition, the roadways above Lakewood and Vermont are closer to the platform than the road above Rosecrans station. The distance between the platform and the bottom of the roadway above is approximately 20' at Lakewood and Vermont stations rather than approximately 30' at Rosecrans. Since the distance is closer, the sound intensity will not decay as much when it reflects back onto the platform, and so increases the noise level.

Although an overhead roadway will increase the average decibel level, it is not the only factor in creating a noisy station. The loudest station, Avalon, has no roadway above it, and Crenshaw and Harbor Stations, which also have no roadway above, are louder than Rosecrans. Other factors, then, likely contribute to high noise levels on platforms.

4.1.2 Traffic Speed

37th Street, Slauson and Lake Street stations had the lowest average noise levels. These low readings at 37th Street are partly attributable to the heavy traffic on the lanes of the Harbor Freeway around the station. Traffic volume is high here, with about 300,000 vehicles passing by daily in each direction, and often slows as it approaches the interchanges of the 10 and 101 freeways and the numerous exit and entrance ramps in downtown Los Angeles. Of the five readings at this station, two were taken at times when traffic in one or both directions of the freeway was moving at 20 mph or less, and two more were taken when traffic was moving at approximately 40 mph in one direction. Cars traveling at lower speeds, particularly below 30 mph, create less tire noise, so the slow traffic contributes to the lower noise levels (FHWA 2007b). The decibel levels at Slauson Station are also likely affected by slower traffic, although only on two of the five days when readings were taken was traffic speed below 20 mph in one direction of the freeway. At Lake Avenue Station, where the average noise levels were slightly lower than those at Slauson Station (81.7 vs. 82.0 dBA), traffic speeds were 45 mph on only one day, and approximately 55 mph on another and during both of these times the slower traffic was going in only one direction while the opposite lanes moved at full speed. Since traffic moved more slowly at the Slauson Station but the noise levels were higher overall, it seems that traffic speeds, while an important factor, are not the only reason why noise levels vary between stations.

It is important to note that although traffic in the general travel lanes was moving slowly at the times we took these readings, the carpool lanes, which are closest to the station platform, were not congested, and cars, trucks and buses passed by at full speed in these lanes. If the carpool lanes were also congested, that noise levels on the station platforms would likely be lower. Since carpool lanes are intended to be free flowing even when the other lanes are congested, however, I believe that the results of the readings collected for this study are comparable to the usual decibel levels at stations when traffic is heavy.

In order to show the differences in noise level caused by traffic speed, I compare the noise levels at three stations, 37th Street, Slauson and Imperial / Wilmington. These levels were measured at locations on the platform facing traffic on the adjacent freeway lanes that was moving at speeds lower than 30 mph, and then when it was moving at full speed. Each of these readings was taken at the same locations in the stations, with similar levels of truck traffic on the roads, so vehicle speed should be the most significant variable in explaining differences in noise levels. Table two shows the noise levels from five different days at 37th Street Station.

Table 4 shows the results from three readings on the 37th Street Station platform.

Readings at 37th Street Station	Reading #1 Speed 10-20 mph	Reading #3 Speed 30 mph	Reading #2 Speed 40 mph	Reading #5 Speed 40 mph	Reading # 4 Speed 65+ mph
Location 5	77.4	74.3	81.9	77.3	84.2
Location 6	75.7	74.3	82.7	77.7	80.9
Location 7	81.6	76.6	89.7	81.5	89.3
Location 8	77.4	75	82.4	78.4	83.2

With the differences between readings taken at times of low speed and high speed ranging from 5 to almost 13 dBA, it is clear that low traffic speed has a significant effect on the noise levels on the 37th Street Station platforms. All reading locations show large drops in decibel levels when traffic speeds fall, although the largest is in location 7. This location, which is the closest to the freeway lanes and the most exposed to noise from passing vehicles, consistently had the highest noise readings in both slow and fast traffic, but clearly is sensitive to changes in traffic speed since decibel levels were in the high 80's when traffic was moving at high speeds, but was in the low 80's and even around 76 dBA when traffic was moving slowly.

Table 5 shows the results from three readings on the Slauson Station platform.

Readings at Slauson Station	Reading #1 Speed 10-20 mph	Reading #5 Speed 20 mph	Reading #2 Speed 55 mph	Reading #3 Speed 65+ mph	Reading # 4 Speed 65+ mph
Location 5	80.5	81.7	82.4	83.1	85.2
Location 6	80.2	80.8	81.5	81.4	80.9
Location 7	82.1	83.5	86.3	84.2	86.5
Location 8	79.8	79.8	81.0	79.5	82.5

Despite similar station layouts and nearly identical traffic speeds and volumes on the adjacent freeway lanes, the variation in noise levels is much lower at Slauson than at 37th Street. The largest difference is less than 5 dBA, and at Location Six on the platform the difference was less than 1 dBA. It is also noteworthy that when traffic is moving slowly, the noise levels at 37th Street are significantly lower than those at Slauson in similar conditions: nearly all recorded decibel levels at 37th Street were in the mid-70's when traffic was moving below 30 mph, while in similar traffic speeds the decibel levels at Slauson were usually in the low 80's. Clearly factors in addition to low traffic speed are responsible for the lower noise levels at 37th Street.

At the Imperial / Wilmington Station on the Green Line, one set of readings captured the noise levels when traffic on the adjacent freeway lane was approximately 30 mph. Table 6 compares this to the levels recorded when traffic was moving full speed:

Table 6 shows the results from three readings on the Imperial/Wilmington Station platform.

Readings at Imperial / Wilmington Station	Reading #2 Speed 30 mph	Reading #1 Speed 65+ mph	Reading #3 Speed 65+ mph	Reading # 4 Speed 65+ mph	Reading #5 Speed 65+ mph	Reading #6 Speed 65+ mph
Location 1	85.9	87.5	83.3	86.3	85.1	86.2
Location 3	86.6	87.7	84.8	86.7	87.3	89.1
Location 5	84.8	86.4	86.0	84.5	84.9	87.6
Location 7	86.3	86.1	83.1	85.8	84.6	87.7

In this case, the differences in noise level are very small, with the largest being about 1.5 dBA. In location 7 the reading was lower when vehicles were traveling at full speed than when traffic was moving at approximately 30 mph. The noise levels at this station may be similar because traffic on the opposite side of the freeway was moving at full speed. Unlike the stations on the Harbor Transitway, where there are two platforms, one at each side of the station with the roadway used by the buses in the center, the stations on the Green Line are all single platforms. As a result, even when taking readings while facing the side of the freeway where traffic was moving slowly, the side of the platform facing the freeway lanes on which vehicles were moving at full speed was only 15 feet away. Reading #3, in which the traffic was moving 65 mph in the direction in which these readings were taken, had traffic moving on the opposite side at approximately 55 mph. This may explain the slightly lower decibel levels for that reading session. On the Harbor Transitway the distance between the two sides of the platform is nearly 40 feet, which reduces some of the noise from the opposite side of the freeway. In general, then, stations on the Harbor Transitway seem to experience noticeable reductions in noise levels on the side of the station next to slow-moving traffic lanes even if the lanes on the opposite side are moving at full speed. In similar conditions stations on the Green Line will not likely experience much, if any, noise reduction because only a short distance separates the location where the reading is taken from the opposite side where traffic is moving faster and making more noise.

4.2 On Platform Design Features

In addition to factors such as traffic speed and distance between the platform and the roadway, outside of the station, design features on the station platforms themselves may affect noise levels. Platforms contain large objects that may block noise from passing vehicles, and also have canopies above the platform that may increase noise by reflecting sound back onto the platform. In this section I examine the effects of these on-platform structures on noise levels.

4.2.1 Obstructions

All stations in the survey contain one or more objects on the platform that may serve to block freeway noise from passengers. These objects include large benches, boxes used to display maps and other information about the transit system, and walls formed by staircases leading from the platform to streets above the station. These objects are made of thick metal or concrete structures and are at least six feet high. If passengers stand where these objects block their line of sight to the freeway, these obstructions seem capable of preventing some sound produced by passing cars from reaching the passengers.

On the single-platform stations on the Green and Gold Lines, however, these objects may have limited ability to block noise because passengers are close to both lanes of freeway travel. While an object may be able to block noise from one side of the freeway, the passenger will still be exposed to noise from the other side, and the distance between both sides of the freeway is not large enough for the noise to decrease significantly before it reaches a passenger on the platform. At the two-platform stations on the Harbor Transitway, on the other hand, objects that block noise from one side of the roadway likely provide better noise protection because the opposite side of the freeway is much further away, up to 40 feet, from the platform on the opposite side of the busway.

4.2.1.1 Benches

The following charts indicate the noise reduction attained by benches at Harbor Transitway Stations. These benches, made of concrete and thick glass blocks, are approximately 6.5 feet tall and 6 feet across. Most stations have twelve benches, six running down the length of each side of the platforms.

Tables 7, 8 and 9 compare average noise levels found at locations in front of and behind the benches at Manchester, Slauson and 37th Street stations. Locations 2 and 6 are taken sitting on a bench in the middle of the station so that the bench blocks noise form the freeway lanes behind the bench, and locations 3 and 7 are taken behind the same bench, so that no large obstacles block noise from the freeway.

Table 7 - Reading at Manchester Station

Readings at Manchester Station	Reading #1	Reading #2	Reading #3	Reading #4	Reading #5	Average
2 (on bench)	83.6	85.4	84.9	83.5	83.4	84.2
3 (behind bench)	85.5	91.1	90.3	88.1	89.9	89.0
6 (on bench)	84.2	83.9	85.6	84.4	85	84.6
7 (behind bench)	89.1	89.6	89.8	89.7	88.6	89.4

Table 8 -Reading at Slauson Station

Readings at Slauson Station	Reading #1	Reading #2	Reading #3	Reading #4	Reading #5	Average
2 (on bench)	81.3	82.1	81.0	80.0	81.0	81.0
3 (behind bench)	82.5	86.7	84.3	85.9	84.0	84.7
6 (on bench)	80.2	81.5	81.4	80.9	80.8	81.0
7 (behind bench)	82.1	86.3	84.2	86.5	83.5	84.5

Table 9 - Reading at 37th Street Station

Readings at 37th Street Station	Reading #1	Reading #2	Reading #3	Reading #4	Reading #5	Average
2 (on bench)	80.6	81.2	76.0	80.7	80.8	80.0
3 (behind bench)	87.1	88.6	82.1	85.9	86.7	86.1
6 (on bench)	75.7	82.7	74.3	80.9	77.7	78.3
7 (behind bench)	81.6	89.7	76.6	85.3	81.5	82.9

On average, the bench provides a 5 decibel reduction in noise level at these station, although the reduction at Slauson station was lower, approximately 3.5 dBA. It should be noted that the average noise levels at these locations, both on and behind the bench, are usually higher than the average for the station as a whole (83.9 dBA at Manchester, 80.8 at 37th Street and 82.0 at Slauson). This is likely because both locations are underneath the station canopy, which generally increases noise by reflecting it back down onto passengers. Locations where a bench is not underneath a canopy would provide more protection.

Figure 4: Map and Information Box at Lake Avenue Station.

4.2.1.2 Map Boxes

All stations have large boxes that display maps and other information. These boxes, which are made of metal and Plexiglas, are approximately 6.5 feet tall, 3 feet wide and half a foot thick. Most stations have three or four boxes on the platform, usually placed towards the center of the station. Tables 10 and 11 list the sound levels recorded at Avalon and Long Beach Stations at two locations on the platform: one where a map box blocks the view of one side of the freeway, and the other in a location where nothing obstructed the view of the freeway.

Table 10 - Reading at Avalon Station

Readings at Avalon Station	Reading #1	Reading #2	Reading #3	Reading #4	Reading #5	Reading #6	Average
Location 4 (Map Box)	89.8	88.0	90.3	87.8	86.9	90.8	89.3
Location 5 (No Map Box)	91.1	87.9	90.4	88.7	88.5	91.6	89.7

Table 11 - Reading at Long Beach Station

Readings at Long Beach Station	Reading #1	Reading #2	Reading #3	Reading #4	Reading #5	Reading #6	Average
Location 1 (No Map Box)	83.3	83.0	82.7	82.4	83.2	85.8	83.4
Location 5 (Map Box)	82.1	81.9	79.3	80.8	83.1	84.0	81.9

The results of the comparison show that, at Avalon station, there is relatively little change, less than one decibel, in noise levels between the two locations. The difference at Long Beach Station is approximately 1.5 dBA. Both of these numbers are small enough that few people would be able to detect a difference between the two. These boxes, therefore, do not provide real relief from noise. The relatively small size of the boxes limits their effectiveness to some extent, but, more importantly, the boxes can only block noise from one side of the freeway. The freeway travel lane that is not blocked is relatively close to passengers standing near the box, leaving them exposed to almost as much noise as they would have experienced if they were not standing near the box.

4.2.1.3 Walls

Lakewood, Vermont and Rosecrans stations are all below street level and so have staircases at both ends of the platform to allow passengers to reach the street above. The sides of these stairs create large, solid walls that block the line of sight to the freeway and so may block noise from passing vehicles. Tables 12 and 13 compare the noise levels at locations next to a wall to those with no objects that may obstruct noise.[4]

Figure 5: Wall Formed by Stairway at Lakewood Station

In the case of Lakewood station, the location next to the wall was, on average, only .3 dBA quieter than the one with no objects that may block noise, small enough to essentially make no difference. The readings at Vermont Station indicate that the location next to the wall is louder than the one away from it, albeit only by 1.5 dB, not enough for most people to recognize a difference.

In addition to the general apparent lack of ability to reduce noise, it should be noted that these walls only exist where a roadway passes directly above the platform. As described in the previous section, the stations beneath roadways are among the loudest in this study because the sound from vehicles on the freeway reflects back down from the bridge above to passengers on the platform. Any protection that the wall provides to passengers from noise coming directly from cars on the freeway would be negated by the additional noise created from the sound reflected down from above.

Table 12 - Reading at Lakewood Station

Readings at Lakewood Station	Reading #1	Reading #2	Reading #3	Reading #4	Reading #5	Average
Location 2 (next to wall)	87.9	87.3	87.1	86.8	88.9	87.6
Location 3 (not next to wall)	87.1	87.9	87.6	87.2	89.7	87.9

4 I do not compare noise levels at Rosecrans Station because readings taken next to the wall were not under the roadway overhead, while readings that were not next to the wall were under the roadway, which, as shown above, increases noise levels significantly. Therefore, a direct comparison is not possible.

Table 13 - Reading at Vermont Station

Readings at Vermont Station	Reading #1	Reading #2	Reading #3	Reading #4	Reading #5	Average
Location 2 (next to wall)	86.4	85.4	87.8	84.6	90.4	86.9
Location 8 (not next to wall)	86.3	84.4	85.5	84.0	87.2	85.5

4.2.2 Canopies

Nearly all stations in the study have canopies to protect passengers from rain and sun. The only exceptions are the three stations, Vermont, Lakewood and Rosecrans, which have overhead roadways since the roads act as de facto canopies. Just as the roadways above stations do, canopies reflect noise from passing vehicles back onto the station platform. Canopies are lower than the overhead roadways, however, and do not cover the entire length of the station so their overall effect on increasing noise on the platform is less marked. For passengers waiting under these canopies, however, the noise is noticeably louder than on uncovered portions of the platform. For example, at the Long Beach Station the noise levels at locations four (not under a canopy) and six (under the canopy), which face the same direction and have no obstructions, show differences in sound levels that are likely caused the presence of the canopy. Table 14 shows the readings at these locations at the station, and Table 15 provides the same information from Allen Station on the Gold Line.

Figure 6: View of Canopy at Lake Station

Table 14 - Reading at Long Beach Station

Long Beach Station	Reading #1	Reading #2	Reading #3	Reading #4	Reading #5	Reading #6	Average
Location 4 (Not Under Canopy)	81.4	78.7	82.0	82.0	81.9	83.9	81.7
Location 5 (Under Canopy)	85.4	83.2	84.3	84.4	84.3	87.3	84.8

Table 15 - Reading at Allen Station

Allen Station	Reading #1	Reading #2	Reading #3	Reading #4	Average
Location 1 (Under Canopy)	84.0	87.8	85.7	84.5	85.5
Location 5 (Not Under Canopy)	85.0	85.8	83.5	83.8	84.5

The readings from Long Beach Station show a marked rise in the noise level at the location under the canopy. At over 3 dBA, the difference between the locations would be immediately noticeable to passengers waiting for their trains. The difference at Allen Station is less marked, but is still consistent enough to indicate that canopies play a significant role in the variations in sound levels.

4.3 Regressions

All of the factors described above may explain the differences in sound level at stations in the study area. In order to determine which are the most significant, and how they interact with one another, I ran regression models using the various factors that may increase or lower sound levels. To account for the different station configurations, I ran separate models for stations with a single, center platform and those with two platforms on either side of a centrally located roadway.[5] For each of these two station types, I ran two models. The first model includes only the presence of canopies or other overhead structures, the presence of objects such benches, walls, and map boxes that may block sound from passing vehicles, and the distance from the platform to the roadway. The second model adds factors unrelated to station design: traffic speed, percentage of cars on the roadway, and the average annual daily throughput on the highway sections adjacent to the station. The results of these regressions appear in tables 16-20.

Table 16: Effects of Station Design Factors on Noise Levels (Single-Platform Stations)

	B	Beta	Sig.
Constant	89.249		
Canopy	6.319	-0.788	> .001
Wall	2.561	0.197	0.003
Bench	-3.609	-0.44	> .001
Distance	-0.125	-0.101	0.104
r-square =	0.439		
N=	150		

5 As noted above, only four stations. 37th Street, Slauson, Manchester and Rosecrans, all on the Harbor Transitway, are of this latter type.

Table 17: Effects of Design and Non-Design Factors on Noise Levels (Single-Platform Stations)

	B	Beta	Sig.
Constant	73.755		
Speed (North)	0.023	0.112	0.0065
Speed (South)	0.15	0.437	>.001
% Cars (North)	0.335	0.202	0.338
% Cars (South)	-0.157	-0.098	0.641
Canopy	6.319	-0.788	> .001
Wall	2.561	0.197	0.003
Bench	-3.609	-0.44	> .001
Distance	-0.125	-0.101	0.104
AADT	-3.49E-05	-0.249	> .001
r-square =	0.727		
N =	150		

Table 18: Effects of Station Design Factors on Noise Levels (Double-Platform Stations)

	B	Beta	Sig.
Constant	81.345		
Canopy	1.407	0.233	> .001
Wall	-0.34	-0.029	0.571
Bench	0.958	0.103	0.038
Distance	0.109	0.204	> .001
r-square =	0.104		
N =	403		

Table 19: Effects of Design and Non-Design Factors on Noise Levels (Double-Platform Stations)

	B	Beta	Sig.
Constant	60.282		
Speed (West)	0.037	0.134	0.001
Speed (East)	0.122	0.319	>.001
% Cars (West)	-23.89	-0.232	0.051
% Cars (East)	53.358	0.524	>.001
Canopy	1.554	0.258	>.001
Wall	-0.531	-0.043	0.292
Bench	0.963	0.103	0.011
Distance	-0.001	-0.003	0.957
AADT	-5.32E-05	-0.483	> .001
r-square=	0.431		
N=	403		

The results indicate that design features such as benches, canopies and walls explain nearly half of the variation in noise at the single-platform stations, with canopies and benches accounting for the largest proportion of the variation. Adding the non-design factors to the model explains nearly three quarters of the variation, although the significance level is so high for some factors that the results of this regression are not entirely trustworthy. In particular, canopies create a marked increase in the noise level, and benches provide some relief from noise. Unfortunately, the distance between roadway and platform shows too high a significance level and so we cannot accurately determine the effect distance has on sound levels. The model that includes more factors provides more explanatory power although several data points have high significance levels and so cannot explain much of the variation.

The regression is not particularly helpful because so many factors have high significance levels, but it seems that design features have less effect on noise levels in the case of center-located station platforms. Even when factoring in non-design elements such as speed of traffic and AADT, the model explains less of the variation in noise than it does for the double-platform stations on the Transitway.

5. Conclusion and Recommendations

5.1 Conclusion

The levels of noise at the stations in this study are high enough to cause annoyance and possibly health problems for people who patronize them. The stations on the Green Line suffer the most from noise, with five of the highest average levels recorded at stations on this route. Gold Line stations are generally the quietest, although Allen Station is significantly louder than the other two stations on the Freeway. Much of the variation in noise levels is due to factors that cannot be controlled by the design and layout of the station: the number, speed and type of vehicles traveling on the adjacent freeway lanes play a large role in the overall noise level at stations. Nevertheless, some design elements, particularly when used on the Harbor Transitway, can reduce noise significantly.

5.2 Recommendations

In light of the findings described above, I recommend the following:

1) Perform studies on the health effects of exposure to noise on transit platforms.

Few studies have examined whether those who are repeatedly exposed to high noise levels for short periods of time suffer from hearing, cardiovascular, or other problems. No studies have examined in depth the extent to which passengers exposed to noise for relatively short periods of time on transit or transit platforms suffer from these problems. While it seems likely that riders who wait at Metro stations in highway medians may suffer from these problems, it is not possible to make a definite connection between noise and health problems without a full study.

2) Attempt to reduce noise levels at existing stations with additional benches.

Metro can make several changes in the design of stations to reduce noise levels on platforms, although the effects are likely to be limited, particularly on Green and Gold Line stations. On Harbor Transitway stations, the large benches provide some noise reduction, albeit only 4 or 5 decibels. Because canopies and overhead roadways increase noise levels, most of these benches should not be located under these overhead structures. Large benches would prove ineffectual for noise reduction at the light rail stations, however, because the bench will only block noise from one side of the freeway, and so will not reduce overall noise levels much, if at all.

3) Investigate ways to dampen or deflect noise that reflects back from canopies and overhead roadways.

Since canopies are necessary at stations to protect passengers from rain or sun, Metro should investigate how to alter them so that they are less prone to increase the noise levels. The shape of the canopies or the material used to construct them may help to reduce the amount of noise reflected back onto the platforms. At several stations on the Green Line the canopies are curved, which reduces the amount of sound that reflects directly back onto passengers waiting below. Noise levels are still high in these locations, however, and materials that absorb sound may further reduce these levels.

4) *Install sound walls at stations.*

The study by ATS Consulting on noise at 37th Street Station indicates that sound walls could reduce the amount of noise by as much as 13 decibels. Clear materials such as Plexiglas can be used to build sound walls that do not have the effect of enclosing the station with dark material. The cost of creating sound walls is high however. To be most effective, the walls should extend past the ends of the station in order to block noise as it travels from cars approaching the station. Walls that do not extend as far beyond the station would be less expensive, but would only reduce the noise levels by 7 or 8 decibels.

Because rail stations are longer than those on the Harbor Transitway, the cost would be higher. Stations on the Transitway are approximately 230 feet long, while those on the Green and Gold Line range from 275 to 325 feet. If the cost per foot for construction is comparable to costs for building walls at the 37th Street station, adding sound walls to rail stations could cost over $280,000 per station. It would also be more difficult to install the sound walls at rail stations because there is little distance between the rail tracks and the highway lanes, so that workers would be working in close proximity to both trains and cars unless Caltrans and Metro are willing to divert traffic around the locations. On the Transitway stations, workers could do much of the construction on the platform itself. Nevertheless, the significant reduction in noise levels that these walls can provide is desirable enough to make the cost and effort worthwhile.

It should be noted, however, that stations with roadways overhead are unlikely to receive as much benefit from sound walls since much of the noise reflecting off the bottom of the roads above, making the walls less effective overall. Unfortunately, therefore, several of the loudest stations would not benefit from this treatment.

5) *Build enclosed waiting areas on platforms.*

Particularly for stations with roadways overhead, a passenger shelter with four walls and a roof may be the best option for reducing noise levels on the platform. Such shelters are relatively inexpensive, with costs averaging approximately $20,000, and could reduce noise levels by 7 or 8 decibels. Although at the loudest stations this reduction is not enough to give passengers complete relief from high noise levels, it is enough slightly more comfortable. If these shelters are constructed in combination with a sound wall, significant noise reduction, over 15 decibels, is possible.

6) *Avoid constructing stations in freeway medians.*

Although siting stations in the median of highways offers Metro some advantages (e.g. lowering land acquisition costs and avoiding community opposition), the high levels of noise on the highway centered platforms should be taken into consideration when deciding on station locations. Metro's Long Range Transportation Plan lists several possible new rail lines that may include stations in the medians of freeways, including on the I-405 over the Sepulveda Pass, and along SR-60 in the San Gabriel Valley. If these lines can be designed so that their stations are not in the middle of the freeways, the passengers on the lines would benefit greatly.

7) *Do not locate stations directly below surface streets.*

The Lakewood, Vermont and Rosecrans stations are among the loudest of all stations studied in large part because of the noise that reflects off of the bottom of the roads back onto the station platforms. If Metro feels it necessary to build stations in highway medians it should not place stations below roadways. Hawthorne Station on the Green Line and Lake Station on the Gold Line, which are below street level but offset from the street above, should be models for the design of any new stations of this type.

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Appendix

Description of stations in study area and locations where readings were taken in each platform.

37th Street Station

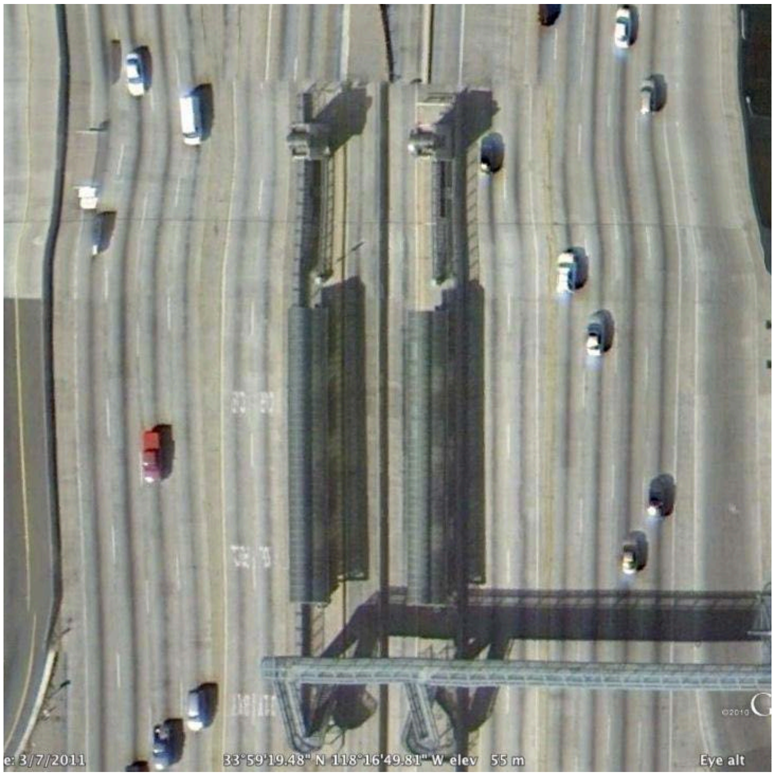
Station Description

Located above surface streets. Roadway for bus passes through the middle of the station, with separate platforms for passengers heading north and south. Stairways at north and south ends of both platforms lead down to 37th Street. On both sides of the platform an elevator is located towards the south end of the platform. A low wall (approximately 3' on the southbound side and 2' high on the northbound side) topped by a wire mesh fence separates the platforms from the freeway lanes. A canopy covers the middle portions of the platforms. Benches with high backings (approximately 6') made of stone and thick glass are located at several spots on the platforms, some under the canopy, some not. Benches face busway, and may block freeway noise. AADT for this section of freeway is 274,000 northbound 284,000 southbound. It is approximately 25 feet from center of northbound platform to #1 lane northbound, 16 feet from center of southbound platform to #1 lane southbound.

Reading Locations

1) North end of the southbound platform, next to stairs past elevator. Take reading facing the busway.
2) Sitting on a bench under canopy approximately in the middle of the southbound platform. Take reading facing busway.
3) Between bench and wall separating platform and freeway on southbound platform. Approximately the middle of the platform, under the canopy. Take reading facing freeway.
4) Next to stairs at south end of the southbound platform. Take reading facing the busway.
5) Next to stairs on south end of the northbound platform. Take reading facing busway.
6) Sitting on a bench under canopy, approximately in the middle of the northbound platform. Take reading facing busway.
7) 7) Between bench and wall separating platform and freeway. Approximately the middle of the platform, under the canopy. Take reading facing freeway.
8) 8) North end of the northbound platform, next to the stairs. Take reading facing the busway.

Slauson Station



Station Description

Located above surface streets. Roadway for bus passes through the middle of the station, with separate platforms for passengers heading north and south. Stairway at south end connects the two platforms together, as well as providing a passage over the freeway for pedestrians. Elevators at north end of the platform on both the northbound and southbound platforms. Stairways leading directly down to Slauson Avenue located near the elevators on the north end on both platforms. A low wall (approximately 3') topped by a wire mesh fence separates the platforms from the freeway lanes. A canopy covers the middle portion of the platforms. Benches with high backings (approximately 6') made of stone and thick glass are located at several spots on the platforms. Benches face busway, and may block freeway noise. AADT for this section of freeway is 307,000 northbound 319,000 southbound. It is approximately 18 feet from center of northbound platform to #1 lane northbound, 14 feet from center of southbound platform to #1 lane southbound.

Reading Locations

1) North end of the southbound platform, near the elevator. Take reading facing the busway.
2) Sitting on a bench under canopy approximately in the middle of the southbound platform. Take reading facing busway.
3) Between bench and wall separating platform and freeway on southbound platform. Approximately the middle of the platform, under the canopy. Take reading facing freeway.
4) Next to stairs at south end of the southbound platform. Take reading facing the busway.
5) Next to stairs on south end of the northbound platform. Take reading facing busway.
6) Sitting on a bench under canopy approximately in the middle of the northbound platform. Take reading facing busway.
7) Between bench and wall separating platform and freeway on northbound platform. Approximately the middle of the platform, under the canopy. Take reading facing freeway.
8) North end of the northbound platform, near the elevator. Take reading facing the busway.

Manchester Station

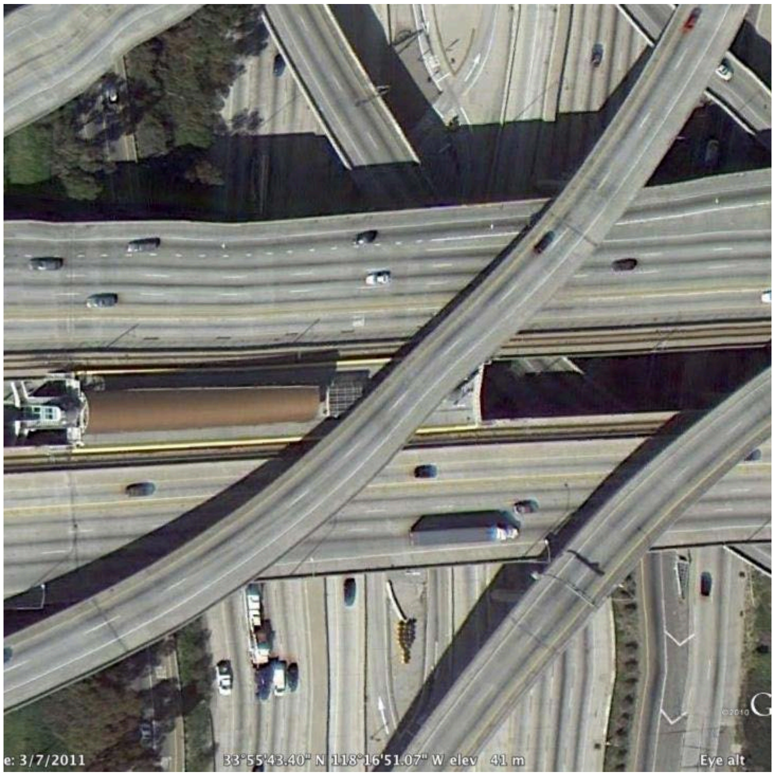
Station Description

Located above surface streets. Roadway for bus passes through the middle of the station, with separate platforms for passengers heading north and south. Stairways at north and south ends of both platforms lead down to Manchester Avenue. On the southbound platform an elevator is located towards the at north end of the platform. On northbound platform the elevator is located towards the south end of the platform. A low wall (approximately 3') topped by a wire mesh fence separates the platforms from the freeway lanes. A canopy covers the middle portions of the platforms. Benches with high backings (approximately 6') made of stone and thick glass are located at several spots on the platforms. Benches face busway, and may block freeway noise. AADT for this section of freeway is 318,000 northbound 322,000 southbound. It is approximately 16 feet from center of northbound platform to #1 lane northbound, 20 feet from center of southbound platform to #1 lane southbound.

Reading Locations

1) North end of the southbound platform, next to stairs past elevator. Take reading facing the busway.
2) Sitting on a bench under canopy approximately in the middle of the southbound platform. Take reading facing busway.
3) Between bench and wall separating platform and freeway on southbound platform. Approximately the middle of the platform, under the canopy. Take reading facing freeway.
4) Next to stairs at south end of the southbound platform. Take reading facing the busway.
5) Next to stairs on south end of the northbound platform. Take reading facing busway.
6) Sitting on a bench under canopy approximately in the middle of the northbound platform. Take reading facing busway.
7) Between bench and wall separating platform and freeway on northbound platform. Approximately the middle of the platform, under the canopy. Take reading facing freeway.
8) North end of the northbound platform, next to the stairs. Take reading facing the busway.

I-105 / Harbor Station (hidden in this picture)



Station Description

The station is not directly next to the travel lanes of the I-110 freeway, but separated from freeway by approximately 30 feet in each direction, although car pool lanes (one on each side) come closer to the platform, approximately 15 feet. Located below I-105 freeway and transition ramps between I-110 and I-105. Stairs at north and south end of platform. Elevator is in middle of the platform. Elevators and stairs lead up to a mezzanine level from which passengers can go to the street or up to the Green Line Harbor Station. Platform is located in the middle of two roadways used exclusively by buses. Large stairways are located at north and south ends. Elevator is in middle of the platform. Large walls for stairs and to support roadways in middle of the platform may block some noise. AADT for this section of freeway is 299,000 northbound 258,000 southbound. Unable to get distance readings from Google Earth because station is below I-105 freeway.

Reading Locations

1) At foot of the north stairs in the middle of the platform, facing the U-shaped barrier. Take reading facing east.
2) On bench in middle of the platform facing west.
3) In middle of platform near elevator. Take reading facing west.
4) On bench in middle of platform facing east.
5) In middle of platform next to south end stairs by sign that says “Northbound and Southbound Buses.” Take reading facing east.
6) At foot of the south stairs in the middle of the platform, facing the U-shaped barrier. Take reading facing west.

Rosecrans Station

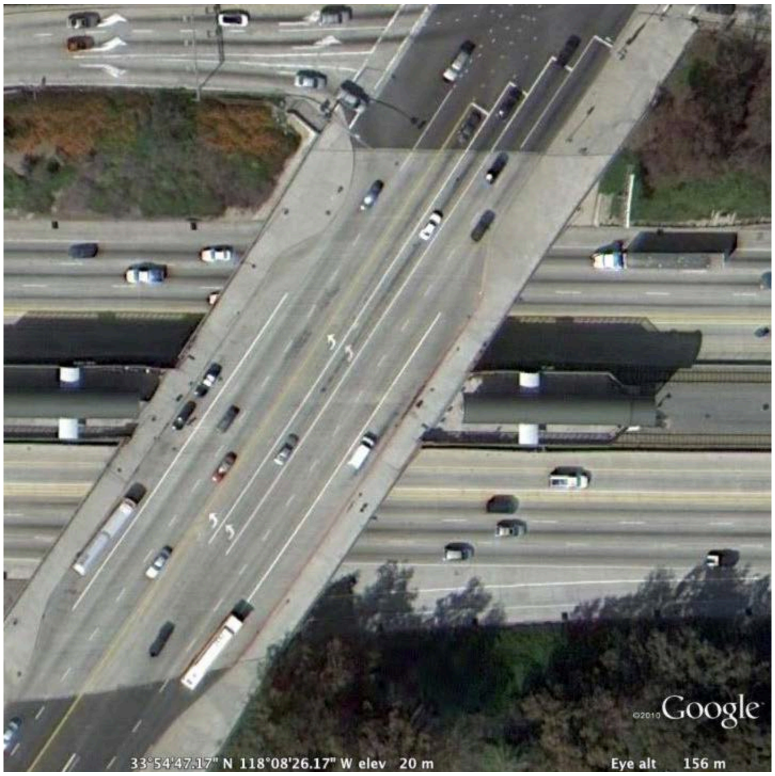
Station Description

Station is located below level of surface streets. Rosecrans Boulevard is directly above the middle portion of the station. Distance between station platform and roadway above is approximately 30'. Roadway for bus passes through the middle of the station, with separate platforms for passengers heading north and south. Stairways at north and south ends of both platforms lead up to Rosecrans Boulevard. Elevators to roadway are on south ends of both platforms. A low wall (approximately 3') topped by a wire mesh fence separates the platforms from the freeway lanes. No canopy over platforms other than the roadway above. Benches with high backings (approximately 6') made of stone and thick glass are located at several spots on the platforms. Benches face busway, and may block freeway noise. The stairs at each corner of the station form a wall between that platform and the freeway that may also block noise. AADT of this section of freeway is 251,000 northbound, 243,000 southbound. It is approximately 18 feet from center of northbound platform to #1 lane northbound, 20 feet from center of southbound platform to #1 lane southbound.

Reading Locations

1) North end of the southbound platform, next to stairs. Not under Rosecrans Boulevard. Take reading facing the busway.
2) Sitting on a bench under Rosecrans Boulevard, approximately in the middle of the southbound platform. Take reading facing busway.
3) Between bench and wall separating platform and freeway on southbound platform. Approximately the middle of the platform, under Rosecrans Boulevard. Take reading facing freeway.
4) Next to stairs at south end of the southbound platform. Take reading facing the busway.
5) Next to stairs on south end of the northbound platform. Take reading facing busway. Not under Rosecrans Boulevard.
6) Sitting on a bench under canopy approximately in the middle of the northbound platform under Rosecrans Boulevard. Take reading facing busway.
7) Between bench and wall separating platform and freeway on northbound platform. Approximately the middle of the platform, under Rosecrans Boulevard. Take reading facing freeway.
8) North end of the northbound platform, next to the stairs. Take reading facing the busway Not under Rosecrans Boulevard.

Lakewood Station



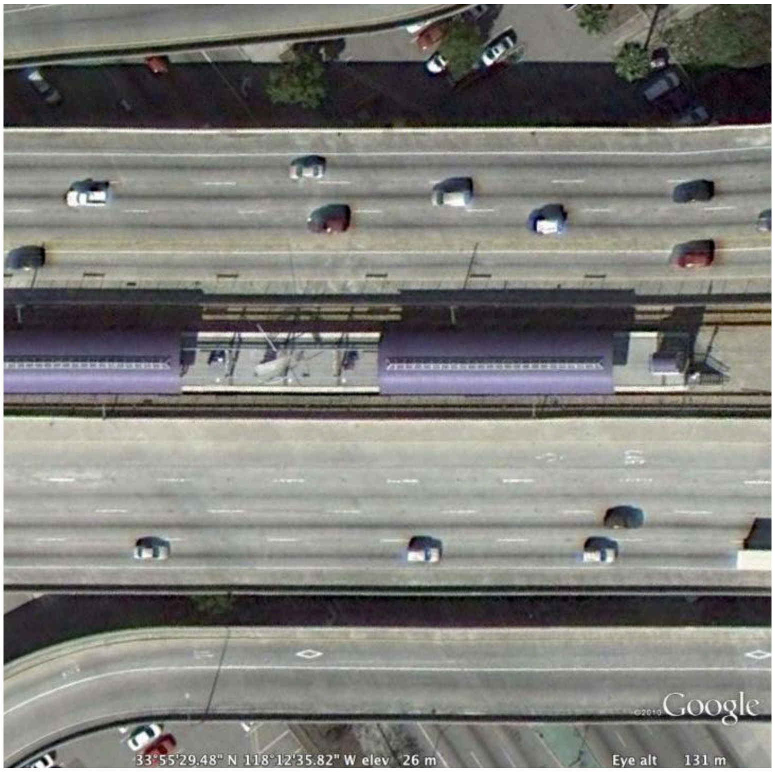
Station Description

The station is located below street level and is accessed via stairs or elevators from Lakewood Boulevard. The middle portion of the station is directly beneath Lakewood Boulevard, which forms a low ceiling above the platform. The east and west sides are below the entrances to the station, which are at street level, but form a higher ceiling than the street itself does, and do not entirely cover the corners of the station. Elevators are at both ends of the station, as are stairs. The structures supporting the stairs form a solid wall that fully blocks the view of the opposite side of the highway. Besides these, there are map boxes about 6' tall and 3' wide as well as large columns supporting the roadway that may block some sounds. AADT for this section of freeway is 222,000 westbound and 207,000 eastbound. It is approximately 35 feet from center of platform to outside of #1 lane westbound, 30 feet eastbound.

Reading Locations

1) Far east side in front of elevator, in middle of platform. No obstructions from road. Take measurement facing westbound traffic. (Under mezzanine).
2) Next to south side of wall formed by stairs, so blocked from view of westbound travel lanes. Take measurement facing the eastbound traffic. (Under mezzanine).
3) At foot of east side stairs, middle of platform. Take measurement facing eastbound traffic. (Under mezzanine).
4) Middle of station in front to map box on east side, so partially blocked from view of eastbound traffic. Take measurement facing westbound traffic. (Under roadway).
5) Next to west side map box, center of platform, so no structures blocking view of road. Take measurement facing eastbound traffic. (Under roadway).
6) Next to north side of wall formed by stairs, so blocked from view of eastbound travel lanes. Take measurement facing the westbound traffic. (Under mezzanine).
7) Foot of west side stairs, middle of platform. No obstructions. Take measurement facing westbound traffic. (Under mezzanine).
8) Far east side in front of elevator, in middle of platform. No obstructions from road. Take measurement facing eastbound traffic. (Under mezzanine).

Long Beach Station



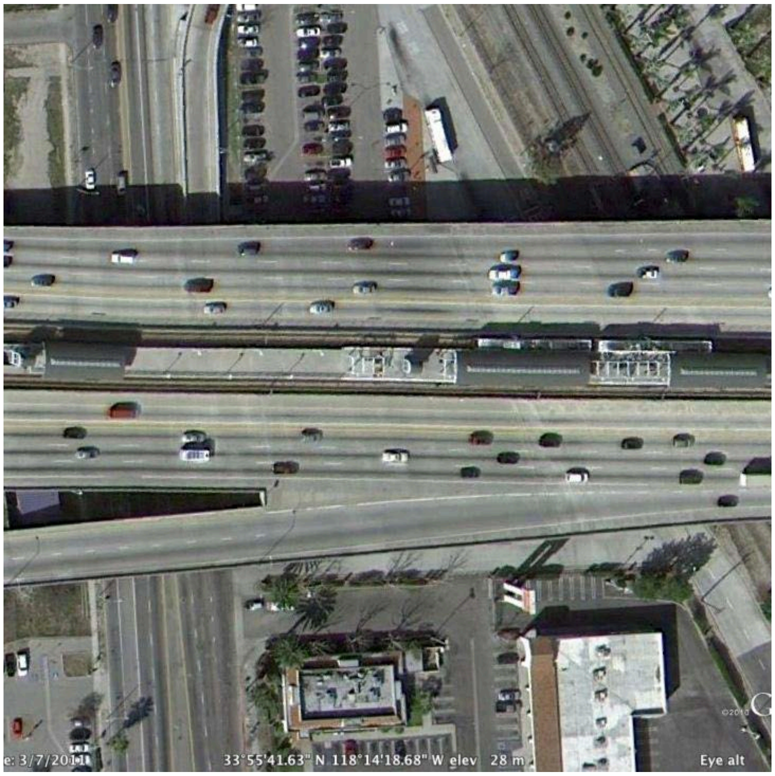
Station Description

Station is above street level with elevators at both east and west ends of platform. The elevator box provides a small amount of cover from traffic noise on the opposite side. Escalators from the street below come into station at the east and west ends, and are under canopies. The canopy is in two sections, leaving an uncovered portion of the platform in the middle of the station. Other than map boxes, there are no structures in the station that obstruct sound. AADT for this section of freeway is 226,000 westbound and 230,000 eastbound. It is approximately 35 feet from center of platform to outside of #1 lane westbound, 30 feet eastbound.

Reading Locations

1) In front of east side elevator. Not under canopy. Take reading facing south.
2) At top of east side escalator, under canopy. Take reading facing north.
3) At top of east side escalator, under canopy. Take reading facing south.
4) Middle of station, not under canopy. Take reading facing north.
5) Middle of station in front of map box. Take reading facing south, so map box blocks view of traffic on opposite side.
6) Along side of west side escalator, under canopy. Take reading facing north.
7) In front of west side elevator, not under canopy. Take reading facing south.

Imperial / Wilmington Station



Station Description

Station is above street level with elevators at east and west ends of platform. A third elevator is located at the far west end of the station, approximately 100 feet beyond the waiting area for trains. The elevator boxes provide a small amount of cover from traffic noise on the opposite side of the box. Escalators from the street below come into station at the east and west ends, and are under canopies. The canopy is in two sections, leaving an uncovered portion of the platform in the middle of the station. Other than map boxes and elevators, there are no structures in the station that obstruct sound. AADT for this section of freeway is 231,000 westbound and 226,000 eastbound. It is approximately 35 feet from center of platform to outside of #1 lane westbound, 30 feet eastbound.

Reading Locations

1) In front of east side elevator, not under canopy. Take reading facing south.
2) At top of east side escalator, under canopy. Take reading facing north.
3) At top of east side escalator, under canopy. Take reading facing south.
4) Middle of station, not under canopy. Take reading facing north.
5) Middle of station in front of map box. Take reading facing south, so map box blocks view of traffic on opposite side.
6) Along side of west side escalator, under canopy. Take reading facing north.
7) Next to west side elevator, not under canopy. Take reading facing south.

Avalon Station

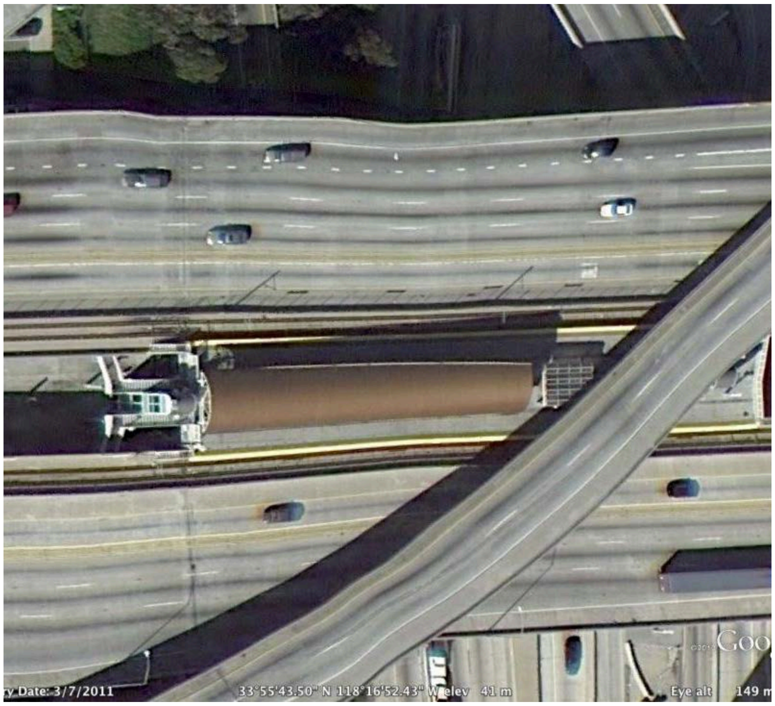
Station Description

Station is above street level with elevators at both east and west ends of platform. The elevator boxes provide a small amount of cover from traffic noise on the opposite side. Escalators from the street below come into station at the east and west ends, and are under canopies. The canopy is a single continuous structure in the middle of the platform, leaving uncovered portions at the far east and west ends of the station. Other than map boxes and elevators, there are no structures in the station that obstruct sound. AADT for this section of freeway is 237,000 westbound and 231,000 eastbound. It is approximately 30 feet from center of platform to outside of #1 lane in both directions.

Reading Locations

1) Far east of platform, past elevator. Not under canopy. Take reading facing south.
2) In front of elevator not under canopy. Take reading facing north.
3) At top of east side escalator, under canopy. Take reading facing south.
4) Middle of station in front of map box under canopy. Take reading facing north, so map box blocks view of traffic on opposite side.
5) Along side of west side escalator, under canopy. Take reading facing south.
6) In front of west side elevator, not under canopy. Take reading facing north.

Harbor Freeway Station



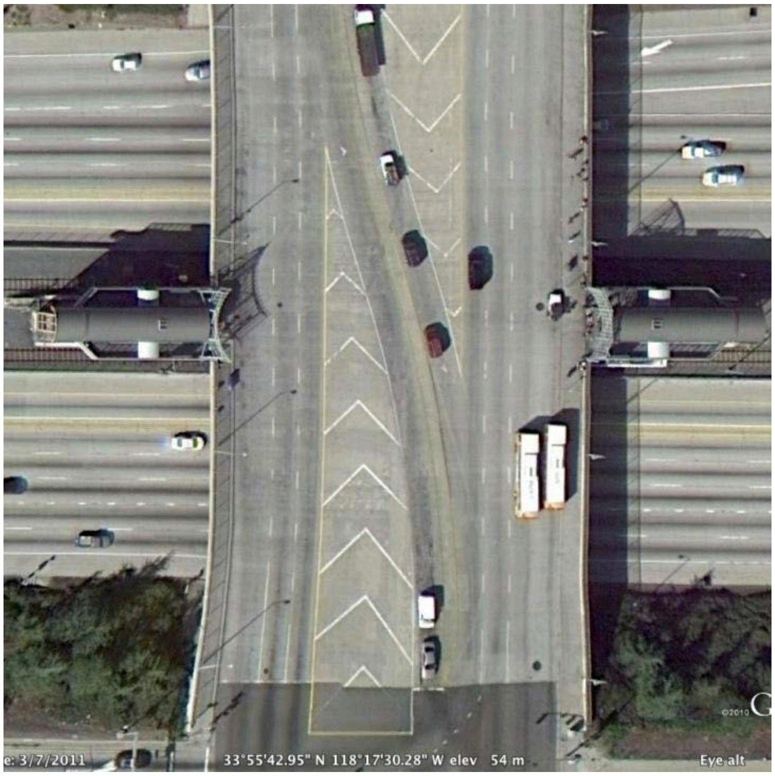
Station Description

Station is above street level with elevators at both east and west ends of platform. Platform is wider than other, and the canopy does not cover the entire width of the platform. The elevator boxes may provide a small amount of cover from traffic noise on the opposite side. Map boxes, which are approximately 6.5 feet tall and 3 feet wide, may also block some noise. Escalators from the street below come into station at the east and west ends, and are under canopies. The canopy is a single continuous structure in the middle and west ends of the platform, leaving uncovered portions at the far east end of the station. Other than map boxes and elevators, there are no structures in the station that obstruct sound. AADT for this section of freeway is 223,000 westbound and 237,000 eastbound. It is approximately 40 feet from center of platform to outside of #1 lane in both directions (30 feet if closer to edge of platform, which is wider than patforms at other stations).

Reading Locations

1) Far east of platform, (past elevator)(?) Not under canopy. Take reading facing south.
2) In front of elevator not under canopy. Take reading facing north.
3) At top of east side escalator, under canopy. Take reading facing south.
4) Middle of station in front of map box under canopy. Take reading facing north, so map box blocks view of traffic on opposite side.
5) Along side of west side escalator, under canopy. Take reading facing south.
6) In front of west side elevator, not under canopy. Take reading facing north.

Vermont Station



Station Description

The station is located below street level and is accessed via stairs or elevators from Vermont Avenue The middle portion of the station is directly beneath Vermont Avenue, which forms a low ceiling above the platform. The east and west sides are below the entrances to the station, which are at street level, but form a higher ceiling than the street itself does, and do not entirely cover the corners of the station. Elevators are at both ends of the station, as are stairs. The structures supporting the stairs form a solid wall that fully blocks the view of the opposite side of the highway. Besides these, there are map boxes about 5' tall and 3' wide as well as large columns supporting the roadway that may block some sounds. AADT for this section of freeway is 240,000 westbound 223,000 eastbound, approximately 45 feet from center of platform to outside of #1 lane westbound, 33 feet eastbound.

Reading Locations

1) Far east side in front of elevator, in middle of platform. No obstructions from road. Take measurement facing westbound traffic. (Under mezzanine).
2) Next to south side of wall formed by stairs, so blocked from view of westbound travel lanes. Take measurement facing the eastbound traffic. (Under mezzanine).
3) At foot of east side stairs, middle of platform. Take measurement facing eastbound traffic. (Under mezzanine).
4) Middle of station in front to map box on east side, so partially blocked from view of eastbound traffic. Take measurement facing westbound traffic. (Under
5) Next to west side map box, center of platform, so no structures blocking view of road. Take measurement facing eastbound traffic. (Under roadway).
6) Next to north side of wall formed by stairs, so blocked from view of eastbound travel lanes. Take measurement facing the westbound traffic. (Under mezzanine).
7) Foot of west side stairs, middle of platform. No obstructions. Take measurement facing westbound traffic. (Under mezzanine).
8) Far east side in front of elevator, in middle of platform. No obstructions from road. Take measurement facing eastbound traffic. (Under mezzanine).

Crenshaw Station

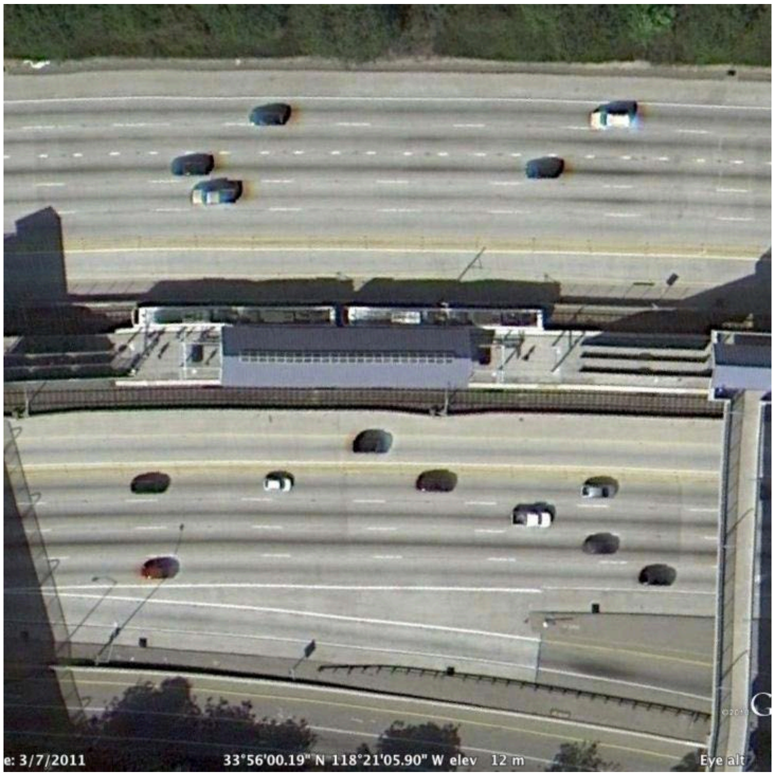
Station Description

Station is above street level with elevators at both east and west ends of platform. The elevator box provides a small amount of cover from traffic noise on the opposite side. Escalators from the street below come into station at the east and west ends, and are under canopies. The canopy is in two sections, leaving an uncovered portion of the platform in the middle of the station. Other than map boxes, there are no structures in the station that obstruct sound. AADT for this section of freeway is 218,000 westbound and 240,000 eastbound. It is approximately 34 feet from center of platform to outside of #1 lane in both directions.

Reading Locations

1) In front of east side elevator. Not under canopy. Take reading facing south.
2) At top of east side escalator, under canopy. Take reading facing north.
3) At top of east side escalator, under canopy. Take reading facing south.
4) Middle of station, not under canopy. Take reading facing north.
5) Middle of station in front of map box. Take reading facing south, so map box blocks view of traffic on opposite side.
6) Along side of west side escalator, under canopy. Take reading facing north.
7) In front of west side elevator, not under canopy. Take reading facing south.

Hawthorne Station



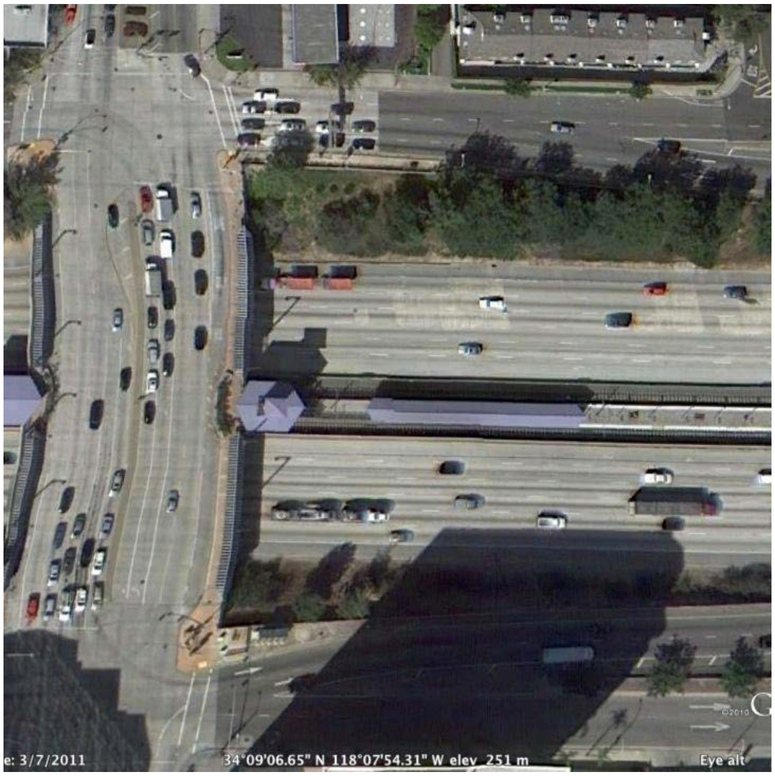
Station Description

Stairs and elevators from Hawthorne Boulevard are at far west end of the station, beyond passenger waiting area of platform. Walkways connect the station platform to the elevators. A canopy covers the middle of the platform, but it is smaller than canopies at other stations, and much of the platform is exposed. A third staircase, leading to a walkway that goes over the eatsbound lanes of the freeway, is at the far east end of the platform. A beam that supports and map boxes may block noise. AADT for this section of freeway is 199,000 westbound and 218,000 eastbound. It is approximately 34 feet from center of platform to outside of #1 lane in both directions.

Reading Locations

1) Far east end of platform by large concrete beam. Not under canopy. Take reading facing north.
2) Foot of east end stairs, under canopy. Take reading facing south.
3) Middle of platform, by low stone bench, under canopy. Take reading facing north.
4) Middle of platform by sculptures, under canopy. Take reading facing south.
5) Foot of west end stairs. Not under canopy. Take reading facing north.
6) By elevator at far west end. Not directly under canopy, but close to the overpass, so sound does echo. Take reading facing south.

Lake Station



Station Description

Station is below street level and accessed by stairs or elevators at the west end of the platform. At the bottom of the stairs are the ticket vending machines and turnstiles. To the east of the turnstiles the passenger waiting area. The western half of the platform is covered by a canopy, while the eastern half is open air. Other than map box, there is nothing that may potentially block noise. AADT for this section of freeway is 295,000 westbound and 294,000 eastbound. It is approximately 25 feet from center of platform to #1 lane westbound, 20 feet to #1 lane eastbound.

Reading Locations

1) Far east end of the station, not under canopy. Take reading facing north.
2) Middle of platform section not under canopy, in front of map box. Take reading facing south.
3) Middle of platform, just outside of canopy section. Take reading facing north.
4) Middle of platform section under canopy, slightly towards the west. Take reading facing south.
5) Middle of platform section under canopy, slightly towards the east. Take reading facing north.
6) West end of station, as close to the entrance as possible. Take reading facing south.
7) West end of station, as close to the entrance as possible. Take reading facing north.

Allen Station

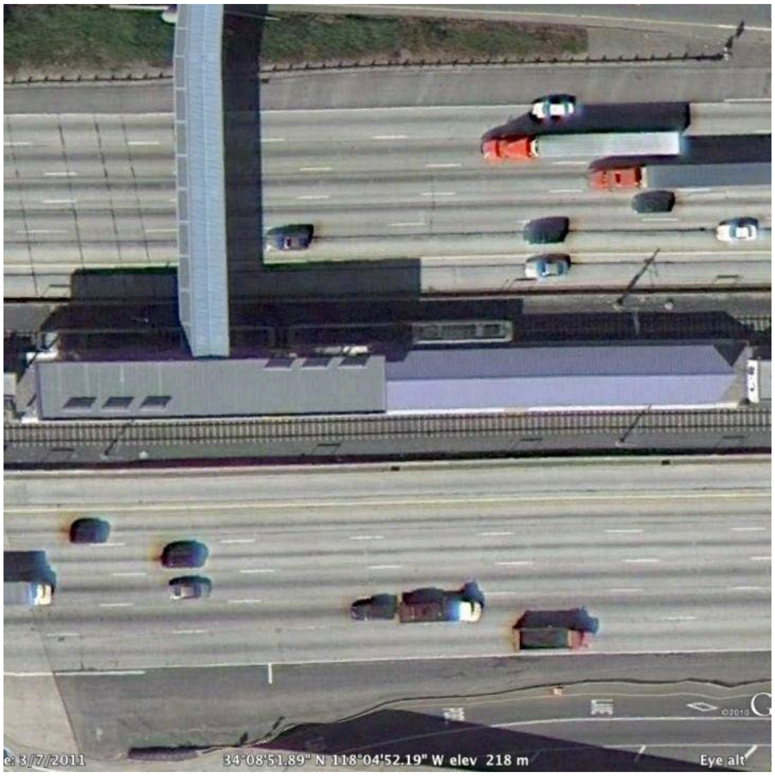
Station Description

Station is above street level, and accessed by stairs and elevator at the east end of the station. A canopy covers almost half the platform on the eastern side, while the western portion is open-air. Other than map boxes, there is nothing on the platform that could block noise from the freeway. AADT for this section of freeway is 280,000 westbound and 294,000 eastbound. It is approximately 25 feet from center of platform to #1 lane westbound, 22 feet to #1 lane eastbound.

Reading Locations

1) At far east end of platform, at top of stairs under canopy. Take reading facing north.
2) Middle of section under canopy. Take reading facing north.
3) West side of section under canopy, in front of map box. Take reading facing south.
4) Just to west of canopy, not under it. Take reading facing south.
5) Middle of western portion not under canopy. Take reading facing north.
6) Far west end of station, not under canopy. Take reading facing south.

Sierra Madre Villa Station



Station Description

Station is above street level and reached by a walkway from the adjacent parking structure on the north side of the freeway. The walkway is above the level of the platform, and passengers access the station from two staircases or two elevators. The forms a canopy over the western portion of the platform, about 15 feet overhead. The eastern half of the platform is covered by a canopy of the normal type. The stairs and elevator may block some noise, as do the map boxes. Because the station is the end of the line, trains wait on the north side tracks and so may block some freeway noise from the westbound traffic lanes. AADT for this section of freeway is 277,000 westbound and 265,000 eastbound. It is approximately 35 feet from center of platform to #1 lane westbound, 33 feet to #1 lane eastbound.

Reading Locations

1) Far east end of station, in front of area where train operators take breaks. Under canopy. Take reading facing north.
2) Middle of section under canopy. Take reading in front of map box facing north.
3) Towards end of section under canopy, but still underneath it. Take reading facing south.
4) Next to east end stairs. Under high canopy. Take reading facing south.
5) Next to east stairs. Under high canopy. Take reading facing north.
6) Between east west end stairs. Take reading facing north.
7) Next to west elevator. Take reading facing south.