5-7-2011

The Impacts of Road Capacity Removal

Jason E. Billings
University of Connecticut - Storrs, jbillings23@gmail.com

The Impacts of Road Capacity Removal

Jason Emery Billings

B.S., Purdue University, 2005

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

at the

University of Connecticut

2011

APPROVAL PAGE

Master of Science Thesis

The Impacts of Road Capacity Removal

Presented by

Jason Emery Billings, B.S.

Major Advisor ______________________________
Norman W. Garrick

Associate Advisor ______________________________
Nicholas E. Lownes

Associate Advisor ______________________________
Carol Atkinson-Palombo

University of Connecticut

2011

ACKNOWLEDGEMENTS

I would like to begin by thanking the New England University Transportation Center and the Dwight David Eisenhower Graduate Transportation Fellowship Program for providing the funding for this project. I would also like to thank my advisor, Dr. Norman Garrick, for persuading me to attend the University of Connecticut and providing me with much needed guidance in the development of this thesis and in the development of my professional abilities. Additional thanks needs to be given to the San Francisco Municipal Transportation Agency, the City of Toronto Transportation Services, the Institute of Transportation Engineers, and the Congress for the New Urbanism for their support in providing data and technical support for this thesis. Finally, I would like to thank my wife, Amy, for her unending support throughout this process.

TABLE OF CONTENTS

ABSTRACT

The road infrastructure of North America is aging, and many governments are faced with a critical choice: do we repair or remove freeways from our urban centers? Freeway repair is exceptionally expensive, but removing a freeway is often seen as a risky venture which may result in negative traffic effects. Therefore, it is necessary to gain a clearer understanding of how removing road capacity effects traffic flow and distribution. A growing number of cities throughout the world have completed road capacity removal projects, which opens up a unique opportunity to study the effects on traffic of these projects. Three freeway segments were ultimately selected for analysis in this study: two in San Francisco and one in Milwaukee. This analysis consisted of identifying changes in the traffic volumes and volume-capacity (V/C) ratios in urban freeways and streets in the areas surrounding the removed freeways. Overall, the results showed that when urban freeways are removed from the network, often the overall traffic flow does not change, instead traffic redistributes throughout the surrounding network. In the case studies examined there was significant excess capacity in the local street network, so the traffic was absorbed by the system without causing the V/C ratios to increase to the level of congestion. With the freeway in place the traffic distribution could be said to be distorted as witnessed by high V/C ratios on the urban freeways and low V/C ratios on urban streets. Removing the freeway resulted in a more balanced distribution in some cases; however the exact nature of the redistribution seems to depend on the replacement boulevard design. The traffic conditions for the pre-freeway situation at these locations were compared to nine other North American cities that are currently considering freeway or other capacity reduction projects. The analysis shows that the distribution of

traffic in these cities was also distorted in a manner similar to our case study locations. This suggests that in each of these cities there is also excess capacity on the surface street network that could absorb traffic that was redistributed due to freeway removal. Traffic redistribution is useful in helping to make the street network more efficient by spreading out traffic throughout the network rather than concentrating it on select roads.

INTRODUCTION

In the 1950s and 1960s, the United States built thousands of miles of freeway infrastructure. Much of this was built in rural areas between cities, but some was constructed right through the urban fabric of the cities themselves. Many people who initially viewed the construction of the freeways within cities as positive quickly changed their opinion once they saw the destruction that building these freeways caused. Homes and businesses were demolished, road networks were disrupted, and these urban freeways came to be seen as eyesores and physical barriers dividing the city. For these reasons and more, protests began in cities throughout the country to stop the construction of freeways through urban areas. These protests halted the construction of numerous freeways throughout the country and cancelled some projects altogether.

However, these protests could not undo the freeways that were already built. Now that nearly 50 years has passed since the construction of many of these urban freeways, local municipalities have come to a critical decision junction. What is to be done with these facilities that are reaching the end of their useful lifespan? One option is to simply rebuild the freeways as they are, but this is an exceptionally expensive option. Many local municipalities are struggling just to balance the budget and are hesitant to take on a project that will ultimately cost hundreds of millions of dollars. The state and federal governments are not in much better positions as they too are struggling just to maintain the road infrastructure that they currently have. Another option is growing in favor. An increasing number of cities throughout the country have demolished segments of their urban freeways and replaced them with at grade boulevards. This option is significantly cheaper and provides a wide array of perceived benefits that include

eliminating a physical barrier in the city, removing the blight often associated with freeways, increasing land values, and revitalizing the local economy through redevelopment opportunities. These reasons would seem to make freeway removal a clear choice, however much uncertainty exists as to the effect a project of this magnitude will have on traffic flow in cities.

Overall, cities in the US are highly dependent on the automobile for travel and therefore anything that involves the removal of a high capacity thoroughfare often encounters significant public scrutiny. The common fear in some quarters is that these projects will result in gridlock throughout the area thus having severe negative effects on commuters and people living within the area. Unfortunately, minimal empirical research exists to answer the question of how exactly traffic is accommodated once a high capacity road is removed from an urban area.

There are some cities, however, that were able to gain the public support necessary to remove segments of their urban freeway system. These cities offer us a unique opportunity to study the changes in traffic before and after the removal. The results from this analysis will be useful in helping other cities assess what will happen to their city when a high capacity road is removed. Many cities throughout the US now have online databases for tracking their current traffic counts on many parts of their road networks. Unfortunately, in many cases these databases do not go back far enough in time to get adequate data prior to removal. Even contacting the transportation agencies in these municipalities did not afford good results as many of these freeway segments were removed between 10 and 20 years ago and it appears that the much of the required data simply does not exist in most cases.

Thankfully, three freeway segments did have some data for performing a case study analysis. The Embarcadero and Central Freeways in San Francisco and the Park East Freeway in Milwaukee were selected for analysis. These case studies were analyzed to determine how removing the freeway affected travel patterns over time. Time periods corresponding to before the removal, during the removal and after the removal were selected for each case study. Data was then compared throughout these time periods to identify any trends that were presented. Average daily traffic (ADT) and volume – capacity (V/C) ratio data was obtained for all three time periods for the three case studies.

But analyzing the traffic distribution in the case studies was only the first part of the analysis. Since many other cities are currently considering road capacity removal projects, the current traffic distribution in these cities needed to be compared to that of the case studies to help determine if excess capacity exists on the surrounding street networks.

BACKGROUND THEORETICAL CONCEPTS

Before delving into this topic, it is important to define some of the terminology that is used in this paper. Traffic redistribution is referenced numerous times throughout this paper, and there are two main categories that this terminology falls into. On a microscopic level, traffic redistribution refers to the modeling of individual driver behavior involved in the selection of specific links in a network. On a macroscopic level, traffic redistribution refers to the examination of aggregate traffic volume data in an area. For the purposes of this analysis, traffic redistribution from the macroscopic perspective was used as ADT data was a main foundation of the analysis.

One last theory that needs to be mentioned is that of Braess' paradox. This concept describes how adding links to a network can actually increase the total cost of the system and the individual cost to the user. Therefore, adding links to a network has the potential to make the network less efficient. The foundations of this theory are utilized in this paper, as the hypothesis is that removing links from a network (or lowering their capacity) can result in an increase in performance. This analysis provides empirical results to support the converse of Braess' paradox (*1*).

POTENTIAL CASE STUDIES

The starting point for this project was to understand what cities throughout the world have embarked on road capacity removal projects and what, if any, traffic data is available for understanding how these changes in highway capacity affected vehicular travel. Overall, 13 freeway or capacity reduction projects were identified in 11 cities throughout the world. Nine of these projects occurred in seven cities throughout North America including Portland, New York City, Chattanooga, Milwaukee, Boston, Toronto and San Francisco. In Europe, three projects were identified in three different cities including Paris, Birmingham and Madrid. Asia had just one project which occurred in the city of Seoul. This is not an exhaustive list as it is likely that other capacity reduction projects have occurred. This list includes completed capacity reduction projects where information was available to identify some results of the removal. Many of these projects have limited results, but they are helpful in creating a framework for future analysis.

North America

Portland, OR – Harbor Drive Freeway

The Harbor Drive freeway was constructed in 1942 as a four lane, three mile long, at-grade road that ran alongside the Willamette River connecting an industrial neighborhood, Lake Oswego, and areas south of the downtown. It served as a physical barrier between downtown and the waterfront and carried approximately 25,000 cars per day at its peak. By 1968, residents were looking for more open space along the waterfront, so a study was initiated to determine if the freeway could be removed. The proposal to close the freeway gained more support when I-405 was completed in 1973 and linked to I-5. In 1974 the freeway was ultimately closed and demolished to make way for the construction of a 37 acre waterfront park (*2*). Figure 1 shows the location of the Harbor Drive Freeway and Figure 2 shows the area before and after removal.

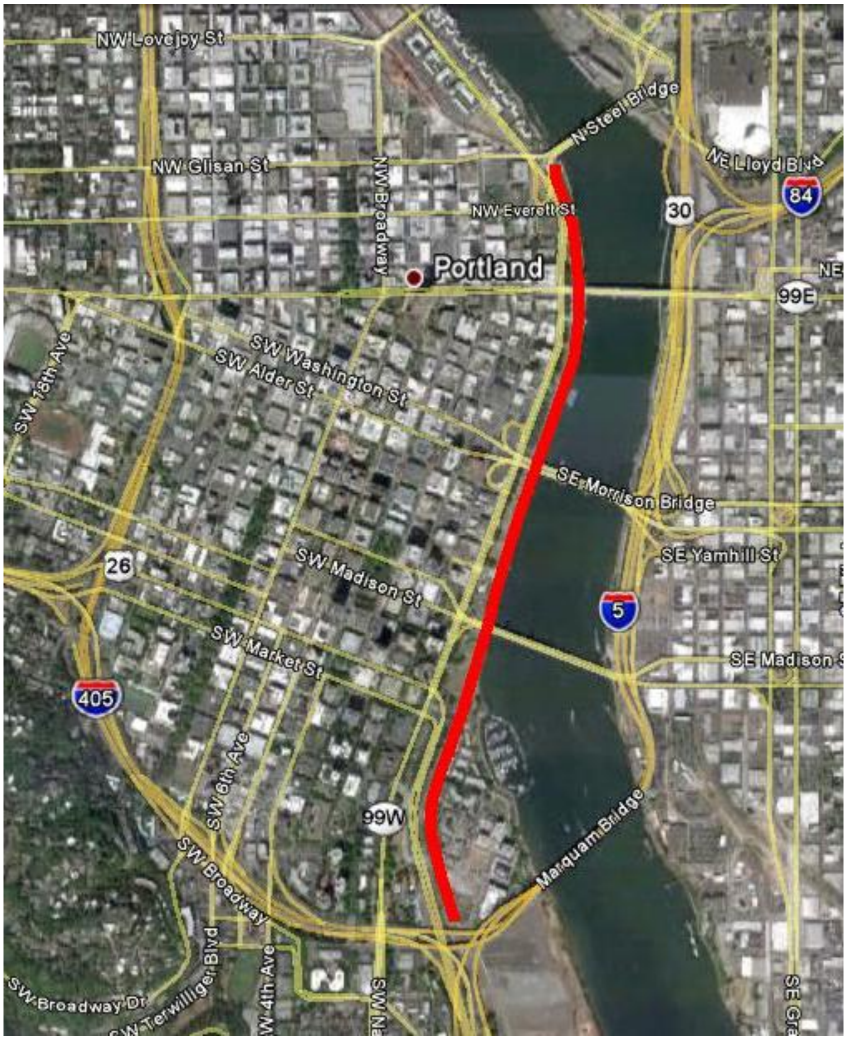


FIGURE 1 Location of the Harbor Drive Freeway

(Source: Google Earth)

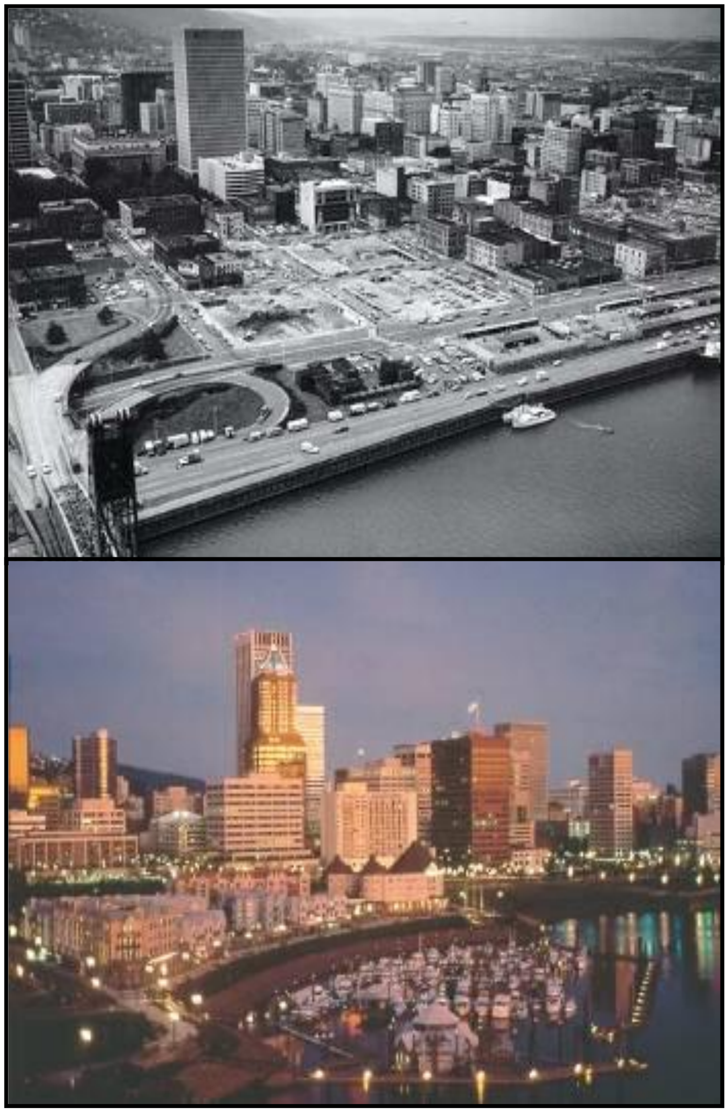


FIGURE 2 Harbor Drive Freeway Before and After Removal

(Source: www.theinfrastructurist.com)

The removal of this freeway was part of a comprehensive plan to better manage traffic within the city. Other parts of this plan included converting all the streets in downtown to one-way, synchronizing traffic lights throughout the area, and decreasing speed limits. When the freeway closed, no discernible negative effects to the traffic flow in the surrounding areas were evident. In addition to the 37 acre waterfront park, three

other major mixed-use development projects were completed in the area which brought increased tax revenue to the city. Property values in the area have also increased substantially since the freeway was removed. In 1974, 75% of the properties in the area were worth the same or less than the land on which they sat. By 2002, the property values had tripled and property value growth in this area was increasing faster than that of the rest of the city of Portland by 7%. Crime has also been reduced significantly in the area. In the redevelopment area crime rate has decreased 65% since 1990 versus a 16% reduction in the city as a whole (*2*).

New York City, NY – Westside Highway

The West Side Highway was constructed in 1948 as a six-lane freeway that ran approximately 5.1 miles south along the Hudson River from 72nd Street to where the West Side Highway connected to the Brooklyn Battery Tunnel (*3*). The highway was an elevated structure that ran over the at-grade West Street and proved to be a physical barrier between New York City and the waterfront. The highway carried approximately 140,000 cars per day at its peak (*4*). By the 1960s, the highway had been significantly degraded by salt and pigeon excrement and badly needed an overhaul. Part of the highway collapsed in 1969 but was quickly repaired. However, in 1973 a cement truck on route to make a repair on another section of the highway caused a 60 foot section of the highway to completely collapse, which forced closure of the section of the highway between the Battery Tunnel and 57th Street until a solution could be determined. Demolition of the unsafe elevated structure began in 1977 and was completed in 1989. The city decided in 1993 to improve the existing West Street (the street underneath West

Side Highway) by adding 19 foot wide landscaped medians, a bicycle path, and a landscaped park along the river. Other urban design elements (decorative street lights, granite paving paths, etc) were added to enhance the connection between the street and the park. This project was completed in 2001. West Street has between three and four lanes in each direction and carries between 65,000 and 139,000 cars per day (*3*,*5*).

When the highway closed in 1973, 53% of the traffic that utilized the corridor essentially disappeared thereby reducing the total traffic volume in the area. Removing the West Side Highway opened up minimal land for redevelopment. The highway was located above a wide existing street, so only a small amount of land was made available by demolishing entrance and exit ramps. This land, however, was used to create a new waterfront park and it opened up the city to the waterfront with the addition of more pedestrian and bicycle friendly surroundings (*3*). Figure 3 shows the location of the freeway and Figure 4 shows before and after pictures of the removal.

FIGURE 3 Location of the West Side Highway

(Source: Google Earth)

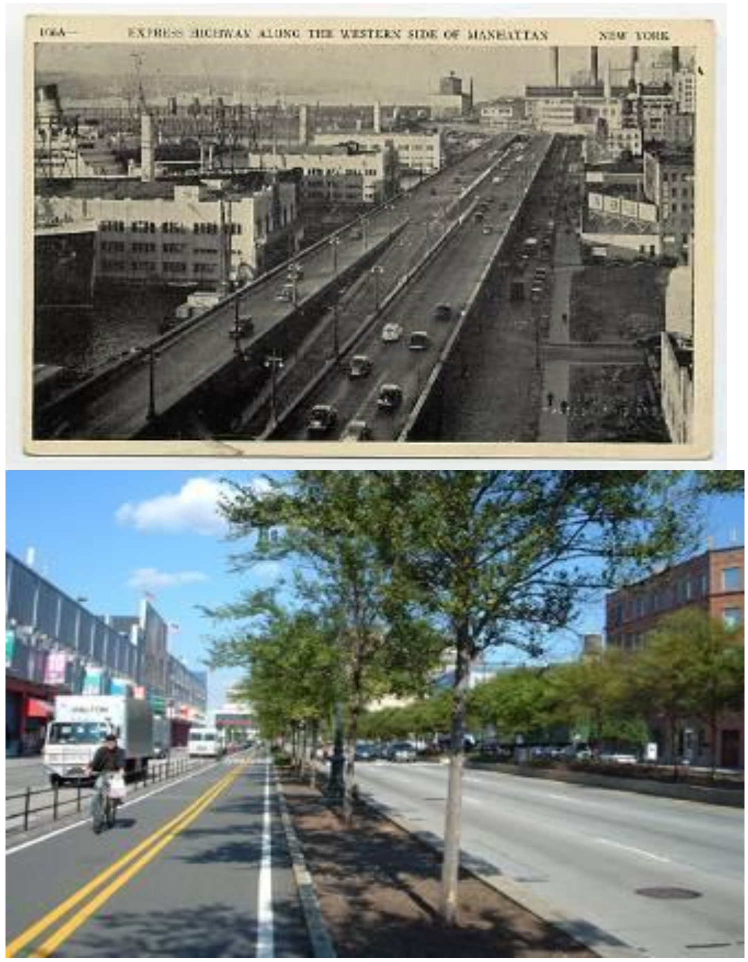


FIGURE 4 West Side Highway Before and After Removal

(Source: The Preservation Institute)

New York City, NY – Broadway Avenue

New York City has a continuous and compact gridded street network. However, there are some instances where this grid pattern is interrupted which makes the traffic situation rather complicated. Broadway Avenue cuts diagonally across the gridded street network through some of the post popular destinations in the city including Times Square. This caused a problem not only for motorists, but also for pedestrians and bicyclists as well. For pedestrians, crosswalks were long and sidewalks were overcrowded which caused

significant safety issues. For motorists, the traffic pattern was confusing and inefficient as six-leg intersections were created by Broadway interfacing with the grid (*6*). Figure 5 illustrates these problems.

FIGURE 5 Broadway Avenue Pedestrian and Motorist Issues

(Source: Green Light for Midtown Evaluation, January 2010)

The two main areas of concern were between 42nd and 47th Streets (Times Square) and between 33rd and 35th Streets (Herald Square) as shown in Figure 6.

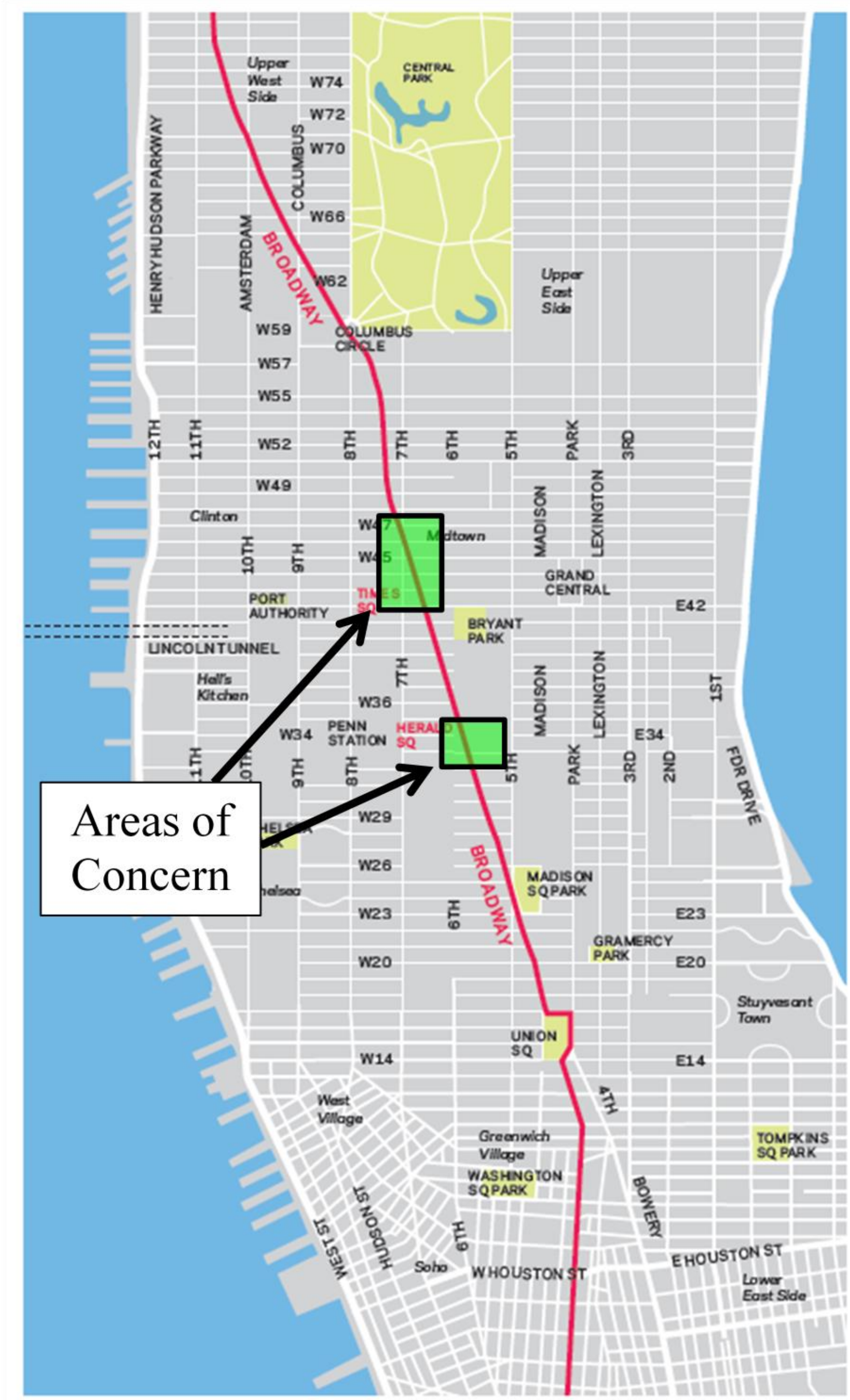


FIGURE 6 Broadway Avenue Areas of Concern

(Source: Green Light for Midtown Evaluation, January 2010)

In order to alleviate these concerns, the decision was made to close these sections of Broadway to traffic and make them car-free zones. This would eliminate the confusing traffic pattern for motorists and provide much more space for pedestrians and bicyclists. These sections of road were closed in May 2009 and opened up to pedestrians by August 2009. The New York City Department of Transportation completed a comprehensive evaluation of the project with data from September/October 2008 and 2009. These are the key findings from this report:

Mobility

- Travel speed for northbound trips increased 17% in West Midtown and 8% in East Midtown
- Travel speed for southbound trips decreased 2% in West Midtown and increased 3% in East Midtown
- Travel speed for eastbound trips increased 5% in West Midtown and 2% in East Midtown
- Travel speed for westbound trips increased 9% in West Midtown and 7% for East Midtown
- 15% improvement in travel time on 6th Avenue and 4% improvement on 7th Avenue
- Bus travel speeds improved by 13% on 6th Avenue and fell by 2% on 7th Avenue

Safety

- Injuries to motorists and passengers in the project area decreased 63%
- Pedestrian injuries decreased 35%

- 80% fewer pedestrians are walking in the roadway in Times Square

Other Results

- 74% of New Yorkers surveyed agree that Times Square has dramatically improved
- Pedestrians in Times Square increased 11%, pedestrians in Herald Square increased 6%
- 57th Street southbound average daily traffic (ADT) decreased 6.9%
- 44th Street southbound ADT decreased 7.6%
- 34th Street northbound ADT increased 3.3%

Overall, this project was seen as a success to both pedestrians and motorists as both groups benefited from the project (*6*).

Chattanooga, TN – Riverfront Parkway

Riverfront Parkway was constructed in the 1960s as an at-grade four-lane freeway intended for use by heavy trucks serving points along the river. This freeway divided downtown Chattanooga from the waterfront. At its peak, the freeway carried approximately 20,000 cars per day, 13,000 of which were heading to or coming from Chestnut Avenue exit for access to the downtown area. In the 1980s, the city tried to improve its public image by improving the quality of its downtown area and its connection to the riverfront. The project at the forefront of the revamping of the city's image was the redesign of the Riverfront Parkway. The parkway redesign included reducing the road down from four lanes to two in most places. A major driving force behind this change was to provide shorter crosswalks for pedestrians, thereby providing

safer pedestrian access to the waterfront. Significant improvements were also made to the adjacent street grid network and recreational parks were constructed along the boulevard. The Riverfront Parkway redesign was completed in 2004 (*2*). Figure 7 shows the location of the Riverfront Parkway.

FIGURE 7 Location of the Riverfront Parkway

(Source: Google Earth)

A new riverfront park and event area was created which attracted more people to the area. The new roadway provided pedestrian access to these attractions which would have been impossible with the old freeway. Connections to the downtown area increased from two freeway interchanges to six street intersections that distributed the traffic more evenly thereby reducing the overall congestion in the area. The area has become very popular and there is now a strong possibility for additional redevelopment opportunities that could bring further benefits to the area (*2*). Figure 8 shows before and after pictures of the Riverfront Parkway.

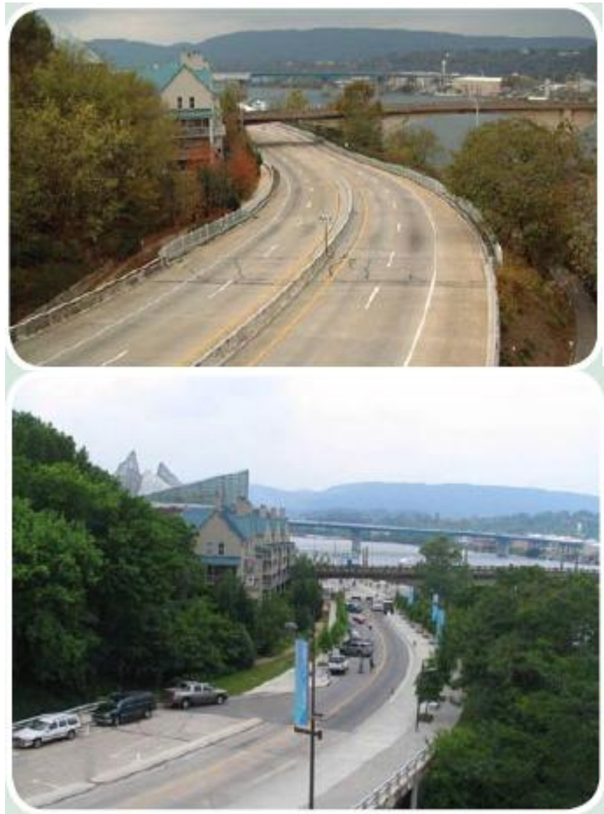


FIGURE 8 Riverfront Parkway Before and After Removal

(Source: Glatting Jackson)

Milwaukee, WI – Park East Freeway

Originally, the Park East Freeway was planned to run from I-43 east to Lake Michigan where it would ultimately connect with I-794. Construction began in the 1960s and the first section of the freeway was opened in 1971. Protests from the local community and environmentalists soon ensued with the primary issue being that the freeway would cut off Juneau Park from the waterfront. These protests were successful in cancelling the remainder of the project in 1972. Only a 0.8 mile elevated section of the freeway was ever constructed. At its peak, this freeway carried approximately 54,000 vehicles per day. This freeway was a physical barrier separating the north side of the city from the

downtown area. This freeway limited access to downtown by only having three exits and interrupting the street grid network. The result was that traffic was forced into just three intersections. Before the project was canceled, the land necessary to complete the rest of the project had already been acquired. This land remained unutilized for 20 years until the 1990s when the state finally removed the land's designation as a transportation corridor. This paved the way for the land to be successfully redeveloped into a mixed-use community. By the late 1990s the freeway was nearly 30 years old and in need of significant repairs. The cost of the repairs was estimated to be $100M while demolishing the freeway only cost $25M. The high cost of repair, the low traffic volume, and the success of the mixed-use community redevelopment helped convince the Governor to proceed with demolishing it between 2002 and 2003 (*7*). The location of the freeway is shown in Figure 9 and Figure 10 shows what the freeway looked like prior to demolition.

FIGURE 9 Location of the Park East Freeway

(Source: Google Earth)

FIGURE 10 Park East Freeway Prior to Demolition

(Source: The Preservation Institute)

The freeway was replaced by McKinley Boulevard which is an at-grade four lane road that has reconnected the street network (*8*). The replacement boulevard currently carries approximately 18,600 vehicles per day (*9*).

The boulevard is still fairly new so many of the redevelopment plans for the area are still in the planning process. Figure 11 shows the land that was made available for redevelopment after the removal of the freeway.

FIGURE 11 Park East Freeway After Removal

(Source: "Walker Proposes Selling County's Park East Land to City", 2009, www.biztimes.com)

However, the Fortune-500 Manpower Corporation moved their headquarters to the area and mixed-use projects are being implemented in the area. Between 2001 and 2006, the average land values per acre increased approximately 180% in the area. Approximately, $340M in redevelopment projects are either under review or have been approved and more projects are in the proposal process (*7*).

Boston, MA – The Central Artery ("The Big Dig")

Constructed in 1959, the Central Artery was a six lane elevated freeway that divided the downtown financial district from the waterfront. At its peak, this freeway carried approximately 190,000 cars per day. Unfortunately, it contained several significant design flaws including twenty-seven on and off ramps and a lack of merge and breakdown lanes. Vehicles that broke down would have no choice but to block an entire

lane of traffic and the numerous areas for merging forced traffic to slow down considerably. Therefore, capacity of the roadway was significantly reduced and congestion was seemingly constant. Funding was secured to move the freeway underground (“The Big Dig”) in the 1980s to relieve the traffic congestion. By the time construction was ready to begin in the 1990s, the Central Artery had an accident rate that was four times the national average. In 2003, the freeway was demolished and rebuilt underground. A surface boulevard was constructed on part of the newly available land to repair the street grid network. Also, four parks were constructed on freed up land between the waterfront and downtown (*10*). The location of the freeway is shown in Figure 12.

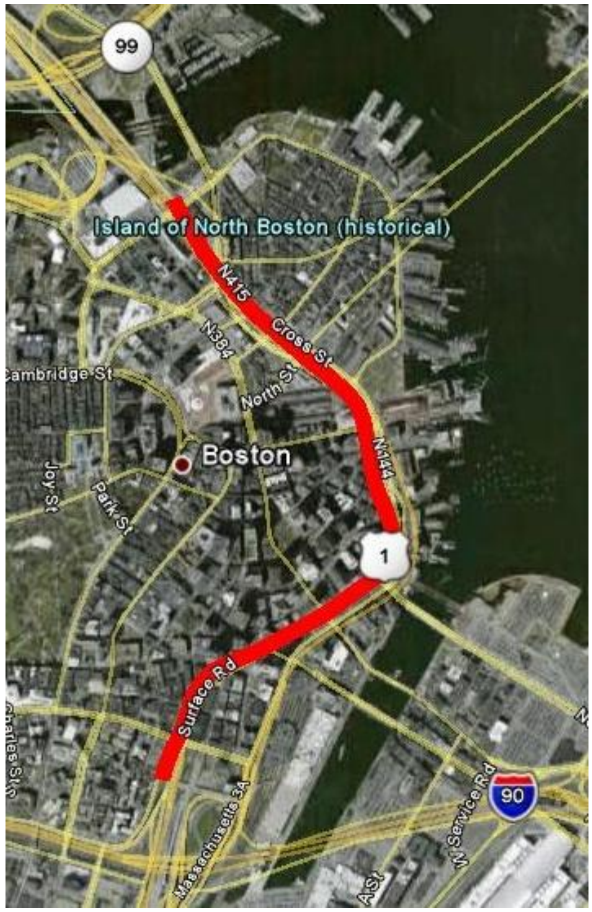


FIGURE 12 Location of the Central Artery

(Source: Google Earth)

This project did remove an elevated freeway from the downtown area; however the total vehicle capacity was actually increased with this project by approximately 60,000 cars per day. The cost of this project was approximately $15 billion, which was about five times the original estimated cost. Because of the excessive costs, some aspects of the project that would have improved mass transit were ultimately cut. However, numerous benefits were still evident. A 2004 study in the Boston Globe found that since the project began, commercial property values in the area increased 79% compared to 41% for the city as a whole. Additionally, a 2006 study by the Massachusetts Turnpike

Authority found that a substantial level of private investment has been attracted as a result of this project. Approximately $5.3 billion in projects recently completed or underway are within a five minute walk of the project area. These projects include 4,200 housing units and are estimated to create 36,000 new jobs (*2*). Figure 13 shows before and after aerial views of the Central Artery.

FIGURE 13 The Central Artery Before and After Removal

(Source: Tufts University)

Toronto, Canada – Gardiner Expressway East

Constructed between 1956 and 1966, The Gardiner Expressway East was a six lane, 0.8 mile long elevated structure that ran above the six lane at grade surface street called Lake Shore Boulevard. It served as a physical barrier between the city of Toronto and the waterfront. This freeway was primarily used to connect to the Gardiner Expressway for

access to downtown Toronto and the industrial waterfront. Shortly after the freeway was constructed, the industrial functions along the waterfront began to decrease as industry moved to cheaper land outside the city that had been made accessible by the construction of other freeways during this time period. This led the city of Toronto to start planning ways of revitalizing the harbor area. The start of this redevelopment plan was to demolish the Gardiner Expressway East. The city came to realize after studying this in the 1990s that it would be more expensive to keep the freeway up than to simply tear it down. Between 2000 and 2002, the freeway was demolished and replaced with an improved Lake Shore Boulevard (*11*). Figure 14 shows the location of the Gardiner Expressway East and Figure 15 shows the area before and after the removal.

FIGURE 14 Location of the Gardiner Expressway East

(Source: "Removing Toronto's Elevated Expressway One Piece at a Time: Dismantling the F.G. Gardiner Expressway East")

FIGURE 15 The Gardiner Expressway East Before and After Removal

(Source: "Removing Toronto's Elevated Expressway One Piece at a Time: Dismantling the F.G. Gardiner Expressway East")

Despite fears of traffic gridlock, no significant increases in traffic congestion have been experienced in the area. The city of Toronto has plans to utilize this area for mixed-use purposes which would infill the area with additional housing, commercial buildings and recreational areas. Another critical part of this project was the construction of a bicycle and pedestrian bridge running over the Don River. Since the Don River is a very busy transportation corridor, the addition of this bridge provided safe and efficient access for bicyclists and pedestrians to areas across the river (*12*).

San Francisco, CA – Embarcadero Freeway

The Embarcadero Freeway was a double deck freeway spur constructed in 1958, which carried approximately 100,000 cars per day at its peak when combined with the surface street that ran directly beneath it (*13,14*). In 1989, the freeway was severely damaged by the Loma Prieta earthquake. The damage caused the freeway to be closed and, after some debate, the 1.2 mile long freeway spur was ultimately removed in 1991 (*13*). Figure 16 shows the location of the freeway.

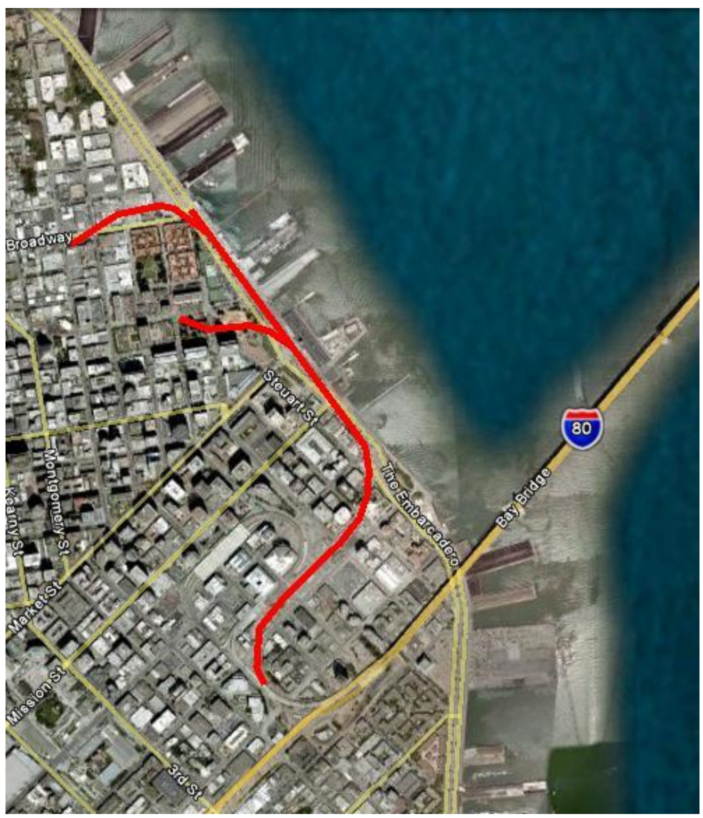


FIGURE 16 Location of the Embarcadero Freeway

(Source: Google Earth)

The removal of this freeway opened up the city to the historic waterfront and provided many opportunities for redevelopment of the area. A landscaped boulevard, called The Embarcadero, along with a pedestrian promenade replaced the freeway and was ultimately completed in 2000 (*13*). Figure 17 shows how the new boulevard compares visually to the freeway that used to occupy the space.

FIGURE 17 Embarcadero Freeway Before and After Removal

(Source: www.flickr.com/photos/v63/228932719/)

This change significantly enhanced access to the waterfront. A trolley line was also added which connected downtown San Francisco and Fisherman's Wharf and carries approximately 20,000 people per day. Redevelopment included remodeling of the

historic Ferry building (vacant for years prior to demolition of the freeway), construction of a multi-block retail and office center, development of the Rincon Hill and South Beach residential neighborhoods, and development of new recreational parks (*13*). The replacement boulevard currently carries approximately 50,000 vehicles per day (*15*).

Some research does exist as to the impacts that this removal had on the surrounding neighborhoods. Robert Cervero, Junhee Kang, and Kevin Shively from the University of California, Berkeley wrote a paper entitled *From Elevated Freeways to Surface Boulevards: Neighborhood, Traffic and Housing Price Impacts in San Francisco*. The neighborhoods analyzed for the Embarcadero Freeway are shown in Figure 18 with the impact zone results being compared to those of the control zones located further away from the area of interest.

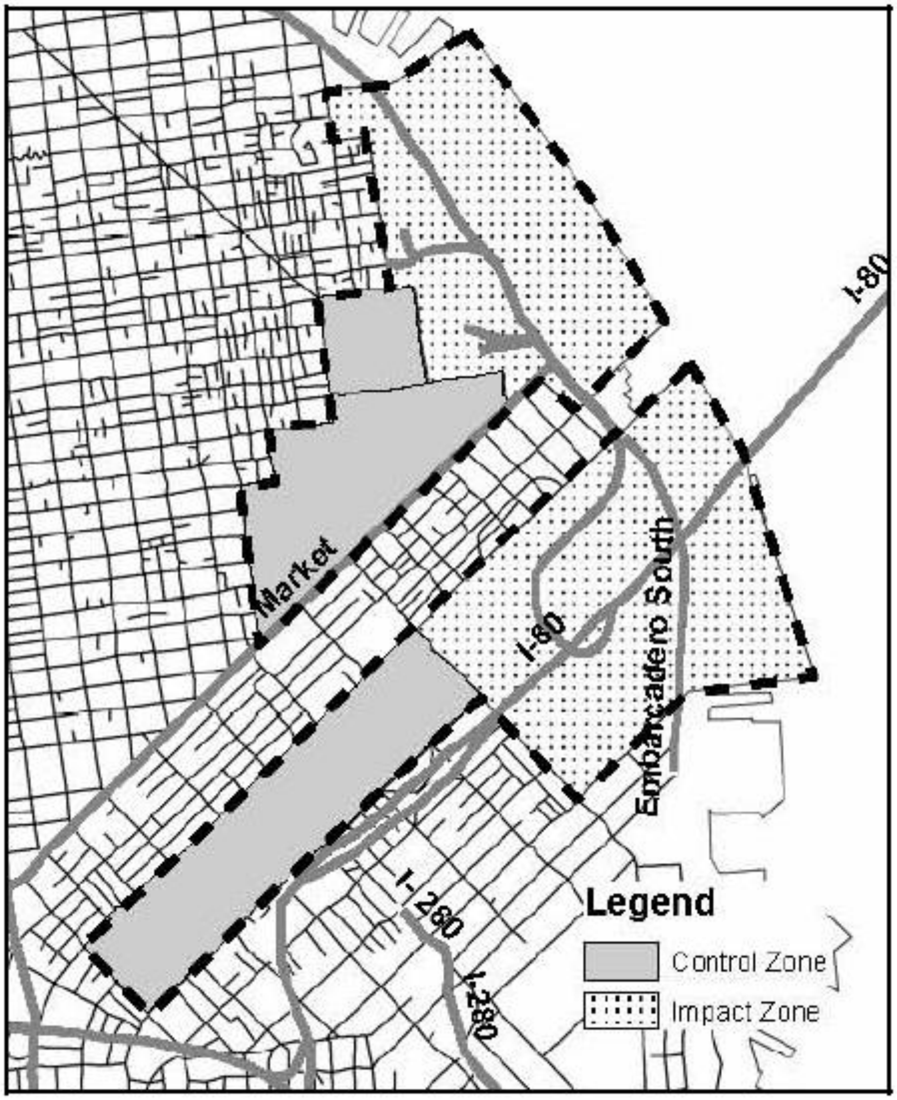


FIGURE 18 Embarcadero Impact and Control Zones

(Source: *From Elevated Freeways to Surface Boulevards: Neighborhood, Traffic and Housing Price Impacts in San Francisco*)

The analysis of these neighborhoods relied heavily on census tract data from 1990 and 2000 but other data sources were also used depending on what data was being investigated. Listed below are some of the key findings:

- 54% increase in housing units in impact zone compared with 31% increase in the control zones
- The number of jobs increased 23% in the impact zone from 1990 – 2005 compared with a 5.5% increase in the control zones
- Employment in Chinatown (northern end of the demolished freeway) fell roughly 33%
- 75% increase in transit commute trips in the impact zone during the 1990s
- From 1990 to 2000, the percentage of people walking to work increased 1.6% in the impact zone versus 1.0% for the control zone

Housing prices in the corridor were also analyzed before and after the removal as a function of distance from the Embarcadero corridor. Figure 19 shows the results of this analysis.

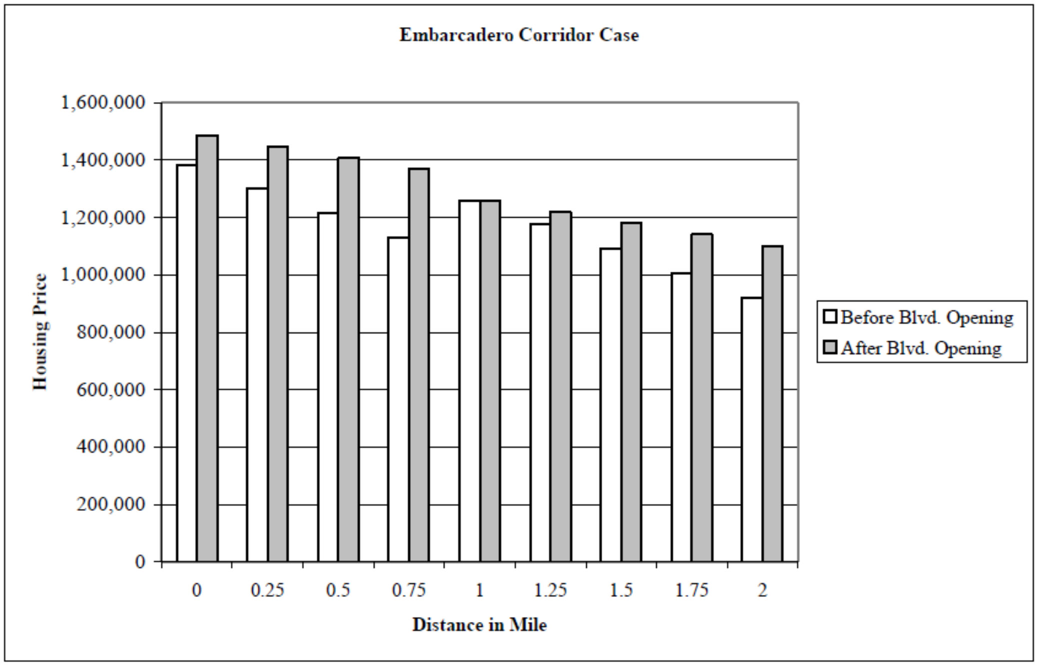


FIGURE 19 Embarcadero Corridor Housing Prices (in 2007 dollars) from 1986 – 2005

(Source: *From Elevated Freeways to Surface Boulevards: Neighborhood, Traffic and Housing Price Impacts in San Francisco*)

As is evident in this figure, housing prices were highest when located closest to the corridor (nearest the waterfront) and they increased after the freeway was removed in nearly all the cases (*16*).

San Francisco, CA – Central Freeway

The Central Freeway was a 0.8 mile long elevated freeway spur constructed during the 1950s. At its peak, the freeway carried approximately 90,000 cars per day. The freeway was a four lane, two-level structure. Similar to the Embarcadero Freeway, the Central Freeway was severely damaged by the Loma Prieta earthquake in 1989. It was removed

in phases between 1989 and 2003 (*17*). Figure 20 shows the location of the Central Freeway.

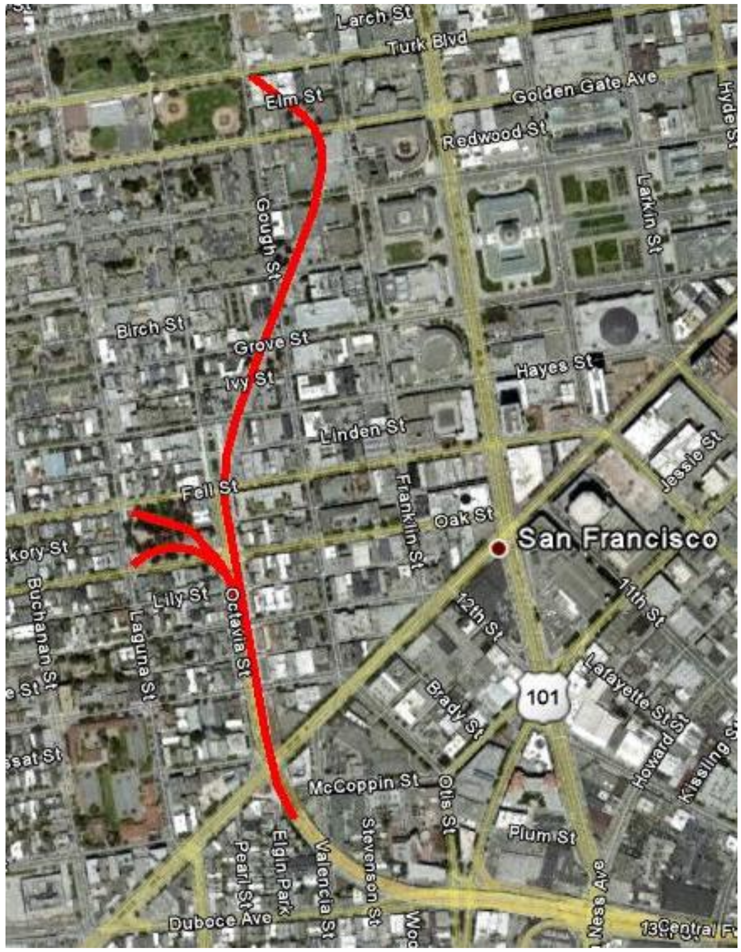


FIGURE 20 Location of the Central Freeway

(Source: Google Earth)

The freeway was replaced by a multi-way surface boulevard in 2006 which carries approximately 52,000 vehicles per day and consists of four lanes for through traffic and two lanes for local traffic and bicycles (separated from the through lanes by a landscaped median and a sidewalk) (*15,17*). Figure 21 shows how the new boulevard compares visually to the elevated freeway.

FIGURE 21 Central Freeway Before and After Removal

(Source: The Preservation Institute)

Demolishing this freeway also opened up the Hayes Valley Neighborhood to redevelopment. Additional housing, public parks, and mass transit were included as part of the redevelopment and parking was intentionally limited to make the area more pedestrian and mass transit friendly (*17*).

Cervero, Kang, and Shively also analyzed the Central Freeway in their paper entitled *From Elevated Freeways to Surface Boulevards: Neighborhood, Traffic and Housing Price Impacts in San Francisco*. The neighborhoods analyzed for the Central Freeway are shown in Figure 22 with the impact zone results being compared to those of the control zones located further away from the area of interest.

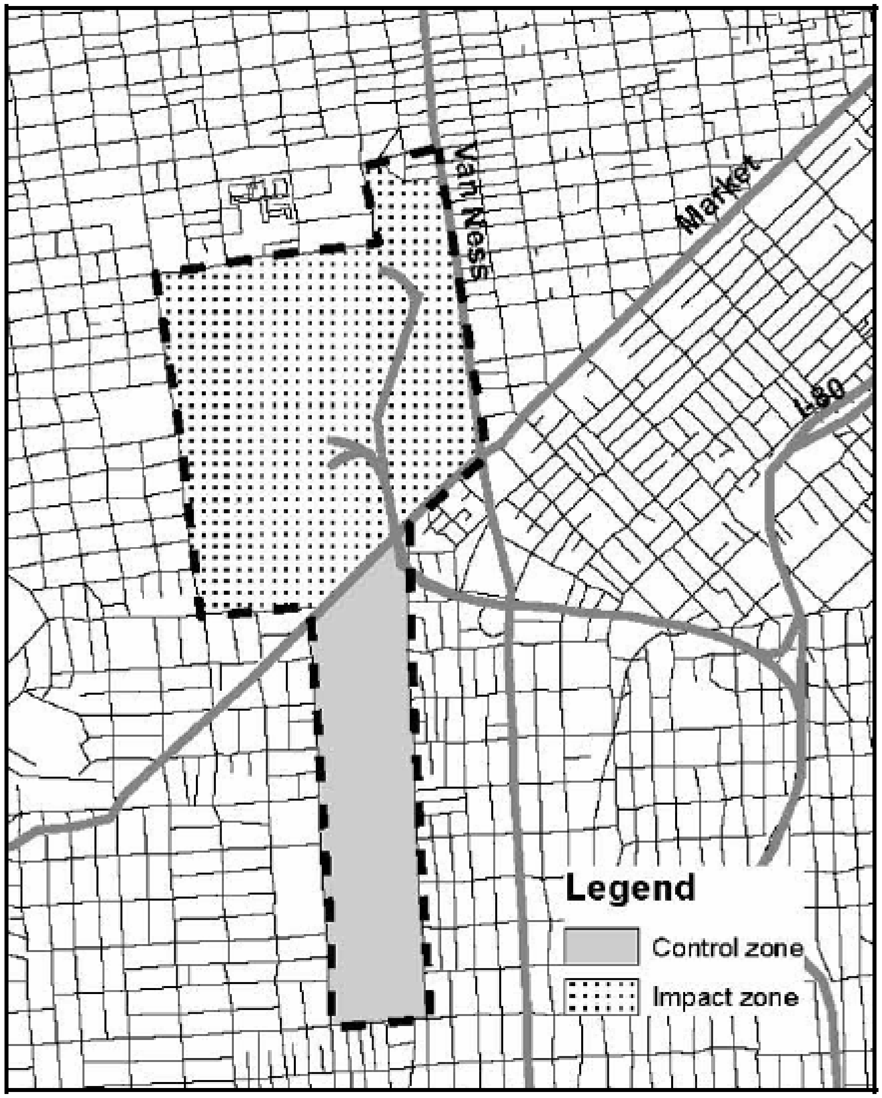


FIGURE 22 Central Freeway Impact and Control Zones

(Source: *From Elevated Freeways to Surface Boulevards: Neighborhood, Traffic and Housing Price Impacts in San Francisco*)

Housing prices were analyzed in a similar fashion to that of the Embarcadero Freeway to see how the prices changed before and after the removal and how distance affected the values. Figure 23 shows the results.

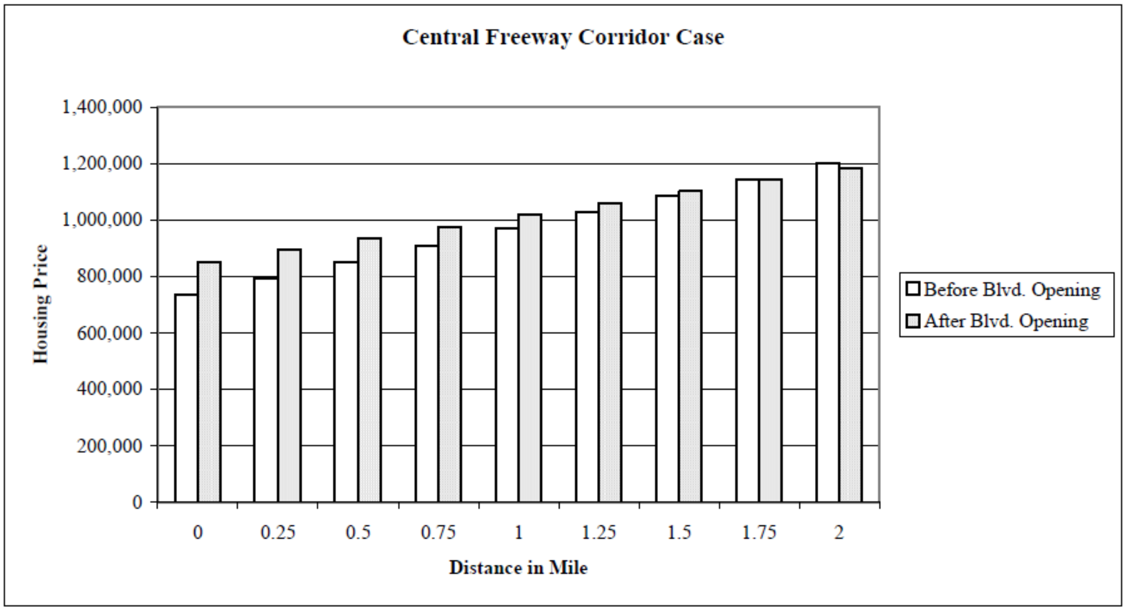


FIGURE 23 Central Freeway Corridor Housing Prices (in 2007 dollars) from 1986 – 2005

(Source: *From Elevated Freeways to Surface Boulevards: Neighborhood, Traffic and Housing Price Impacts in San Francisco*)

These results show that there is a fairly large difference between before and after housing values closest to the boulevard. However, the further away from the corridor the houses are the smaller this difference is until there is essentially no difference (*16*).

Another key finding from this paper was from a survey sent out by the San Francisco Department of Parking and Traffic shortly after the freeway closed and before

the boulevard opened. This survey asked people how their travel behavior changed when the freeway was closed. Figure 24 shows the results of this survey.

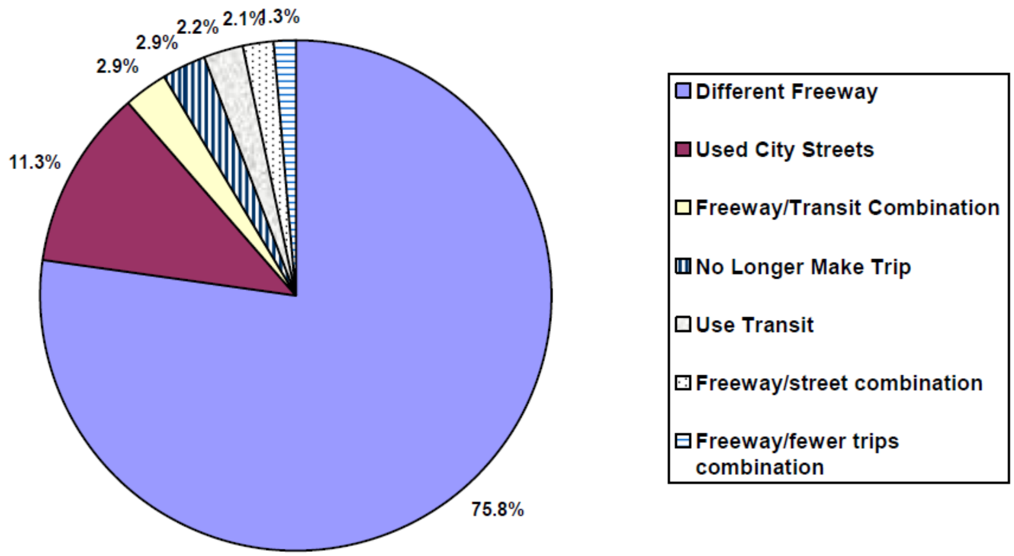


FIGURE 24 Changes in Travel Behavior due Central Freeway Removal

(Source: *From Elevated Freeways to Surface Boulevards: Neighborhood, Traffic and Housing Price Impacts in San Francisco*)

This figure shows that, during the closure of the freeway, most of the traffic redistributed to another freeway or to other streets. But it also shows that just over 4% use transit or do not make the trip anymore which indicates that some of the traffic formerly utilizing the freeway no longer occurs (*16*).

Europe

Paris, France – Georges Pompidou Expressway

The Georges Pompidou Expressway is a two-lane at-grade freeway constructed in 1967 along the east bank of the Seine River that carries approximately 70,000 cars per day. It is a physical barrier between the city and the waterfront of the Seine. This freeway is primarily used for travel to and from the center of Paris. In 2001, Bertrand Delanoe was elected mayor of Paris based on a platform of support for public transportation, walking and bicycling. In the summer of 2002, the City decided to turn the freeway into the Paris Plage (Paris Beach) in order to attract more people to the area. In order to create this place, the City closed the street 24 hours a day between July 21 and August 18, $1.5 million euros was spent to bring in palm trees, beach umbrellas, beach chairs, an outdoor climbing wall, outdoor cafes, refreshment stands, bicycle rentals and enough sand to create sections of sandy beach. Approximately 1.7 miles of the expressway was closed for the beach. Because of its success, the closure of the freeway has become an annual event and talks have begun to make the closure of the freeway permanent (*18*). The location of the freeway is shown in Figure 25.

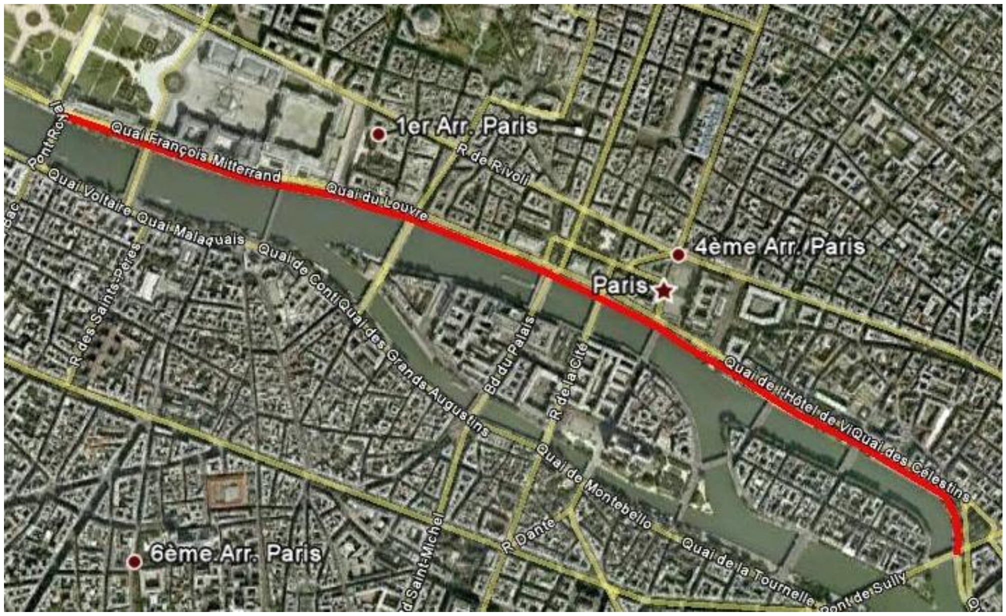


FIGURE 25 Location of the Georges Pompidou Expressway

(Source: Google Earth)

On the first day the Paris Plage was open, it attracted approximately 600,000 visitors. Throughout the rest of the month, it attracted 2 million visitors. No significant traffic problems in the surrounding area were evident during this time; however traffic is normally lower between July and August because it is the vacation season for Parisians. No specific economic data was immediately available, but it is likely that significant economic benefits have been experienced in the area. The closure of the Pompidou Expressway was part of a larger comprehensive plan to reduce automobile use and reduce greenhouse gas emissions throughout the city. This plan included installing bus-bicycle-taxi only lanes (no automobiles) and a new tramway line (*18*). Figure 26 shows the expressway when used by vehicles and when used by pedestrians.

FIGURE 26 Georges Pompidou Expressway Before and After Closure

(Source: www.flickr.com (top) and Project for Public Spaces (bottom))

Birmingham, England – Masshouse Circus

Masshouse Circus was one of several large elevated roundabouts built as part of the Queensway in the 1960s. The Queensway was a ring road built around the city of Birmingham and came to be known as the “concrete collar” because it served as a physical barrier to growth of the downtown area. The city decided to remove this elevated roundabout and replace it with a surface boulevard which would spur redevelopment opportunities and provide better transit and pedestrian access to the area

(*19*). Demolition of the roundabout and redevelopment of the road system took place between 2001 and 2003. Figure 27 shows the location of the Masshouse Circus and Figure 28 shows a before image of the area and a schematic of a possible after image of the area. No other data was available at the time this paper was written.

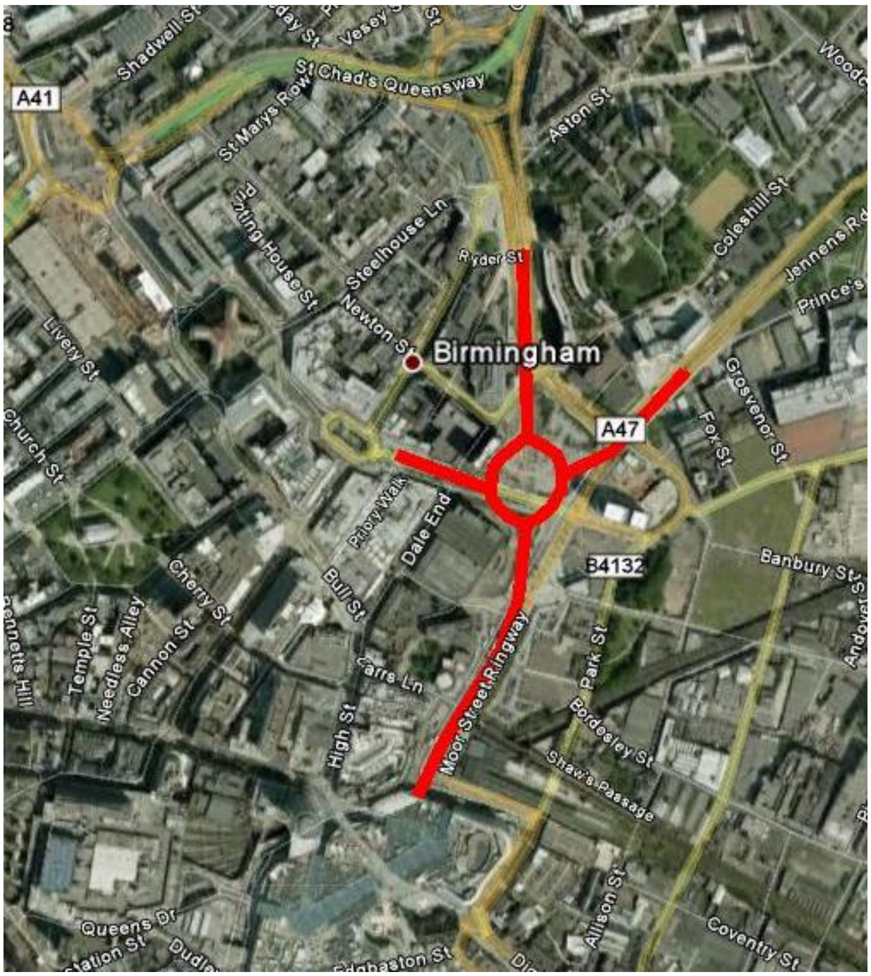


FIGURE 27 Location of the Masshouse Circus

(Source: Google Earth)

FIGURE 28 Masshouse Circus Before and After Removal

(Source: http://www.giffordgraduates.uk.com/civil.htm)

Madrid, Spain – M-30

The M-30 is an elevated ring road which was constructed in phases from the 1970s that surrounds the city of Madrid. It quickly became one of the most congested roadways in

Spain with an ADT of approximately 205,000. Air pollution for cars utilizing the roadway also became a problem. Figure 29 shows how the M-30 surrounds the city.

FIGURE 29 Location of M-30

(Source: http://palma.fis.ucm.es/~fidel/zoom_m30.jpg)

With the aforementioned problems and the fact that the structure was in need of significant structural repairs, the city decided to proceed with the Madrid Calle 30 project. The project called for the refurbishment of some section of the roadway while placing many sections of the roadway underground as tunnels. The goals were to increase capacity of the roadway while reclaiming land for redevelopment and cleaning up the Manzanares River. The project was awarded in 2003 for just under 4 billion euros and was completed in 2007. Construction took place on 99 kilometers of roadway with 56 kilometers being constructed as underground tunnels (*20*). No other data was available at the time this paper was written.

Asia

Seoul, South Korea – Cheonggye Freeway

Between 1958 and 1976, the Cheonggyecheon ("clear valley stream") was put underground. This allowed for the construction of the Cheonggye Elevated Highway and the Cheonggye Road above it in the 1970s. The elevated freeway section was four lanes wide and approximately 3.6 miles long. There were also four additional lanes of traffic in each direction on the at-grade portion of the road. At its peak, the combined traffic count on both roads was approximately 168,000 cars per day (60% of which was through traffic). Initially, this freeway was seen as a symbol of South Korea's progress in coming into modern times. However, four decades on, the freeway came to be known as the most noisy and congested section of the city. In order to revitalize this section of the city, the elevated freeway and the adjacent at-grade road were removed between 2003 and

2005. The formerly covered stream became the centerpiece of a 3.6 mile linear park. Two one-way streets that were each three lanes wide were also installed on either side of the stream. The removal of this freeway, however, was just one part of a larger comprehensive traffic management plan enacted by the city. In 1996, the city began charging tolls to enter the city at peak times for private vehicles with less than three passengers. In 1997, the city began making regular fee increases for parking. A "No Driving Day" program was established in 2003 which gave drivers discounts on tolls and car services in exchange for not driving into the city one weekday per week. Gas taxes were increased and an incentive-based traffic demand management program was established with local employers. Finally, the city's bus system was completely restructured in 2004 which included a network of median bus-only lanes and coordinating fares and schedules with the subway system (*2*). Figure 30 shows the area before and after the removal of the freeway.

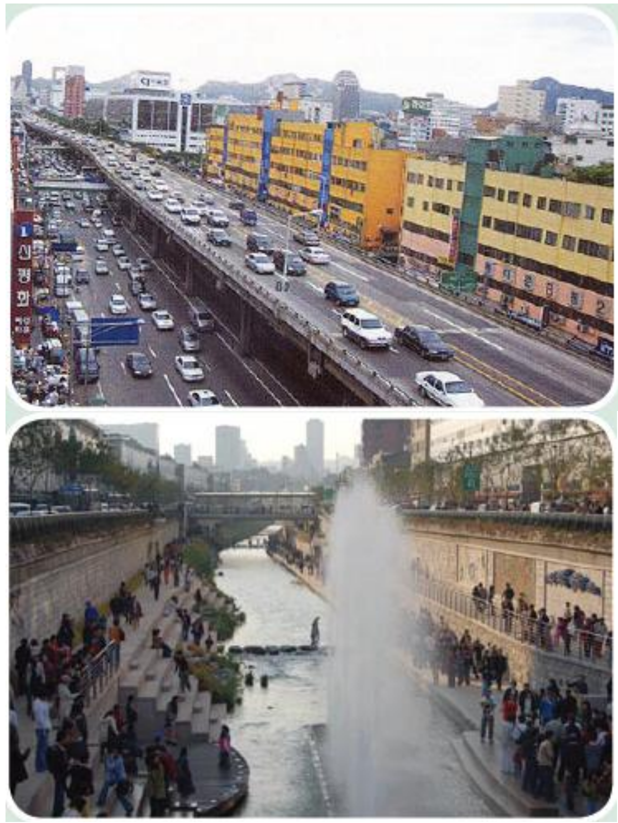


FIGURE 30 The Cheonggye Freeway Before and After Removal

(Source: Seoul Metropolitan Government (top) and

www.flickr.com (bottom))

The new park attracted approximately 90,000 visitors per day in the 15 months after it opened, 30% of which were from outside the metropolitan area. In a 2005 study, it was found that adjacent land parcel values increased by an average of 30% since the freeway was removed. After the comprehensive traffic management plan was fully implemented, traffic going into the downtown area decreased by 9%. An unexpected environmental benefit came when it was found that temperatures in the area adjacent to the stream were seven degrees Fahrenheit cooler than at locations a quarter mile away. In terms of economics, the Seoul Development Institute has estimated long term benefits at

$8.5 to $25 billion and approximately 113,000 new jobs thanks to the revitalization of the Cheonggyecheon (*2*).

Summary of Findings

After reviewing all the possible case studies, it became evident that there was a lack of comprehensive research that had been accomplished in regards to the effect these removals had on traffic flow and distribution. Significant research existed in some cases regarding points of interest such as land value, housing prices, and job creation. However, when it came to understanding what happened to traffic in the area, the research was mainly limited to the change in traffic solely on the boulevard. Much of the research discussed significant decreases in traffic when only comparing the traffic of the freeway with that of the boulevard. Comparing the freeway to the replacement boulevard presents somewhat of a slanted argument as the boulevard capacity is significantly less than that of the freeway, so of course traffic on the boulevard will be lower than that which was previously carried by the freeway. It was hypothesized that much of the traffic previously carried by the freeway would be redistributed to the surrounding network. The manner in which the aggregated traffic volumes change seems to be critical to understanding the true effect of these projects as the primary objection to these projects are often based on fear of traffic related project.

ROAD CAPACITY REMOVAL

Research in this area is significantly limited as there are still only a few cities throughout the world that have accomplished projects that ultimately removed capacity from the road

network. Many cities are still looking to widen streets and highway to handle the perceived growth in the number of vehicles traveling on the roadways. One paper was found that did do research in this area.

Cairns, Hass-Klau and Goodwin published a report in 1998 entitled *Traffic Impact of Highway Capacity Reductions: Assessment of the Evidence*. The motivation from this report came after a different report was completed in 1994 in regards to the concept of induced demand. This concept identifies that building more roads actually has the effect of generating traffic which means many new roads are congested shortly after they are constructed. The authors thought that if this concept was true when building roads, would the reverse be true about eliminating them? Would removing roads actually cause traffic to disappear? The report examined approximately 60 locations throughout Europe, North America, and Asia where road capacity was reduced via a variety of mediums (permanent road closure or removal, designated bus-only lanes, car-free zones, etc.). The authors found that in most cases traffic chaos was predicted, yet this hardly ever was the case. They found no instances of long-term gridlock, but some cases did have initial short-term disturbances while drivers adjusted their behavior to the new situation. On average, it was found that between 14% and 25% of traffic that used the route could not be found in the surrounding street network. They did find that the results varied widely and depended upon the context of the removal. For example, removals that made transit more accessible were more likely to see shifts from driving to transit than cases that did not address this. Driver behavior was identified as the main reason for the traffic disappearance. When a driver's route is closed, they will first choose the easiest option which is to use their car on neighboring streets or change their time of travel to avoid the

most congested times. If these adjustments begin to cause more problems for the driver, then more drastic measures are taken such as moving, changing jobs, or changing mode choice. All these decisions would result in the disappearance of some of the traffic (*21*).

This report did help to explain why traffic disappears when road capacity is removed from a network, but it did not explain how the distribution of traffic throughout the network changes. For example, are the local streets adjacent to the freeways now suffering from severe congestion? Did the congestion experienced on the freeway simply shift to another road thereby just moving the congestion to a different location? This research projects seeks to answer these questions amongst several others to bring about a better understanding of the effects that removing road capacity has on traffic in the surrounding area.

TRANSPORTATION RESEARCH BOARD PAPER

This section includes a draft of a paper that is being planned for submission for presentation at the 2012 Transportation Research Board annual meeting. This paper includes the traffic analysis of the Central and Embarcadero Freeways in San Francisco and the Park East Freeway in Milwaukee. This paper aims to understand how the removal of these freeways affected traffic in the surrounding areas. ADT data before, during, and after the removal was analyzed to determine what happened to the traffic previously carried by the freeway. V/C ratios were also compared during these time periods to determine the performance of the surrounding network in absorbing some of this traffic. The results of this analysis are then compared to nine other cities throughout North America that are currently considering projects which will remove capacity from their road networks. This comparison will help determine if excess capacity exists in the surrounding local street network of each of the nine cities.

Introduction

The late 1950s and 1960s were the peak period of freeway construction in North America. At the time, these freeways were seen not only as a means of increasing mobility between cities but also as a way of relieving congestion in cities. This meant that many miles of freeways were constructed directly through dense urban centers. In order to construct these freeways, thousands of citizens had to be relocated and large swaths of urban land were cleared of buildings. For these reasons, citizens protested the further expansion of freeways in many cities including San Francisco, Boston, New York and Washington, DC. These protest movements stopped some expansions of urban freeways, but not before numerous freeways were constructed in hundreds of North American cities.

Now that many of these freeways are reaching the end of their lifespan, governments are faced with a critical decision. Repairing or rebuilding urban freeways can be very expensive and it is becoming increasingly difficult for governments to find the funds for such a major undertaking. An emerging idea that is taking hold in scores of cities across the country is that of eliminating sections of freeways from within the urban fabric of cities as a means of removing a barrier and freeing up land for redevelopment. Often the plan involves replacing the freeway with a lower speed boulevard, which can enhance access in the local area. The cost of removing the freeway is typically much lower than the cost of rebuilding it, and therefore removal is an attractive option to governments from an economic standpoint.

In many cases, however, the idea of freeway removal meets resistance because of concerns that reduction in any road capacity will have negative effects on traffic locally

and throughout the city. Over the past two decades a small but growing number of cities throughout North America have completed projects which have resulted in the removal of road capacity from urban areas. Some of these projects are now mature enough that they can provide a more comprehensive understanding of how capacity removal affects traffic flow and distribution.

In this study we look at three different case studies: two of which are located within the city of San Francisco and one is located within the city of Milwaukee. The first part of this analysis involved understanding how the traffic redistributed after the capacity was removed from the network. Traffic volume data was analyzed to determine the traffic changes throughout the surrounding street network and throughout the area as a whole. This data represents the changes occurring within the network, but an understanding of the network's ability to absorb this redistribution is also required. Therefore, a comparison of the volume-capacity ratios before, during and after the capacity removal was conducted to determine the traffic concentration changes for each case study. This same analysis procedure for the volume-capacity ratios was then applied to nine other cities throughout North America that are considering freeway removal projects. This was done to determine if the distribution of traffic in these cities on a macroscopic level is similar to the pre-removal condition of the case study locations. The results of this analysis help to develop a more comprehensive understanding of how traffic networks react to the removal of significant capacity, and specifically, to the removal of limited access roadways in urban areas.

Background

Embarcadero Freeway – San Francisco, CA

Like most other US cities, San Francisco was not immune to the freeway building boom of the 1950s and 1960s. The original freeway master plan for San Francisco was crafted in 1948 by the California Department of Highways and included miles of freeways that would surround and cross the city. However, after residents saw the destructive results that the first sections of freeways brought to their city, protests ensued and many freeway projects were either only partially completed or cancelled altogether. Figure 31 shows the original freeway plan and identifies the freeways that were built, canceled and removed.

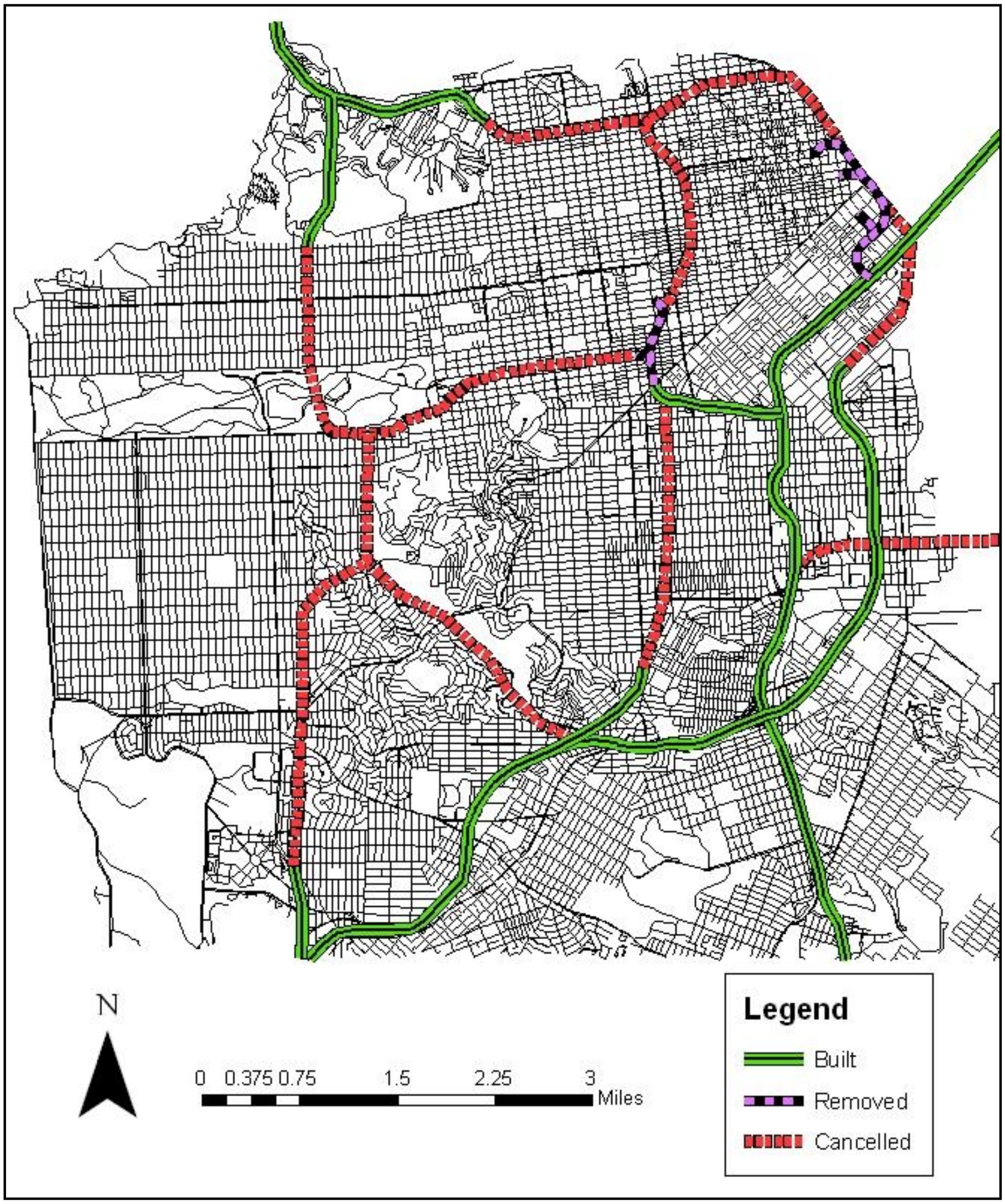


FIGURE 31 San Francisco Freeways – Built, Canceled, and Removed

The Embarcadero Freeway was planned to be a double deck freeway running along the northern waterfront to connect the Golden Gate Bridge with the Oakland Bay Bridge. Ultimately, a 1.2 mile section of this freeway built in 1958 was the only part ever

completed. This section of freeway was built above a surface street which also utilized the corridor. After it was built many citizens fought to have the structure removed as they considered it a barrier dividing the city from the waterfront. For years this debate ensued with significant support on both sides of the argument, but the Loma Prieta earthquake of 1989 brought the issue to a critical decision point. Due to the severe structural damage suffered during the earthquake, the Embarcadero was immediately closed to traffic. The debate over the fate of the Embarcadero after the earthquake was relatively straight forward as the costs of retrofitting the existing structure were financially crippling (*22)*. A plan was made to replace the freeway with an at-grade boulevard, which would allow the reconnection of the waterfront to the city. The damaged freeway was torn down in 1991 and construction of the boulevard was completed in 2000. It is important to note that this new boulevard functions as a standard part of the network. Turns are allowed to and from the boulevard at numerous locations, which allows it to blend in with the existing street network and the waterfront. Figure 2 shows how the new boulevard compares visually to the freeway that used to occupy the space. In addition to reconnecting the city to the waterfront, this project allowed for the addition of a trolley line connecting the Castro district to downtown San Francisco and Fisherman's Wharf. Redevelopment that followed in the area included the remodeling of the historic Ferry building (vacant for years prior to demolition of the freeway), construction of a multi-block retail and office center, development of the Rincon Hill and South Beach residential neighborhoods, and development of new recreational parks (*13*). At its peak, the Embarcadero freeway in combination with the companion surface street carried approximately 100,000 vehicles per day. The replacement boulevard carries

roughly 50,000 vehicles per day, 50% of the volume previously carried by the freeway (*14*,*15*).

Central Freeway – San Francisco, CA

As was the case for the Embarcadero Freeway, only a portion of the Central Freeway was ever constructed. Originally, the Central Freeway was designed to provide access to the Civic Center from US-101 and to continue north to ultimately connect to the Golden Gate Bridge. A 1.8 mile double deck spur west of I-80 was the only portion of this freeway ever constructed. Of this segment, 0.8 miles was constructed north of Market Street through the Hayes Valley residential neighborhood. This freeway was also damaged by the Loma Prieta earthquake, but the process of removing this freeway was much more complicated than for the Embarcadero Freeway. The northern most section of the freeway providing connections to Franklin and Gough Streets was demolished shortly after the earthquake. In 1996, the rest of the upper deck of the freeway north of Market Street was demolished due to structural issues which brought the issue of what to do with the rest of the freeway to the forefront. Figure 32 shows the stages in which the freeway was demolished. Traffic was allowed to operate on all sections of the freeway shown in the various stages of the figure.

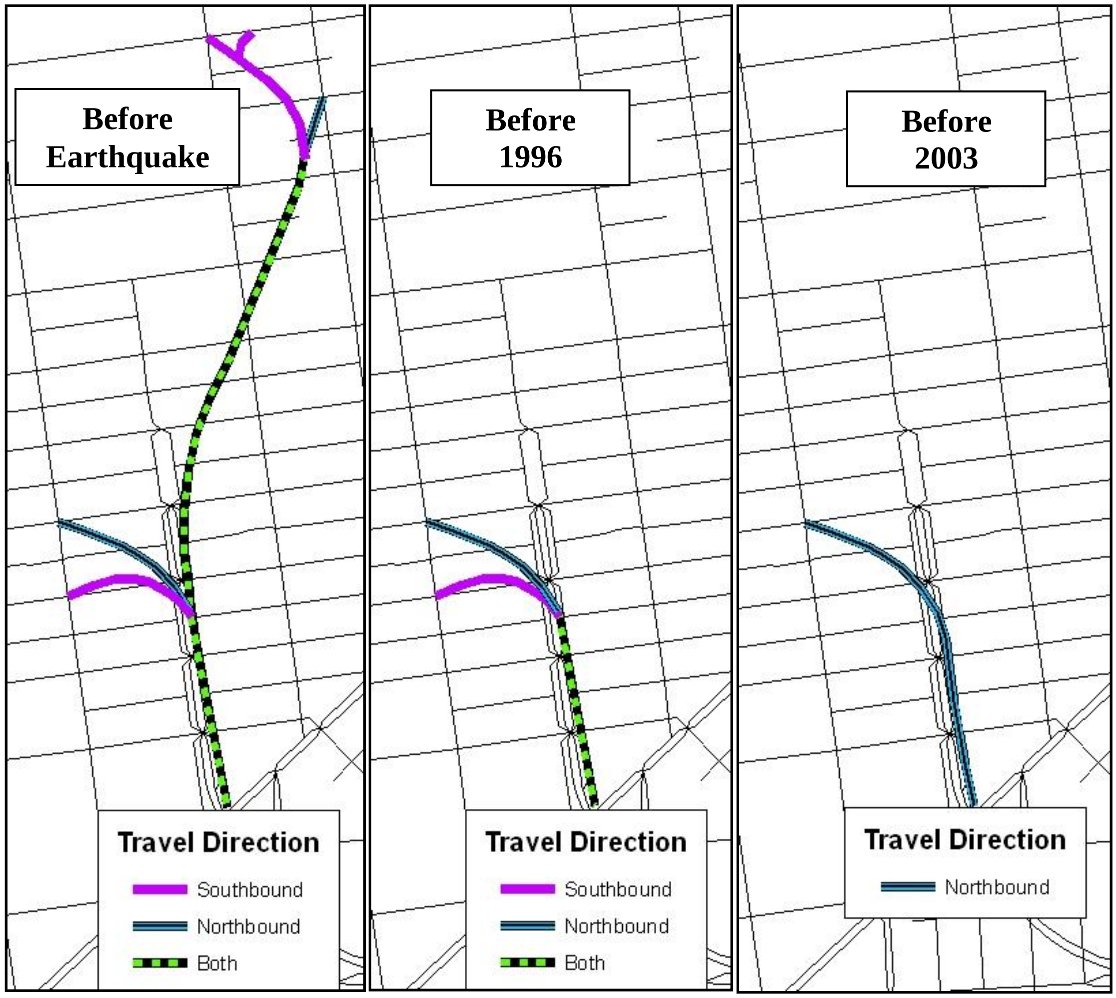


FIGURE 32 Central Freeway Phased Demolition

Whereas proponents of removing the Embarcadero included the powerful businesses and individuals involved in the downtown waterfront, proponents of removing the Central Freeway mainly included residents of largely poor minority neighborhoods which surrounded the freeway. Thus, the process of garnering enough support to approve the removal of the Central Freeway was extremely difficult (*16*). After much debate, a plan was finally approved in 1999 to replace the freeway with a multi-way boulevard named Octavia Boulevard. Multi-way boulevards differ from conventional boulevards by having the higher speed through traffic lanes separated by a median from one-way slower

speed local access lanes. Figure 33 illustrates this point by showing a typical intersection design of a multi-way boulevard.

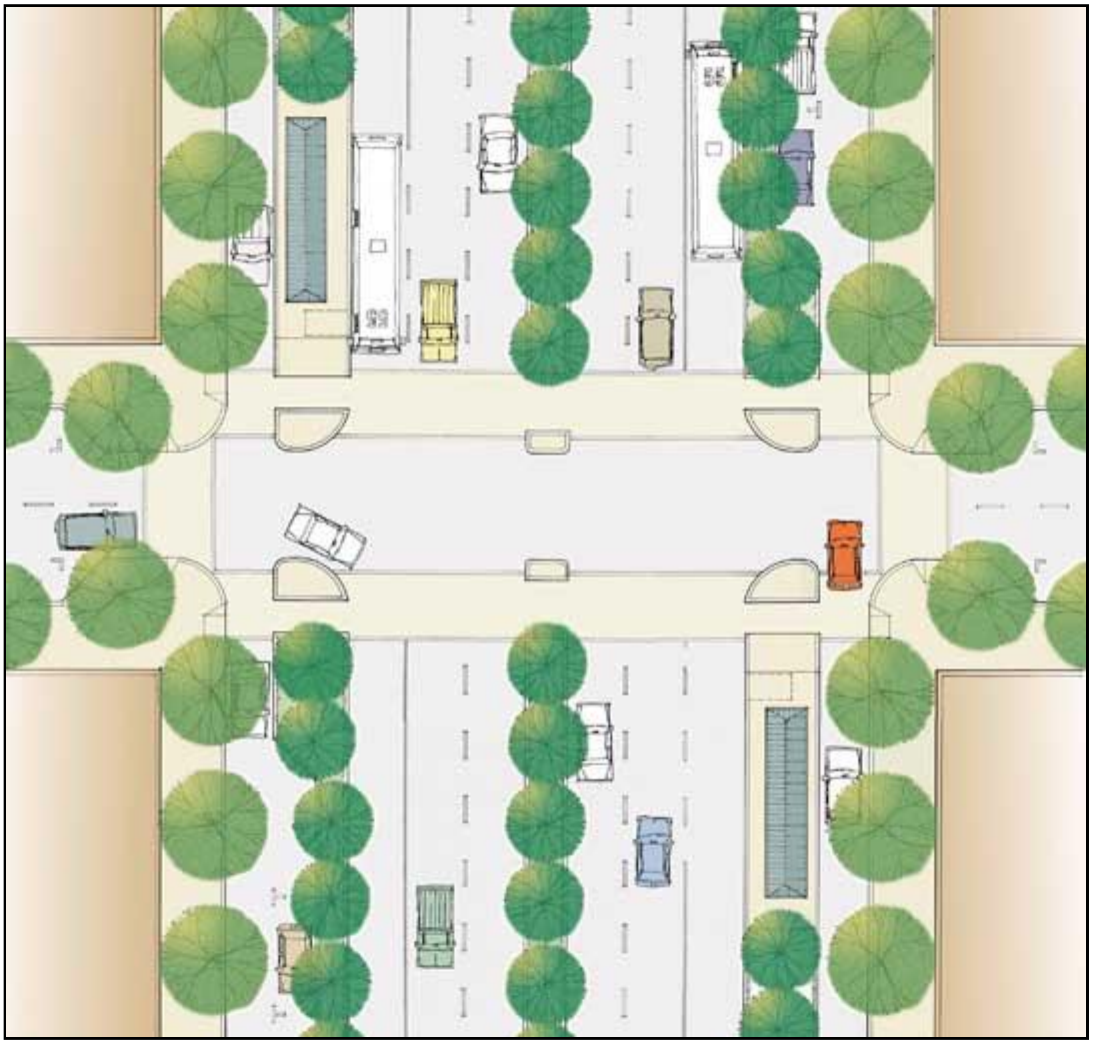


FIGURE 33 Multi-way Boulevard Intersection

(Source: http://pedshed.net/blog/wp-content/uploads/2007/08/boulevard.jpg)

Based on the design, the integration of this boulevard with the surrounding street networks is much different than that of the Embarcadero. Once on Octavia Boulevard, left turns are prohibited until the end of the boulevard at Fell Street. The reason for this

prohibition is due to the number of conflict points caused if left turns are allowed (*23*). Multi-way boulevards are essentially six way intersections as the local access roads are separated by medians from the main through lanes. Prohibiting left turns from the through lanes decreased the number of conflict points thus, in theory, making the intersections safer (*23*). However, drivers are also forced to take less direct routes when accessing areas to their left, which makes the road a limited access thoroughfare which is more similar in operation to a freeway. The overall design of this boulevard was also done as a compromise between commuters who utilized the highway and residents who live in the area. Replacing the freeway with a boulevard provided redevelopment opportunities for the neighborhoods and a more pleasing environment in which to live. At the same time, this specific design allows commuters a quicker trip through the area by limiting turns to and from the boulevard. Prior to the earthquake, the Central Freeway carried approximately 90,000 vehicles per day. Today, Octavia Boulevard carries roughly 52,000 vehicles per day which is 57.8% of the volume previously carried by the freeway (*14,15*).

Park East Freeway – Milwaukee, WI

Similar to San Francisco, Milwaukee also had a plan for surrounding and crisscrossing their downtown with freeways that was approved by voters in 1948. Though not part of the original plan, the Park East Freeway was added to the plan ten years later. The freeway was intended to run from I-43 east to Lake Michigan where it would connect with the Lake Freeway and ultimately I-794 (*7*). Figure 34 shows the 1965 freeway plan for this freeway as well as the section of freeway that was constructed and later removed.

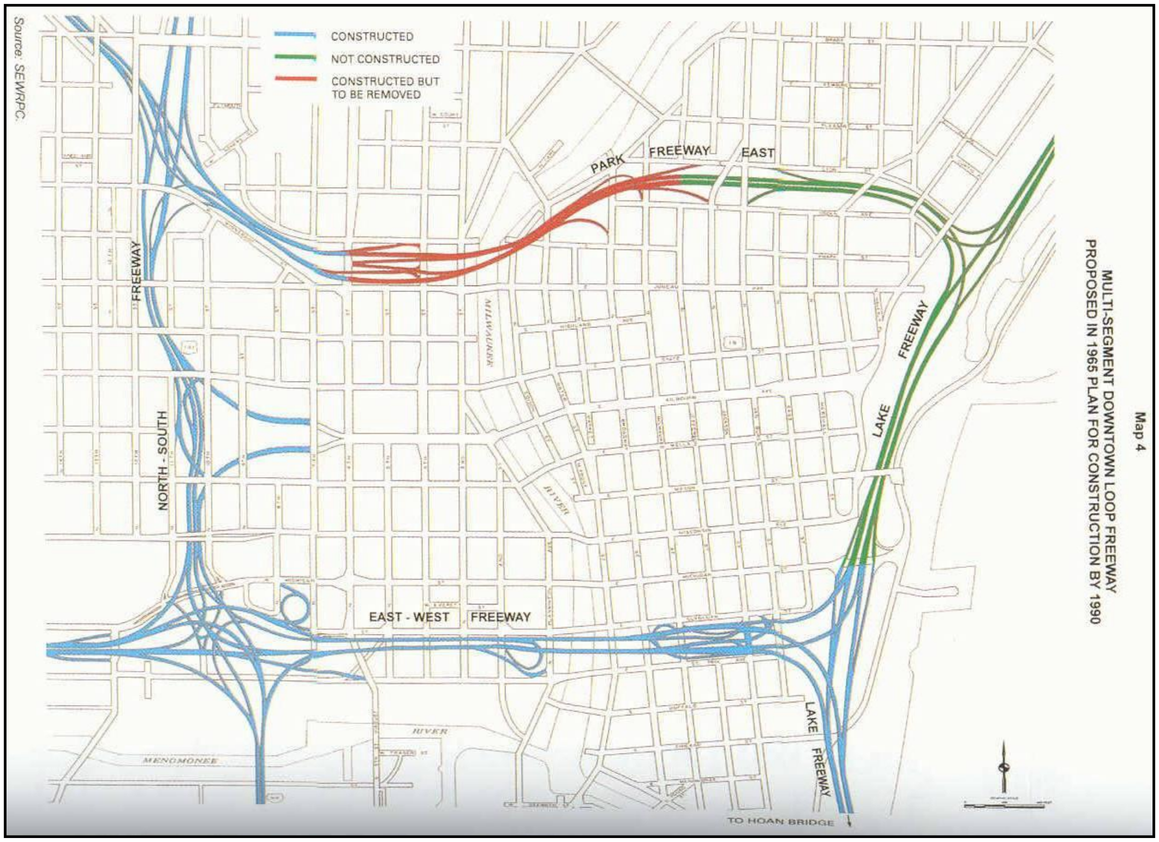


FIGURE 34 1965 Park East Freeway Plan

(Source: Southeast Wisconsin Regional Planning Commission)

Construction on the freeway began in the late 1960s and the first section of the freeway was opened to traffic in 1971. Protests were mounted shortly thereafter by local communities and environmental activists with the primary concern being that the freeway would cut off Juneau Park from the waterfront. These protests were strong enough to cancel the rest of the project in 1972. Only 0.8 miles of this elevated freeway were ever constructed. Before the project was canceled, the land necessary to complete the rest of the project had already been acquired. This land remained unutilized for 20 years until the 1990s when the state finally removed the land's designation as a transportation

corridor. This paved the way for the land to be redeveloped into a mixed-use community. The success of this redevelopment convinced Mayor John Norquist to start pushing to remove urban freeways as a way to revitalize areas within downtown Milwaukee. Two freeways were originally considered for removal: I-794 and the Park East Freeway. I-794 carried roughly twice the traffic that the Park East Freeway carried, so the removal of the Park East Freeway came to be seen as a means of achieving urban renewal while minimizing the impact to the existing transportation system. Ultimately, the freeway was demolished in 2002 and was replaced with McKinley Avenue by 2003. This boulevard functions similar to the Embarcadero in the sense that it is well connected to the surrounding street network (*7*). Since the freeway was never completed to the waterfront, it was significantly underutilized and only saw ADT of 54,000 vehicles per day at its peak. The replacement boulevard now carries 18,600 vehicles per day, 34.4% of the volume previously carried by the freeway (*9*).

Research Approach

Time Period and Traffic Data Selection

A key component of the analysis is understanding how traffic distribution changed before, during and after the removal of the freeways. Therefore, time periods for the "before", "intermediate" and "after" situations had to be selected for each case study. These time periods were selected based on the timeline for removal and the availability of average daily traffic (ADT) data.

For the Embarcadero, limited data was available for the "before" situation as the Loma Prieta earthquake occurred over 20 years ago. Only one source of ADT data was found for the "before" situation which was a report created by the San Francisco Department of Parking and Traffic in 1992 titled *South of Market Cordon Count – Pre-Earthquake and Current* (*14*). Based on this report, the "before" time period for the Embarcadero assessment was specified as 1988. This report was also the driving force behind street selection for the Embarcadero as the same streets needed to be used throughout all the time periods to ensure an accurate comparison. Ultimately, there were 13 streets or freeway sections selected for the Embarcadero analysis. The "intermediate" period for the Embarcadero was selected as 1993 – 1999. During this period, the freeway was completely removed, but the replacement boulevard was under construction. The construction of the boulevard was completed in phases, so portions of it were open to traffic at different times throughout this period. The "after" period was selected as 2000 – 2008 since the boulevard was completed in 2000. Data from the San Francisco Municipal Transportation Agency (SFMTA) was utilized for the "intermediate" and "after" periods (*15*).

Time periods for the Central Freeway were more complicated as the process of removing the freeway occurred in multiple stages over a range of years. More interest in the changes in the area around the Embarcadero was evident as no reports or data were available for the Central until the mid 1990s. Therefore, data was not obtained for a time period prior to the earthquake. It is important to note that Octavia Boulevard did not replace the entire length of the Central Freeway. The length of freeway demolished shortly after the earthquake was not replaced by a road. Only the sections of freeway

demolished after 1996 were replaced by the boulevard. Therefore, the "before" period was identified as 1995 – 1996 which corresponds to the period right before the first part of the freeway that would ultimately be replaced by Octavia Boulevard was removed. The "intermediate" period was identified as 2005 as this was the time when the freeway was completely removed but the boulevard was not yet open to traffic. The "after" period was identified as 2006 – 2008 after Octavia Boulevard was completed. ADT data for all three time periods was available for 9 streets/freeways from the SFMTA (*15*).

The "before" period for the Park East Freeway was selected to be 1999 – 2001 when the freeway was still in full operation. 2003 was selected as the "intermediate" period as the freeway was completely removed but the boulevard was not fully operational, though some sections were open to traffic. 2008 was selected as the "after" period as the boulevard was completely finished by this point in time. ADT data for the 14 streets/freeways analyzed was available from the Wisconsin Department of Transportation for all three time periods (*9*).

ADT to Peak Hour Flow Conversion

ADT data cannot be compared directly to peak hour capacity data. The ADT data needed to be converted to peak hour flow data in order to proceed with the comparison. Peak hour flow data was unavailable for the streets under investigation, so a design hour factor had to be utilized. Design hour factors identify the portion of ADT which is included in the peak hour of traffic flow. AASHTO recommends k-factors in the range of 0.08 – 0.12 for urban areas and the *Highway Capacity Manual (HCM)* recommends a default value of 0.09 be used. The upper end values of this range are more appropriate for cities

that see travel mainly during peak times (i.e. commuter cities). Because San Francisco consists of a combination of commuters from the suburbs and those living and working within the city limits, the default value of 0.09 was chosen. However, a value of 0.12 was selected for Milwaukee because the city has more of a suburban demographic than San Francisco. Multiplying this value by the ADT data resulted in peak hour traffic flow data.

Capacity Data

For San Francisco, the SFMTA utilizes a Synchro traffic flow model, which can be used to estimate the capacity of any given section in the road network. Capacities for all streets utilized in this analysis were obtained from this model. Capacities for the Central and Embarcadero Freeways, however, had to be estimated separately as these roads no longer exist and therefore there is no capacity data available. The *HCM* identifies a detailed process for estimating multilane highway capacity which involves utilizing factors to adjust for elements such as lane width, access points and percentage of heavy vehicles. Data of this detail was unavailable for these freeways, so the equation to calculate base capacity, without adjustment factors, from *HCM* exhibit 21-3 was used.

$$\text{Base Capacity} = 1000 + 20 \cdot FFS,\ FFS \le 60$$

The free flow speed (FFS) was estimated to be 50 miles per hour since these freeways are in an urban area. The base capacity was then multiplied by the number of lanes to obtain the freeway segment capacity utilized in the analysis.

For Milwaukee, specific peak hour capacity data was unavailable, so capacity estimation techniques were utilized. The capacity values were estimated utilizing the same technique that was used for the Embarcadero and the Central Freeways. For the urban streets, the *HCM* recommends using a default saturation flow value of 1900 passenger cars per hour per lane. Appendix N of the *Highway Performance Monitoring System (HPMS) Field Manual* recommends using a default green-cycle (g/C) ratio of 0.45 for urban streets. The g/C ratio was multiplied by the saturation flow value to obtain an estimated capacity per lane. The capacity for left turn lanes was multiplied by an additional factor of 0.35 based on techniques listed in Appendix N of the *HPMS Field Manual*. The number and type of lanes was determined from aerial photographs from Google Earth.

Volume-Capacity Ratios

Volume-capacity (V/C) ratios observed throughout a network are useful in identifying how traffic is distributed throughout an area. High V/C ratios indicate roads that are heavily used whereas low V/C ratios indicate underutilized roads. Additionally, it can be seen if certain road types (i.e. highways) are being utilized more or less than the local street network. V/C ratios for this analysis were determined by dividing the peak hour traffic flow obtained from the ADT data by the capacity obtained from the Synchro traffic flow model or *HCM* estimate.

Results and Discussion

The first portion of this analysis involved analyzing the changes in ADT in each street/freeway and in the surrounding network as a whole. Table 1 shows the results for the Embarcadero.

TABLE 1 Embarcadero Freeway Traffic Volume Changes

Primary Street	At	Cross Street	Trav. Dir.	ADT (Before)	ADT (Inter.)	ADT (After)	Before/ After % Change
Embarcadero Freeway/Blvd	North of	Mission	S	48,800	24,653	23,443	-52.0%
Embarcadero Freeway/Blvd	North of	Mission	N	49,400	26,026	24,837	-49.7%
Fremont	South of	Howard	N	12,700	36,230	37,043	191.7%
1st	South of	Howard	S	9,500	21,382	20,147	112.1%
2nd	South of	Howard	S	4,100	10,239	9,795	138.9%
3rd	South of	Howard	N	25,800	29,679	29,630	14.8%
4th	South of	Mission	S	14,100	21,201	18,755	33.0%
4th	North of	Harrison	S	18,500	29,337	28,954	56.5%
5th	South of	Howard	S	6,300	11,671	9,275	47.2%
5th	South of	Howard	N	8,300	13,576	12,688	52.9%
6th	South of	Howard	S	15,000	19,859	20,601	37.3%
6th	South of	Howard	N	9,000	14,480	15,021	66.9%
6th	North of	Brannan	S	24,000	16,363	20,508	-14.6%
6th	North of	Brannan	N	21,300	15,624	20,218	-5.1%
			Total	**266,800**	**290,320**	**290,915**	**9.0%**

As can be seen in this table, the replacement boulevard only carried about half of the traffic volume previously carried by the freeway. Even though this was a significant decrease in volume, there were also several streets that experienced significant increases in the range of 100% to 200%. It is also important to note that the area as a whole saw a 9.0% increase in traffic after the capacity was removed when comparing the before and after periods. These increases were sources of concern which would be investigated in

the V/C ratio analysis to determine if the streets had the excess capacity to absorb this traffic. There were minimal changes from the intermediate to the after periods, so most of the redistribution occurred right after the freeway was removed and remained essentially the same after the completion of the boulevard.

The results of the V/C analysis for the Embarcadero are shown in Figure 35.

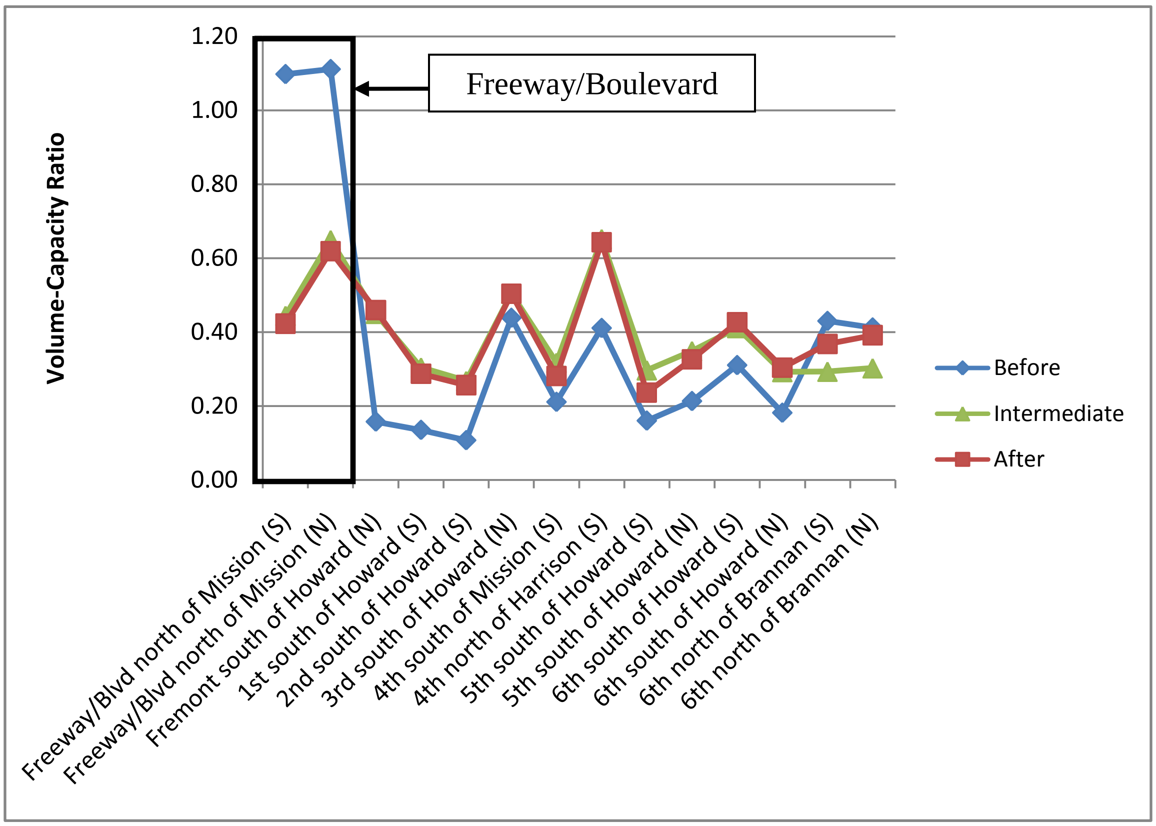


FIGURE 35 Embarcadero Corridor V/C Analysis

Prior to the removal of the freeway, it can be seen that the distribution of traffic was very concentrated on the freeway and very low on the neighboring street network. Thus, the local street network had significant excess capacity that was not being utilized because so

much traffic was associated with the freeway. However, after the freeway was removed, the distribution of traffic throughout the area became more balanced. The concentration of the traffic on the replacement boulevard decreased while the concentration on many of the other streets increased. This shows that the network is being more uniformly utilized and results in a more balanced network which is not so heavily reliant on one or two select roadways. In other words, San Francisco was able to utilize existing excess capacity to replace the lost freeway capacity. This figure also shows that the intermediate and after distributions are essentially the same which suggests that the removal of the freeway was the primary driving force behind the redistribution.

Table 2 shows the traffic volume analysis results for the Central Freeway.

TABLE 2 Central Freeway Traffic Volume Changes

Primary Street	At	Cross Street	Trav. Dir.	ADT (Before)	ADT (Inter.)	ADT (After)	Before/ After % Change
Central Freeway/ Octavia Blvd	North of	Market	N	46,550	---	26,487	-43.1%
Central Freeway/ Octavia Blvd	North of	Market	S	46,550	---	36,469	-21.7%
Oak	West of	Laguna	E	47,137	25,462	41,434	-12.1%
Fell	West of	Laguna	W	42,730	18,323	32,677	-23.5%
Turk	East of	Gough	W	11,566	11,779	11,992	3.7%
Fell	West of	Gough	W	15,498	16,645	16,837	8.6%
Gough	North of	Page	S	18,397	27,143	10,419	-43.4%
Van Ness	North of	Hayes	S	27,913	37,295	20,120	-27.9%
Golden Gate	West of	Gough	E	8,724	8,906	9,087	4.2%
			Total	**265,065**	**145,553**	**205,522**	**-22.5%**

This table shows that the replacement boulevard carries roughly two-thirds of the volume previously carried by the freeway when both north and south directions are considered. The Central Freeway did not experience the large increases in the surrounding network

that the Embarcadero did. In fact, most of the streets had significant decreases in traffic volume. However, the intermediate data shows that the traffic dropped to nearly half of the before volume during this time period. This suggests that people may have avoided the area during the construction of the new boulevard since no sections of it were open to traffic during this time. Traffic did rebound in the area after the boulevard was completed, but there was still a 22.5% decrease in volume when comparing the before and after time periods. What happened to this traffic is not fully understood, though it is possible that some of the traffic from the Central Freeway corridor shifted north to the Embarcadero corridor since they are only separated by 1.5 miles.

The results of the V/C analysis for the Central Freeway are displayed in Figure 36.

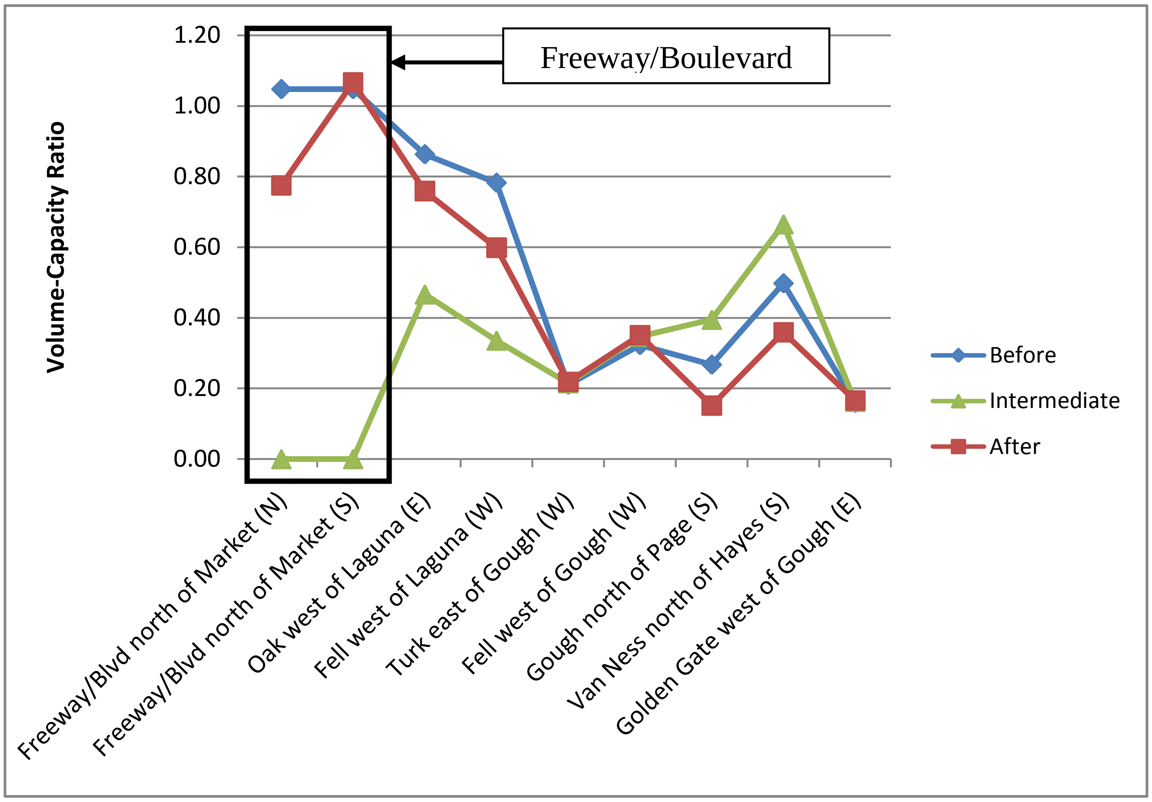


FIGURE 36 Central Corridor V/C Analysis

Similar to the Embarcadero, the area around the Central Freeway saw very high traffic concentrations at the freeway and lower concentrations on the local streets. Oak and Fell Street did see fairly high concentrations as well, but these streets led directly to or from ramps from the Central Freeway so this is understandable. When the freeway was removed and replaced with a boulevard, the traffic distribution did not change like the situation with the Embarcadero. In fact, the distribution remained essentially the same with the boulevard having a very high traffic concentration and the local streets having significant excess capacity. The distribution did change during the intermediate period as neither the freeway nor the boulevard were available for use during this time.

Interestingly enough, the intermediate distribution appears more balanced as there are no V/C ratios above 0.70 as there were in the before and after distributions. This suggests that not just freeways, but roads that operate similar to freeways have a distorting affect on traffic in an area. When no roads similar in operation to freeways were present in the network (intermediate period) the distribution was not distorted.

Table 3 shows the traffic volume analysis results for the Park East Freeway.

TABLE 3 Park East Freeway Traffic Volume Changes

Primary Street	At	Cross Street	Trav. Dir.	ADT (Before)	ADT (Inter.)	ADT (After)	Before/ After % Change
Park East Freeway/ McKinley Ave	East of	I-43	Both	52,100	16,500	18,600	-64.3%
Park East Freeway/ McKinley Ave	East of	6th	Both	25,600	2,100	15,800	-38.3%
6th	South of	McKinley	Both	15,300	14,100	25,200	64.7%
6th	North of	McKinley	Both	7,800	9,600	23,400	200.0%
4th	North of	McKinley	Both	6,400	6,400	3,500	-45.3%
4th	South of	McKinley	Both	7,100	11,900	4,800	-32.4%
Juneau	East of	6th	Both	10,600	11,900	7,800	-26.4%
Martin Luther King Jr	South of	Juneau	Both	7,400	7,700	8,000	8.1%
Water	South of	McKinley	Both	18,300	21,800	16,300	-10.9%
Water	North of	Cherry	Both	17,500	19,100	15,300	-12.6%
Ogden	East of	Jefferson	Both	13,700	3,400	4,000	-70.8%
Van Buren	South of	Lyon	Both	9,100	14,000	10,300	13.2%
Juneau	East of	Water	Both	8,200	13,500	8,900	8.5%
Milwaukee	South of	Lyon	Both	1,900	1,900	2,400	26.3%
			Total	**201,000**	**153,900**	**164,300**	**-18.3%**

Similar to the Central Freeway, the Park East Freeway saw a significant reduction in traffic volume in the intermediate time period. Some of this volume returned in the after period, but overall there was still an 18.3% decrease in traffic volume when comparing the before and after periods. The changes seen in individual streets, however, were

unique from the other two case studies. Some streets experienced substantial increases, while others experienced large decreases. The effects of these changes on traffic concentration needed to be investigated in the V/C portion of the analysis.

The results of the V/C analysis are shown in Figure 37.

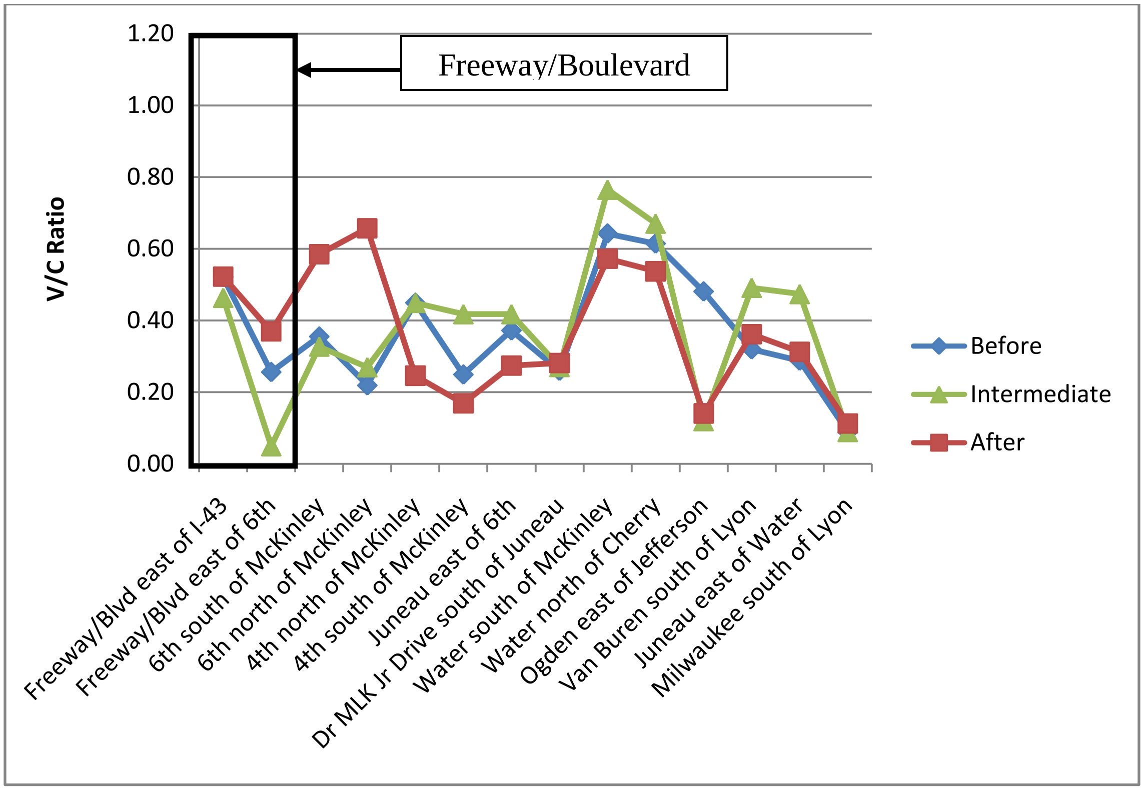


FIGURE 37 Park East Corridor V/C Analysis

The Park East Freeway is different from the two San Francisco case studies in the fact that it did not experience high levels of congestion. This is indicated by the relatively low V/C ratios seen in the before period. Even though this freeway was underutilized, the removal of it still caused the distribution of traffic in the area to change. The intermediate data shows that significant increases were experienced on the eastern side of

the freeway corridor (streets go from western-most to eastern-most when reading from left to right) and significant decreases were experienced on the freeway/boulevard. Once the boulevard was fully opened to traffic, traffic rebounded on the western side of the corridor and dipped back down to levels similar to the before period in the eastern section of the corridor. Overall, the corridor did not see any excessively high V/C ratios which means that even though the distribution did change throughout the area, it still remained fairly balanced.

Removing the urban freeway segments in all three case studies caused traffic in the surrounding area to redistribute, albeit in different ways. The Embarcadero and Park East Freeway corridors both experienced redistributions that were fairly balanced with no excessively high or low V/C ratios. The Central Freeway, however, experienced a redistribution similar to the "before" condition which was still distorted with very high V/C ratios on the replacement boulevard. These results suggest that the specific type of boulevard design may have a significant effect on how the traffic redistributes. Both the Embarcadero Boulevard and McKinley Avenue were fully connected into the street network so that they functioned very similar to the other streets around them. Octavia Boulevard, however, was completely different than all the streets around it with its multi-way boulevard design. This design significantly limited turning movements from the boulevard and in essence forced people to stay on the road until it ended. This design functions similar to a freeway in the sense that there are only limited points at which to exit. This difference in boulevard construction might explain why the distribution of traffic changed in different ways. With the Embarcadero and Park East Freeways, an elevated freeway was replaced with a street which functioned as just another part of the

existing local street network. This resulted in a significant change in the route choices in the area which explains the more balanced distribution. The Central Freeway was replaced by a street that still acted as a funnel for traffic in the area, so the distribution of traffic in the area remained distorted. More case studies would need to be incorporated to determine the precise nature of traffic redistribution effects for each road design type, but the results suggest that road design does play a key role in the redistribution process.

Applicability to Other Cities

Many cities throughout North America are considering freeway removal projects within their urban areas. A major roadblock to these projects is the lack of understanding as to what will actually happen to traffic in the area when the capacity is removed. In order to help remove this roadblock, the results of the case study portion of this analysis were applied to nine cities throughout North America that are potential candidates for road capacity removal projects. Table 4 lists the cities used in this analysis and the roads that are being considered for removal.

TABLE 4 Cities with Potential Capacity Removal Projects

City	State	Potential Removal Project
Hartford	Connecticut	I-84 Viaduct
New Haven	Connecticut	SR-34
Indianapolis	Indiana	I-65/I-70
Louisville	Kentucky	I-64
Baltimore	Maryland	Jones Falls Expressway
Buffalo	New York	Buffalo Skyway
Seattle	Washington	Alaskan Way Viaduct
Toronto	Ontario	Gardiner Expressway
New Orleans	Louisiana	I-10

The most current available ADT data was collected for 3 freeways and 12 streets per city (*24*,*25*,*26*,*27*,*28*,*29*,*30*,*31*,*32*,*33*,*34*,*35*). Similar to the case studies, ADT data was converted to peak hour flow utilizing k-factors ranging from 0.09 – 0.12 depending upon the travel characteristics of the city. Specific peak hour capacity data was unavailable, so capacity estimation techniques were utilized for both the freeways and urban streets as stated in the "Research Approach" portion of this paper. The V/C ratios for the freeways were then averaged as were the V/C ratios for the streets. These average values were then compared to those of the Embarcadero and Central Freeways prior to removal. The results of this analysis are shown in Figure 38.

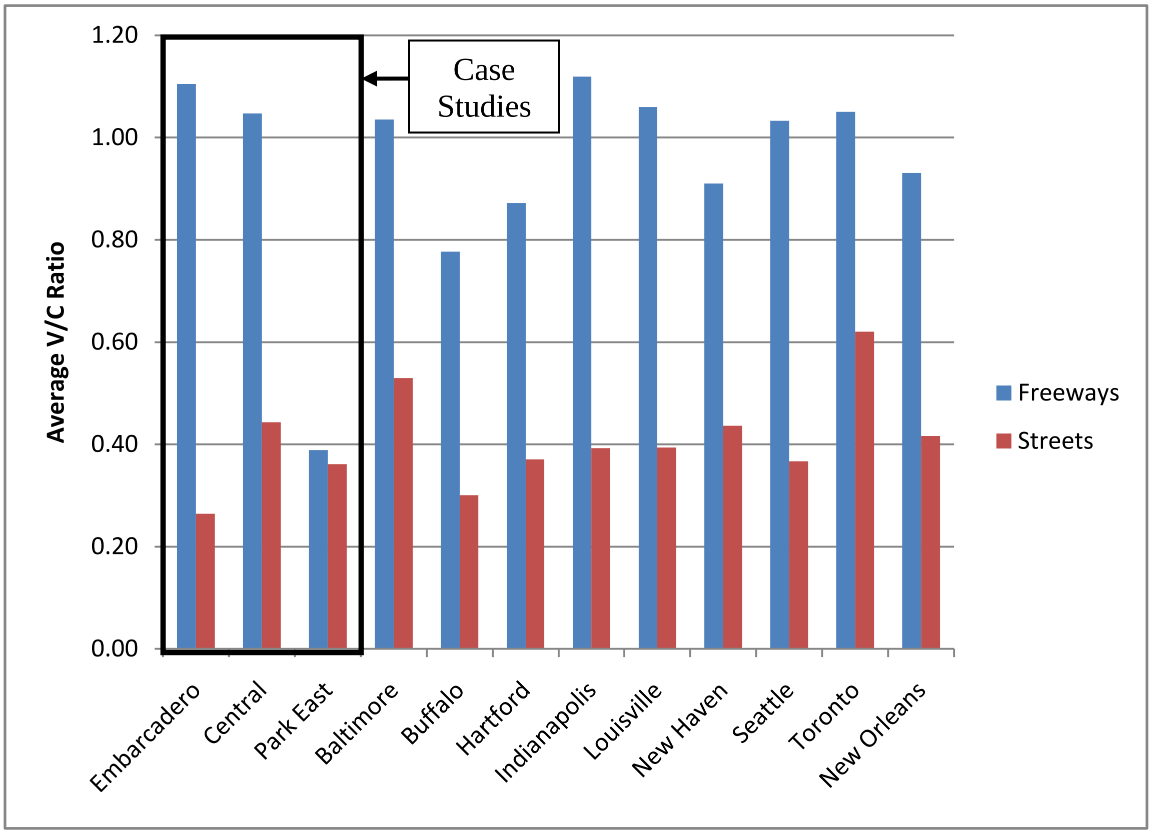


FIGURE 38 Average V/C Ratios for Case Studies and 9 North American Cities

These results show a similar traffic distribution in these nine cities as was seen in the San Francisco case studies. The urban freeways have very high V/C ratios whereas the streets have low V/C ratios. The Milwaukee case study is different from the other case studies and the nine other cities. The reason for this difference is likely because the freeway in question was underutilized and experienced low V/C ratios, which is not the case in the other cities. The similarity to the San Francisco distributions indicates that other cities throughout North America are experiencing distorted traffic distributions with high concentrations on urban freeways and low concentrations on urban streets. Therefore, it

is likely that these cities could see a more balanced distribution if they proceed with removing segments of their urban freeways.

Conclusions

As our road infrastructure ages, more and more cities will be faced with the decision of what to do with urban freeways and other high capacity roads within their urban core. With local budgets tightening, it is likely that more cities will begin considering the removal of these roads as a way to save on costly maintenance and rebuilding costs. From a community standpoint, removing these roads is seen as a way of freeing up land for redevelopment to help revitalize the neighborhoods. Without an adequate understanding of the redistribution process, it will be difficult for municipalities to garner enough support to proceed with these projects. This project has shown how the traffic distribution within three case study areas changed when segments of urban freeways were removed. Initially, both areas in San Francisco saw high traffic concentration on the freeways and significant unused capacity on the surrounding street network. The Milwaukee case study had significant unused capacity in both the freeway and urban streets as the freeway was underutilized. In the case of the Embarcadero and Park East Freeways, the freeways were replaced with a traditional boulevard which resulted in a more balanced distribution of traffic. The Central Freeway, however, was replaced with a multi-way boulevard which differs significantly in design from a traditional boulevard by the addition of separated local traffic lanes. This design functions more similarly to a freeway with somewhat limited movements from the through lanes and higher speeds than on many of the surrounding local streets. Because of these differences in design, the

Central Freeway saw the traffic distribution remain distorted with high traffic concentrations on the boulevard and lower concentrations on other surrounding streets. These results suggest that a difference in road design can have significant effects on traffic distribution and therefore careful consideration must be given as to what is the desired effect after the boulevard is constructed. Doing similar analyses in nine other North American cities showed that they currently have traffic distributions similar to the pre-removal condition of the San Francisco case studies. Therefore, these cities would be good candidates for pursuing the capacity removal projects which have been discussed in order to bring a more balanced traffic distribution to their network. It is likely that many other cities throughout North America have similar traffic distributions and this shows that excess capacity in the surrounding street network does exist in most cases to absorb the traffic that is currently carried by segments of urban freeways. With the results of this analysis, municipalities can make more accurate assessments of post-removal traffic distribution by comparing their network to those analyzed in this paper.

CONCLUSIONS

As our road infrastructure continues to age, more and more cities will be forced to decide what to do with segments of their urban freeways. From an economic standpoint, rebuilding these freeways is a very expensive venture that many cities cannot afford. Replacing these freeways with a boulevard is a lower cost solution that can meet their transportation needs without breaking their budget. Socially speaking, many of these freeways were built on top of and through existing neighborhoods. For years, communities have been forced to deal with large, loud, unsightly structures, and now there is an opportunity to reconnect these neighborhoods and encourage redevelopment. However, most people throughout North America travel via their automobile. So removing a high capacity road from the network comes as a concern to many motorists. The biggest objection to freeway removal is based on the fear that removal will cause substantial negative traffic effects, possibly even gridlock. Therefore, a better understanding is required of how traffic flow changes and redistributes after road capacity is removed.

A growing number of cities throughout the world have already completed capacity removal projects. Minimal research exists as to the traffic related results of embarking on these projects. The research that does exist tends to focus on aspects such as housing prices and land values. Some research does exist as to the effects on traffic, but they tend to focus on just the difference between the freeway and the new boulevard and not the changes in traffic behavior throughout the surrounding area. Because traffic distribution is such a sensitive part of the decision making process, a detailed traffic

analysis is required in order to provide more information to municipalities facing the tough decision as to the fate of their urban freeways.

The traffic volume analysis showed that removing the urban freeways caused the distribution of traffic in the surrounding area to adjust. The pre-removal condition in the San Francisco case studies showed a distorted distribution with high V/C ratios on urban freeways and low V/C ratios on urban streets. The pre-removal condition in Milwaukee did not see high V/C ratios in either the urban streets or freeways, which is likely because the freeway was significantly underutilized. When the freeways were removed, traffic shifted to the surrounding street network and some of the traffic disappeared from the area entirely. The largest decrease in traffic volume occurred in the intermediate time period and the volume rebounded somewhat once the boulevard was completed. The distribution for the Embarcadero Freeway became much more balanced after the freeway was removed. The distribution for the Park East Freeway was balanced before and after the freeway removal, but there were changes in the V/C ratios of some of the streets. The distribution for the Central Freeway, however, initially changed when the freeway was removed and the boulevard was not yet opened. But, after the boulevard was opened, the distribution returned to the pre-removal condition. The results suggest that this may be because of the road design that was employed in the Central Freeway.

The Embarcadero and Park East Freeways were both replaced by traditional boulevards that were well connected to the street network and provided numerous choices for travel routes. The Central Freeway employed a multi-way boulevard which operates more similar to a freeway. Because multi-way boulevards have separate one-way local travel lanes, intersection design is difficult as turning movements from the main through

lanes can cause significantly more conflict points than a traditional intersection. Therefore, in this case, the design limited left hand turns in many locations because this was felt to be safer. In essence, this created a limited access roadway which funneled traffic through a corridor. Since only one case study was used for this type of road design, it is difficult to make a definitive observation that can be applied across the board. However, based on the three case studies it does appear that the design of the replacement roadway does play some role in the redistribution process.

Nine other cities that are currently considering urban freeway removal projects were selected to see how their current traffic distribution compares to those of the case studies. The results showed that the distribution of traffic in all these cities was distorted with large differences between the V/C ratios of urban streets and freeways. Therefore, it can be seen that significant excess capacity exists in the surrounding networks which can be used to absorb some of the traffic carried by the freeways in question if they are ultimately removed. It is hoped that based on the results of this work, local municipalities will be able to make more informed decisions when considering what to do with their aging urban freeways.

FUTURE RESEARCH

This project provides a good baseline for what cities can expect to happen to the traffic distribution in the area around a capacity removal project. However, much can be gained by building on this thesis and refining some of the processes. Adding more cities to the case study list would be helpful in presenting a more comprehensive picture of the effects of capacity removal on traffic distribution. Unfortunately, there are a limited number of

case studies to choose from and the older case studies do not have good data that can be used in a detailed analysis. As more cities embark on the process of capacity removal projects, it is likely that data would be available, as they are more current, and could therefore be used to strengthen this analysis.

The analysis presented in this paper centers around V/C ratios of streets and freeways. For the case studies in San Francisco, volume and capacity data was available thus eliminating the need to estimate these parameters. With the other cities currently considering capacity removal projects, capacity estimation techniques had to be utilized. This means the results were limited in their ability to specifically present the current situation in these cities. Utilizing traffic simulation models for these cities would expand upon the limited data that is available.

The results presented in this paper suggest that the design of the replacement road affects the nature of traffic redistribution. Unfortunately, too few case studies were available to make definitive conclusions. Employing more case studies and classifying them by replacement road design can help provide a more comprehensive understanding of this matter.

REFERENCES

1. Sheffi, Y. *Urban Transportation Networks.* Prentice Hall, Inc., New Jersey, 1985.

2. *6 Case Studies in Urban Freeway Removal*. City of Seattle. http://www.cityofseattle.net/transportation/docs/ump/06%20SEATTLE%20Case%20studies%20in%20urban%20freeway%20removal.pdf. Accessed November 10, 2009.

3. *New York, NY: West Side Highway*. The Preservation Institute. http://www.preservenet.com/freeways/FreewaysWestSide.html. Accessed October 15, 2009.

4. *West Side (Joe DiMaggio) Highway: Historic Overview*. http://www.nycroads.com/roads/west-side/. Accessed October 28, 2009.

5. *Traffic Data Viewer*. New York State Department of Transportation. http://www.nysdot.gov/tdv. Accessed November 10, 2009.

6. *Green Light for Midtown Evaluation*. New York City Department of Transportation. January 2010.

7. *Milwaukee, WI: Park East Freeway*. The Preservation Institute. http://www.preservenet.com/freeways/FreewaysParkEast.html. Accessed October 20, 2009.

8. Bessert, C. *Milwaukee Freeways: Park Freeway*. http://www.wisconsinhighways.org/milwaukee/park.html. Accessed November 6, 2009.

9. *Milwaukee County Traffic Counts.* http://www.dot.wisconsin.gov/travel/counts/milwaukee.htm. Accessed November 6, 2009.

10. *History of the Central Artery/Tunnel Project*. Massachusetts Department of Transportation. http://www.masspike.com/bigdig/background/history.html. Accessed November 17, 2009.

11. *Technical Briefing: Gardiner/Lake Shore Corridor*. Toronto Waterfront Revitalization Corporation. http://www.waterfrontoronto.ca/dbdocs/451ad1fc5015e.pdf. July 2004.

12. Llewellyn-Thomas, K. *Dismantling the F.G. Gardiner Expressway East: Removing Toronto's Elevated Expressway One Piece at a Time*. http://www.tac-atc.ca/english/resourcecentre/readingroom/conference/conf2003/pdfs/gadiner.pdf. 2002.

13. *San Francisco, CA: Embarcadero Freeway*. The Preservation Institute. http://www.preservenet.com/freeways/FreewaysEmbarcadero.html. Accessed October 1, 2009.

14. *South of Market Cordon Count – Pre-Earthquake and Current*. San Francisco Department of Parking and Traffic, 1992.

15. *Traffic Volume Information*. San Francisco Municipal Transportation Agency. http://www.sfmta.com/cms/vhome/hometraffic.htm. Accessed on June 5, 2010.

16. Cervero, R., J. Kang, and K. Shively. *From Elevated Freeways to Surface Boulevards: Neighborhood, Traffic, and Housing Price Impacts in San Francisco*. University of California Transportation Center, December 2007.

17. *San Francisco, CA: Central Freeway*. The Preservation Institute. http://www.preservenet.com/freeways/FreewaysEmbarcadero.html. Accessed October 1, 2009.

18. *Paris, France: Georges Pompidou Expressway*. The Preservation Institute. http://www.preservenet.com/freeways/FreewaysPompidou.html. Accessed November 12, 2009.

19. *Masshouse Circus*. City of Birmingham. http://www.birmingham.gov.uk. Accessed on March 5, 2010.

20. *M30 Madrid Calle 30 Project, Madrid, Spain*. Net Resources International, Inc. http://www.roadtraffic-technology.com/projects/m30_madrid/. Accessed on March 5, 2010.

21. Cairns, S., C. Hass-Klau, P. B. Goodwin. *Traffic Impact of Highway Capacity Reductions: Assessment of the Evidence*. Landor Publishing, 1998.

22. Hastrup, S. Battle for a Neighborhood. *Places*, Vol. 18, No. 2, 2006, pp. 66 – 71.

23. MacDonald, E. Building a Boulevard. *Access*, No. 28, 2006, pp. 2 – 9.

24. *Traffic Monitoring Volume Information*. Connecticut Department of Transportation. http://www.ct.gov/dot/cwp/view.asp?a=3532&q=330402. Accessed February 5, 2011.

25. *2008 Traffic Volumes State Maintained Highway Network*. Connecticut Department of Transportation. http://www.ct.gov/dot/lib/dot/documents/dpolicy/traflog/traflog08.pdf. Accessed February 5, 2011.

26. *Traffic Count Maps*. Indianapolis Metropolitan Planning Organization. http://www.indympo.org/Data/Maps/Pages/TrafficCountMaps.aspx. Accessed February 7, 2011.

27. *INDOT Average Daily Traffic and Commercial Vehicles*. Indiana Department of Transportation. http://dotmaps.indot.in.gov/apps/trafficcounts/. Accessed February 7, 2011.

28. *Traffic Counts and Count Stations*. Kentucky Transportation Cabinet. http://transportation.ky.gov/planning/maps/count_maps/count_maps.asp. Accessed February 7, 2011.

29. *Traffic Volume Maps*. Maryland State Highway Administration. http://www.sha.maryland.gov/Traffic_Volume_Maps/06_Traffic_Volume_Maps.pdf. Accessed February 8, 2011.

30. *BMC Traffic Count Database*. Baltimore Metropolitan Council. http://bmc.baltometro.org/traffic/Traffic.aspx. Accessed on February 8, 2011

31. *Maps*. Greater Buffalo-Niagara Regional Transportation Council. http://www.gbnrtc.org/maps/. Accessed February 8, 2011.

32. *Traffic Flow Data and Maps – 2008*. Seattle Department of Transportation. http://www.cityofseattle.net/transportation/tfdmaps.htm. Accessed February 9, 2011.

33. *2009 Annual Traffic Report*. Washington State Department of Transportation. http://www.wsdot.wa.gov/mapsdata/travel/pdf/Annual_Traffic_Report_2009.pdf. Accessed February 9, 2011.

34. *Average Weekday, 24 Hour Traffic Volume (Most Recent Counts from 2005 – 2009)*. Toronto Transportation Services. http://www.toronto.ca/transportation/publications/brochures/24hourvolumemap.pdf. Accessed February 9, 2011.

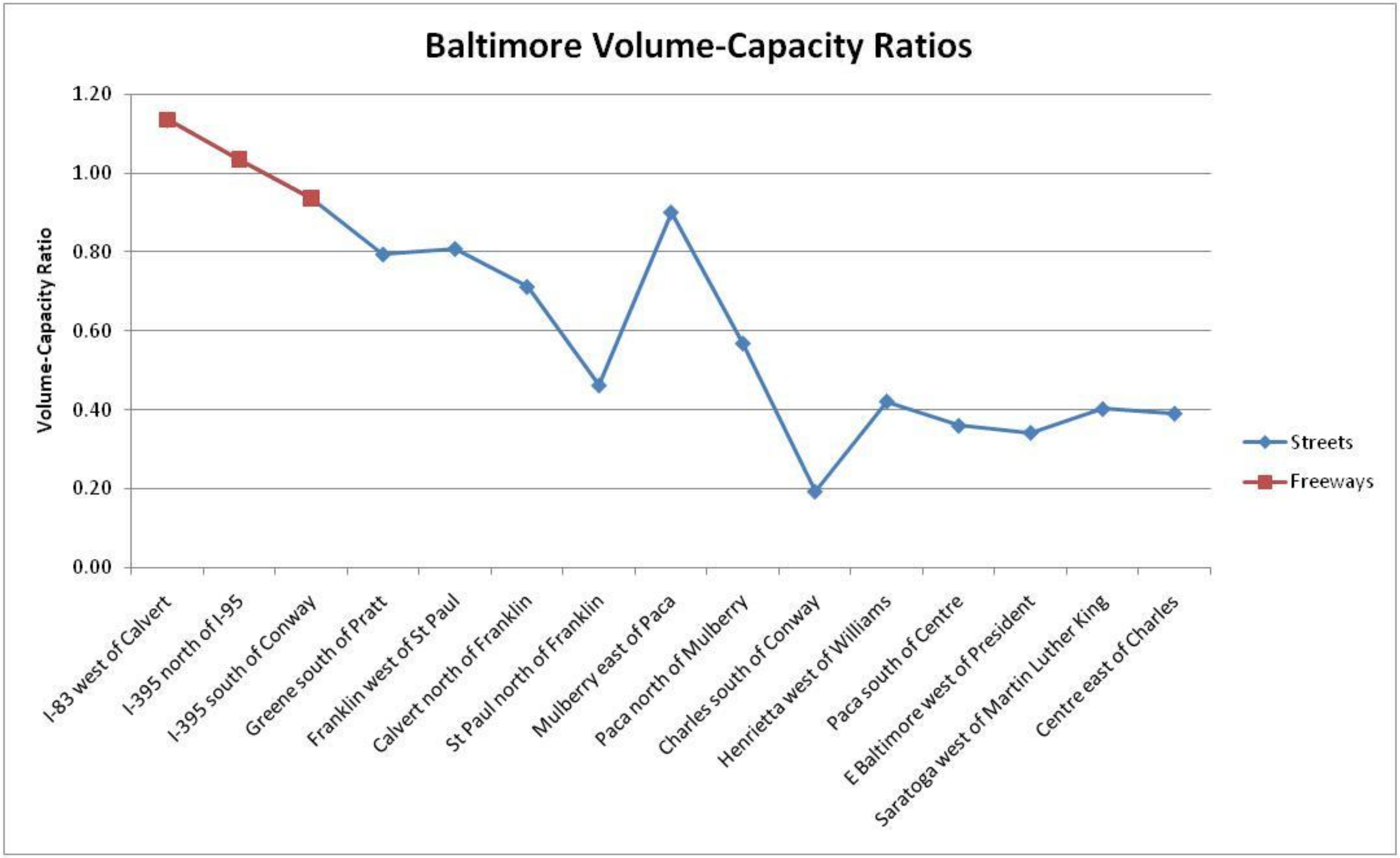
35. *Traffic Counts*. Regional Planning Commission for Jefferson, Orleans, Plaquemines, St. Bernard and St. Tammany Parishes. http://www.norpc.org/traffic_counts.html. Accessed March 15, 2011.

APPENDIX A: V/C ANALYSIS FOR BALTIMORE, MD

Design Hour Factor (K-Factor)	0.12
Year Range	2003 - 2006

Primary Street	At	Cross Street	Travel Direction	ADT	Peak Flow (pcph*)	Capacity (pcph*)	V/C Ratio	Lanes	Road Type
I-83	West of	Calvert St	Both	113,480	13,618	12,000	1.13	6	Freeway
I-395	North of	I-95	Both	103,480	12,418	12,000	1.03	6	Freeway
I-395	South of	Conway St	Both	56,180	6,742	7,200	0.94	4	Freeway
Greene St	South of	Pratt St	S	16,980	2,038	2,565	0.79	3	Street
Franklin St	West of	St Paul St	W	17,280	2,074	2,565	0.81	3	Street
Calvert St	North of	Franklin St	N	15,220	1,826	2,565	0.71	3	Street
St Paul St	North of	Franklin St	S	9,880	1,186	2,565	0.46	3	Street
Mulberry St	East of	Paca St	E	19,260	2,311	2,565	0.90	3	Street
Paca St	North of	Mulberry St	N	10,942	1,313	2,309	0.57	2	Street
Charles St	South of	Conway St	Both	4,130	496	2,565	0.19	3	Street
Henrietta St	West of	Williams St	Both	6,010	721	1,710	0.42	2	Street
Paca St	South of	Centre St	N	5,130	616	1,710	0.36	2	Street
E Baltimore St	West of	President St	Both	7,317	878	2,565	0.34	3	Street
Saratoga St	West of	Martin Luther King Blvd	Both	5,736	688	1,710	0.40	2	Street
Centre St	East of	Charles St	E	8,354	1,002	2,565	0.39	3	Street

* pcph = passenger cars per hour

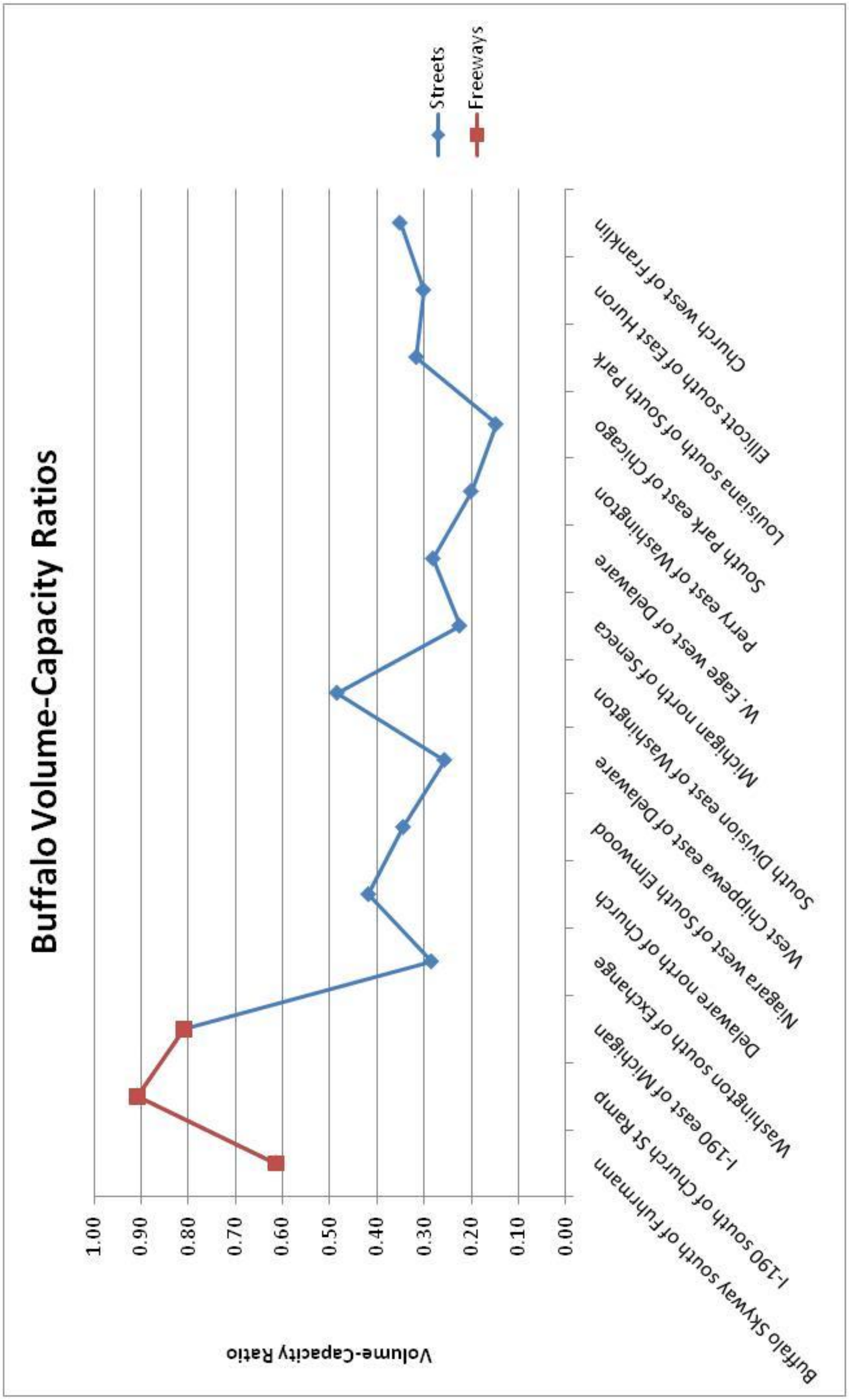

Baltimore Volume-Capacity Ratios
Volume-Capacity Ratio
1.20
1.00
0.80
0.60
0.40
0.20
0.00
I-83 west of Calvert
I-395 north of I-95
I-395 south of Conway
Greene south of Pratt
Franklin west of St Paul
Calvert north of Franklin
St Paul north of Franklin
Mulberry east of Paca
Paca north of Mulberry
Charles south of Conway
Henrietta west of Williams
Paca south of Centre
E Baltimore west of President
Saratoga west of Martin Luther King
Centre east of Charles
Streets
Freeways

APPENDIX B: V/C ANALYSIS FOR BUFFALO, NY

Design Hour Factor (K-Factor)	0.12
Year Range	2002 - 2007

Primary Street	At	Cross Street	Travel Direction	ADT	Peak Flow (pcph*)	Capacity (pcph*)	V/C Ratio	Lanes	Road Type
Buffalo Skyway	South of	Fuhrmann Blvd Ramp	Both	40,900	4,908	8,000	0.61	4	Freeway
I-190	South of	Church St Ramp	Both	90,800	10,896	12,000	0.91	6	Freeway
I-190	East of	Michigan Ave	Both	80,900	9,708	12,000	0.81	6	Freeway
Washington St	South of	Exchange St	Both	8,100	972	3,420	0.28	4	Street
Delaware Ave	North of	Church St	Both	11,900	1,428	3,420	0.42	4	Street
Niagara St	West of	South Elmwood Ave	Both	9,800	1,176	3,420	0.34	4	Street
West Chippewa St	East of	Delaware Ave	Both	7,300	876	3,420	0.26	4	Street
South Division St	East of	Washington St	E	13,800	1,656	3,420	0.48	4	Street
Michigan Ave	North of	Seneca St	Both	6,400	768	3,420	0.22	4	Street
W Eagle St	West of	Delaware Ave	Both	4,000	480	1,710	0.28	2	Street
Perry St	East of	Washington St	Both	2,850	342	1,710	0.20	2	Street
South Park Ave	East of	Chicago St	Both	2,100	252	1,710	0.15	2	Street
Louisiana St	South of	South Park Ave	Both	4,500	540	1,710	0.32	2	Street
Ellicott St	South of	East Huron St	Both	4,290	515	1,710	0.30	2	Street
Church St	West of	Franklin St	Both	10,000	1,200	3,420	0.35	4	Street

* pcph = passenger cars per hour



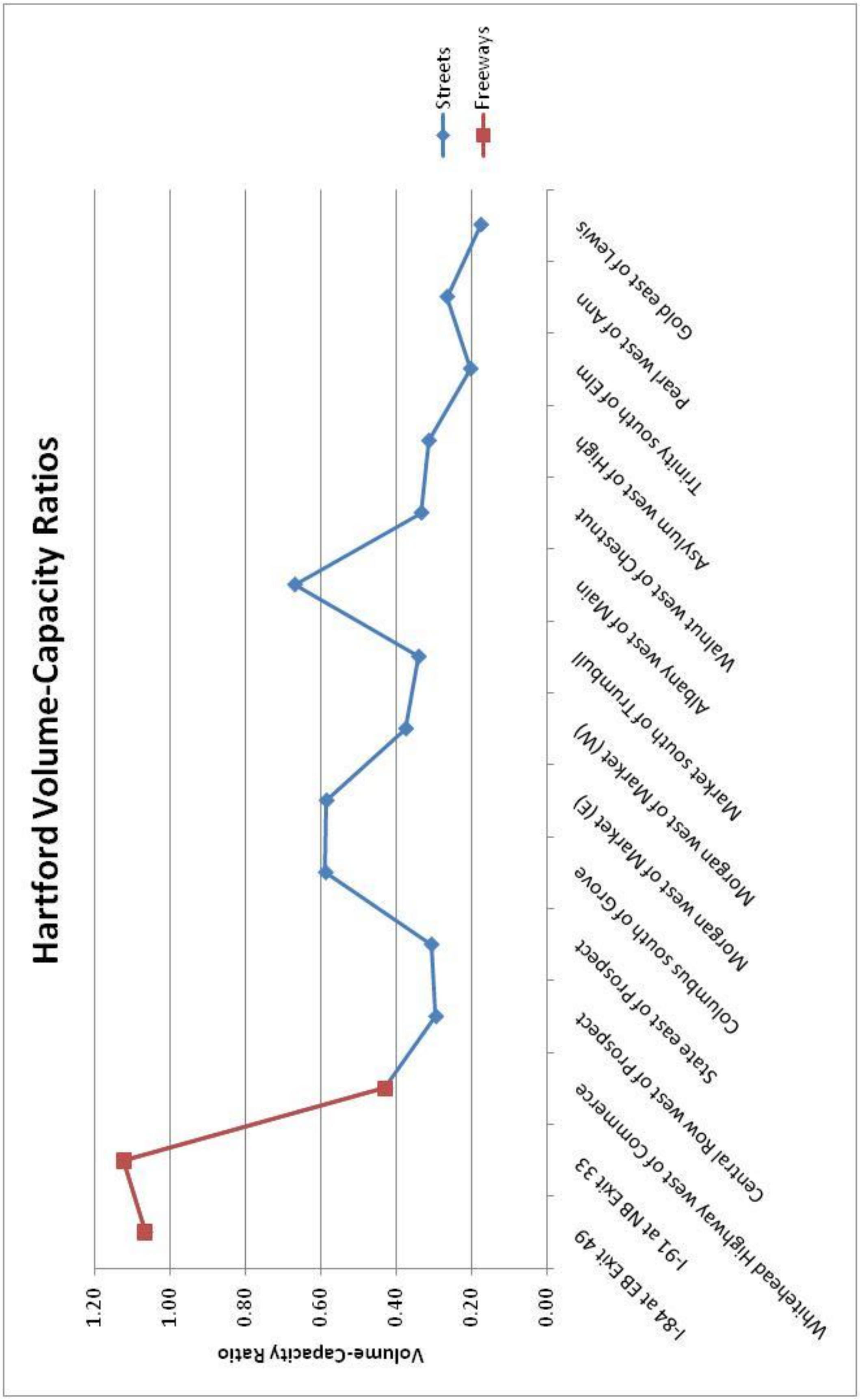
Buffalo Volume-Capacity Ratios
Volume-Capacity Ratio
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Buffalo Skyway south of Fuhrmann
I-190 south of Church St Ramp
I-190 east of Michigan
Washington south of Michigan
Delaware north of Exchange
Niagara west of Church
West Chippewa east of South Elmwood
South Division east of Delaware
Michigan north of Washington
W. Eage west of Delaware
Perry east of Washington
South Park east of Chicago
Louisiana south of South Park
Ellicott south of East Huron
Church west of Franklin
Streets
Freeways

APPENDIX C: V/C ANALYSIS FOR HARTFORD, CT

Design Hour Factor (K-Factor)	0.12
Year Range	2008 - 2009

Primary Street	At	Cross Street	Travel Direction	ADT	Peak Flow (pcph*)	Capacity (pcph*)	V/C Ratio	Lanes	Road Type
I-84		EB Exit 49 (High St)	Both	159,900	19,188	18,000	1.07	9	Freeway
I-91		NB Exit 33	Both	149,500	17,940	16,000	1.12	8	Freeway
Whitehead Highway (SR-598)	West of	Commerce St	Both	28,600	3,432	8,000	0.43	4	Freeway
Central Row	West of	Prospect St	Both	10,500	1,260	4,275	0.29	5	Street
State St	East of	Prospect St	Both	15,300	1,836	5,985	0.31	7	Street
Columbus Blvd	South of	Grove St	Both	18,200	2,184	3,719	0.59	4	Street
Morgan St	West of	Market St	E	12,500	1,500	2,565	0.58	3	Street
Morgan St	West of	Market St	W	7,200	864	2,309	0.37	2	Street
Market St	South of	Trumbull St	Both	11,400	1,368	4,019	0.34	4	Street
Albany Ave	West of	Main St	Both	14,300	1,716	2,565	0.67	3	Street
Walnut St	West of	Chestnut St	Both	9,500	1,140	3,420	0.33	4	Street
Asylum St	West of	High St	Both	13,400	1,608	5,130	0.31	6	Street
Trinity St	South of	Elm St	Both	5,784	694	3,420	0.20	4	Street
Pearl St	West of	Ann St	Both	5,100	612	2,309	0.27	2	Street
Gold St	East of	Lewis St	Both	5,000	600	3,420	0.18	4	Street

* pcph = passenger cars per hour

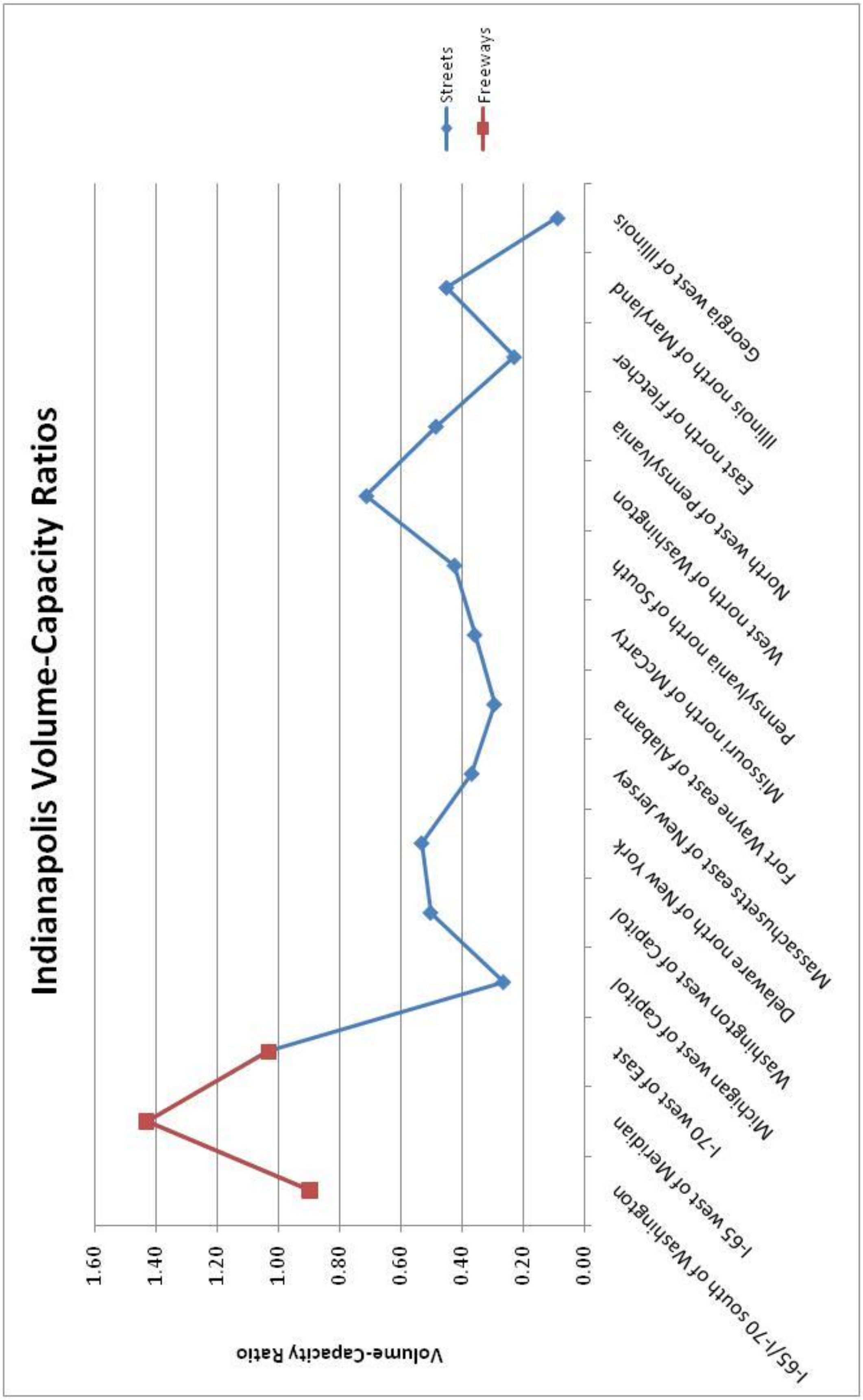

Hartford Volume-Capacity Ratios
Volume-Capacity Ratio
1.20
1.00
0.80
0.60
0.40
0.20
0.00
I-84 at EB Exit 49
I-91 at NB Exit 33
Whitehead Highway west of Commerce
Central Row west of Prospect
State east of Prospect
Columbus south of Grove
Morgan west of Market (E)
Morgan west of Market (W)
Market south of Trumbull
Albany west of Main
Walnut west of Chestnut
Asylum west of High
Trinity south of Elm
Pearl west of Ann
Gold east of Lewis
Streets
Freeways

APPENDIX D: V/C ANALYSIS FOR INDIANAPOLIS, IN

Design Hour Factor (K-Factor)	0.12
Year Range	2009 - 2010

Primary Street	At	Cross Street	Travel Direction	ADT	Peak Flow (pcph*)	Capacity (pcph*)	V/C Ratio	Lanes	Road Type
I-65/I-70	South of	Washington St	Both	104,550	12,546	14,000	0.90	7	Freeway
I-65	West of	Meridian St	Both	143,030	17,164	12,000	1.43	6	Freeway
I-70	West of	East St	Both	103,100	12,372	12,000	1.03	6	Freeway
Michigan St	West of	Capitol Ave	W	5,670	680	2,565	0.27	3	Street
Washington St	West of	Capitol Ave	W	14,340	1,721	3,420	0.50	4	Street
Delaware St	North of	New York St	N	15,170	1,820	3,420	0.53	4	Street
Massachusetts Ave	East of	New Jersey St	Both	5,250	630	1,710	0.37	2	Street
Fort Wayne Ave	East of	Alabama St	Both	5,670	680	2,309	0.29	2	Street
Missouri St	North of	McCarty St	N	10,220	1,226	3,420	0.36	4	Street
Pennsylvania St	North of	South St	Both	12,100	1,452	3,420	0.42	4	Street
West St	North of	Washington St	Both	35,530	4,264	5,985	0.71	7	Street
North St	West of	Pennsylvania St	Both	13,830	1,660	3,420	0.49	4	Street
East St	North of	Fletcher St	Both	8,750	1,050	4,574	0.23	5	Street
Illinois St	North of	Maryland St	N	16,060	1,927	4,275	0.45	5	Street
Georgia St	West of	Illinois St	Both	2,490	299	3,420	0.09	4	Street

* pcph = passenger cars per hour

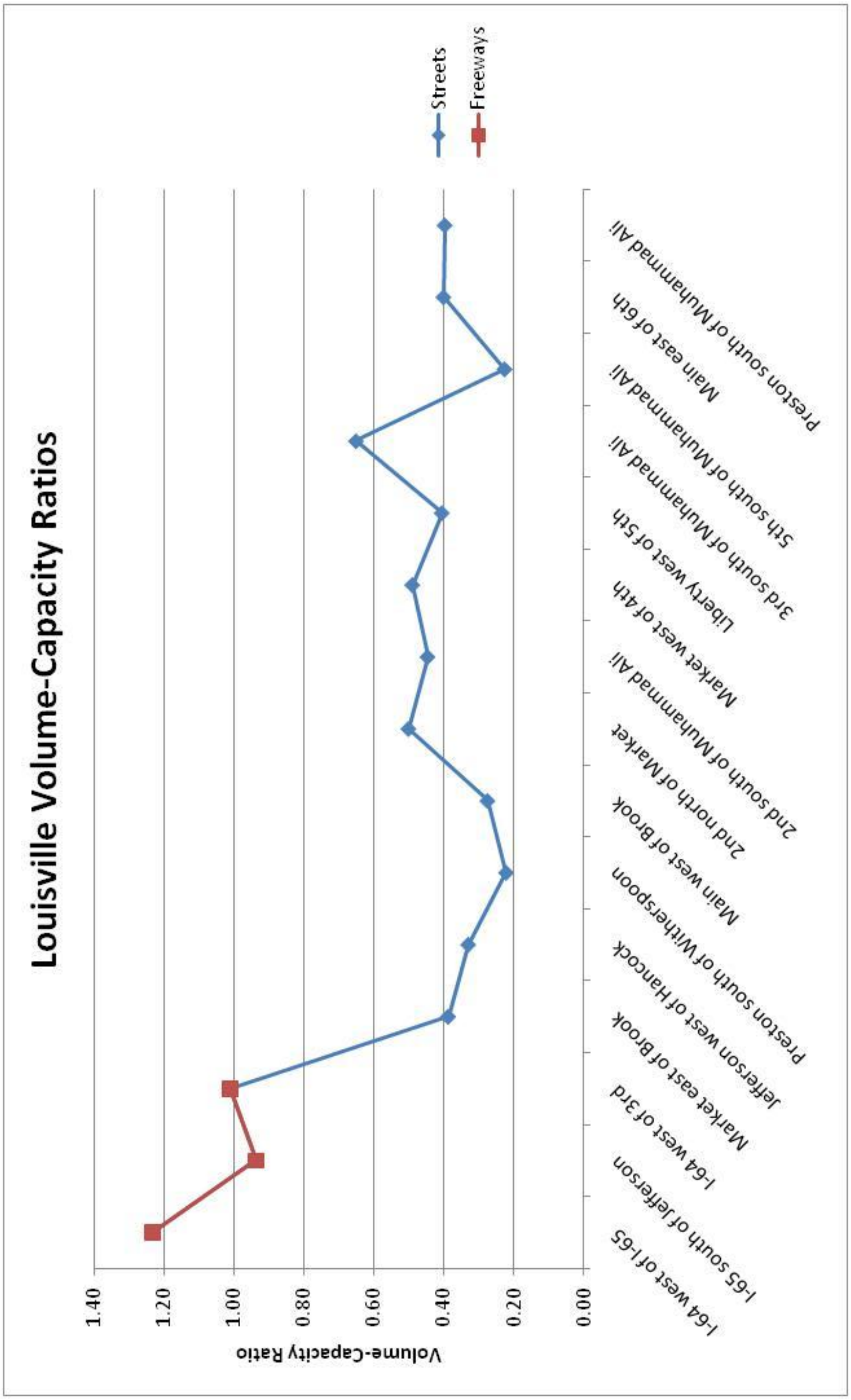

Indianapolis Volume-Capacity Ratios
Volume-Capacity Ratio
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Georgia west of Illinois
Illinois north of Maryland
East north of Fletcher
North west of Pennsylvania
West north of Washington
Pennsylvania north of South
Missouri north of McCarty
Fort Wayne east of Alabama
Massachusetts east of New Jersey
Delaware north of New York
Washington west of Capitol
Michigan west of Capitol
I-70 west of East
I-65 west of Meridian
I-65/I-70 south of Washington
Streets
Freeways

APPENDIX E: V/C ANALYSIS FOR LOUISVILLE, KY

Design Hour Factor (K-Factor)	0.12
Year Range	2005 - 2008

Primary Street	At	Cross Street	Travel Direction	ADT	Peak Flow (pcph*)	Capacity (pcph*)	V/C Ratio	Lanes	Road Type
I-64	West of	I-65	Both	143,621	17,235	14,000	1.23	7	Freeway
I-65	South of	Jefferson St	Both	93,707	11,245	12,000	0.94	6	Freeway
I-64	West of	3rd St	Both	101,146	12,138	12,000	1.01	6	Freeway
Market St	East of	Brook St	Both	11,032	1,324	3,420	0.39	4	Street
Jefferson St	West of	Hancock St	W	9,395	1,127	3,420	0.33	4	Street
Preston St	South of	Witherspoon St	Both	6,308	757	3,420	0.22	4	Street
Main St	West of	Brook St	W	7,828	939	3,420	0.27	4	Street
2nd St	North of	Market St	Both	21,391	2,567	5,130	0.50	6	Street
2nd St	South of	Muhammad Ali Blvd	Both	15,886	1,906	4,275	0.45	5	Street
Market St	West of	4th St	E	13,945	1,673	3,420	0.49	4	Street
Liberty St	West of	5th St	E	5,774	693	1,710	0.41	2	Street
3rd St	South of	Muhammad Ali Blvd	S	9,264	1,112	1,710	0.65	2	Street
5th St	South of	Muhammad Ali Blvd	N	4,832	580	2,565	0.23	3	Street
Main St	East of	6th St	W	13,404	1,608	4,019	0.40	4	Street
Preston St	South of	Muhammad Ali Blvd	N	8,480	1,018	2,565	0.40	3	Street

* pcph = passenger cars per hour

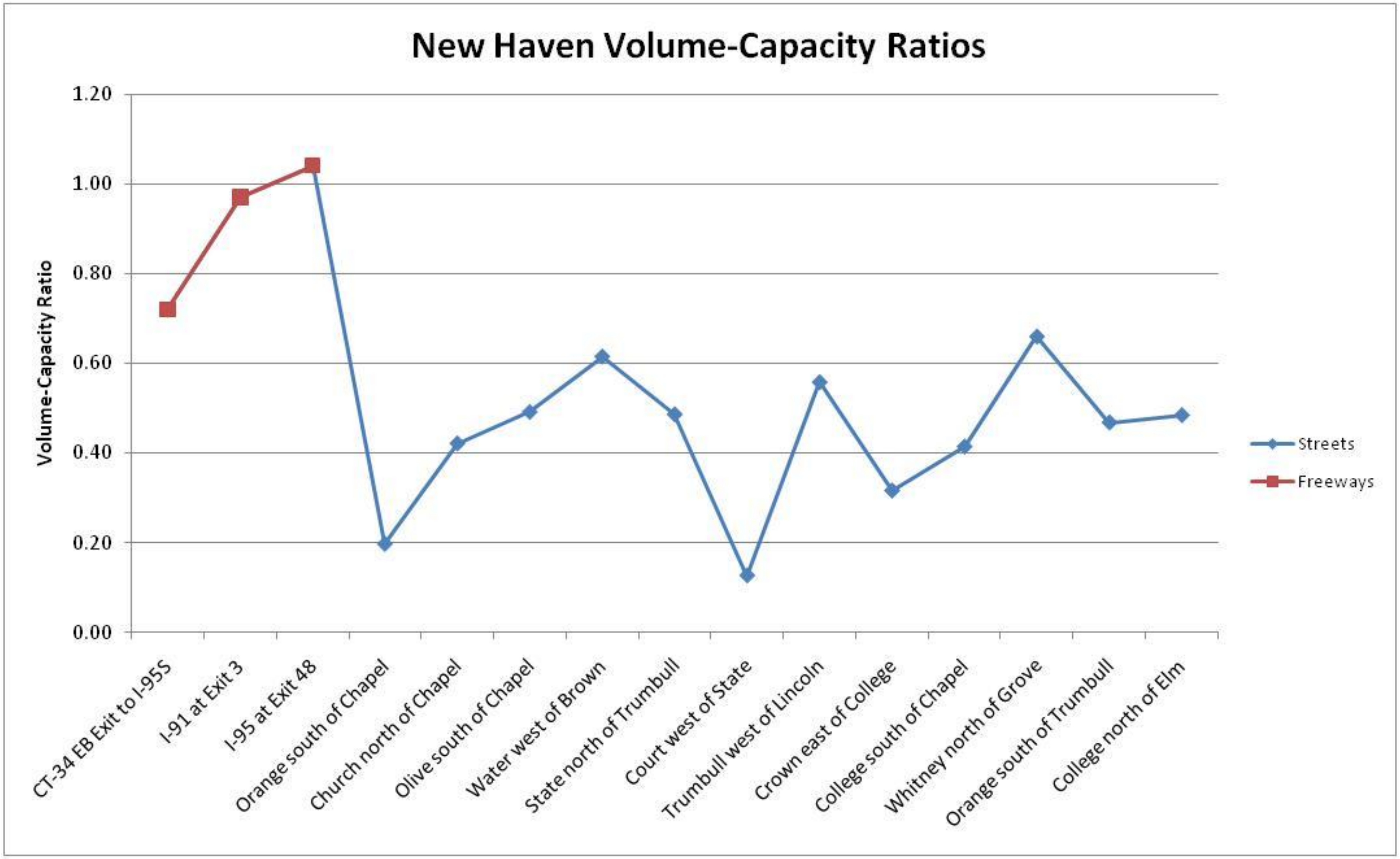

Louisville Volume-Capacity Ratios
Volume-Capacity Ratio
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
I-64 west of I-65
I-65 south of Jefferson
I-64 west of 3rd
Market east of Brook
Jefferson west of Hancock
Preston south of Witherspoon
Main west of Brook
2nd north of Market
2nd south of Muhammad Ali
Market west of 4th
Liberty west of 5th
3rd south of Muhammad Ali
5th south of Muhammad Ali
Main east of 6th
Preston south of Muhammad Ali
Streets
Freeways

APPENDIX F: V/C ANALYSIS FOR NEW HAVEN, CT

Design Hour Factor (K-Factor)	0.12
Year Range	2009

Primary Street	At	Cross Street	Travel Direction	ADT	Peak Flow (pcph*)	Capacity (pcph*)	V/C Ratio	Lanes	Road Type
CT-34		EB Exit to I-95S	Both	72,000	8,640	12,000	0.72	6	Freeway
I-91		Exit 3	Both	129,300	15,516	16,000	0.97	8	Freeway
I-95		Exit 48	Both	138,800	16,656	16,000	1.04	8	Freeway
Orange St	South of	Chapel St	S	2,800	336	1,710	0.20	2	Street
Church St	North of	Chapel St	N	9,000	1,080	2,565	0.42	3	Street
Olive St	South of	Chapel St	Both	7,000	840	1,710	0.49	2	Street
Water St	West of	Brown St	Both	10,300	1,236	2,009	0.62	2	Street
State St	North of	Trumbull St	Both	11,600	1,392	2,864	0.49	3	Street
Court St	West of	State St	E	900	108	855	0.13	1	Street
Trumbull St	West of	Lincoln St	Both	15,900	1,908	3,420	0.56	4	Street
Crown St	East of	College St	W	4,500	540	1,710	0.32	2	Street
College St	South of	Chapel St	S	5,900	708	1,710	0.41	2	Street
Whitney Ave	North of	Grove St	N	9,400	1,128	1,710	0.66	2	Street
Orange St	South of	Trumbull St	Both	10,000	1,200	2,565	0.47	3	Street
College St	North of	Elm St	Both	6,900	828	1,710	0.48	2	Street

* pcph = passenger cars per hour



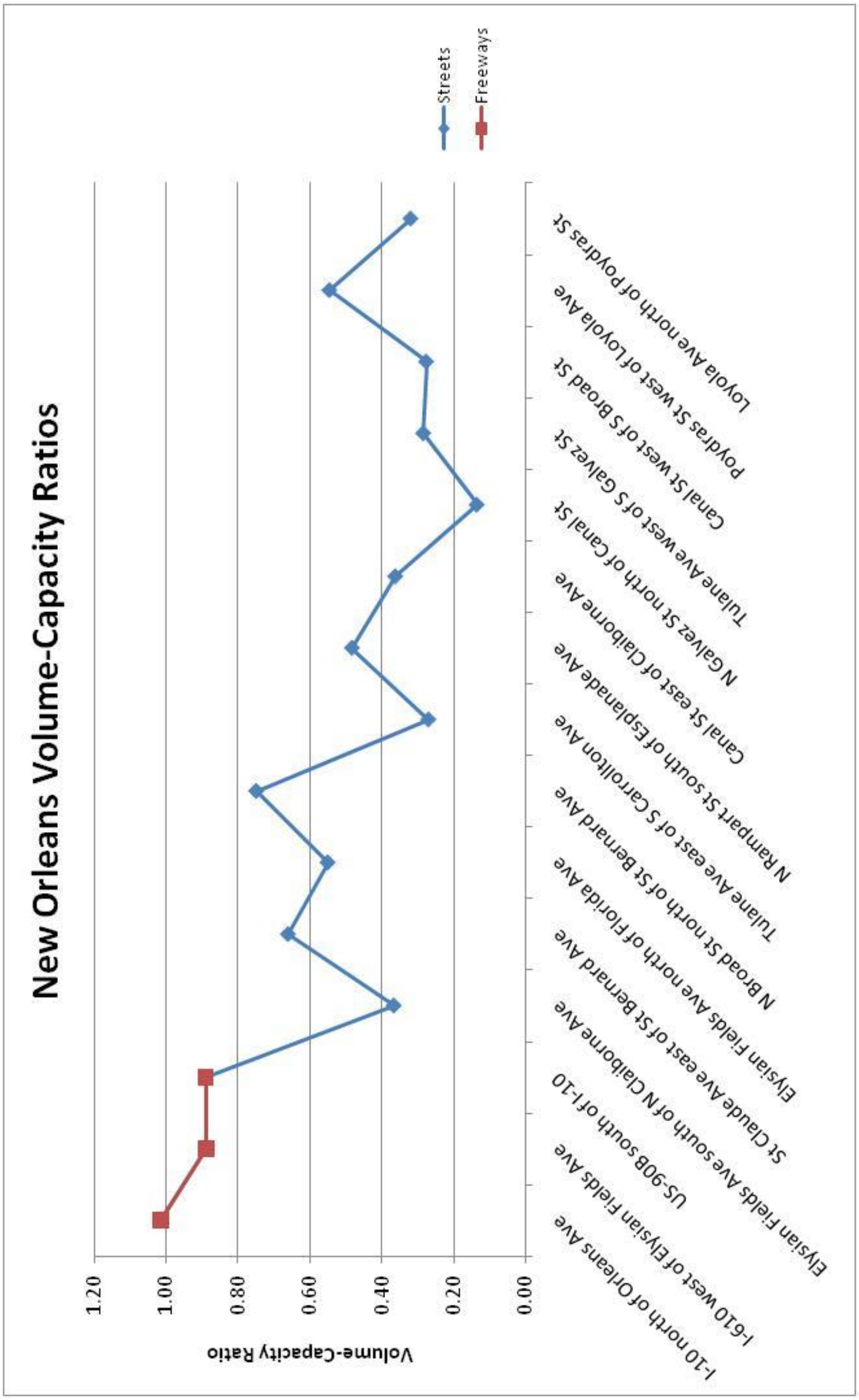
New Haven Volume-Capacity Ratios
Volume-Capacity Ratio
1.20
1.00
0.80
0.60
0.40
0.20
0.00
CT-34 EB Exit to I-95S
I-91 at Exit 3
I-95 at Exit 48
Orange south of Chapel
Church north of Chapel
Olive south of Chapel
Water west of Brown
State north of Trumbull
Court west of State
Trumbull west of Lincoln
Crown east of College
College south of Chapel
Whitney north of Grove
Orange south of Trumbull
College north of Elm
Streets
Freeways

APPENDIX G: V/C ANALYSIS FOR NEW ORLEANS, LA

Design Hour Factor (K-Factor)	0.09
Year Range	2007 - 2008

Primary Street	At	Cross Street	Travel Direction	ADT	Peak Flow (pcph*)	Capacity (pcph*)	V/C Ratio	Lanes
I-10	North of	Orleans Ave	Both	135,266	12,174	12,000	1.01	6
I-610	West of	Elysian Fields Ave	Both	118,506	10,666	12,000	0.89	6
US-90B	South of	I-10	Both	98,851	8,897	10,000	0.89	5
Elysian Fields Ave	South of	N Claiborne Ave	Both	20,856	1,877	5,130	0.37	6
St Claude Ave	East of	St Bernard Ave	Both	25,098	2,259	3,420	0.66	4
Elysian Fields Ave	North of	Florida Ave	Both	31,354	2,822	5,130	0.55	6
N Broad St	North of	St Bernard Ave	Both	30,948	2,785	3,719	0.75	4
Tulane Ave	East of	S Carrollton Ave	Both	16,266	1,464	5,429	0.27	6
N Rampart St	South of	Esplanade Ave	Both	18,324	1,649	3,420	0.48	4
Canal St	East of	Claiborne Ave	Both	20,622	1,856	5,130	0.36	6
N Galvez St	North of	Canal St	Both	5,135	462	3,420	0.14	4
Tulane Ave	West of	S Galvez St	Both	16,180	1,456	5,130	0.28	6
Canal St	West of	S Broad St	Both	15,720	1,415	5,130	0.28	6
Poydras St	West of	Loyola Ave	Both	31,084	2,798	5,130	0.55	6
Loyola Ave	North of	Poydras St	Both	18,197	1,638	5,130	0.32	6

* pcph = passenger cars per hour

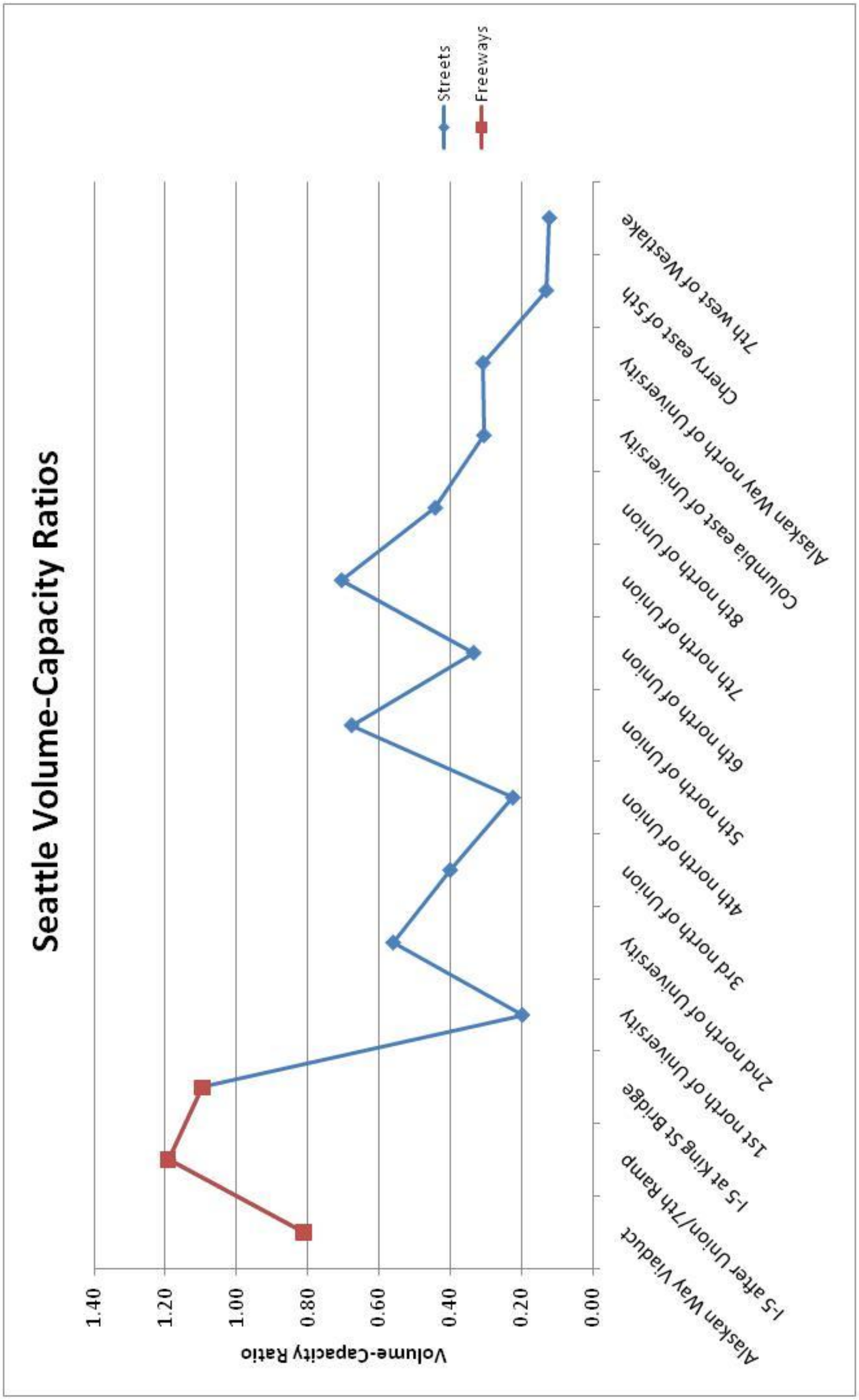

New Orleans Volume-Capacity Ratios
Volume-Capacity Ratio
1.20
1.00
0.80
0.60
0.40
0.20
0.00
I-10 north of Orleans Ave
I-610 west of Elysian Fields Ave
US-90B south of I-10
Elysian Fields Ave south of N Claiborne Ave
St Claude Ave east of St Bernard Ave
Elysian Fields Ave north of Florida Ave
N Broad St north of St Bernard Ave
Tulane Ave east of S Carrollton Ave
N Rampart St south of Esplanade Ave
Canal St east of Claiborne Ave
N Galvez St north of Canal St
Tulane Ave west of S Galvez St
Canal St west of S Broad St
Poydras St west of Loyola Ave
Loyola Ave north of Poydras St
Streets
Freeways

APPENDIX H: V/C ANALYSIS FOR SEATTLE, WA

Design Hour Factor (K-Factor)	0.09
Year Range	2008

Primary Street	At	Cross Street	Travel Direction	ADT	Peak Flow (pcph*)	Capacity (pcph*)	V/C Ratio	Lanes	Road Type
Alaskan Way Viaduct				108,200	9,738	12,000	0.81	6	Freeway
I-5	After	Union St/7th Ave Ramp	Both	212,000	19,080	16,000	1.19	8	Freeway
I-5	At	S King St Bridge	Both	146,000	13,140	12,000	1.10	6	Freeway
1st Ave	North of	University St	Both	7,500	675	3,420	0.20	4	Street
2nd Ave	North of	University St	S	21,300	1,917	3,420	0.56	4	Street
3rd Ave	North of	Union St	Both	15,200	1,368	3,420	0.40	4	Street
4th Ave	North of	Union St	N	8,500	765	3,420	0.22	4	Street
5th Ave	North of	Union St	S	19,300	1,737	2,565	0.68	3	Street
6th Ave	North of	Union St	N	12,700	1,143	3,420	0.33	4	Street
7th Ave	North of	Union St	Both	13,400	1,206	1,710	0.71	2	Street
8th Ave	North of	Union St	Both	8,400	756	1,710	0.44	2	Street
Columbia St	East of	5th Ave	W	8,700	783	2,565	0.31	3	Street
Alaskan Way	North of	University St	Both	11,700	1,053	3,420	0.31	4	Street
Cherry St	East of	5th Ave	E	3,700	333	2,565	0.13	3	Street
7th Ave	West of	Westlake Ave	Both	4,600	414	3,420	0.12	4	Street

* pcph = passenger cars per hour



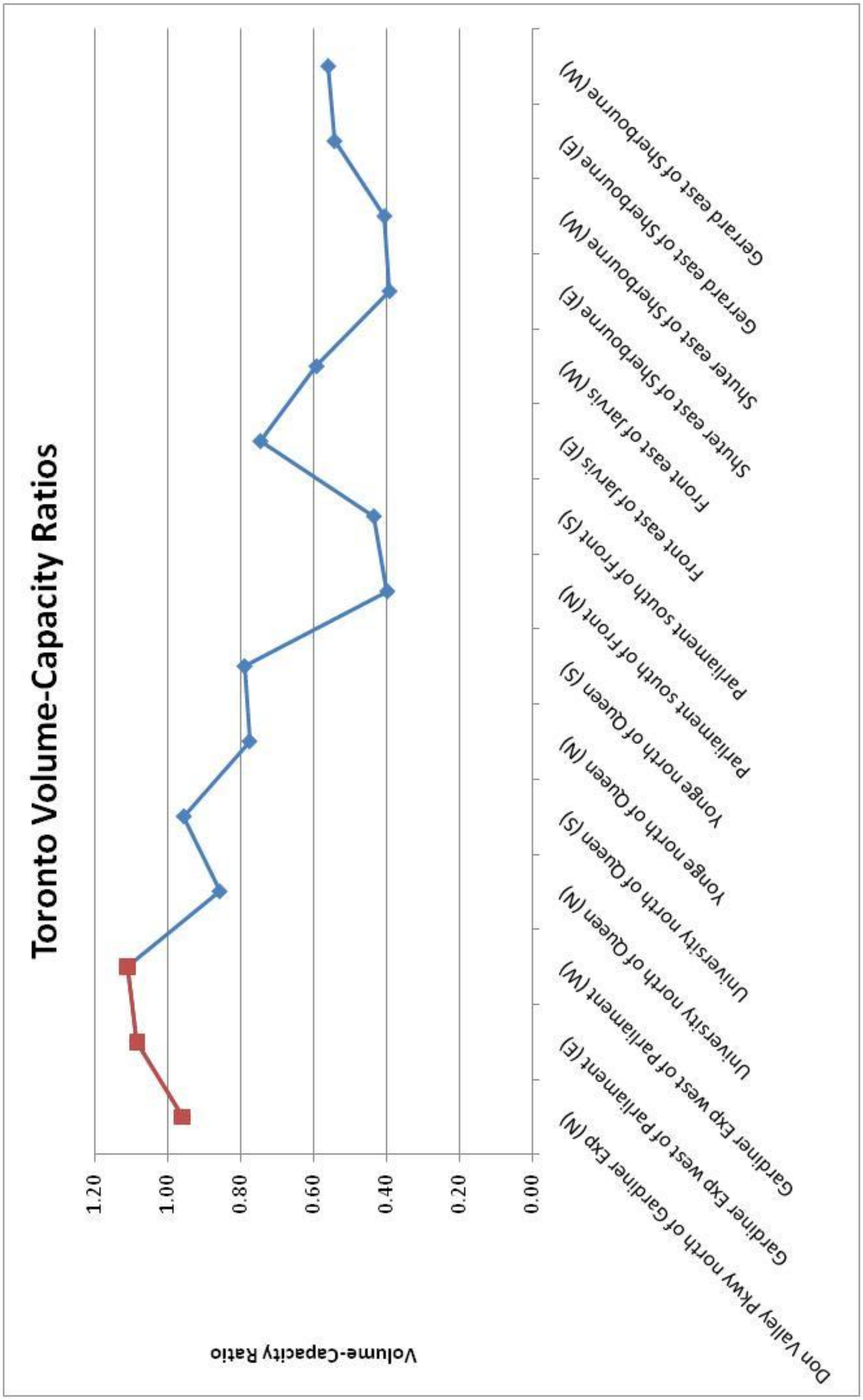
Seattle Volume-Capacity Ratios
Volume-Capacity Ratio
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Streets
Freeways
Alaskan Way Viaduct
I-5 after Union/7th Ramp
I-5 at King St Bridge
1st north of University
2nd north of University
3rd north of Union
4th north of Union
5th north of Union
6th north of Union
7th north of Union
8th north of Union
Columbia east of University
Alaskan Way north of University
Cherry east of 5th
7th west of Westlake

APPENDIX I: V/C ANALYSIS FOR TORONTO, ON

Design Hour Factor (K-Factor)	0.12
Year Range	2005 - 2008

Primary Street	At	Cross Street	Travel Direction	ADT	Peak Flow (pcph*)	Capacity (pcph*)	V/C Ratio	Lanes	Road Type
Don Valley Parkway	North of	Gardiner Expressway	N	32,000	3,840	4,000	0.96	2	Freeway
Gardiner Expressway	West of	Parliament St	E	54,144	6,497	6,000	1.08	3	Freeway
Gardiner Expressway	West of	Parliament St	W	55,420	6,650	6,000	1.11	3	Freeway
University Ave	North of	Queen St	N	24,409	2,929	3,420	0.86	4	Street
University Ave	North of	Queen St	S	27,196	3,264	3,420	0.95	4	Street
Yonge St	North of	Queen St	N	11,041	1,325	1,710	0.77	2	Street
Yonge St	North of	Queen St	S	11,233	1,348	1,710	0.79	2	Street
Parliament St	South of	Front St	N	5,670	680	1,710	0.40	2	Street
Parliament St	South of	Front St	S	6,194	743	1,710	0.43	2	Street
Front St	East of	Jarvis St	E	10,613	1,274	1,710	0.74	2	Street
Front St	East of	Jarvis St	W	8,429	1,011	1,710	0.59	2	Street
Shuter St	East of	Sherbourne St	E	5,584	670	1,710	0.39	2	Street
Shuter St	East of	Sherbourne St	W	5,784	694	1,710	0.41	2	Street
Gerrard St	East of	Sherbourne St	E	7,730	928	1,710	0.54	2	Street
Gerrard St	East of	Sherbourne St	W	7,973	957	1,710	0.56	2	Street

* pcph = passenger cars per hour


Toronto Volume-Capacity Ratios
Volume-Capacity Ratio
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Don Valley Pkwy north of Gardiner Exp (N)
Gardiner Exp west of Parliament (E)
Gardiner Exp west of Parliament (W)
University north of Queen (N)
University north of Queen (S)
Yonge north of Queen (N)
Yonge north of Queen (S)
Parliament south of Front (N)
Parliament south of Front (S)
Front east of Jarvis (E)
Front east of Jarvis (W)
Shuter east of Sherbourne (E)
Shuter east of Sherbourne (W)
Gerrard east of Sherbourne (E)
Gerrard east of Sherbourne (W)