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Investigating the Effectiveness of Traffic Calming Strategies on Driver Behavior, Traffic Flow and Speed

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This report highlights the findings of a project to determine the impact of traffic calming strategies on driver behavior, traffic flow, and speed.

Researchers used a number of different approaches, including a literature search to determine results at a national level and local before-and-after studies in areas that implemented new traffic calming strategies. Researchers also compared an actual street before and after implementation of traffic calming devices to a driver simulation study of a street with and without traffic calming devices.

Research results indicate that traffic calming can have a limited impact on average driver speed. The greatest impacts on speed often occur in reducing the number and speed of outliers, or those who travel at speeds greater than the 85th percentile speed. The report details the impact of different types of traffic calming strategies on traffic speed and volume.

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Investigating the Effectiveness of Traffic Calming Strategies On Driver Behavior, Traffic Flow and Speed

Final Report

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EXECUTIVE SUMMARY

Introduction

The focus of this report is to follow up on earlier, more general traffic calming concepts and specifically measure the effectiveness of traffic calming strategies on driving behavior, traffic flow and speed. Local officials and engineers often struggle to decide what type of traffic calming strategy should be installed to address concerns from the public and within their agency. This report continues the work of two earlier studies funded by the Minnesota Local Road Research Board (LRRB) on traffic calming entitled:

- *Traffic Calming Activity in Minnesota*, Report Number 1998-04
- *Effective Traffic Calming Applications and Implementation,* Report Number 1999-01

These earlier reports provided insight into what traffic calming strategies were being implemented in Minnesota. A key finding of the earlier report was that very little *before* and *after* speed and volume measurements were available for determining the effectiveness of traffic calming devices.

This study specifically focused on gathering *before* and *after* traffic data at locations in Minnesota where traffic calming was being implemented. Additionally, in conjunction with another, concurrent, LRRB-funded study, this study investigated the possibility of using a laboratory driving simulator to measure, as well as predict, the effectiveness of various traffic calming strategies. This was done by simulating roadways with and without various traffic calming devices, and measuring the speeds at which drivers chose to pass through the simulated environments.

The intent of this report is not to answer all of the questions on traffic calming, but rather to measure the effectiveness of traffic calming strategies in Minnesota. Although this was accomplished, many additional questions were posed during the research process - questions that agencies, along with their citizen groups, need to define and answer in order to design and select the most appropriate and effective traffic calming strategies.

Why is traffic calming being done?

- Requests from citizens/neighborhood
- Safety concerns
- Reduce the need for enforcement

Traffic calming is often implemented either for inappropriate reasons or to address issues that are not clearly understood. A clear and definitive understanding of the issues, concerns and options is necessary for both the engineer and the public to determine the appropriate actions. Education, awareness and citizen involvement is instrumental in implementing an effective traffic calming program.

What is the function of transportation system elements (i.e., arterials, collectors, residential streets) and does the public understand these functions?

Although these roadway designations (and usage) are common to engineers, the general public is often not aware of them or their design function. This lack of knowledge can often be the cause of discrepancies between engineers (roadway's design function) and neighborhood citizens' groups. Education is often a key initial step. Defining the transportation system and its functional elements so that the public has a better, clearer understanding, is crucial when working with citizens' groups in addressing concerns and developing traffic calming strategies.

How is effectiveness of traffic calming defined?

- Reduction in the mean speeds
- Reduction in the 85th percentile speeds
- Reduction in the highest speeds
- Reduction in the number of calls (complaints, inquiries)
- Residents feel safer
- Active response to public request

Determining if a solution is effective requires an understanding of expectations. Too often with traffic calming there is not a clear definition of project goals/outcomes. Officials and citizens need to understand what is desired versus what is achievable.

How do the goals of traffic calming coexist with the goals of traffic engineering?

Officials constantly work to make streets and roads safer and less disruptive to residents and non-motorists. The solution is not easy; it is complicated by the fact that while many citizens want the traffic calmed on their street, they also want to be able to drive unimpeded through other neighborhoods. Combining quality of life, sustainable community goals and cost-effective transportation is the key to an effective traffic calming solution.

Background

Roads designed to increase livability in terms of decreased congestion and increased travel efficiency and vehicular safety may at the same time work against livability by encouraging high vehicle speeds and volumes. These in turn increase noise levels and the risk of crashes with pedestrians and bicyclists. The response to this situation has been the application of traffic calming strategies.

Definition

As defined by the Institute of Transportation Engineers (ITE), traffic calming is:

The combination of many physical measures that reduce the negative effects of motor vehicle use, alter driver behavior and improve conditions for non-motorized street users.

More broadly defined, traffic calming applies to a number of transportation techniques developed to reduce motorist speed, decrease traffic volumes, increase safety for pedestrians and non-motorists, and to educate and increase awareness of the traveling public.

Research Procedure

The focus of this study was to determine the effectiveness of traffic calming in Minnesota. The research process included the following steps:

- Literature review
- Survey of Minnesota cities and counties
- Monitoring test sites (measuring the *before* and *after* effects of traffic calming devices)
- Evaluating a laboratory driving simulator to measure/predict the effectiveness of traffic calming

Literature Review

Although limited information was found specifically on the effectiveness of traffic calming devices, two significant resources were found:

- The Federal Highway Administration (FHWA) has created a Web site on traffic calming, http://www.fhwa.dot.gov/environment/tcalm/index.htm
- The FHWA and ITE have published a very thorough and comprehensive document entitled *Traffic Calming: State of the Practice,* which can be found at: http://www.ite.org/traffic/tcstate.htm#tcsop

An alphabetical, comprehensive listing of the various traffic calming strategies was compiled from the literature review and from previous LRRB reports. This listing, which is Appendix A of this report, includes the following categories for each traffic calming strategy:

- Description
- Cost
- Performance
- Benefits
- Drawbacks
- Additional information (resources)

Survey of Minnesota Cities and Counties

Although the FWHA/ITE manual is a very comprehensive document, most of the case studies and resources were from references that did not have winter conditions as severe as those in Minnesota. When selecting a traffic calming strategy in Minnesota, in addition to the engineering concerns, a designer must also take into account the issues of snow removal, snow storage and visibility (winter roadways are often covered by snow, salt, sand, etc., which make surface roadway markings difficult to see).

Because of this, the second phase of this study was to survey Minnesota cities and counties to determine what traffic calming strategies have been implemented and which have been effective. Although, as with the literature search, very little *before* and *after* traffic data was available locally, the ancillary comments from this survey provide some insight as to the effectiveness of traffic calming devices in Minnesota. The findings and comments from this survey have been included in Appendix B.

Test Sites

The next phase of the study was to monitor test sites to measure the effectiveness of traffic calming strategies in Minnesota. The test sites were selected through a solicitation of Minnesota cites and counties - inquiring which agencies currently had traffic calming projects scheduled. The desire was to obtain a variety of traffic calming devices, on a variety of roadway classifications. The following traffic calming devices were evaluated in this phase of the study:

- Choker
- Landscaping
- Lane reduction (converting four-lane to two-lane with continuous center left-turn lane)
- Pavement marking (and signage)
- Raised crosswalk

These devices were located on roadways with classifications ranging from residential (local) to arterial.

Before and *after* speed data was collected at each site prior to and after installing the traffic calming device.

Simulation Evaluation

The next phase of this study was to use laboratory driving simulation as a method of evaluating the effectiveness of traffic calming. The two specific goals of this phase were to:

- Evaluate the use of driver simulation to determine the effectiveness of traffic calming as it would relate to a real situation
- Measure the incremental (or bundling) effect of multiple traffic calming devices

The simulation experiments were conducted at the University of Minnesota Human Factors Research Laboratory. Approximately 20 participants (ages 18-65, both male and female) were used as subjects for each of the simulation experiments.

Findings and Conclusions

It should be noted that the sample size of each traffic calming devices was small - one or two sites plus the simulation. For a more conclusive determination of the effectiveness, it is recommended that more sites be evaluated. Based of the results from this limited study, the following conclusions were made:

- Chokers appear to reduce vehicle speeds; however, they may have a reduced impact on vehicles as they exit traffic-calmed areas and enter different areas.
- Words painted on the pavement do not appear to reduce vehicle speeds; however, pavement markings in the form of chevrons supplemented with speed limit signage appear to reduce vehicle speeds. As the chevron paint begins to fade, vehicle speeds increase, but do not return to pre-calming speed levels.
- The reconfiguration from a four-lane to a three-lane roadway reduce vehicle speeds provided there is enough critical traffic volume. If traffic volumes are too low, platooning will occur only occasionally and significant reductions in speeds will not be achieved.

- Data indicates that raised crosswalks have a localized effect that extends only several hundred feet from the device. The variability of driver behavior increases as they approach raised crosswalks. Drivers may be unsure about how to react when they approach them, causing inconsistent driving behavior. In addition, the speeds approaching raised crosswalks do not drop to the same extent as the vehicle speeds departing from the device.

- The simulation experiments indicate that curb treatments, when reviewed as a grouped condition did result in a statistically significant influence on vehicle speeds ($p<0.05$). The test results also showed that the median island/choker combination caused a drop in the mean vehicle speed beyond what could be obtained by the median island or choker individually and that the vehicle speed associated with this combination of devices was statistically significant. The addition of plantings adjacent to the road did result in reduced vehicle speeds, but the reduction in speeds was not statistically significant.

- While the simulator accurately predicts that the implementation of the traffic calming measures reduces vehicle speeds, the calibration procedure does not provide an easy, straightforward replication of the field data. Additional work is needed to better understand the relationship between the simulation data and observed data.

The literature review and a portion of these results used changes in mean and/or 85th percentile speed as the measure of effectiveness. However, a conclusion from this research is that these statistics alone may not fully measure the effectiveness of traffic calming. As stated earlier, the effectiveness of traffic calming should be defined using a combination of the following:

How is effectiveness of traffic calming defined?

Quantitative Data

- Reduction in the mean speeds
- Reduction in the 85th percentile speeds
- Reduction of the highest speeds

Qualitative/Perceptual Data

- Reduction in the number of calls (complaints, inquiries)
- Residents feel safer
- Active response to public request

Effectiveness can often be relative. What a traffic engineer can measure is not always the same as what the public perceives. Much of the data gathered in this report found statistically significant reductions of two to three miles per hour. Can the public perceive this difference? The data also indicated that the number of drivers traveling at excessive speeds were reduced. Can the public perceive this difference? Would they deem this successful? Determining effectiveness is dependent on clearly identifying the condition - from both an engineering and a public perspective.

Every situation is unique - the neighborhood circumstances, the traffic patterns and conditions, and the public's concerns. Although it can be concluded that traffic calming devices are effective, "effective" needs to be defined for each situation. This definition needs to be addressed and understood before selecting a traffic calming device and determining if it is effective.

CHAPTER 1: INTRODUCTION

Traffic volumes are shifting from arterials onto local residential streets, increasing the attention being paid to the concept of traffic calming. Transportation officials must balance the need for an efficient transportation system with the safety and convenience of pedestrians, bicyclists and homeowners.

> *Traffic calming is an attempt to balance the needs of the motorists, non-motorist and residents. Residents and non-motorists are beginning a movement to "reclaim" their streets. In many ways, this appears to go against the traditional goal of traffic engineering, which is to move traffic quickly and efficiently.*

Implementation of traffic calming measures is usually controversial. Local government engineers and council or board members frequently receive requests for traffic calming measures from residents. But seldom is there full agreement among neighborhood residents regarding the benefits of implementing traffic calming measures. According to a survey of traffic engineers done by ITE, traffic claming devices were usually supported by neighbors but opposed by citywide users. Neighborhood residents, both for and against proposed traffic calming measures, are approaching city councils trying to attain or defeat the projects.

> *Most drivers want to get to their destination as quickly as possible. As neighborhood residents, these same people want to live on a quiet and peaceful street with low traffic volumes and speeds. While driving, most people think that the posted speed limit of 30 mph is safe and appropriate. When people are standing in their front yards, watching their children play or conversing with a neighbor, most people perceive a car moving down their street at 30 mph as driving too fast.*

All parties (engineering staff, elected officials and neighborhood residents) look for "hard" data to make informed decisions regarding the implementation of traffic calming measures. One of the goals of this research project is to provide *before* and *after* traffic data measured at locations where traffic calming devices were installed.

This research project is a follow-up study to two previous studies funded by the Minnesota Local Road Research Board (LRRB) entitled:

- *Traffic Calming Activity in Minnesota* (Report Number 1998-04)

- *Effective Traffic Calming Applications and Implementation* (Report Number 1999-01)

The earlier research indicated that over 50 percent of the responding municipalities had implemented or planned to implement traffic measures, but very little *before* and *after* data was being collected on the effectiveness of these devices, once installed.

Therefore, this research study collected data from Minnesota streets and designed a simulation experiment to Minnesota roadway design standards. This is important because traffic calming results from other geographic areas may not be directly applicable to Minnesota for the following reasons:

- Minnesota receives a higher annual average snowfall amount (which stays on the ground for longer periods of time) than most areas. Snowplowing and snow storage considerations significantly influence the design and selection of traffic calming devices in Minnesota.
- Most local streets in Minnesota have a minimum speed limit of 30 mph. This speed limit impacts people's perception regarding what is a safe speed at which to travel along residential streets. It also impacts the design of streets because the design must be able to safely accommodate vehicles moving at that speed.

Historically in the United States, traffic calming is typically interpreted as physical or perceptual modifications to the built environment to influence driver behavior. However, in portions of the United States and in a few other countries, there is a new philosophy being implemented. This philosophy is based on the observation that drivers have become less courteous in their driving and that physical modifications to the roadway alone will not solve the problem. This approach advocates that social norms and values must be changed to make discourteous driving an unacceptable behavior. People must also modify their travel patterns to reduce the number of automobile trips they make every day (Engwicht, 1999). This approach and the physical and perceptual measures examined in this report are not mutually exclusive. Rather, this alternative approach can be seen as complementary in dealing with the problem.

CHAPTER 2: RESEARCH GOALS AND METHODOLOGY

Research Goals

The earlier LRRB research on traffic calming provided insight as to what traffic calming measures were being implemented in Minnesota. That research highlighted the fact that very little *before* and *after* data had been collected. In addition, while reviewing the traffic calming projects that had been implemented, it was found that several projects have implemented multiple traffic calming measures simultaneously, making it difficult to assess the effectiveness of the individual traffic calming devices. In light of these findings, this research project was designed to achieve the following goals:

- **Increase the level of *before* and *after* data available to decision-makers and interested individuals.**

  Several approaches were used to accomplish this goal:

  a. A literature review was performed to compile *before* and *after* data on the effectiveness of various traffic calming measures. The review includes data for traffic calming measures implemented throughout the country, as well as Minnesota.

  b. *Before* and *after* data was solicited from local municipalities on previous installations of traffic calming devices to supplement the data collected as part of the study.

  c. *Before* and *after* traffic data was measured on several projects that were planned to be constructed during the course of the research project.

- **Examine the impacts of "bundling" traffic calming measures.**

  Many traffic calming projects implement several traffic calming measures simultaneously. Generally, this is a good approach because the traffic calming elements are integrated into a larger streetscape improvement project. The challenge with examining the data associated with projects utilizing several measures is that it is difficult to determine which, or to what degree, the individual traffic calming measures impact vehicle speeds or volumes. It was hypothesized at the beginning of the research that “bundling” traffic calming measures would produce greater impact on vehicle speeds than if the measures had been implemented individually.

- **Collaborate with the University of Minnesota to model and test various traffic calming scenarios using a driving simulator.**

  During the time of this project, the LRRB was also funding a project at the University of Minnesota that was examining how drivers’ perception of the built environment impacted their behavior. The LRRB and the two teams decided that the end result for each project would be stronger if the two teams collaborated on the project.

  Utilizing the University’s driving simulator, a segment of the research project was designed to evaluate if simulation could be used to predict (or measure) the effectiveness of traffic calming devices before, or instead of, actually physically building them.

Research Methodology

The research project consisted of six steps:

- Literature review
- Survey of Minnesota cities and counties
- Test sites (measuring the *before* and *after* effects of traffic calming devices)
- Simulation models
- Conclusions and next steps

Chapters 3 through 7 describe each of these steps in more detail.

CHAPTER 3: LITERATURE REVIEW

Literature reviews were conducted on both a national and local basis. The information provides both a national view of the concepts, applications and results of traffic calming as well as a view of local applications and results. The literature review focused on *before* and *after* data for:

- Average speeds
- 85th percentile speeds
- Traffic volumes

National Literature Review

The initial literature search was conducted in September 1999, with a second follow-up search conducted in December 2000.

The initial literature search began with a review of the Transportation Research Board's (TRB) on-line transportation database known as TRIS (Transportation Research Information Services). Results of the TRIS search revealed only a few articles relating to the types of traffic calming devices available in the market, as well as information on initiating traffic calming programs for local communities. Most of the information found in the TRIS database focused on the potential effects of traffic calming devices on bicyclists and emergency service vehicles. No specific information on *before* and *after* speeds and/or traffic volumes was found.

Because the TRIS search resulted in very little information on the effectiveness of traffic calming devices on speeds or traffic volumes, a search was conducted on the World Wide Web. The Web search revealed thousands of Web sites dedicated to the topic of traffic calming. Most of the sites fell into one of the following categories:

- Types of traffic calming devices
- Effects on bicycle traffic
- Effects on emergency vehicles
- Proponents of traffic calming measures
- Opponents to traffic calming measures

In general, there were very few sites that had information on *before* and *after* data. The few sites that contained information on *before* and *after* speeds and/or volumes for specific traffic control devices were from municipalities that had traffic calming programs. Most of the information came from the cities of (their Web sites can be found in Appendix A):

- Bellevue, Washington
- Charlotte, North Carolina
- Portland, Oregon
- Seattle, Washington.
- Ventura, California

Results from these communities indicated that a reduction in speeds, traffic volumes and crashes could be obtained with certain types of traffic calming devices. Table 3-1 summarizes the overall reduction in speeds, volumes and accidents (crashes) reported by these agencies.

Table 3-1
Effectiveness of Traffic Calming Devices – Initial Literature Search [(A)]

Traffic Calming Device	Average Percentage Change in 85th Percentile Speeds	Average Percentage Change in Average Speeds	Average Percentage Change in Traffic Volumes	Average Percentage Change in Auto Collisions
Chicane	-6%	-	-15%	-
Cul-De-Sac or Street Closure	-8.6%	-	-33%	-
Diagonal Diverter	-	-	-30%	-
Speed Hump	-28%	-15%	-13%	-38%
Traffic Circle	-	-	-	-73%

[(A)] Some of the studies were limited in nature and are not applicable to all roadways
Source: Individual cities' Web sites

The results in Table 3-1 demonstrate that traffic calming can have an impact in reducing speeds, traffic volumes and crashes. However, the information was limited to only a few cities and a small number of traffic calming devices. *Before* and *after* information was not found on other popular devices such as entrance treatments, exclusion lanes, median barriers, narrowing lanes, chokers, semi-diverters and speed tables. Please refer to Appendix A for information about these devices.

Because of the growing nationwide interest in traffic calming, a second literature review was conducted in December 2000, more than a year after the original literature search. Once again, TRIS and the World Wide Web were searched and although, again, limited information on the effectiveness of traffic calming devices was found, two significant resources were located:

- FHWA Web site on traffic calming, www.fhwa.dot.gov/environment/tcalm.index.html
- A comprehensive report prepared by the ITE and published by the FHWA entitled, *Traffic Calming: State of Practice*, www.ite.org/traffic/tcstate.htm#tcsop

The FHWA/ITE report is a very conclusive document that thoroughly reviews all aspects of traffic calming from a national perspective. The following tables (Tables 3-2 through 3-4) are excerpts from this document, highlighting some specific data on the effectiveness of traffic calming devices.

Table 3-2
Traffic Calming Devices Impacts On Speed

Device	Sample Size	85th Percentile Before Speed (mph)	85th Percentile After Speed (mph)	Average Change in Speed (mph)	Average Percent Change
12-foot Humps	179	35	27.4	-7.6	- 22%
14–foot Humps	15	33.3	25.6	-7.7	- 23%
22-foot Tables	58	36.7	30.1	-6.6	- 18%
Longer Tables	10	34.8	31.6	-3.2	- 9%
Raised Intersections	3	34.6	34.3	-0.3	- 1%
Circles	45	34.2	30.3	-3.9	- 11%
Narrowings	7	34.9	32.3	-2.6	- 4%
One-Lane Slow Points	5	33.4	28.6	-4.8	- 14%
Diagonal Diverters	7	29.3	27.9	-1.4	- 4%

Source: FHWA/ITE: *Traffic Calming: State of Practice,* pg 104

Table 3-3
Traffic Calming Devices Impacts On Traffic Volumes

Device	Sample Size	Average Change in Volume (Vehicles per Day)	Average Percentage Change in Volume (Vehicles per Day)
12-foot Humps	143	-355	- 18%
14–foot Humps	15	-529	- 22%
22-foot Tables	46	-415	- 12%
Circles	49	-293	- 5%
Narrowings	11	-263	- 10%
One-Lane Slow Points	5	-392	- 20%
Full Closures	19	-671	- 44%
Half Closures	53	-1,611	- 42%
Diagonal Diverters	27	-501	- 35%

Source: FHWA/ITE: *Traffic Calming: State of Practice,* pg 106

Table 3-4
Traffic Calming Devices Impacts On Collisions

Device	Number of Sites	Average Annual Collisions [A]		
		Before Calming	After Calming	Percentage Change
12-foot Humps	50	2.62	2.29	- 13%
14–foot Humps	5	4.36	2.62	- 40%
22-foot Tables	8	6.71	3.66	- 45%
Circles (without Seattle data)	17	5.89	4.24	- 28%
Circles (with Seattle data) [B]	130	2.19	0.64	- 71%

Source: FHWA/ITE: *Traffic Calming: State of Practice,* pg 112

[A] Average annual number of collisions, typically based upon a 12-month data collection period.

[B] Intersection collisions only.

The information presented in the FHWA/ITE manual is carefully qualified to explain that the impacts of traffic calming devices are highly case-specific, depending on the geometrics and spacing of measures, availability of alternative facilities, treatment of other streets in areawide applications and other factors (*Traffic Calming: State of Practice,* pg 100).

Additionally, the manual explains that data used in the report is summarized from hundreds of studies throughout the United States. Because the data was not collected from one source, it is unclear where speed measurements were taken in relation to the traffic calming device. Measurements taken close to a device are generally lower than those taken further away. As there is limited information on how the data was obtained, it should be used cautiously (*Traffic Calming: State of Practice,* pg. 103).

The FHWA/ITE report further indicates that impacts on traffic volumes are even more case-specific than speed. Impacts on traffic volumes depend on the network of streets in the area, rather than the characteristic of the specific street itself. Availability of other routes may have as much impact on volumes as do the geometrics and spacing of traffic calming measures. Additional impacts may also depend upon how much is through traffic versus local traffic. Traffic calming measures may be able to reduce some through trips, but it is difficult for them to divert local traffic that needs to use the roadway.

The FHWA/ITE report indicated that it is difficult to obtain conclusive impacts for collision reduction. The report stated that most safety studies fail to take into account the influence of weather, road conditions, traffic diversion and changes in crash reporting.

As noted, the FHWA/ITE report indicated several caveats about the data listed within their report. Two additional caveats should also be noted:

- *Before* and *after* crash comparisons can only be ascertained over a period of time (typically, a minimum of three years).
- It is not clear from the report whether the data reported was normalized to take into account the various traffic variables (volume, speed, etc.).

It should be also noted that all of the information identified in the ITE report was from cities that did not have heavy winter snowfall.

Local Literature Review

As stated earlier, because of the winter maintenance issues within Minnesota, several traffic calming devices (which are effective in warmer climates) may not produce the same results. Therefore, in addition to conducting a review of national literature on traffic calming, an attempt was made to gather empirical results from *before* and *after* studies in Minnesota. Two reports published by the LRRB provided insight on local attempts at traffic calming. In 1998, the LRRB published *"Traffic Calming Activity in Minnesota."* This report included *before* and *after* data on speeds and volumes for five communities and eight roadways. Results indicate that choker, speed humps, street closures and turn restrictions can provide a reduction in speeds and traffic volumes. Table 3-5 lists local results from "*Traffic Calming Activity in Minnesota"* as well as new data that resulted from a follow up survey performed in 2001 (see Chapter 4).

Table 3-5
***Before* and *After* Data from Traffic Calming Projects in Minnesota**

City	Project Location	Project Description	85th Percentile Speeds (mph)			ADT		
			Before	After	Percentage Change	Before	After	Percentage Change
Blaine	Davenport Street NE	Speed humps	38	30	-21%	N/A	N/A	N/A
Blaine	Baltimore Street NE	Speed humps	34	28	-18%	N/A	N/A	N/A
Brooklyn Park (1)	West River Road and Riverdale Drive	Street closure of both roads between 73rd Avenue and Brookdale Drive.	45	35	-22%	888	738	-17%
Burnsville (1)	Hollow Park Drive	Turn restrictions to right-out only	31	29	-7%	1,200	780	-35%
Burnsville (1)	140th Street, Friendship Lane, Stevens Avenue, 139th Street and Thomas Avenue.	Speed humps on all of these streets to discourage cut-through traffic and speeds	34	29	-15%	985	625	-37%
Burnsville (1)	Knox Drive	Speed humps	29	27	-7%	690	485	-30%
Burnsville (1)	James Avenue	Street closure	32	30	-6%	1,600	825	-48%
Fridley (1)	Meadow-moor Drive	Street closure	30	30	0	N/A	N/A	N/A
Minneapolis	Franklin Avenue at Emerald Street SE	Traffic Circle (Temporary) Station 1 (2)	EB 40	EB 34	-15%	EB 3,198	EB 4,791	50% (5)
			WB (4)	WB 35	--	WB (4)	WB 5,410	--
Minneapolis	Franklin Avenue at Emerald Street SE	Traffic Circle (Temporary) Station 2 (3)	EB 37	EB 30	-19%	EB 3,185	EB 4,663	46% (5)
			WB 35	WB 31	-11%	WB 3,886	WB 5,389	39% (5)

Table 3-5 Cont'd
***Before* and *After* Data from Traffic Calming Projects in Minnesota**

City	Project Location	Project Description	85th Percentile Speeds (mph)			ADT		
			Before	After	Percentage Change	Before	After	Percentage Change
Oakdale	11th Street	Stop signs	38	32	- 16%	775	648	- 16%
St. Louis Park [(1)]	West 38th Street	Diagonal diverters and stop signs	N/A	N/A	N/A	5,700	4,000	-30%
St. Paul	Central Avenue between Dale Street and Western Avenue	Speed humps (series of three)	40	35	-13%	1,297	1,264	-3%
St. Paul [(1)]	Cleveland Avenue at Montreal Avenue	Chokers on east side of Cleveland at Montreal	41	39	- 5%	N/A	N/A	N/A
St. Paul	Fairview Avenue	Change from 4-lane facility to a 3-lane facility	(6)	(6)	(6)	14,741	14,183	- 4%
St. Paul	Otis Avenue	Speed humps (temporary)	35	28	- 20%	933	928	- 1%

EB=Eastbound; WB=Westbound

(1) Data in the Traffic Calming Activity in Minnesota Report was documented as kilometers per hour. To be consistent with other data documented in this report, the measurements were converted to miles per hour.

(2) Station 1 is located 50 feet west of Emerald Street on Franklin Avenue.

(3) Station 2 is located 200 feet west of Emerald Street on Franklin Avenue.

(4) Data not available.

(5) *Before* data collected in November 1996, *After* data collected in April 1997.

(6) Data provided indicates that the percentage of vehicles traveling 33 mph or greater, decreased from 53 percent (before) to 31 percent (after).

Findings and Conclusions of Literature Review

The traffic calming devices presented in the literature review did reduce vehicle speeds, traffic volumes and crash rates. Speed humps and speed tables (which incorporate changes in vertical alignment) showed greater reductions in vehicle speeds than devices that incorporated horizontal shifts (traffic circles and one-lane slow points) or roadway narrowings.

The 12-foot to 14-foot humps reduced speeds to a greater extent than the 22-foot and longer tables. Longer speed tables, even though not as effective in slowing vehicles, may be appropriate to roadways that need to service emergency vehicles or transit buses.

Half closures appear to be as effective as full road closures for reducing traffic volumes, which still allow select vehicular flow through the intersection.

The ITE data indicates that speed humps and speed tables reduce both vehicle speeds and traffic volumes. This fact must be well understood when implementing this device both in terms of desired and actual outcomes. If they are installed purely to reduce vehicle speeds, they may have the unintended result of diverting traffic to adjacent streets.

When the Minnesota literature data was compared to the national data, road closures, diagonal diverters and turn restrictions produced results similar to the national summary. The speed humps did not reduce speeds to the same extent, as the national summary, yet diverted more traffic. It is likely that this is the result of street network patterns more than the design of the speed humps.

CHAPTER 4: SURVEY OF MINNESOTA CITIES AND COUNTIES

Although the FWHA/ITE manual is a very comprehensive document, most of the case studies and resources were from references that did not have winter conditions as severe as those in Minnesota. When selecting a traffic calming strategy in Minnesota, in addition to the engineering concerns, a designer must also take into account the issues of snow removal, snow storage and visibility (winter roadways are often covered by snow, salt, sand, etc., which make surface roadway markings difficult to see).

Because of this, the second phase of this study was to survey Minnesota cities and counties to determine what traffic calming strategies have been implemented and which have been effective. Although, as with the literature search, very little *before* and *after* traffic data was available locally, the ancillary comments from this survey provide some insight as to the effectiveness of traffic calming devices in Minnesota. The findings and comments from this survey have been included in Appendix B.

The report, *"Effective Traffic Calming Applications and Implementation,"* indicated actual and perceived outcomes of traffic device installations. However, the report did not provide actual numbers for speed and traffic volume reduction. Instead, the report indicated if there was a reduction in speeds or a decrease in traffic volumes. Because the report did not present actual numbers, data from it has not been included.

CHAPTER 5: TEST SITES

Solicit Test Sites

Municipalities and counties in Minnesota were surveyed to find out if they had any traffic calming measures scheduled for construction in the next year. In particular, the research team tried to locate projects scheduled for construction on roadways with functional classifications higher than a residential street. Traffic calming projects on streets with classifications higher than residential typically are more difficult to implement due to the perceived and/or actual conflict between the need to move emergency vehicles and higher volumes of traffic, and neighborhood residents' desire for calm and quiet streets.

The test streets selected ranged in classification from arterial to residential. The test sites contain a variety of traffic calming measures with some incorporating physical elements and others incorporating more perceptual measures. Table 5-1 provides a summary of the test sites selected.

Collection of *Before* and *After* Data

Before and *after* traffic data was collected for each of the test sites. Each site was assessed individually with respect to traffic calming objectives and site conditions to determine the data collection methodology to be used. It should be noted that most traffic calming measures typically have a localized impact on vehicle speeds (speeds will decrease as drivers approach a traffic calming device and will increase as they move away from the device). In gathering data for this report, spot speeds were collected by different agencies and at approximately the same locations. Therefore, a portion of the speed differential may be a result of different data collection methodologies. However, the data gathered does provide strong indications regarding the effectiveness of the various devices. The approach used at most of the test sites was to record the highest speed (with radar guns) attained within a predetermined zone near where the traffic calming device was going to be constructed and within a predetermined zone setback from the traffic calming device.

Table 5-1
Test Site Summary

City	Street	Traffic Calming Device	Before Data	After Data	Comments
Eagan	Ashbury Road at Birchpond Road	Choker	11/17/98 and 11/23/98, 100-400' west of intersection	11/29/99 and 11/30/99, east of intersection, 200' from choker	*Before* data (spot speeds) was collected by SRF; *after* data (spot speeds) was collected by the City of Eagan. Note: Although *before* and *after* data collection locations were not identical, the data still provides an indication regarding the effectiveness of the traffic calming device implemented.
Eagan	Ashbury Road at Ashbury Place/ Ashbury Court	Pavement Markings	11/17/98 and 11/23/98, midway between Ashbury Place and Baltic Avenue intersections	11/30/99 and 12/01/99, midway between Ashbury Place and Baltic Avenue intersections	
Eagan	Blackhawk Hills Rd/ Blackhawk Lake Dr	Choker	11/17/98 and 11/23/98, 75'-450' east of intersection	12/01/99 and 12/02/99, 100' east of choker	
Eagan	Deerwood Drive	Pavement markings and signage	5/29/97 and 5/30/97, east terminus of eastbound chevron	07/10/97 (1 week after implementation), 08/27/97 (6 weeks), 02/05/98 (28 weeks), 11/16/99 (2 years after implementation), 7/10/01 (4 years), east terminus of eastbound chevron	*Before* and first four *after* data (spot speeds) were collected by City of Eagan. City resurfaced and repainted chevrons in the spring of 2001. 7/10/01 data (spot speeds) collected by SRF.
Eagan	Wescott Road	Conversion from 4-lane to 3-lane.	9/99, data collected at four stations along length of road	10/99, data collected at four stations along length of road	*Before* and *after* data (tube counts, 48 hour)
Minneapolis	Franklin Avenue	Conversion from 4-lane to 3-lane, chokers and landscaping	11/11/98, spot speed data collected at three stations along length of road. Pedestrian and bicycle data collected at four stations	7/10/01, data collected at three stations along length of road. Pedestrian and bicycle data collected at four stations.	Spot speeds were taken when traffic signals were green through the corridor to record vehicles at peak speed.
Savage	Joppa Avenue	Raised pedestrian crossing and lane edge striping	4/21/99 and 5/3/99, 100' – 300' south of parking lot entrance	11/25/00 and 11/29/00; one set collected 150' – 250' south of parking lot entrance; second set collected 0'-100' south of parking lot entrance	Second *after* data collected to assess speed impacts further from the raised crosswalk.

Findings

The following is a summary of each of the test sites along with their results, statistical summaries and findings from the research. The findings presented here attempt to explain the effectiveness of the traffic calming measures by means of the following statistics:

- Changes in mean and 85th percentile speeds

  These are standard measures used by the engineering community to compare vehicle speeds. The 85th percentile speed can be defined as the speed below which 85 percent of the vehicles travel.

- Statistical procedures (t-tests)

  A t-test provides the probability that the difference in two means is statistically significant. The basic assumption of the t-test is that the data is normally distributed or that the sample sets are of equal size (note: several of the data sets for the test sites are not of equal size). Normality was approximately true for most of the speed data, but was not quantitatively verified. P-values are reported for data sets on which t-tests were performed. It is customary to use 95 percent as the threshold certainty for statistical significance; if the p-value is less than 0.05 (5 percent), then it can be said that the difference between the means of the two samples is statistically significant.

  Ultimately, what the t-test tells us is whether a traffic calming device impacts vehicle speeds. When the difference in mean speeds is statistically significant at a 95-percent confidence level, there is a 95-percent probability that the difference is the result of the traffic calming measure.

- Comparison of standard deviations

The standard deviation gives an indication of the variability of the data. The standard deviation is a measure of how much the speed counts vary around the mean speed. The larger the standard deviation, the more spread out the individual counts are from the mean speed. This measure gives some indication of how drivers react to the traffic calming measures. If the standard deviation for the *after* data is smaller than the standard deviation for the *before* data, this may indicate that vehicles are traveling more consistently near the mean speed. If the standard deviation for the *after* data is larger than the standard deviation for the *before* data, it means that there is a higher variability in driver behavior due to the traffic calming measure. Standard deviations do increase as vehicle speeds increase. Due to the fact that the speed reductions achieved with the traffic calming devices were small (typically 2 – 5 mph), it was felt that the changes in standard deviation were the result of driver behavior and not speed variation.

- Examination of speeds exceeding the 85th percentile speed

The actual success of traffic calming projects may not be so much the reduction of mean or 85th percentile speeds, but a reduction in the number of vehicles that travel at excessive speeds. Vehicles traveling at excessive speeds were defined as those exceeding the 85th percentile speed calculated for the *before* data. To evaluate the reduction of excessive speeds, the highest speeds recorded for the pre- and post-calming data sets were compared. In addition, the percentage of post-calming speeds exceeding the pre-calming 85th percentile speed was calculated.

Ashbury Road at Birchpond Road. *Traffic Calming Device: Choker*

The choker appeared to reduce vehicle speeds. Both the mean and 85th percentile speeds decreased after the choker was installed. The drop in the mean speed was statistically significant at a 95-percent confidence level. Only one percent of the eastbound and two percent of the westbound post-calming vehicles exceeded the pre-calming 85th percentile speed.

These chokers were functioning as gateway elements for this neighborhood to physically slow vehicles and to provide visual cues regarding appropriate driving speeds in the neighborhood. Even though the speeds decreased, it appears that the chokers may have less of an impact on vehicles as they exit the calmed area and enter the open parkland. The highest speed recorded after calming for westbound vehicles (54 mph) was 10 mph higher than the highest speed recorded prior to calming (44 mph). This increase in the highest recorded speed for exiting vehicles also occurred at the Blackhawk Hills Road choker.

Eagan, MN Ashbury Road at Birchpond Road

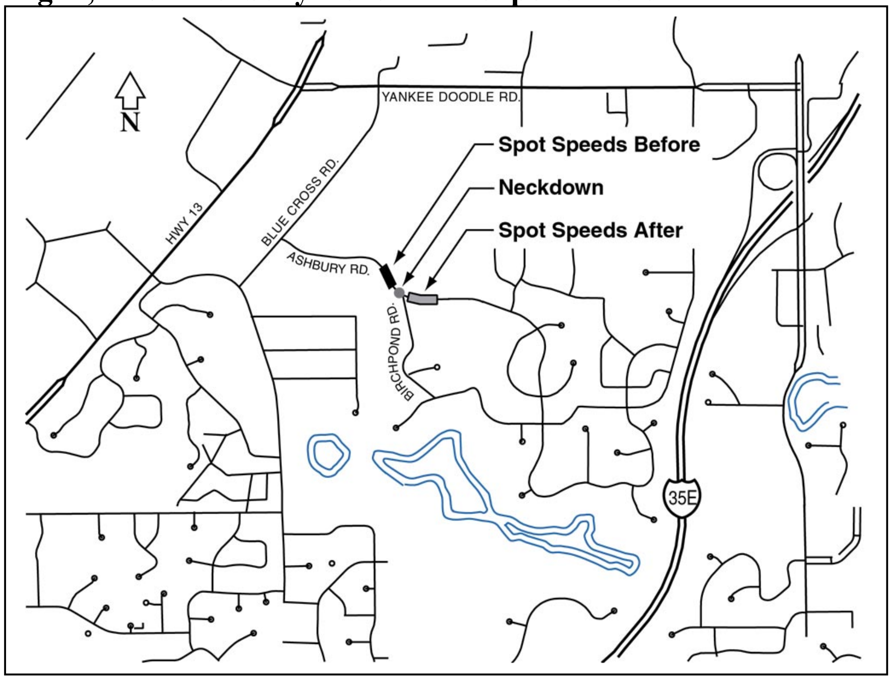

Figure 5-1: Site Map

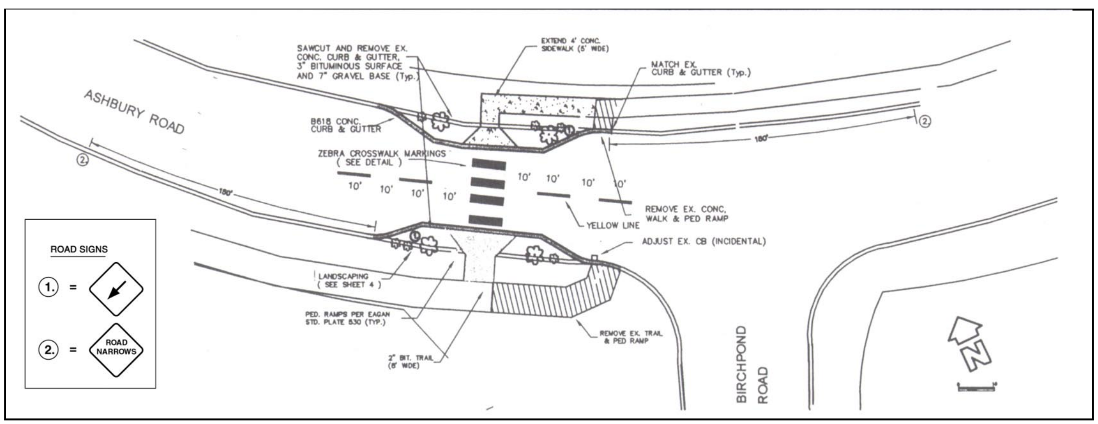

Figure 5-2: Site Design

Figure 5-3: Site Conditions - Before

Figure 5-4: Site Conditions - After

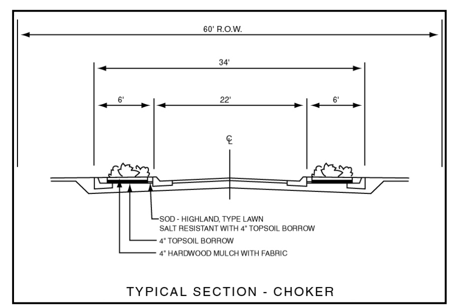

Figure 5-5: Roadway Section

Table 5-2
Eagan, MN Ashbury Road at Birchpond Road

Environment	Residential neighborhood that lies between an Interstate and a major employment campus (Figure 5-1). This test site is located at the western entrance to the neighborhood that functions as a transition point between the campus and the neighborhood. There is open space along both sides of the street this point. Neighborhood residents felt that there were an excessive number of commuters cutting through the neighborhood along Ashbury Road. They also felt that vehicle speeds were too high. This street is classified as local residential street and has a posted speed limit of 30 mph.							
Traffic Calming Strategy	**Choker** The existing 34-foot street was narrowed to 22 feet at the choker, which was landscaped with shrubs and incorporated a marked pedestrian crosswalk (Figures 5-2 through 5-5). Signage indicating road narrowing was placed 150 feet prior to the choker on both approaches. Additional signage was placed just at the start of the choker to notify drivers of the change in the curb line. The choker has approximately 45 feet of yellow centerline skip striping extending out from both sides of the crosswalk. The yellow striping was added during construction of the choker because residents were concerned about vehicles crossing the centerline as they passed through the choker.							
ADT	950 – 1,050							
Data Summary	Mean Speed Before	Mean Speed After	Change	Percent Change	85th Percentile Speed Before	85th Percentile Speed After	Change	Percent Change
Eastbound	34	30	-4	-12%	36	32	-4	-11%
Westbound	34	31	-3	-9%	39	35	-4	-10%
Findings	t-test: Difference between *before* and *after* speeds is statistically significant at a 95-percent confidence level for both eastbound and westbound traffic. P-value = 0.00 (eastbound) and 0.02 (westbound)							

Analysis of Highest Speeds	% of *after* vehicles exceeding the *before* 85% Speed	Highest Speeds (mph) Before	Highest Speeds (mph) After
Eastbound	1%	44	38
Westbound	2%	44	54

Ashbury Road at Ashbury Place/Ashbury Court. *Traffic Calming Device: Pavement Marking*

The pavement markings did not appear to reduce vehicle speeds. The mean and 85th percentile speeds for the westbound traffic decreased, while the mean and 85th percentile speeds for the eastbound traffic increased. The differences in the mean speeds were not statistically significant for vehicles traveling in either direction.

Eagan, MN Ashbury Road at Ashbury Place/Ashbury Court

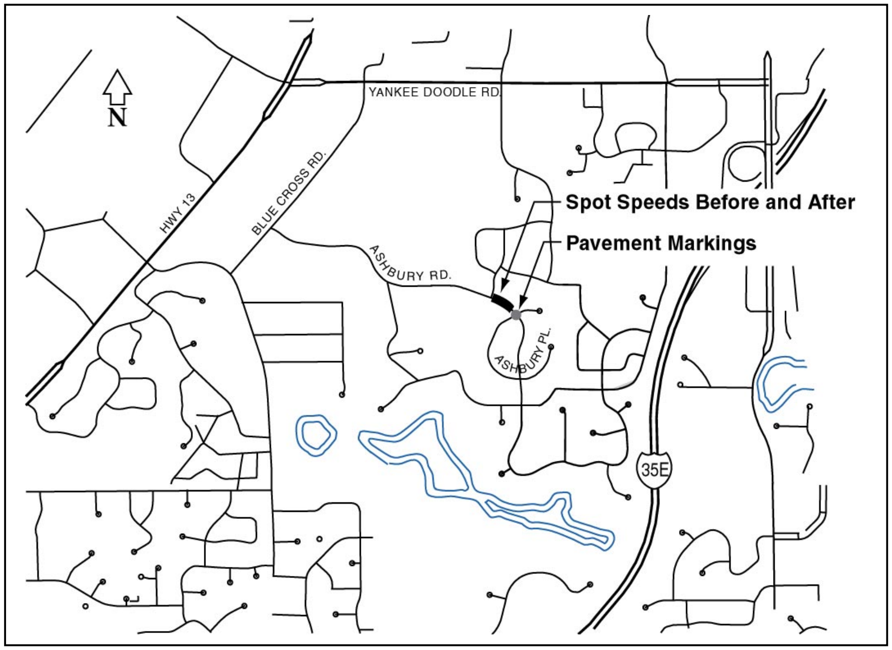

Figure 5-6: Site Map

Figure 5-8: Site Conditions - Before

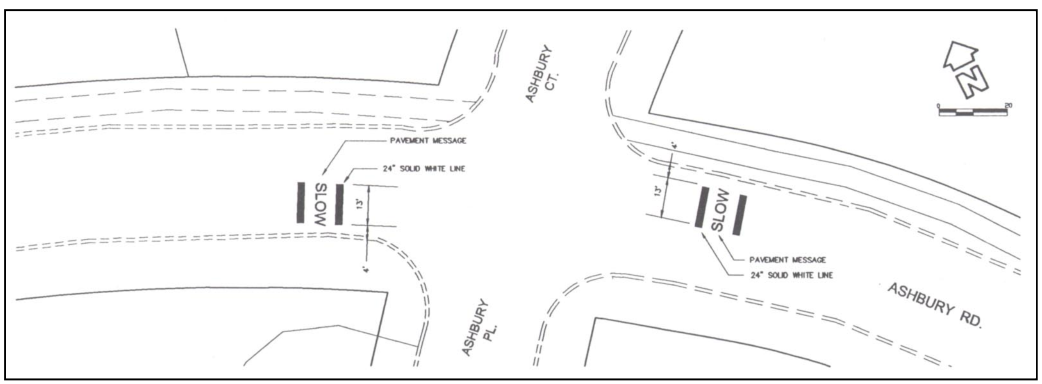

Figure 5-7: Site Design

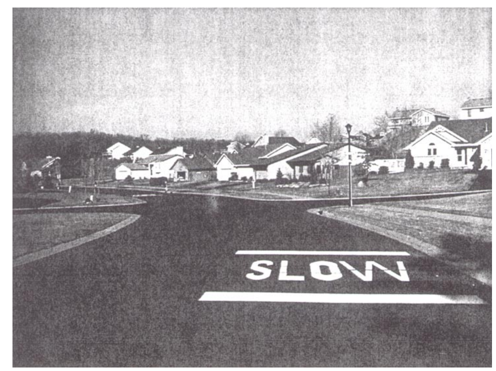

Figure 5-9: Site Conditions - After

Table 5-3
Eagan, MN Ashbury Road at Ashbury Place/Ashbury Court

Environment	Residential neighborhood that lies between an Interstate and a major employment campus (Figure 5-6). Traffic on Ashbury Place and Ashbury Court is stopped at the intersection giving, traffic along Ashbury Road right-of-way through the intersection. There are single-family residential lots on all four quadrants of the intersection. Neighborhood residents felt that there were an excessive number of commuters cutting through the neighborhood along Ashbury Road. They also felt that vehicle speeds were too high. This street is classified as local residential street and has a posted speed limit of 30 mph.							
Traffic Calming Strategy	**Pavement Markings** The City painted a "SLOW" pavement message on Ashbury Road approximately 30 feet back from the intersection for both eastbound and westbound traffic (Figures 5-7 through 5-9).							
ADT	950 – 1,050							
Data Summary	Mean Speed Before	Mean Speed After	Change	Percent Change	85th Percentile Speed Before	85th Percentile Speed After	Change	Percent Change
Eastbound	29	30	1	3%	33	35	2	6%
Westbound	28	28	0	0%	32	31	-1	-3%
Findings	t-test: Difference between *before* and *after* speeds is <u>not</u> statistically significant at a 95-percent confidence level for both eastbound and westbound traffic. P-value = 0.28 (eastbound) and 0.81 (westbound)							
	<u>Analysis of Highest Speeds</u>	<u>% of *after* vehicles exceeding the *before* 85% Speed</u>	<u>Highest Speeds (mph)</u> <u>Before</u>	<u>After</u>				
	Eastbound	25%	37	43				
	Westbound	12%	38	36				

Blackhawk Hills Road at Blackhawk Lake Drive. *Traffic Calming Device: Choker*

The choker appeared to reduce vehicle speeds. Both the mean and 85th percentile speeds decreased after the choker was installed. The drop in the mean speed was statistically significant at a 95-percent confidence level. When reviewing vehicles traveling at excessive speeds, seven percent of the eastbound and eight percent of the westbound post-calming vehicles exceeded the pre-calming 85th percentile speed.

Even though the speeds decreased, it appears that the chokers may have a lesser impact on vehicles as they exit the calmed area and enter the multi-family neighborhood that has a 40 mph speed limit. The highest speed recorded after calming for eastbound vehicles (42 mph) was 3 mph higher than the highest speed recorded prior to calming (39 mph). This increase in the highest recorded speed for exiting vehicles also occurred at the Ashbury Road/Birchpond Road choker.

Eagan, MN Blackhawk Hills Road at Blackhawk Lake Drive

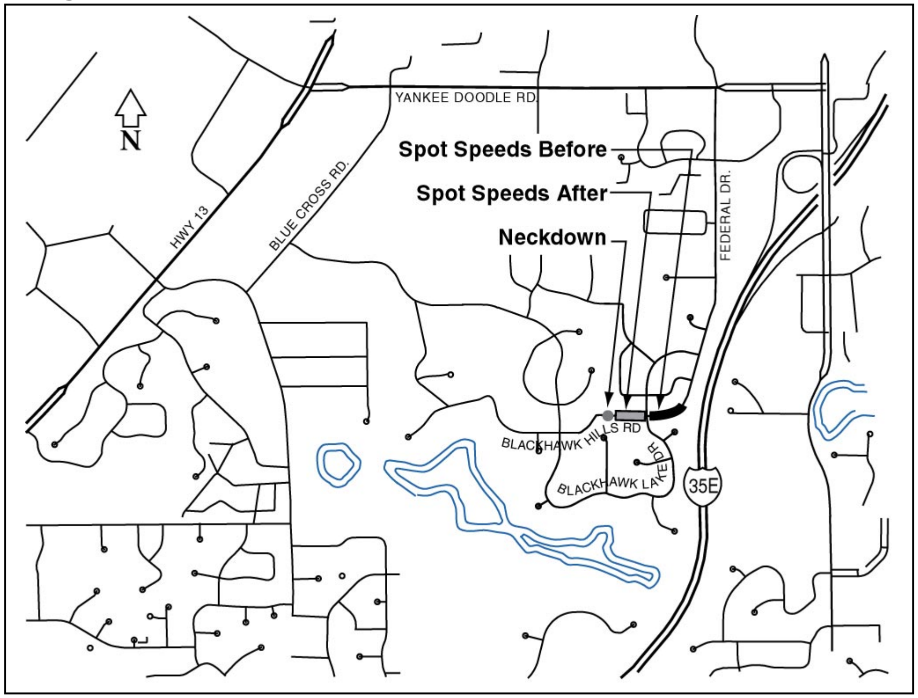

Figure 5-10: Site Map

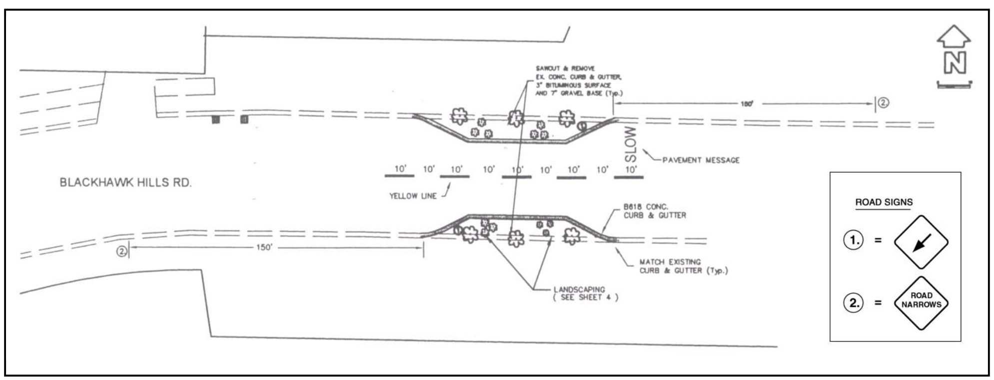

Figure 5-11: Site Design

Figure 5-12: Site Conditions - Before

Figure 5-13: Site Conditions - After

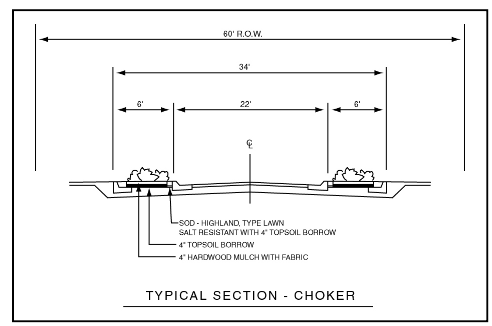

Figure 5-14: Roadway Section

Table 5-4
Eagan, MN Blackhawk Hills Road at Blackhawk Lake Drive

<table>
<tr><td>Environment</td><td colspan="8">Residential neighborhood that lies between an Interstate and a major employment campus (Figure 5-10). This test site is the eastern entrance to the neighborhood. Drivers approaching from the north along Federal Drive, move down a hill, posted at 40 mph and then make a sharp curve to the right at the bottom of the hill. The posted speed limit also drops to 30 mph at this point. The road name changes to Blackhawk Hills Road and consists predominantly of single-family residences. Neighborhood residents felt that there were an excessive number of commuters cutting through the neighborhood along Blackhawk Hills Road. They also felt that vehicle speeds were too high. This street is classified as local residential street and has a posted speed limit of 30 mph.</td></tr>
<tr><td>Traffic Calming Strategy</td><td colspan="8">Choker
The existing 34-foot street was narrowed to 22 feet at the choker and landscaped with shrubs (Figures 5-11 through 5-14). Signage indicating road narrowing was placed 150 feet prior to the choker on both approaches. Additional signage was placed just at the start of the choker to notify drivers of the change in the curb line. Yellow centerline skip striping runs through the choker. The yellow striping was added during construction of the choker because residents were concerned about vehicles crossing the centerline as they passed through the chokers.</td></tr>
<tr><td>ADT</td><td colspan="8">950 – 1,050</td></tr>
<tr><td>Data Summary</td><td>Mean Speed Before</td><td>Mean Speed After</td><td>Change</td><td>Percent Change</td><td>85th Speed Percentile Before</td><td>85th Speed Percentile After</td><td>Change</td><td>Percent Change</td></tr>
<tr><td>Eastbound</td><td>33</td><td>30</td><td>-3</td><td>-9%</td><td>36</td><td>33</td><td>-3</td><td>-8%</td></tr>
<tr><td>Westbound</td><td>32</td><td>31</td><td>-1</td><td>-3%</td><td>37</td><td>35</td><td>-2</td><td>-5%</td></tr>
<tr><td rowspan="4">Findings</td><td colspan="8">t-test: Difference between before and after speeds is statistically significant at a 95-percent confidence level for the eastbound but not for the westbound traffic. P-value = 0.01 (eastbound) and 0.17 (westbound)</td></tr>
<tr><td colspan="2"><u>Analysis of Highest Speeds</u></td><td colspan="2"><u>% of after vehicles exceeding the before 85% Speed</u></td><td colspan="4"><u>Highest Speeds (mph)</u>
<u>Before</u> / <u>After</u></td></tr>
<tr><td colspan="2">Eastbound</td><td colspan="2">7%</td><td colspan="2">39</td><td colspan="2">42</td></tr>
<tr><td colspan="2">Westbound</td><td colspan="2">8%</td><td colspan="2">46</td><td colspan="2">42</td></tr>
</table>

Deerwood Drive. *Traffic Calming Device: Pavement Markings and Signs*

The pavement markings and signage appeared to reduce vehicle speeds. The *before* data was compared to data collected at different time periods subsequent to implementation. *After* data collected one week and six weeks after implementation both showed comparable reductions in mean and 85th percentile speeds. The speed data collected 28 weeks after implementation still showed a reduction in mean and 85th percentile speeds, but not to the same extent as the initial *after* data. The data collected two years after implementation only showed minor reductions in mean and 85th percentile speeds from the *before* data.

Data collected four years after implementation, in 2001, after the City resurfaced and repainted the pavement markings, showed reductions in mean and 85th percentile speeds similar to the data collected one week and six weeks after the initial implementation.

Data for all of the collection periods, except one, showed a substantial decrease in percentage of vehicles exceeding the pre-calming 85th percentile speeds. The highest speed recorded dropped 11 mph on average.

It appears that while speeds increase over time, they never return to the pre-calming levels. There are two possible reasons for the increase in speeds over time. One is that drivers become accustomed to the pavement markings, and therefore the markings have a decreased effect on drivers' perceptions and behavior. The other is that, over time, the paint on the roadway fades, resulting in a decreased impact on drivers. The data collected after the repainting supports the concept that the subsequent increase in speeds may be more a result of fading paint than drivers becoming accustomed to the chevrons.

Eagan, MN Deerwood Drive

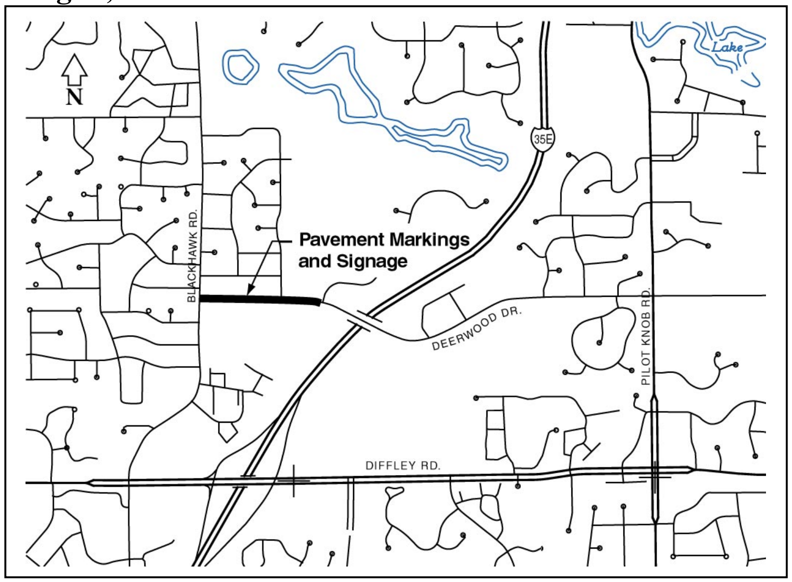

Figure 5-15: Site Map

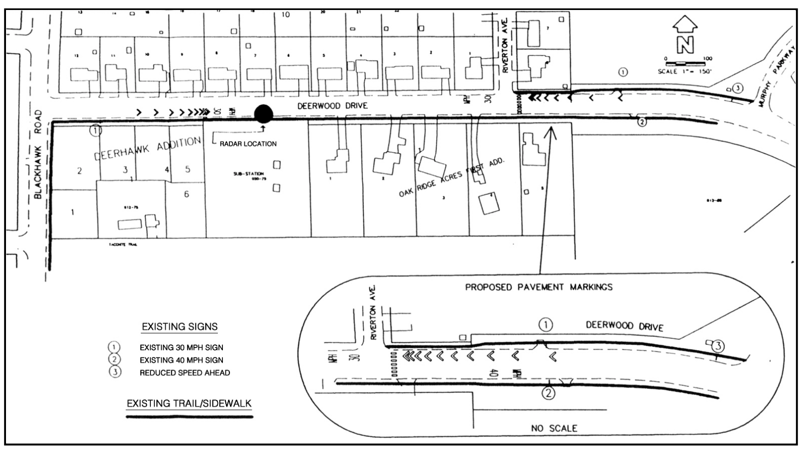

Figure 5-16: Site Design

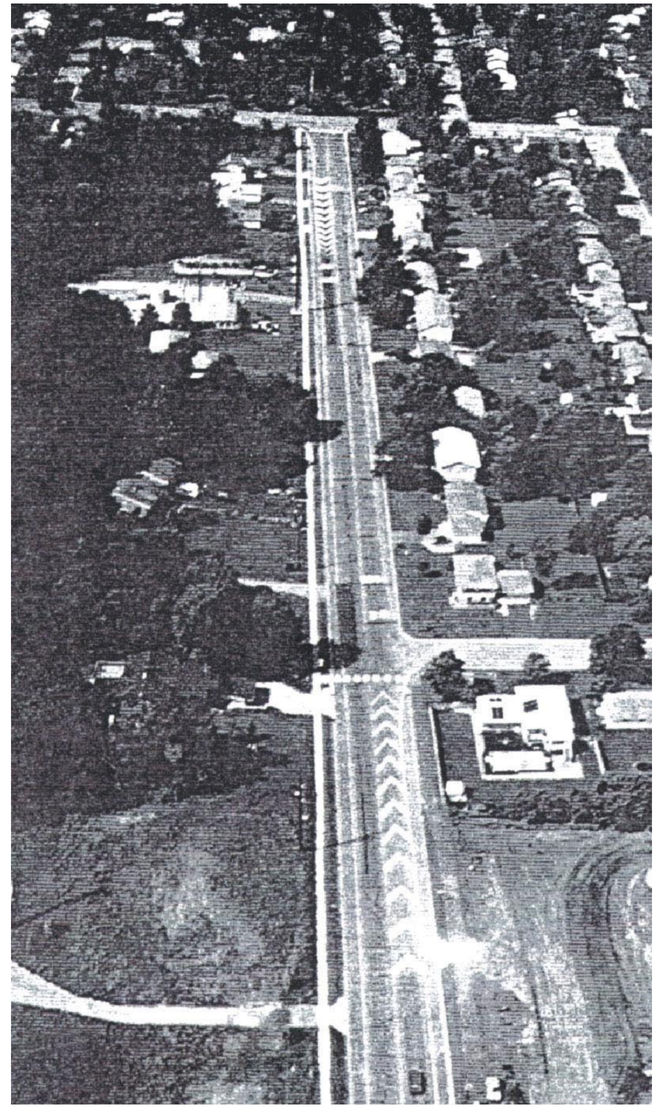

Figure 5-17: View of Roadway After Implementation

Table 5-5
Eagan, MN Deerwood Drive

Environment	This test site is located on Deerwood Drive between Blackhawk Road and Murphy Parkway (Figure 5-15). Deerwood Drive is classified as a community collector street. The roadway has a posted speed limit of 30 mph between Blackhawk Road and a point approximately 230 feet east of Riverton Avenue, while the remainder of the street has a posted speed limit of 40 mph. The roadway is 48 feet wide with a 16-foot travel lane and an 8-foot safety lane in each direction. The land use within the test site consists predominantly of single family residential. Neighborhood residents were concerned with the vehicle speeds.							
Traffic Calming Strategy	**Pavement markings and signage** The City implemented the following pavement markings and signage: • A converging chevron pattern (in each travel lane). Chevrons were painted on the roadway surface in a manner that decreased the width of the chevrons and the spacing between them to give the illusion that the vehicle is moving faster than it actually is as it passes over the pavement markings (Figures 5-16 and 5-17). • A "30 MPH" pavement message (in both the eastbound and westbound travel lanes) • A pedestrian crosswalk (painted blocks and signs) at the east leg of the Riverton Avenue intersection • High visibility wind spinners on speed limit signs							
ADT	4,000 (1996)							
Data Summary	Mean Speed Before	Mean Speed After	Change	Percent Change	85th Speed Percentile Before	85th Speed Percentile After	Change	Percent Change
Eastbound								
Wk 1	37	32	-5	-14%	42	35	-7	-17%
Wk 6	37	32	-5	-14%	42	35	-7	-17%
Wk 28	37	33	-4	-11%	42	36	-6	-14%
2 Yrs	37	35	-2	-5%	42	39	-3	-7%
4 Yrs *	37	31	-6	-16%	42	35	-7	-17%
Westbound								
Wk 1	35	32	-3	-9%	39	34	-5	-13%
Wk 6	35	32	-3	-9%	39	34	-5	-13%
Wk 28	35	33	-2	-6%	39	35	-4	-10%
2 Yrs	35	34	-1	-3%	39	38	-1	-3%
4 Yrs *	35	31	-4	-11%	39	34	-5	-13%

* The road was resurfaced (seal coat) and repainted just prior to data collection in the 4th year.

Table 5-5
Eagan, MN   Deerwood Drive Cont'd

Findings	t-test: Difference between *before* and *after* speeds is statistically significant at a 95-percent confidence level for both eastbound and westbound traffic. P-value = 0.00 (both eastbound and westbound)				
	Analysis of Highest Speeds		% of *after* vehicles exceeding the *before* 85% Speed	Highest Speeds (mph)	
				Before	After
	Eastbound	Wk 1	1%	58	44
		Wk 6	0%	58	46
		Wk 28	2%	58	48
		2 Yrs	3%	58	46
		4 Yrs	0%	58	39
	Westbound	Wk 1	4%	53	45
		Wk 6	1%	53	40
		Wk 28	4%	53	48
		2 Yrs	10%	53	48
		4 Yrs	2%	53	40

Wescott Road. *Traffic Calming Device: Lane Reduction*

The reconfiguration from a four-lane to a three-lane roadway appears to reduce vehicle speeds. Stations 1 and 3 showed decreased mean and 85th percentile speeds after implementation of the three-lane roadway configuration. The speed reductions associated with Station 2 were substantially less than Stations 1 and 3. One possible reason for the variance is that this data collection point was located at the bottom of a valley. Therefore, the roadway grade may have been more of a factor for these speeds than the change in lane configuration.

Station 4 showed only minor decreases in the eastbound mean and 85th percentile speeds and the westbound mean speed. The Station 4 westbound 85th percentile speed increased slightly. One possible explanation is that traffic volumes are lower at this station than at the other stations along the roadway. Lower traffic volumes decrease the chance of being caught behind a slower vehicle; therefore, speeds are higher along this segment of the roadway. This indicates that a three-lane configuration may need a critical traffic volume to make it a successful traffic calming technique. If traffic volumes are too low, platooning will occur only a small portion of the time and a significant reduction in mean and 85th percentile speeds will not be achieved.

Eagan, MN   Wescott Road

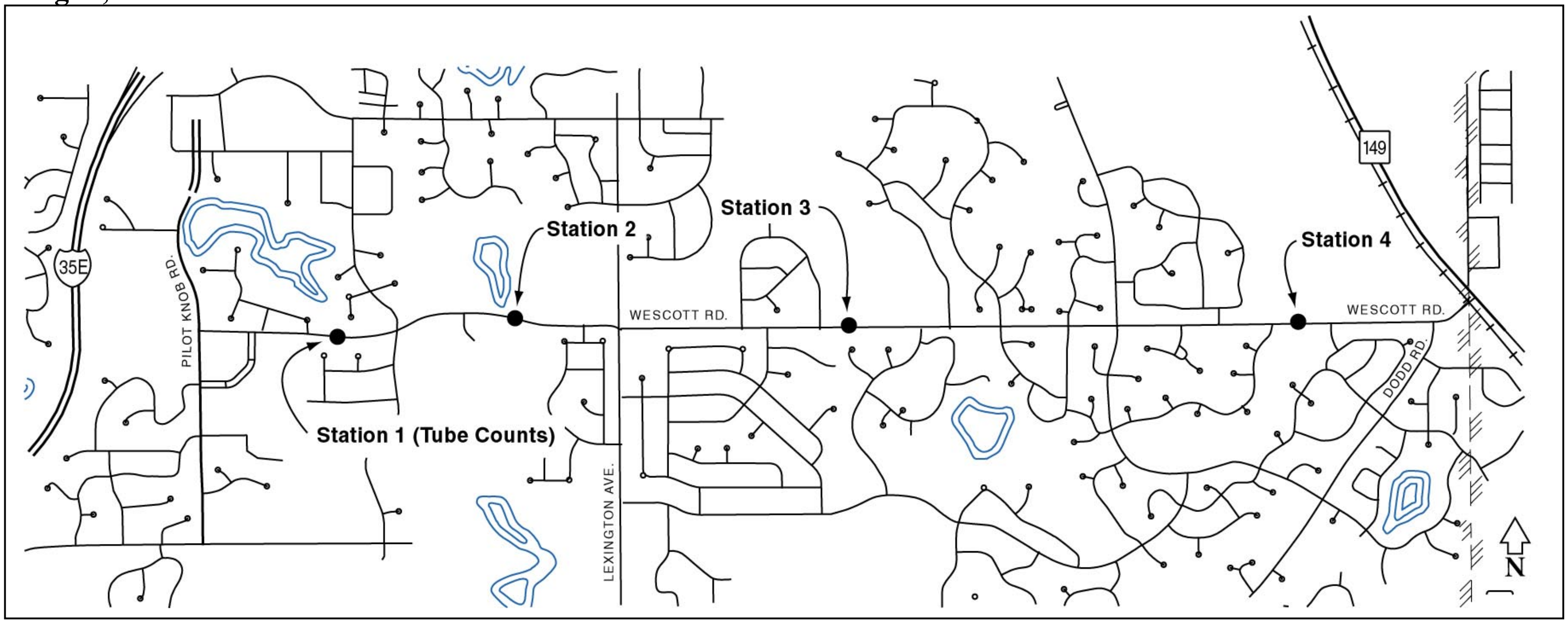

Figure 5-18: Site Map

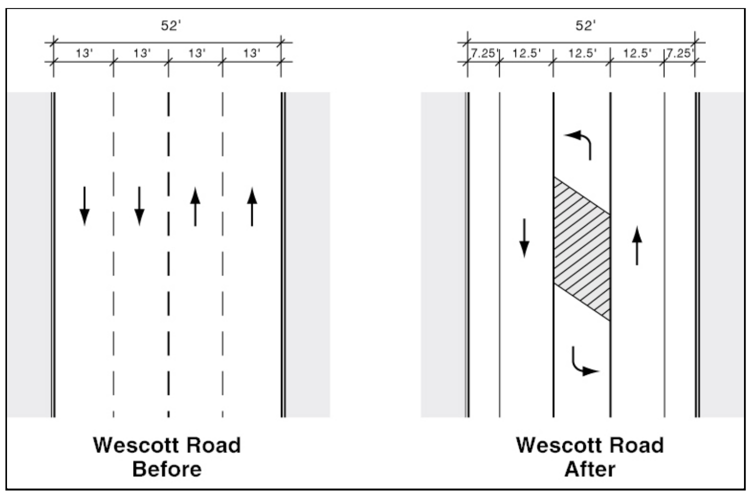

Figure 5-19: Site Conditions *Before* and *After*

Table 5-6
Eagan, MN   Wescott Road

Environment	This test site runs the full length of Wescott Road (three miles) from Pilot Knob Road to TH 149 (Figure 5-18). The test site is classified as a B-minor arterial street and has a posted speed limit of 35 mph. The predominant land uses along Wescott Road consist of institutional (City Hall, community library and school) between Pilot Knob Road and Lexington Avenue and residential between Lexington Avenue and TH 149, with the exception of a church, a school and a large corporate campus north of Wescott just west of TH 149. The street was originally designed to have two travel lanes in each direction.							
Traffic Calming Strategy	**Three-lane configuration** The City re-striped the road to have one 12.5-travel lane and a 7-foot safety lane in each direction, along with a 12.5 foot-center left-turn lane (Figure 5-19). Speed reduction is achieved by the platooning effect of slower drivers forcing drivers behind them to travel at their speed. Faster vehicles are no longer able to pass these slower vehicles.							
ADT	Varies across its length ranging between 5,400 and 9,100 (1998)							
Data Summary	Mean Speed Before	Mean Speed After	Change	Percent Change	85th Speed Percentile Before	85th Speed Percentile After	Change	Percent Change
Eastbound								
Station 1	41	40	-1	-2%	47	45	-2	-4%
Station 2	48	48	0	0%	53	53	0	0%
Station 3	47	45	-2	-4%	52	49	-3	-6%
Station 4	45	44	0	-2%	52	51	-1	-2%
Westbound								
Station 1	43	40	-3	-7%	48	45	-3	-7%
Station 2	49	48	-1	-2%	54	53	-1	-2%
Station 3	46	42	-4	-9%	52	48	-4	-8%
Station 4	42	41	-1	-2%	48	48	0%	0%
Findings	t-test: Data not available Analysis of Highest Speeds: Data not available							

Franklin Avenue. *Traffic Calming Devices: Lane Reduction, Choker, Plantings*

Vehicle Speeds

All of the test sites, except westbound Elliot Avenue, showed reductions in the mean and 85th percentile speeds, decreased standard deviations and substantial reductions in the percentage of vehicles exceeding the pre-calming 85th percentile speed. With the exception of westbound Elliot Avenue, the highest speed recorded dropped an average of 8.5 mph. The t-test indicated that the difference in mean speeds was statistically significant for the eastbound sites (Elliot, 11th and Bloomington Avenues), but not for the westbound sites. A review of the westbound Elliot Avenue data indicates that the speed counts are not normally distributed and may be distorting the statistical analysis for this site. Based upon the statistical procedures performed, excluding westbound Elliot Avenue, the reconstruction project appeared to be effective in reducing vehicle speeds, but it is not clear which aspect of the project (three-lane configuration, chokers or new street trees) impacted speeds.

Pedestrian and Bicycles

After implementation, pedestrian activity increased slightly at two test sites and decreased at the other six test sites. The drop in pedestrian activity was not anticipated given that the reconstruction project enhanced the space and quality of the pedestrian environment. One possible explanation for the decrease may be that pedestrians chose an alternative transportation mode such as bicycling during the summer months. The increase in bicycle counts more than offsets the decrease in pedestrian activity.

The number of bicyclists increased substantially. A portion of this increase is probably due to the season the data was collected (*before* = November 1998, *after* = July 2001), which makes it difficult to determine what portion of the activity increase is due to changes in the street environment.

Minneapolis, MN Franklin Avenue

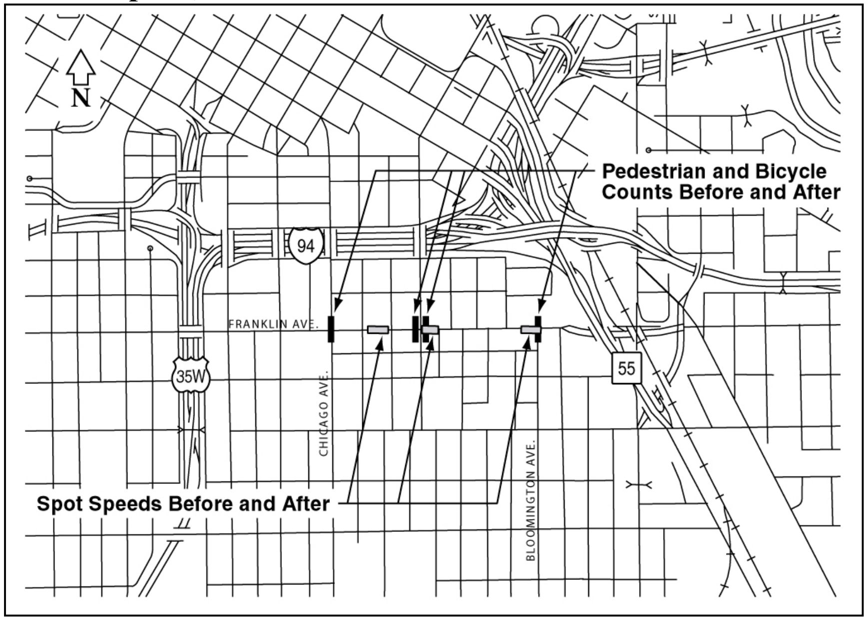

Figure 5-20: Site Map

Figure 5-22: Site Conditions - Before

Figure 5-23: Site Conditions - After

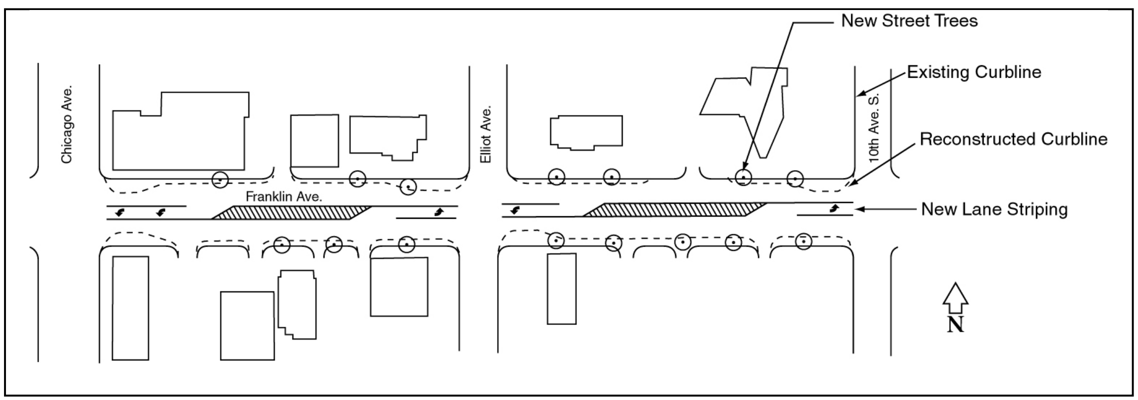

Figure 5-21: Site Design

Table 5-7
Minneapolis, MN Franklin Avenue

Environment	The City of Minneapolis reconstructed an eight-block segment of Franklin Avenue from Chicago Avenue to 16th Avenue (Figure 5-20) to improve the image of this commercial corridor. Franklin Avenue is classified as an arterial street and has a posted speed limit of 30 mph. Prior to reconstruction, the street had a width of 60 feet throughout the corridor, consisting of two travel lanes in each direction, plus on-street parking along both sides. Five intersections along the corridor were signalized.
Traffic Calming Strategy	**Three-lane configuration, chokers and landscaping** The reconstructed street utilized a three-lane configuration consisting of one travel lane in each direction and a continuous left-turn lane in the center. Chokers were constructed to reduce pedestrian crossing distances and to create protected parking bays and bus bays. The reconstructed street varies in width from 38 feet to 54 feet. The reclaimed roadway space was used to increase sidewalk widths. The existing traffic signals were replaced and reinstalled at the pre-construction locations. New street furniture was installed; along with public art pieces, pedestrian scale street lights and street trees (Figures 5-21 through 5-23).
ADT	14,500 (1998)

Data Summary	Mean Speed Before	Mean Speed After	Change	Percent Change	85th Speed Percentile Before	85th Speed Percentile After	Change	Percent Change	Standard Deviation Before	Standard Deviation After
Spot Speeds:										
Eastbound										
Elliot Avenue	31	28	-3	-10%	36	32	-4	-11%	7.5	5.8
11th Avenue	28	23	-5	-18%	32	26	-6	-19%	7.5	4.7
Bloomington Avenue	31	28	-3	-10%	36	31	-5	-14%	8.3	4.7
Westbound										
Elliot Avenue	28	27	-1	-4%	33	32	-1	-3%	6.9	8.2
11th Avenue	27	24	-3	-11%	31	28	-3	-10%	6.6	5.9
Bloomington Avenue	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 5-7
Minneapolis, MN Franklin Avenue Cont'd

Pedestrian and Bicycle counts	Pedestrian Before	Pedestrian After	Change	Percent Change	Bicycle Before	Bicycle After	Change	Percent Change [A]
Eastbound								
Chicago Avenue	122	95	-27	-22%	3	36	33	1100%
11th Avenue (east side)	116	108	-8	-7%	10	67	57	570%
11th Avenue (west side)	108	91	-17	-16%	7	72	65	930%
Bloomington Avenue	98	106	8	8%	12	63	51	425%
Westbound								
Chicago Avenue	135	155	20	15%	3	39	36	1200%
11th Avenue (east side)	143	117	-26	-18%	5	60	55	1100%
11th Avenue (west side)	120	98	-22	-18%	8	44	36	450%
Bloomington Avenue	102	95	-7	-7%	19	62	43	225%

Findings

t-test: Difference between *before* and *after* speeds is statistically significant at a 95 percent confidence level for all test sites except westbound Elliot Avenue.

P-VALUES

Eastbound		*Westbound*	
Elliot Avenue	0.02	Elliot Avenue	0.38
11th Avenue	0.00	11th Avenue	0.03
Bloomington Avenue	0.02	Bloomington Avenue	n/a

Analysis of Highest Speeds	% of *after* vehicles exceeding the *before* 85% Speed	Highest Speeds (mph) Before	Highest Speeds (mph) After
Eastbound			
Elliot Avenue	5%	42	38
11th Avenue	0%	42	27
Bloomington Avenue	0%	42	35
Westbound			
Elliot Avenue	13%	39	39
11th Avenue	0%	38	30
Bloomington Avenue	n/a	n/a	n/a

[A] Change in bicycle counts probably due to data being collected in different seasons (*Before*: November and *After*: July)

Joppa Avenue

Traffic Calming Devices: Raised Crosswalk and Lane Narrowing

The raised crosswalk appears to be effective in decreasing vehicle speeds within approximately 100 feet of the device. At this distance from the device, mean and 85th percentile speeds decreased significantly. The t-test indicated that the difference in the mean speeds was statistically significant. The highest speeds after implementation did not even reach the pre-calming 85th percentile speed. The standard deviation for the northbound traffic dropped after implementation, but the southbound standard deviation increased after implementation. The data was collected north of the raised crosswalk; northbound traffic had just crossed the device and the southbound traffic was approaching the device. The implementation of the raised crosswalk increased the variability of driver behavior as they approached the device. In addition, the speeds approaching the device did not drop to the same extent as the speeds for the vehicles departing from the device, indicating that drivers do not slow down for the device until they are very close to it.

After data for northbound Joppa Avenue was also collected approximately 300 feet north of the raised crosswalk. As stated earlier, this was done to see how far the speed impacts associated with the raised crosswalk extended from the device. The mean speed, the 85th percentile speed and the standard deviation were only slightly lower than the pre-calming condition. The highest speed recorded after calming was 4 mph lower than the highest speed recorded prior to calming with 7 percent of the post-calming vehicles exceeding the pre-calming 85th percentile speed. The data indicates that the raised crosswalk has a minor impact on vehicle speeds up to 300 feet from the device. This is consistent with findings from other traffic calming projects. The increase in speed, 300 feet from the raised crosswalk, also indicates that the narrowing of the travel lanes did not influence vehicle speeds.

Savage, MN   Joppa Avenue

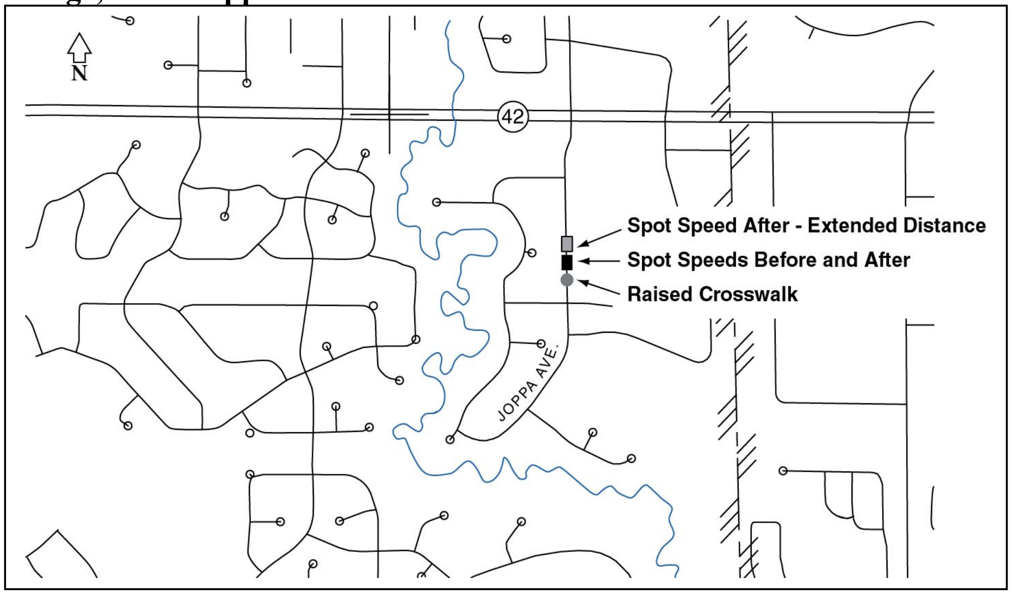

Figure 5-24: Site Map

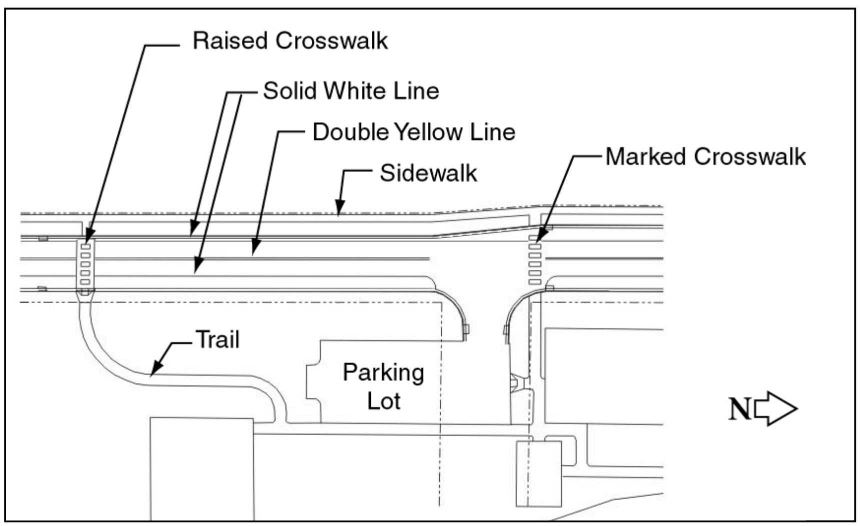

Figure 5-25: Site Design

Figure 5-26: Site Conditions – After (view North)

Figure 5-27: Site Conditions – After (view South)

Table 5-8
Savage, MN Joppa Avenue

Environment	This test site is located on Joppa Avenue between River Bend Place and 144th Street, adjacent to a community park. The road functions as the main entrance street to a large cul-de-sac community consisting of approximately 200 households (Figure 5-24). The road is classified as a residential street and has low traffic volumes. The posted speed limit is 30 mph. Neighborhood residents were concerned with the speed of vehicles as they passed the park. The roadway transitions from 44 feet to 37 feet near the parking lot entrance.
Traffic Calming Strategy	**Raised crosswalk and lane striping** The City constructed a raised crosswalk to slow vehicle speeds and increase pedestrian safety. City also striped the edge of the travel lane to visually narrow the roadway. (Figures 5-25 through 5-27).
ADT	1,600 (estimate)

Data Summary	Mean Speed Before	Mean Speed After	Change	Percent Change	85th Speed Percentile Before	85th Speed Percentile After	Change	Percent Change	Standard Deviation Before	Standard Deviation After
Northbound										
100 feet from raised crosswalk	34	22	-12	-35%	38	26	-12	-32%	7.0	5.3
300 feet from raised crosswalk	34	33	-1	-3%	38	37	-1	-3%	7.0	6.6
Southbound										
100 feet from raised crosswalk	33	23	-10	-30%	37	28	-9	-24%	6.3	7.1
300 feet from raised crosswalk	33	n/a	n/a	n/a	37	n/a	n/a	n/a	n/a	n/a

Findings

t-test: Difference between *before* and *after* speeds is statistically significant at a 95-percent confidence level for both northbound and southbound traffic. P-value = 0.00 (both northbound and southbound)

Analysis of Highest Speeds	% of *after* vehicles exceeding the *before* 85% Speed	Highest Speeds (mph) Before	Highest Speeds (mph) After
Northbound			
100 feet from raised crosswalk	0%	47	30
300 feet from raised crosswalk	7%	47	43
Southbound			
100 feet from raised crosswalk	0%	43	33
300-feet from raised crosswalk	n/a	n/a	n/a

CHAPTER 6: SIMULATION MODELS

Two simulation models were developed to evaluate the effectiveness of traffic calming measures in reducing vehicle speeds.

Franklin Avenue Model

The purpose of this experiment was to obtain simulation data that could be compared to field data to see how well the simulation was able to predict driver behavior associated with the traffic calming techniques implemented. This experiment consisted of modeling one of the actual test sites, Franklin Avenue (Minneapolis, MN), before and after implementation of traffic calming devices (lane reduction, chokers and plantings). Participating subjects "drove" the simulated scenarios using the University of Minnesota's traffic simulator. Reactions were recorded and findings analyzed to determine the effectiveness of the traffic calming devices.

Twenty participants between the ages of 18 and 65 years (ten females and ten males) were used as subjects. Each participant had a valid driver's license at the time of the experiment. Following a training session intended to familiarize them with driving on virtual roadways, the participants "drove" the stretch of Franklin Avenue starting at Chicago Avenue and ending just before Hiawatha Avenue. The drivers were told to drive as they normally would. They could reference a speedodometer while driving.

The two conditions were presented such that half of the participants drove "old" Franklin first, then "calmed" Franklin, while the other half drove "calmed" Franklin first, followed by "old" Franklin (within subjects design controlled for order effects)[1]. Participants were randomly assigned to their first condition. The two test conditions were separated by a short pause.

[1] A *within subjects* test design requires that all participants drive through both test conditions (*before* and *after*). *Controlled for order effects* means that the test is designed to have half of the participants drive "old" Franklin first and the other half drive "calmed" Franklin first. This is done to ensure that the test results are not biased due to the order in which participants experience the two test conditions.

Findings

The mean vehicle speed for "calmed" Franklin Avenue was 1.7 mph slower than the mean speed for "old" Franklin Avenue (see Table 6-1). A paired sample t-test indicated that the participants drove "calmed" Franklin Avenue at statistically significant reduced speeds than "old" Franklin Avenue (p=0.025).

Table 6-1
Paired Samples Statistics for "Old" and "Calmed" Franklin Avenue

	Mean Speed	Sample Size	Standard Deviation
Mean Speed (mph) *Before*	28.2	20	3.9
Mean Speed (mph) *After*	26.5	20	3.0

Calibration results

The research project started with the assumption that the simulator could predict changes in driver behavior (i.e. that the implementation of traffic calming devices will cause drivers to slow down). The research project was designed to test this assumption by comparing the simulation findings to field data, which up to this point, the research team of the University of Minnesota did not have an opportunity to test. Even though it was not assumed that the simulator could accurately predict actual speeds because the virtual environment created by the simulator is not identical to the real world, the research team did evaluate how close the simulation findings were to actual speeds.

The simulator accurately predicted that the implementation of traffic calming devices would reduce vehicle speeds. It also predicted vehicle speeds that were similar to those collected in the field. Both of these items support the use of the simulator as a valid approach to testing traffic calming strategies. Unfortunately, the data calibration did not provide an easy, straightforward replication of the field data.

It should be noted that the calibration evaluation is based upon a very small sample set and therefore, it is difficult to provide definitive conclusions; but some general observations can be made.

The speeds at which the participants drove through the simulation at Elliot Avenue were essentially the same as the observed data (see Table 6-2). The speeds at which participants drove through the simulation at 11th Avenue were faster than the field data. The discrepancy in the difference in means and the ratio of means indicates that the differences between the field and simulated samples are site specific.

Table 6-2
Summary of Simulation and Field Data

	Elliot Avenue (old)	Elliot Avenue (calmed)	Change	11th Avenue (old)	11th Avenue (calmed)	Change
Simulator Mean Speed (mph)	31.2	29.3	-1.9	33.5	30.6	-2.9
Simulator Standard Deviation	4.3	5.0	0.7	5.3	4.5	-0.8
Field Mean Speed (mph)	31.3	28.3	-3.0	27.6	22.6	-5.0
Field Standard Deviation	7.5	5.6	-1.9	7.5	4.7	-2.8
Difference of Means (A)	-0.1	1.0		5.9	8.0	
Ratio of Means (B)	1.0	1.0		1.2	1.4	

(A) Simulation mean less observed mean

(B) Simulation mean divided by observed mean

The standard deviations for the simulator experiment were consistently lower than the field data, which implies there was less variability in driver behavior in the simulation data than in the field data. The field data showed a drop in the standard deviations for Elliot Avenue and 11th Avenue after the implementation of the traffic calming devices, where the simulator standard deviations did not consistently decrease for the "calmed" scenarios.

From available data, it appears that the simulator did not produce a relationship to field data that was consistent throughout the simulation model. Once again, it needs to be stressed that these observations are based upon only two test sites. If spot speeds had been collected at a larger number of test sites, trends between the simulator and field data may have been revealed.

While the data calibration did not provide an easy, straightforward conversion factor for the data, the use of the simulator appears to be a valid approach of testing traffic calming strategies. Additional data is needed to further understand the relationship between the simulation data and observed data.

Residential Street Model

The second simulation was designed to address the following two issues:

- What is the effectiveness of traffic calming devices designed for residential streets with a collector functional classification?
- Is there an incremental effect associated with implementing multiple traffic calming devices at one location?

Residential Street – Collector classification

The roadway used in the simulation model was designed to mimic a residential collector roadway located in a suburban setting. This street style was selected because city engineers were receiving requests for traffic calming on suburban residential streets with a collector functional classification. It is on roads such as these where there is the greatest potential for discrepancy between resident requests and intended roadway function.

The test street was designed to have a width of 42 feet (curb face to curb face). The houses were setback from the roadway 47 feet and had sideyard widths of 35 feet. The houses along the street were representative of 1970's and 1980's two-story housing styles with attached garages and driveways leading out to the street.

Many streets that are classified as collectors or arterials receive Municipal State Aid funding for construction and maintenance. This funding source requires compliance with design standards as a condition of funding. It was decided that for this simulation the traffic calming devices designed for testing would comply with State Aid design criteria in order to determine if effective traffic calming devices could be designed for roads designed to comply with State Aid standards. It should be noted that State Aid design criteria are less restrictive on vehicle movement than many traffic calming measures allowed in other areas of the country and abroad.

Incremental Effects

The second simulation focused on three specific traffic calming devices (chokers, median islands and plantings adjacent to the roadway). The simulation was set up to measure vehicle speeds associated with each of the devices. The simulation also incorporated scenarios that utilized more than one traffic calming device to determine the incremental impact on vehicle speeds of using more than one device.

Test Methodology

The experiment consisted of two independent variables:

Curb Treatments:

- Chokers
- Median islands
- Chokers/median island combination
- Control – typical residential street with no curb modifications

Plantings:

- Curb treatments with plantings
- Curb treatments without plantings
- Control - typical residential street with no curb modifications or plantings

The simulation was organized into two distinct test groups. The first test group included each of the curb treatment alternatives, but excluded the plantings. The second test group added plantings to each of the curb treatments. The groups were organized as follows:

No Planting Conditions:

- Chokers
- Median islands
- Chokers/median island combination
- Control – typical residential street with no curb modifications[2]

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[2] Note that the control condition is identical for both test blocks.

Plantings Conditions:

- Chokers with plantings
- Median islands with plantings
- Chokers/median island combination with plantings
- Control – typical residential street with no curb modifications or plantings[3]

Twenty-three participants between the ages of 18 and 65 years (12 females and 11 males) piloted the wrap-around simulator. Each participant had a valid driver's license at the time of the experiment. Following a training session intended to familiarize them with driving on computer-generated virtual roadways, the participants drove the simulation model. The drivers were told to drive as they normally would. They could reference a speedodometer while driving.

The two groups of conditions were again presented in a within subjects design controlled for order effects[4] so that half the participants drove the No Plantings group first followed by the Plantings group while the other half drove the Plantings group first followed by the No Plantings block. The order of conditions within each group was randomized and participants were randomly assigned to their order of conditions. Each group of conditions was five miles and the conditions within each group were uninterrupted. There was a short break between each group.

The University of Minnesota research team performed a two-way analysis of variance (ANOVA) on the data collected using the simulator to determine whether the traffic calming devices (curb treatments and/or plantings) affected vehicle speeds.

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[3] Note that the control condition is identical for both test blocks.

[4] A *within subjects* test design requires that each subject drives each of the test conditions. *Controlled for order effects* means that each participant experiences the test conditions in a different randomized order. This is done to ensure that the test results are not biased due to the order in which participants experience the test conditions.

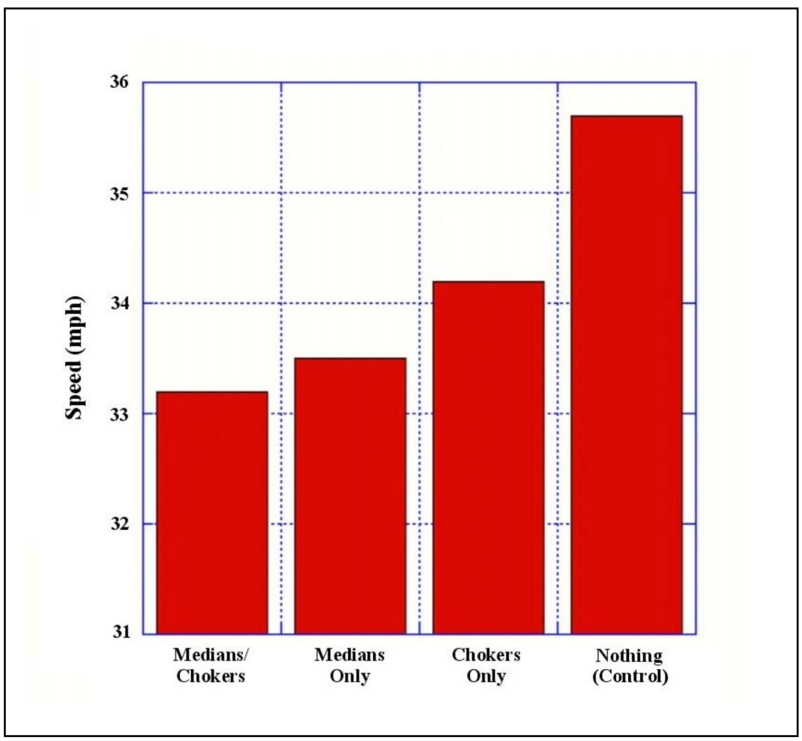
Findings

Curb Treatments

The two-way ANOVA indicated that curb treatments, when reviewed as a grouped condition, did result in a statistically significant influence on vehicle speeds ($p<0.05$). The test results also showed that the median island/choker combination caused a drop in the mean vehicle speed beyond what could be obtained by the median island or choker individually and that the vehicle speed associated with this combination of devices was statistically significant (see Figure 6-1).

It is important to note that the traffic calming devices used for this simulation were designed to comply with State Aid standards. The simulation findings showed that these devices did reduce vehicle speeds.

Figure 6-1
Effect of Curb Treatments on Vehicle Speed

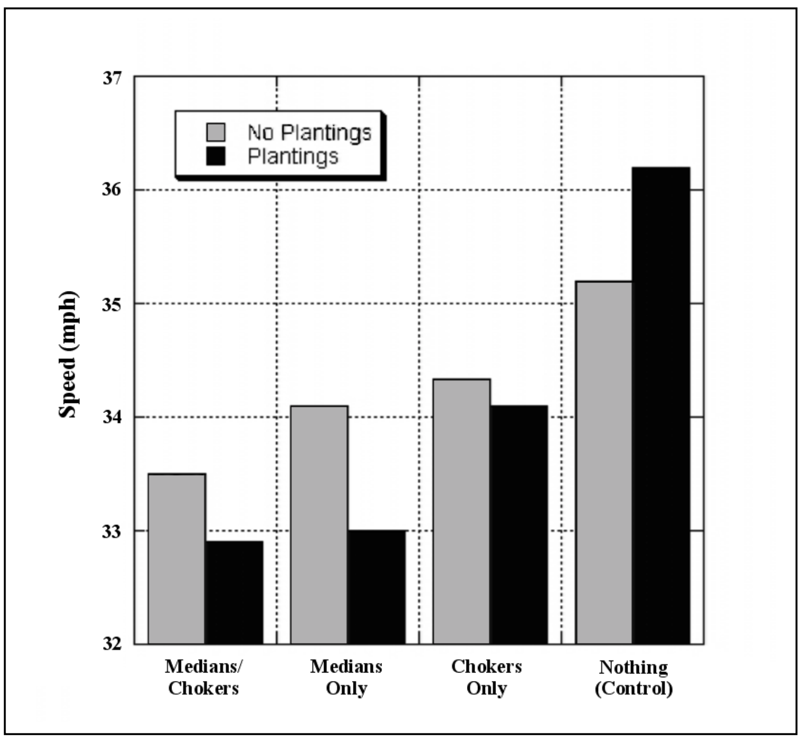


Even though the drop in speed for the median island/choker combination was found to be statistically significant (2.5 mph drop in mean vehicle speed), this may not be the best choice of application. The experiment showed a drop of approximately 2.2 mph in mean speed for the median island. The additional speed reduction achieved (0.3 mph) may not justify the additional cost to implement the median island/choker combination versus a median island alone.

Plantings

The experiment also tested the effect of curbside plantings on vehicle speeds. Adding plants to the various curb treatment scenarios did drop vehicle speeds for each of the curb treatments (see Figure 6-2), but the drop in speed, ranging between 0.2 to 1.1 mph, was not statistically significant.

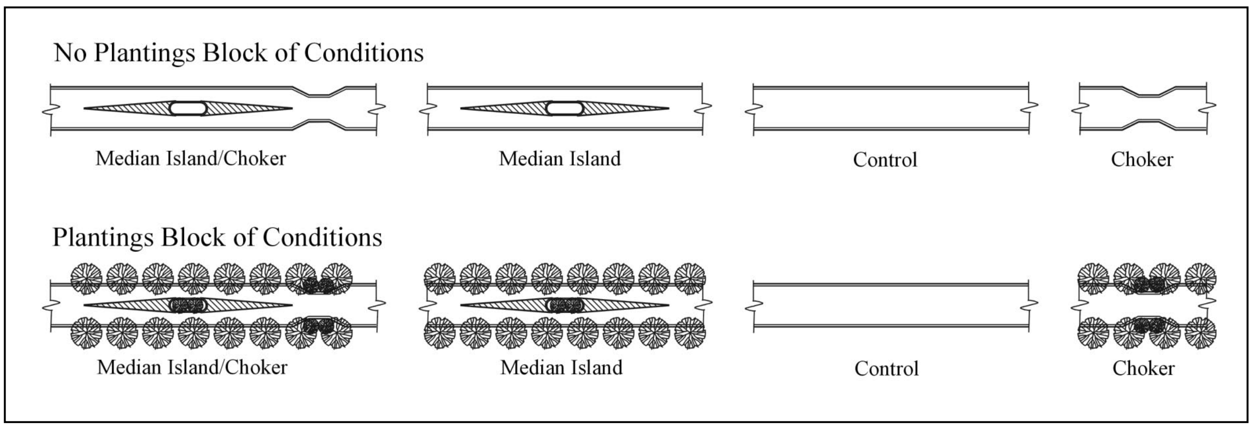
Figure 6-2
Effect of Plantings on Vehicle Speeds



The two-way ANOVA did reveal a statistically significant interaction for the control condition (no traffic calming devices) between the planting and non-planting test groups ($p<0.01$). This control condition was identical for both test groups, yet the mean speed for the control condition in the planting test group was significantly higher than in the non-planting test group.

The vegetation in the planting test group was continuous except at the control condition (see Figure 6-3). One interpretation for this difference may be that this continuous vegetation created a sense of enclosure. Once the vegetation was removed (the control condition), the sense of enclosure was lost and the participants responded by increasing their driving speeds.

Figure 6-3
Test Group Concepts



Limitations of Simulation Models

The simulator presented several limitations that affected the choice of what traffic calming measures to model, and the extent to which the built condition could be simulated. First, the simulator did not provide a method of testing changes in vertical alignment, such as speed humps. Secondly, the simulator did not have enough computing power to include all of the components of a “real” street in the simulation such as pedestrians, other moving automobiles and complete landscaping. It was felt, however, that the essential components of the streetscape were included in the models so as to make them valid research tools.

It should be noted that the design of the simulation experiments measured the effect of the traffic calming measures on driving behavior the first time a driver experienced the environment. The design of the simulation tests were such that bias associated with testing order was negated. Yet, there is a belief that people who are not familiar with traffic calming devices may initially drive slower, but will increase their driving speed as they acclimate to the this new environment. The budget established for this research project did not allow for participant to drive through the simulation environments numerous times. Therefore, it should be understood that the simulation experiments do not address long-term driver behavior.

Additional Simulation Modeling Information

Additional information regarding the simulation testing methodology and can be found in a report prepared by the University of Minnesota research team titled, *Investigating the Effects of Traffic Calming Strategies on Driver Behavior.* Additional information regarding the wrap-around simulator's equipment specifications can be found in Appendix C.

CHAPTER 7: CONCLUSIONS AND NEXT STEPS

Conclusions

Test Sites

Chokers appear to reduce vehicle speeds. This was supported by both field and simulation findings. It appears that the chokers may have a lesser impact on speeds as vehicles exit traffic-calmed areas and enter different areas.

Words painted on the pavement do not appear to reduce vehicle speeds. However, pavement markings in the form of chevrons, supplemented with speed limit signage, appear to reduce vehicle speeds. As the chevron paint begins the fade, vehicle speeds increase, but do not return to the pre-calming levels. The data collected after repainting the chevrons indicated that vehicle speeds decreased again.

The reconfiguration from a four-lane to a three-lane roadway appears to reduce vehicle speeds. The data indicates that the three-lane configuration might need a critical traffic volume to make it an effective traffic calming technique. If traffic volumes are too low, platooning will occur only occasionally and significant reductions in mean and 85th percentile speeds are not achieved.

The implementation of the raised crosswalk increased the variability of driver behavior as they approached the device, as indicated by an increase in the standard deviation. People may still be unfamiliar with this device and unsure how to react when they approach it, resulting in inconsistent driving behavior. In addition, the speeds approaching the device did not drop to the same extent as the vehicle speeds departing from the device, which indicates that drivers are not slowing down for the device until they are very close to it.

The data indicates that the raised crosswalk had a localized effect extending only several hundred feet from the device. This is similar to and supports previous research performed by others.

Simulation

Franklin Avenue Model

This traffic calming project which consisted of multiple devices (lane reductions, chokers and plantings) did result in reduced vehicle speeds. Due to the simultaneous implementation of these devices, it is not possible to determine to what extent each of these techniques contributed to the speed reduction achieved.

The simulator accurately predicted a reduction in vehicle speeds with the implementation of traffic calming measures. Based upon the results of a very small sample, the calibration findings do not provide an easy, straightforward conversion factor between the simulation and field data, and results appear to be site specific. Additional research is needed to further understand the relationship between the simulation data and observed data.

Residential Street Model

The simulation experiments showed statistically significant reduction in vehicle speeds associated with the curb treatment group, with the median island/choker combination providing the greatest speed reduction. The addition of plants to the curb treatments did slow vehicle speeds, but the incremental drop in speed was not statistically significant.

When dealing with traffic calming projects, it is important to realize that the project may produce other results beyond reductions in speed. The incremental benefit received by utilizing more than one traffic calming device in terms of reduced speed, reduced volume or enhanced aesthetics must also be weighed against the incremental cost to implement each additional device. This usually must be done on a case-by-case basis.

The interaction for the control condition between the planting and non-planting test blocks may have implications for the use of vegetation in traffic calming projects and for streetscapes applications. There may be an unexpected rise in vehicle speeds where the vegetation, or the sense of enclosure, is discontinued for any reason. This interaction should be tested further to better understand the implications for traffic calming and streetscape applications.

Finally, traffic calming devices designed to State Aid standards did reduce vehicle speeds. It is likely that greater speed reductions could have been achieved if narrower travel lanes or more abrupt travel lane curvature had been used. But it does indicate that traffic calming devices may be designed to address the concerns of both residents and engineers for streets with functional classifications higher than residential (local). As stated earlier in the report, the success of these projects is contingent upon the establishment of clear traffic calming goals early in the implementation process.

Additional Conclusions

As with most research projects, some of the most interesting and relevant questions arise during the evaluation of the data. This project was no exception. While reviewing the literature review and field data, the following question arose:

What is the appropriate measure of effectiveness for traffic calming devices?

Typically, the effectiveness of a traffic calming device is presented as a change in the mean or the 85th percentile speed, or as changes in traffic volumes and crash rates. Yet, none of these techniques tells the entire picture and at times can be misleading. For example, much of the literature review data indicates speed reductions ranging between 10 – 20 percent. But upon closer examination, the actual reductions in 85th percentile speeds are only 2 – 5 mph, which may be barely perceptible to a person standing on the sidewalk. Based upon anecdotal assessments of effectiveness received from city engineers, residents have expressed satisfaction with traffic calming measures that only achieve 85th percentile speed reductions in the range of 2 – 5 mph. The actual effectiveness of traffic calming projects may not be so much the reduction of mean or 85th percentile speeds, but rather, a reduction in those few vehicles that travel at excessive speeds. The findings from the test sites support this observation. Most of the projects showed substantial decreases in the number of incidents of excessive speeds as measured by the percentage of *after* vehicles exceeding the *before* 85th percentile speed. Therefore, the effectiveness of traffic calming should be defined using a combination of the following:

Quantitative Data

- Reduction in the mean speeds
- Reduction in the 85th percentile speeds
- Reduction of the highest speeds

Qualitative/Perceptual Data

- Reduction in the number of calls (complaints, inquiries, etc.)
- Residents feel safer
- Active response to public request

Effectiveness can often be relative. What a traffic engineer can measure is not always the same as what the public perceives. Much of the data gathered in this report found statistically significant reductions of two to three miles per hour. Can the public perceive this difference? The data also indicated that the number of drivers traveling at excessive speeds were reduced. Can the public perceive this difference? Would they deem this successful? Determining effectiveness is dependent on clearly identifying the condition - from both an engineering perceptive and a public perceptive.

Every situation is unique - the neighborhood circumstances, the traffic patterns and conditions, and the public's concerns. Although it can be concluded that traffic calming devices are effective, "effective" needs to be defined for each situation. This definition needs to be addressed and understood before selecting a traffic calming device and determining if it is effective.

Next Steps

Over the course of performing this research, the following issues came to light that the research team felt warranted additional investigation. Additional research on these topics would greatly benefit engineers and the public in making informed decisions regarding the implementation of traffic calming projects.

Develop a Local Traffic Calming Qualitative Information Database

There are many agencies within Minnesota that have implemented traffic calming devices. Even though these agencies did not collected *before* and *after* data, representatives from these agencies can still provide worthwhile insight regarding effectiveness of these projects to other agencies and individuals who are interested in implementing similar devices. It is suggested that research be performed to gather and organize qualitative information on existing projects into a reference database.

Develop a Model Traffic Calming Implementation Program

A traffic calming project can only be effective if a clear definition of "effective" is established at the beginning of the process. Neighborhood residents, city engineers and elected officials may all have different expectations for a project that may lead to dissatisfaction and frustration if not properly addressed. Therefore, in order to achieve a successful project, it is important to set up a process to establish a common understanding and common expectations for all involved. It is suggested that research be performed to develop a model process for the implementation of traffic calming projects to ensure that community needs are met.

Develop Best Practices for the Collection of Traffic Calming Data

Most of the data presented in this report had to be accompanied with disclaimers because almost all of the data collected utilized slightly different data collection methodologies. For many devices, the location and timing of data collection does impact the results. While it is believed that the data presented does provide indications of effectiveness, it is not possible to provide definitive conclusions due to these discrepancies. The collection of before and after data is important and requires a commitment of time and money. It is believed that a formalized process of collecting traffic data (when, where and how) and qualitative data (resident surveys) will provide added benefit for the time and money invested in the data collection effort. A formalized process will allow for the establishment of a reference database that will allow for greatly enhanced analysis and findings.

APPENDIX A

Literature Review Results

Appendix A

Appendix A summarizes the information that was collected as part of a literature review of *before* and *after* data for traffic calming measures. Included in the summary are descriptions of various traffic calming measures (listed alphabetically):

- A picture
- A sketch of the measure
- A brief description of the measure
- The cost of the measure
- Any *before* and *after* data related to the performance of the measure
- Benefits and drawbacks associated with the measure
- Sources of additional information

Chicane

Description	Created by placing curb extensions in a staggered pattern along both sides of the street, chicanes force drivers to move at a slower speed. They are landscaped with trees and shrubs.
Cost	$5,000 - $10,000 per location, depending upon existing street conditions
Performance	From Charlotte, NC, 6 percent reduction in 85th percentile speed 15 percent reduction in traffic volumes
Benefits	▪ Little if any impediment to transit/bus service ▪ Little or no increase in noise levels
Drawbacks	▪ Emergency vehicles may be impacted ▪ Parking may need to be removed around the chicane ▪ Street may look cluttered if not designed properly ▪ May be difficult to see and plow in the winter
Additional information	www.ci.fairfax.va.us, www.ci.charlotte.nc.us, www.trans.ci.portland.or.us. Saffel, Amy. *Effective Traffic Calming Applications and Implementation*. St. Paul: Minnesota Department of Transportation, 1998.

Chokers

Description	A physical reduction of road width at an intersection through widening of street corners. Also referred to as bumpouts or neckdowns. The purpose is to discourage through traffic, reduce speeds and provide a refuge for pedestrians.
Cost	Cost can vary, depending upon the landscaping and drainage issues associated with the location.
Performance	No completed studies were found on this measure.
Benefits	▪ Increased pedestrian safety due to shorter intersection crossing ▪ May decrease traffic volumes ▪ Should not impair emergency response vehicle ▪ May be aesthetically pleasing
Drawbacks	▪ May impair some transit/bus service ▪ May decrease parking
Additional information	

Cul-de-sac/Street Closure

Description	Physical barriers placed at the end of a street or mid-block, which stop the traffic flow. They are intended to reduce cut-through traffic on local streets.
Cost	$20,000 or more. Right-of-way acquisition and drainage issues can add significantly to the cost.
Performance	In 1997, the Local Road Research Board in Minnesota reported: ▪ Varied impacts on 85th percentile speeds and traffic volumes. ▪ In some cases, the impact to 85th percentile speeds was negligible (zero to four percent) and in one case, speed was reduced by 22 percent. ▪ Traffic volume decreases ranged from 17 to 48 percent ▪ *Note: The data summarized by the Local Road Research Board contained information for only three streets and may not be applicable for all road closures.*
Benefits	▪ Reduces traffic volumes ▪ Reduces noise levels ▪ Decreases speeds ▪ Increases safety
Drawbacks	▪ Limits access ▪ May increase traffic volumes on adjacent roadways ▪ May hinder transit/bus service – new routes may need to be created ▪ Hinders emergency vehicles
Additional information	**www.trans.ci.portland.or.us,** Robinson, Ferrol and Joni Giese. *Traffic Calming Activity in Minnesota*. St. Paul: Minnesota Department of Transportation, 1997 Saffel, Amy. *Effective Traffic Calming Applications and Implementation*. St. Paul: Minnesota Department of Transportation, 1998.

Diagonal Diverter

Description	Diagonal diverters are a barriers placed diagonally across an intersection. They are intended to reduce cut-through traffic on local streets.
Cost	$15,000 to $35,000, depending upon the intersection.
Performance	Local Road Research Board report on traffic calming in Minnesota (1997) indicated: ▪ Decreased traffic volumes by 30 percent on W. 38th Street in St. Louis Park. ▪ *Note: Data summarized by the Local Road Research Board contained information for only one street and may not be applicable for all roads.*
Benefits	▪ Reduces traffic volumes ▪ Restricts vehicle access while maintaining bicycle and pedestrian access ▪ No parking impacts ▪ No increase in noise
Drawbacks	▪ Prohibits or limits access and movement (some consider this an advantage; others see it as a disadvantage) ▪ Restricts access for emergency vehicles ▪ Restricts access for transit/bus service
Additional information	**www.trans.ci.portland.or.us** Robinson, Ferrol and Joni Giese. *Traffic Calming Activity in Minnesota*. St. Paul: Minnesota Department of Transportation, 1997 Saffel, Amy. *Effective Traffic Calming Applications and Implementation*. St. Paul: Minnesota Department of Transportation, 1998.

Entrance Treatments

Description	Entrance treatments are physical and textural changes to neighborhood entries, which may take the form of curbline modifications, changes in materials or landscaping or signage. Entrance treatments inform drivers that they are entering a residential area.
Cost	$5,000 and $20,000
Performance	No completed studies were found on this measure.
Benefits	▪ Drivers are made more aware of their environment ▪ No impact on emergency service vehicles ▪ No impact on transit/bus service ▪ Limited or no parking impacts
Drawbacks	▪ Limited influence on speed ▪ Not likely to reduce traffic volumes ▪ May increase noise (rough pavement surfaces)
Additional information	**www.trans.ci.portland.or.us**

Exclusion Lane

Description	Designed for a particular type of vehicle, excluding all other vehicles, (i.e., bus-only lanes, bicycle lanes and car pool lanes). Exclusion lanes are intended to change traffic patterns by giving priority to certain types of vehicles.
Cost	$2,000 to $10,000
Performance	No completed studies were found on this measure.
Benefits	▪ Transit vehicle flow may improve ▪ Emergency vehicles are not hindered ▪ Traffic volumes may decrease ▪ Safety for bicyclists or pedestrians may be increased
Drawbacks	▪ Parking may be lost
Additional information	**www.trans.ci.portland.or.us**

Median Barrier

Description	An island or curb located on the centerline of a street and intended to reduce traffic volumes. Placement is usually at intersections or at mid-block and continuing through intersections with cross streets. A median barrier may also be referred to as a pedestrian refuge, providing a stopping point for pedestrians crossing the roadway.
Cost	$8,000 to $20,000
Performance	No completed studies were found on this measure.
Benefits	▪ Facilitates pedestrian movement ▪ Makes pedestrian crossing points visible to drivers ▪ Prevents vehicles from passing other vehicles that are turning ▪ Separates opposing vehicle travel lane ▪ May reduce speeding ▪ May improve safety through access limitations ▪ May visually enhance the street through landscaping ▪ May negate the need for a traffic signal
Drawbacks	▪ May require major parking removal ▪ May limit access and movement from driveways ▪ Restricts access for emergency service vehicles
Additional information	**www.trans.ci.portland.or.us** Saffel, Amy. *Effective Traffic Calming Applications and Implementation*. St. Paul: Minnesota Department of Transportation, 1998.

Narrowing Lane

Description	Narrowing of road lanes can be done either by moving the actual curb line physically inward or altering the appearance of the road width through the use of pavement markings. The purpose is to reduce speeds.
Cost	Cost can vary significantly, as inexpensive as $0.20 per foot (if the pavement markings are altered) or over $50.00 per foot (if curbs are moved inward).
Performance	No completed studies were found on this measure.
Benefits	▪ Pavement markings are inexpensive and can be implemented quickly ▪ Can be complimented with landscaping to enhance the roadway (if curblines are modified) ▪ No increase in traffic noise ▪ May reduce traffic speeds ▪ Should not impair emergency vehicles ▪ Should not impair transit
Drawbacks	▪ May increase regular maintenance if pavement markings are used ▪ May result in some parking loss
Additional information	Saffel, Amy. *Effective Traffic Calming Applications and Implementation*. St. Paul: Minnesota Department of Transportation, 1998.

Semi-Diverter

Description	Islands or curb extensions that block one lane of a street; they are usually placed at an intersection. Semi-diverters are intended to reduce volumes by allowing only one lane of travel and can be used as a pedestrian refuge.
Cost	$2,500 to $20,000, depending on landscaping and drainage issues.
Performance	No completed studies were found on this measure.
Benefits	▪ Allows for movement of emergency vehicles ▪ No noise impacts ▪ Reduces traffic volumes
Drawbacks	▪ Parking opportunities may be impacted to permit emergency vehicle access ▪ May impact transit/bus routes ▪ May decrease emergency vehicle movement, if improperly designed
Additional information	**www.trans.ci.portland.or.us** Saffel, Amy. *Effective Traffic Calming Applications and Implementation*. St. Paul: Minnesota Department of Transportation, 1998.

Speed Hump

<table>
<tr><td>Description</td><td colspan="4">Asphalt or rubber mounds that run the full width of a roadway, typically 3-4 inches high, 14-22 feet in length. They are intended to reduce vehicle speeds to 20-25 miles per hour. Speed humps are normally installed on local and collector streets.</td></tr>
<tr><td>Cost</td><td colspan="4">$7,000 per pair. Cost may be higher if there are drainage issues.</td></tr>
<tr><td rowspan="8">Performance</td><td>Location</td><td>Reduction in 85th Percentile Speed</td><td>Reduction in Traffic Volume</td><td>Reduction in Crashes</td></tr>
<tr><td>Bellevue, WA</td><td>31%</td><td></td><td></td></tr>
<tr><td>Charlotte, NC</td><td>11%</td><td>13%</td><td></td></tr>
<tr><td>Portland, OR</td><td>24%</td><td>12%</td><td></td></tr>
<tr><td>14-foot speed humps</td><td>to 25.8 mph</td><td>33%</td><td>48%</td></tr>
<tr><td>22-foot speed humps</td><td>to 29.9 mph</td><td>21%</td><td>32%</td></tr>
<tr><td>Minneapolis, MN</td><td>to 18 mph</td><td></td><td></td></tr>
<tr><td>Burnsville, MN</td><td>8%</td><td>33%</td><td></td></tr>
<tr><td>Benefits</td><td colspan="4">▪ Reduces speeds
▪ Usually reduces traffic volumes
▪ Does not require parking removal or interfere with bicycle/pedestrian traffic</td></tr>
<tr><td>Drawbacks</td><td colspan="4">▪ Can potentially increase noise
▪ Can cause traffic to shift to parallel residential or collector streets
▪ May decrease emergency vehicle response times</td></tr>
<tr><td>Additional information</td><td colspan="4">www.ci.charlotte.nc.us, www.ci.fairfax.va.us, www.trans.ci.portland.or.us

Robinson, Ferrol and Joni Giese. Traffic Calming Activity in Minnesota. St. Paul: Minnesota Department of Transportation, 1997.

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U.S. Department of Transportation. Case Study No. 19 – Traffic Calming, Auto Restricted Zones and Other Traffic Management Techniques – Their Effects on Bicycling and Pedestrians. Washington, D.C.: Federal Highway Administration, 1994.</td></tr>
</table>

Speed Table

Description	Raised sections of a street or intersection that are long and flat on top, so both the front and back wheels of a vehicle are on the table at the same time. They are similar to speed humps except that they are longer and flatter on top and can run from curb line to curb line, or be located in sets adjacent to one another. Their purpose is to decrease vehicular speed and provide more visibility and safety for pedestrians crossing the street.
Cost	Generally cost less than speed humps because they do not run the full width of the roadway.
Performance	No completed studies were found on this measure.
Benefits	▪ Slows vehicular speed ▪ May reduce traffic volumes ▪ Allows large vehicles to pass over the table with minimal disruption. ▪ Improves the safety of pedestrians and bicyclists ▪ Does not interfere with drainage (if they do not run from curb to curb) ▪ Does not interfere with most emergency vehicles ▪ Does not hinder snow removal
Drawbacks	▪ May require some parking loss ▪ May have an increase in the amount of noise due to braking
Additional information	**www.ci.charlotte.nc.us** Saffel, Amy. *Effective Traffic Calming Applications and Implementation*. St. Paul: Minnesota Department of Transportation, 1998.

Traffic Circle

Description	Traffic circles are raised islands placed in an intersection. They are usually landscaped with ground cover and street trees. Their purpose is to reduce the number of angles, collisions, vehicle speeds and traffic volumes.
Cost	$3,000 and $15,000 depending on landscaping and drainage issues.
Performance	**Seattle, WA:** 94 percent reduction in accidents. Case Study No. 19 reports that traffic circles have become popular because they have reduced the number of collisions at previously high-accident intersections. **Portland, OR:** 58 percent reduction in multi-vehicle collisions and 31 percent reduction in reported intersection collisions. Both Cities have found slight decreases in traffic speeds and little evidence to support the claims of a reduction in traffic volumes
Benefits	▪ Reduces vehicle speeds ▪ Improves safety conditions for vehicles ▪ Can be visually attractive
Drawbacks	▪ Reduces parking ▪ May lead to an increase in bicycle/pedestrian/automobile conflicts due to narrowed lane ▪ May reduce emergency vehicle movement if vehicles are parked illegally near the circle ▪ May interfere with snow removal
Additional information	**www.ci.fairfax.va.us**, **www.trans.ci.portland.or.us** and **www.usroads.com** Saffel, Amy. *Effective Traffic Calming Applications and Implementation*. St. Paul: Minnesota Department of Transportation, 1998. U.S. Department of Transportation. *Case Study No. 19 – Traffic Calming, Auto Restricted Zones and Other Traffic Management Techniques – Their Effects on Bicycling and Pedestrians*. Washington, D.C.: Federal Highway Administration, 1994.

APPENDIX B

Summary

Survey of Minnesota Cities and Counties

Appendix B

In June of 2001, a survey was distributed to all Minnesota cities that have a population greater than 5,000 along with the 10 counties within the Twin City metropolitan area. The survey asked respondents to identify any traffic calming initiatives implemented by their community. Respondents that indicated use of traffic calming devices were also asked if they had collected *before* and *after* data.

Approximately 150 surveys were distributed via e-mail. A total of 48 responses were received by August 15, 2001. Of the surveys that were returned, 18 communities (38 percent) indicated that they had installed some type of traffic calming device. Unfortunately, most of those communities indicated that they had not collected *before* and *after* data. Only eight (44 percent) of the communities that had installed devices had completed both *before* and *after* data collection by the time the survey was returned. Three of the agencies, however, indicated that they intended to collect *before* and *after* data on their next project or were in the process of collecting *after* data for projects just completed. Comments from the agencies that installed traffic calming devices are found in Table B-2.

Follow-up telephone calls were made to agencies that indicated they had collected *before* and *after* data. Three of the agencies forwarded the results of their studies. Table B-2 shows the results of devices implemented in the cities of Blaine, Oakdale and St. Paul, Minnesota.

Table B-1
2001 Survey – Before and After Data

City	Device	Location	Before 85th Percentile Speed (mph)	After 85th Percentile Speed (mph)	Percent change
Blaine	Speed humps	Davenport Street NE	38	30	- 21%
Blaine	Speed humps	Baltimore Street NE	34	28	- 18%
Oakdale	Stop signs	11th Street	32	27	- 16%
St. Paul	Temporary speed humps	Otis Avenue	34	28	- 18%
St. Paul	Speed humps	Central Avenue	40	35	- 13%

The City of St. Paul also reported converting Fairview Avenue from a four-lane facility to a three-lane facility. They indicated that there was a 4 percent decrease in traffic volumes and a 61 percent decrease in crashes. In addition, they indicated that before the change in lane configuration, 53 percent of the drivers drove at speeds greater than 33 mph. After the lane change configuration, only 31 percent of the drivers drove at speeds greater than 33 mph.

Table B-2
Traffic Calming Devices Implemented – Results from 2001 Survey

Type of Device	*Comments*	*Agency*
Count Down Timers, Speed Humps, Median Islands, etc	We have experimented with a plethora of measures. We have some limited studies on various devices and empirical information on others.	City of St. Paul
Chokers	We do not have any *before* or *after* data. The neckdowns were installed to improve sight distance.	City of Farmington
	Data was collected.	City of Eagan
	We have used chokers (from 32 to 28 feet) in several instances. We have also used landscaped medians, narrowed lanes and landscaping. We have made a decision not to use speed humps in any instances. We have not collected any *before* or *after* data. Most of the measures used have been part of street reconstruction or new construction.	City of Golden Valley
Neighborhood Signs	The signs are privately owned. They are put up and taken down periodically to remind drivers of the nature of the street.	City of Chanhassen
Numerous Types	Numerous neighborhoods have conducted traffic studies to collect data and identify issues. These studies were performed by various consultants.	City of Minneapolis
Speed Humps and Raised Crosswalks	We installed some speed humps and raised crosswalks along a two-mile stretch of West River Parkway in 1998. Consultants gathered traffic speeds and counts *before* and *after* the installation.	City of Minneapolis
Speed Humps	We installed speed humps in two locations in the summer of 2000. A report was prepared. In addition, we are installing speed awareness devices in 14 locations. We will also be conducting a neighborhood speed awareness program.	City of Blaine
	We have installed one set of speed humps. We are still collecting data.	City of Woodbury
	We have installed three speed humps on a dead end road that leads to a private country club for a back access driveway. There is no *after* data available.	City of Orono

Table B-2
Traffic Calming Devices Implemented – Results from 2001 Survey Cont'd

Type of Device	*Comments*	*Agency*
Speed Humps Cont'd	We have implemented a few speed hump installations. We have not collected much data on speeds or volumes. Currently the City has installed speed humps at two locations, and the Council has approved the installation of a new set of humps. We have *before* data for the new project; however, we will not have any *after* data until later this summer (2001). In addition, we will be converting Plymouth Blvd from four lanes to two lanes with on-street parking. Data will be available later this year (2002).	City of Plymouth
	We have installed temporary speed humps on a few sites. Following their installation, interest in permanent humps diminished.	City of Andover
Stop Signs	We have installed stop signs on a street with intersection cul-de-sacs at 350-foot spacings. The volumes have not changed, but the average and 85th percentile speeds have dropped five miles per hour.	City of Oakdale
	We have implemented a few traffic calming devices (stop signs). We have also studied many devices and locations. The City is currently in the middle of implementing a device. We do not have any *after* data.	City of Richfield
Streetscaping, Chokers, Semi-Diverters, Cul-de-Sacs, Edge Stripes	No effort was made to collect *afte*r data.	City of Rochester
Traffic Circle	We constructed a traffic circle in a new development; we do not have any *before* data. We will be reconstructing a roadway with a narrower than normal sections (28 feet) next year in an attempt to calm traffic. *Before* data has been collected for this roadway. Just a note, both of the roadways are State Aid routes.	City of Brooklyn Park

APPENDIX C

University of Minnesota
Human Factors Research Laboratory's
Wrap-around Driving Simulator
(WAS) Equipment Specifications

Appendix C

University of Minnesota, Human Factors Research Laboratory's wrap-around driving simulator (WAS) equipment specifications

The wrap-around driving simulator (WAS) at the University of Minnesota's Human Factors Research Laboratory is a fixed base driving simulator, consisting of a full-body 1990 Acura Integra RS enclosed in a spherical wood and steel dome measuring 12.5 feet (3.81 meter) high at its apex with a 15.5 feet (4.73 meter) internal diameter. The car has sensors to detect accelerator, brake and steering inputs, providing a real-time interface for the driver. Force feedback was applied to the steering wheel through the steering column with a torque motor. The speedometer was functional, and powered by a small motor that was controlled by the main simulator computer.

The virtual environment through which the participants drove was generated with an SGI Onyx computer (Reality Engine 2). The programming was done using MultiGen-Paradigm Vega and SGI Performer APIs. The main simulator computer was a PC running Linux, which processed all vehicular sensors and controllers. The vehicular hardware interfaced the main simulator computer by means of a National Instruments AT-MIO-16E-10 data card. Information from this computer was transmitted to and from the Onyx via TCP/IP. The Onyx calculated the vehicle dynamics and generated the visual scenario.

A Proxima 9250+ projector, operating at a resolution of 1240 X 768 was used to create the visual scene inside the simulator. The virtual roadway was projected onto the mid-section of a curved seamless 24 feet (7.32 meter) x 8 feet (2.44 meter) screen positioned in front of the car. The projector provided a 52-degree forward view.

Engine/road noise was generated by the Onyx and fed through a Cerwin-Vega satellite and subwoofer system (mounted in the trunk of the vehicle) and two Aura bass shakers mounted under the front seats. A separate stereo receiver (Sony #STR-D365, Tokyo) powered this supplemental system.

APPENDIX D

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