Temporary Speed Hump Impact Evaluation

CTRE Project 00-73

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EXECUTIVE SUMMARY

The main objective of this research was to evaluate the impact of temporary speed humps and speed tables on vehicle speeds, vehicle speed profiles, and traffic volumes along local and/or collector streets in several rural Iowa cities. A 25 mile per hour (mph) temporary speed hump and a 30 mph temporary speed table, both made of recycled rubber, were purchased to test the impact of temporary devices. Two cities volunteered and the speed hump/table was installed on two test streets in the city of Atlantic (Roosevelt Drive and Redwood Drive) and one test street in the city of Le Claire (Canal Shore Drive). The speed hump was installed first and then converted to a speed table. Each device was installed for a period of at least two weeks at the same location. Speed, volume, and resident opinion data were then collected and evaluated.

In general, the devices were shown to be effective with the temporary speed table performing as well or better than the speed hump. Both the speed hump and the speed table were effective in reducing mean speeds at the device and immediately downstream, while speeds immediately upstream and farther downstream were less likely to be affected. The speed hump and speed table also reduced the number of vehicles exceeding the speed limit in the immediate vicinity of the devices.

However, it should be noted that neither Roosevelt Drive nor Redwood Drive in Atlantic had a significant speeding problem before the devices were installed. Canal Shore Drive in Le Claire was not experiencing a speeding problem at all. As a result, the study is not able to address the impact of the temporary devices on excessive speeds. An evaluation of the 85th percentile speeds indicates that both the temporary speed hump and temporary speed table effectively reduce 85th percentile speeds at the location of the device and for at least the length of data collection downstream (about 400 feet). However, 85th percentile speeds upstream of the device were not significantly influenced by the presence of either device, which suggests that a single speed hump or table is only effective in the immediate vicinity. In addition, the speed table appeared to decrease downstream speeds more than the speed hump although the opposite was expected. Finally, comparison of the results with results from other studies indicates that both speed humps and speed tables reduce the 85th percentile vehicle speeds as effectively in small rural communities as they do in larger urbanized areas.

Optimum spacing of speed humps/tables was also evaluated using vehicle speed profiles. Spacing values of 220 feet to 285 feet were calculated for temporary speed humps on Roosevelt Drive and Redwood Drive. This range of spacing is shorter than most values used by other jurisdictions, but still similar to these values.

The short-term impacts of the speed hump/table were also evaluated. Unfortunately, there were no definitive conclusions as to whether the speed hump or table was able to impact speeds short-term. After the device was removed several sections of the test sites had lower speeds than before the devices were installed. However for other sections, speeds were not significantly different after the devices were removed. In general however, once the devices were removed the number of vehicles exceeding the speed limit remained lower than before installation.

Overall, an analysis of the volume data collected did not indicate any reductions in traffic volumes along Roosevelt Drive, Redwood Drive, or Canal Shore Drive that would suggest traffic diversion occurred. Thus, it can be concluded that the temporary devices did not divert traffic for the three test sites. This was expected because the primary function of speed humps and speed tables is their impact on vehicle speed and not traffic volumes. In addition, there were no parallel streets for volume diversion to occur. Small sample size, however, limits the strength of this conclusion.

The results of the resident survey in this study were consistent with those reported in other jurisdictions. Overall more respondents were supportive of the use of the temporary speed hump/table than opposed. Many of the residents who participated in the resident survey perceived reduced traffic speeds but no change in traffic volume. A number of positive comments were also received about increased safety levels, greater attention from drivers, and the less severe profile of the speed hump/table when compared to the more familiar speed bump. However, the responses from the resident survey related to the preference of temporary device were not conclusive. Temporary speed humps were preferred on Redwood Drive and Canal Shore Drive, and temporary speed tables were preferred on Roosevelt Drive. The majority of the respondents, however, indicated they had no preference or did not respond to question seven.

The results of this research in Atlantic and Le Claire show the effectiveness of temporary speed humps and temporary speed tables and the effectiveness of traffic calming in small rural cities. It is recommended that small rural jurisdictions may consider temporary speed humps and/or temporary speed tables as a possible solution to concerns of speeding traffic on residential streets.

The temporary speed hump and temporary speed table used in this study were easily installed and removed with little damage to the existing pavement. These temporary devices provide jurisdictions with a valuable opportunity to test the use of speed humps and/or speed tables on residential streets and determine whether they are an effective solution to a particular traffic problem. They also provide an opportunity to evaluate the public's opinion of the devices. Although up-front costs of the temporary devices may be higher than installing a permanent device, should a permanent device be rejected by the public or not function effectively, additional costs are incurred in the removal process, especially if a number of devices are installed. These temporary devices may also be ideal for jurisdictions that have concerns of snow removal or those that experience unwanted traffic characteristics during certain times of a year only (e.g., recreational areas). However, more than one device may be necessary to maintain lowered speeds throughout an area.

INTRODUCTION

Speed humps have been widely used by some local jurisdictions in the United States and can be an effective device for reducing cut-through traffic and vehicle speeds on local and collector roads. A number of studies have shown that speed humps are effective in reducing vehicle speeds especially at the devices.

However, some jurisdictions have been hesitant to install speed humps and/or speed tables for a variety of reasons. For example, many jurisdictions are concerned about snow removal, public acceptance, and the cost associated with removal of a permanent device if it does not function effectively. Many agencies across the United States have developed traffic calming programs by first implementing temporary traffic calming (Noyes and Associates, 1998). The advantage of using a temporary program prior to permanent installation is that it provides an opportunity for jurisdictions to test traffic calming devices for effectiveness and obtain public input at a relatively low cost (Noyes and Associates, 1998). Temporary devices can also be removed for the winter months if snow removal is a significant concern.

Problem Statement

Numerous studies have indicated that speed humps and speed tables effectively reduce traffic speeds and/or volumes. However, the majority of studies were conducted in densely populated areas. Consequently, the effectiveness of speed humps/tables in smaller particularly rural cities has not been thoroughly evaluated. Speed humps or table may perform differently in smaller cities since traffic patterns and volumes are different than for large urbanized areas. The level of acceptance towards traffic calming devices may also be different. Additionally, a general lack of driver experience with speed hump devices may also have an impact on their speed reduction capabilities.

One way for small communities to evaluate traffic calming without investing significant time and resources is to use temporary devices and evaluate their impact. However, while some jurisdictions have used temporary speed humps and temporary speed tables, the effectiveness of these devices has not been evaluated in great detail nor have any comparisons been made between the temporary devices and permanent devices. Most of the studies available on the effectiveness of speed humps are for *permanent* speed humps. It is has been speculated that it may be possible to slow speeds and/or reduce traffic volumes for a period of time after a temporary speed hump has been removed. If true, the installation of temporary speed humps on different roadways within a neighborhood (on a rotating but irregular time period basis) may decrease the overall neighborhood speeds and/or traffic volumes. This would produce temporary impacts similar to the multiple speed hump installations that are part of a neighborhood speed hump program. The mid- to long-term impacts of temporary speed humps should be investigated.

Additionally although they have been shown to be effective at reducing speeds in the vicinity of the device, little research has been done to evaluate how drivers react to the devices in terms of how vehicles speeds changes with respect to the location of the speed hump(s). Consequently, the approach to spacing devices has not been quantitative and may be the reason there is a large number of sometimes overlapping speed hump spacings suggested in different jurisdictions. An effective speed hump(s) installation should slow traffic to the objective speed over as long a roadway segment as possible. Therefore, knowing the start and end of the vehicle decelerations and accelerations related to speed humps is important for speed and safety purposes. The goal with any installation would be to slow traffic over as long a roadway segment as possible, but with the smallest number of speed humps. Vehicles traveling at a constant, but decreased speed (due to proper speed hump spacing) may also decrease noise and pollution levels. This approach to speed hump installation should increase the level of safety along the roadway segment (by reducing the severity of the crashes that do occur), but also more effectively use the funding available for speed hump installation. The spacing of speed humps that meets these objects needs to be quantitatively determined.

Research Objectives

The main objective of *Temporary Speed Hump Impact Evaluation* was to evaluate the impact of temporary speed humps and speed tables on the vehicle speeds, vehicle speed profiles, and traffic volumes along local and/or collector streets in several rural Iowa cities. More specifically, the objective included the following:

- Evaluate the effectiveness of 25-mph temporary speed humps in rural cities in reducing average vehicle speeds. Specifically, this research intended to address whether speed humps were as effective in rural areas as they have been shown to be in urban areas.
- Evaluate the effectiveness of temporary speed humps in reducing top vehicle speeds. The impact that traffic calming devices have on drivers traveling at speeds significantly over the speed limit is as important as whether the average vehicle speed is reduced.
- Evaluate the use of temporary speed humps in reducing average vehicle speeds and top vehicle speeds as compared to speed humps. If the speed table could be shown to be as effective in reducing top speeds, its use may be recommended over the hump since it is more comfortable for drivers to traverse, due to the flatter surface, and may provide less impact to ambulance or fire services.
- Collect vehicle speed profiles to determine how vehicles negotiate the devices and to quantify hump/table spacing requirements to maintain optimum speeds.
- Evaluate the short-term speed reduction effects of the temporary devices.
- Evaluate the response of rural residents to speed hump/tables and compare their attitudes with those of urban areas.

Organization of Report

The second section, Background, includes a detailed literature review that focuses on speed humps and speed tables. This literature review contains a description of currently used speed hump and speed table designs, currently used spacing criteria for speed humps and tables, the advantages and disadvantages associated with speed humps and speed tables, and the results from resident surveys conducted in several jurisdictions in the United States. The next section, Data Methodology, discusses the site selection process and a description of the test sites used in this study. A brief description of the temporary speed hump/table installation process, the traffic control devices used, and the data collection methodology employed is also discussed. The Data Analysis and Results section focuses on the data evaluation process, discussing the evaluation of speed profiles, vehicle speed data, temporary speed hump/table spacing, and traffic volume data. In the next section, the evaluation and results of the resident survey are discussed and compared to other resident surveys conducted in the United States. The final section, Conclusions and Recommendations, summarizes the results of the evaluation process and the conclusions reached. Also included are suggestions for future research and recommendations for jurisdictions considering the implementation of temporary speed humps and/or temporary speed tables.

BACKGROUND

The concept of traffic calming was introduced in the Dutch town of Delft in 1970 when city officials built a 0.26-foot (8-centimeter) road hump at the end of an alley (Schlabbach, 1997). The concept of traffic calming has spread throughout Europe, Canada, the United States, and Australia. In 1975, Berkeley, California, implemented the first major traffic calming program in the United States. Traffic calming programs can now be found throughout the United States. At least 60 local governments in 22 states now have traffic calming programs (Weinstein and Deakin, 1999). Since various interpretations of what traffic calming is have emerged, the Institute of Transportation Engineering (ITE) developed a standard definition of traffic calming in 1997. Their definition is as follows:

> Traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior, and improve conditions for non-motorized street users. (Lockwood, 1997)

This definition was intentionally made broad to apply to all the situations in which traffic calming may be an option but narrow enough to carry a definite meaning.

A number of traffic calming programs have been successfully implemented in the United States. A variety of traffic calming devices have been utilized in these programs including closures, diverters, chicanes, traffic circles, roundabouts, and speed humps. Speed humps, the most common device, are vertical undulations 3 to 4 inches in height that span the width of the roadway with various lengths (measured in the direction of travel). A speed hump is designed so that a driver feels discomfort if the hump is traversed at a speed above the determined safe or design speed. Speed humps, also known as sleeping police officers, are self-enforcing, but are often opposed by fire and rescue agencies due to concerns of increased emergency response times (Ewing, 1999; Mulder, 1998).

Speed humps have been used successfully in many cities in the United States including Portland, Oregon; Phoenix, Arizona; and Montgomery County, Maryland. Speed humps also have been widely used by some local jurisdictions in the United States and can be an effective device for reducing cut-through traffic and vehicle speeds on local and collector roads.

History of Traffic Calming

The concept of traffic calming originated in the Netherlands. In the 1960s, traffic volumes in the Netherlands increased as the automobile became more popular. By the late 1960s, Dutch transportation officials began receiving public complaints about speeding traffic through residential neighborhoods (Schlabbach, 1997). Early attempts at traffic calming were in response to these complaints. In 1970, the Dutch town of Delft installed the first traffic calming device, a 3-inch speed bump constructed at the end of an alleyway to slow traffic. Similar road bumps were also installed at about the same time in the Dutch towns of Rotterdam and Utrecht, along with other speed inhibiting devices like road narrowings (Schlabbach, 1997).

The success of the speed inhibiting measures used in the Netherlands led other European countries to experiment with these devices. Germany began experimenting with narrowings, roundabouts, and textured surfaces around 1977 (Schlabbach, 1997; Ewing, 2000). These devices proved to be as successful in Germany as they were in the Netherlands (Ewing, 2000). Similar traffic calming programs were developed in Norway, Sweden, Switzerland, England, France, Austria, Israel, and Japan (Ewing, 1999).

The concept of traffic calming eventually spread to other regions of the world including Australia, Canada, and the United States. Berkeley, California, and Seattle, Washington, were the first jurisdictions in the United States to attempt traffic calming. Berkeley is often given credit for being the first jurisdiction in the United States to implement a citywide traffic calming plan, which occurred in 1975 (Ewing, 1999).

The use of speed humps in the United States began in 1979 when the United States Federal Highway Administration (FHWA) began testing speed humps on a closed site in St. Louis, Missouri (ITE Traffic Engineering Council, 1997; Smith and Appleyard, 1981). The tests were conducted on a closed test site to evaluate the safety of speed humps prior to their installation on public streets (Smith and Appleyard, 1981). About the same time, Sacramento, California, conducted their own closed-site tests on speed humps (Smith and Appleyard, 1981). The results of the St. Louis and Sacramento tests convinced the FHWA that speed humps could be used safely on public streets (Smith and Appleyard, 1981). In 1980, the first speed humps, a series of three, were installed on La Canada, a public street, in the city of Brea, California (Smith and Appleyard, 1981). Results of the Brea installation were favorable, and in 1983, a Subcommittee of the California Traffic Control Devices Committee issued a report in favor of speed hump use on public streets (ITE Traffic Engineering Council, 1997; Smith and Appleyard, 1981). Today, numerous jurisdictions across the United States have implemented traffic calming programs, using a variety of traffic calming devices.

Traffic Calming Devices

Traffic calming devices are used to reduce speed and/or volumes along residential streets and may be grouped as either volume control or speed control devices (Ewing, 1999). Schematics of several commonly used volume and speed control devices are provided in Appendix A.

Volume Control Devices

Volume control devices are used where a reduction in traffic volume is desired. A typical application of a volume control device may be on a roadway where a significant number of vehicles are using a residential street as a through route. Volume control devices are physical devices or restrictions that discourage, and in some cases prohibit, through traffic movements.

The most common volume control device is a full or partial street closure (Ewing, 1999). Cul-de-sacs and dead-end streets are examples of a full street closure (see Figure A.1 in Appendix A). Half- or partial street closures exist when only one lane of traffic is closed or blocked for a short distance on an otherwise two-way street (Figure A.2). With a half-street closure, access can be provided to vehicles exiting a residential area while prohibiting through traffic from entering the residential area. The disadvantages of closures include concerns about emergency response time, street network connectivity and capacity, and traffic diversion to parallel streets (Ewing, 1999). A similar volume control traffic calming device is the diagonal or semi-diverter (see Figures A.3 and A.4). In addition, forced turn islands (see Figure A.5) can also be used to reduce traffic volumes.

Speed Control Devices
Speed control measures are physical devices designed to reduce vehicle speed. Some of these devices have also been shown to have an impact on traffic volumes. Speed control devices can be divided into three categories: horizontal measures, narrowings, and vertical measures (Ewing, 1999).

Horizontal speed control measures are physical devices that require vehicles to shift laterally. Drivers must reduce their vehicle speed to comfortably maneuver through and around the shift. The most commonly used horizontal measure is the traffic circle (see Figure A.6) (Ewing, 1999). Traffic circles are typically raised circular islands located in the center of an intersection. Typical concerns related to the implementation of traffic circles are the ability of large vehicles to maneuver around an obstacle with a small radius, the safety of pedestrians and bicyclists, and the cost of implementation (Ewing, 1999). However, all of these concerns have been addressed, and traffic circles are the most common horizontal traffic calming measure used in the United States (Ewing, 1999).

Another horizontal speed control device is the “chicane” (see figure A.7). A chicane is a series of curb extensions or bulbouts placed on opposite sides of the street in an alternating pattern. The alternating pattern may also be achieved with the painting of designated on-street parking areas. To maneuver through a chicane, a vehicle is forced to weave in a serpentine fashion. Like traffic circles, the biggest disadvantage of the chicane is often the cost associated with construction and curb realignment (Ewing, 1999).

Road narrowings are created when the travel lane is physically reduced or perceived to be reduced by the driver and are often used to “pedestrianize” an intersection by creating shorter crossing distances (Ewing, 1999). Several different methods and devices have been used to narrow the travel way. Examples of narrowings include “neckdowns” (see Figure A.8), the addition of a center island (see Figure A.9), and “chokers” (see Figure A.10). Properly designed narrowings also decrease the crossing distance for pedestrians and/or operate as a pedestrian refuge (Ewing, 1999).

Vertical speed control measures are physical devices designed to vertically displace the frame of a vehicle. Drivers must reduce speed to comfortably traverse this type of obstacle. Examples of vertical speed control measures include raised intersections, speed humps, and speed tables (Ewing, 1999). A raised intersection is a flat plateau that encompasses the entire intersection (see Figure A.11). Speed humps, not to be confused with the speed bump (vertical undulations three to six inches in height and one to three feet in the direction of travel) are typically parabolic in shape, three to four inches in height, 12 feet in length, and span the entire width of the roadway (Ewing, 1999; ITE Traffic Engineering Council, 1997). However, other speed hump designs do exist. Speed humps are designed to create a rocking motion that increases driver discomfort as crossing speed increases. A typical speed hump is shown in Figure 1. Speed tables are essentially flat-topped speed humps that function in the same manner. The flat portion of the table is typically longer than the wheelbase of a passenger car. Speed tables are sometimes referred to as “Seminole County speed humps” or “trapezoidal speed humps” (Ewing, 1999). Speed tables also are often used at pedestrian crossings and may be referred to as a raised crosswalk (Ewing, 1999). A typical speed table is shown in Figure 2.

Figure 1. Typical Speed Hump
(Traffic Calming for Communities, 2001)

Figure 2. Typical Speed Table
(Traffic Calming for Communities, 2001)

Temporary Traffic Calming

Many agencies across the United States have developed traffic-calming programs by first implementing temporary traffic calming programs. The advantage of using a temporary program prior to permanent installation is that it provides an opportunity for jurisdictions to test traffic calming devices for effectiveness and obtain public input at a relatively low cost (Noyes and Associates, 1998).

Temporary and Permanent Speed Hump/Table Design

In the United States, there are no nationally accepted standards or design guidelines for traffic calming devices except for speed humps. In 1993, ITE developed "Guidelines for the Design and Application of Speed Humps" (ITE Traffic Engineering Council, 1997). These design guidelines are based on a 12-foot Watts style (or parabolic) speed hump. Despite these guidelines, a number of speed hump designs are used (Ewing, 1999). When designing a speed hump, the construction material to be used, the location and placement of the hump(s), the geometric shape and size of the speed hump(s), and the necessary signs and pavement markings all need to be considered and are discussed in the following sections. These same considerations also apply to speed table installations.

Construction Materials and Practices

Permanent speed humps/tables are usually concrete or asphalt, while temporary speed humps/tables are typically made of recycled rubber. Temporary devices are anchored into the existing pavement rather than installed as an integral part of the roadway. Fargo, North Dakota, Portland, Oregon, and Concord, California, all have installed temporary speed humps (Templeton and Rees, 2001; Tebinka, 2001; City of Portland, 2001). Experiences with the temporary devices varied. City officials in Fargo did not believe that temporary hump impacts were representative of permanent devices because of a 0.75-inch lip on the temporary speed hump, which they felt impacted performance. Officials in Concord experienced problems with distortion in speed hump shape due to vehicle movement and changes in temperature (Templeton and Rees, 2001; Tebinka, 2001). Additionally, debris caught under the rubber mats causing additional lifting and curling of the edges during heavy rainfalls (Templeton and Rees, 2001). Portland, however, has installed a number of temporary speed humps, and no problems have been reported (City of Portland, 2001).

Permanent devices are made of a more rigid material and are constructed as an integral part of the roadway. The materials used include hot mix asphalt, cast-in-place concrete, pre-cast concrete sections, and brick/concrete pavers. No information was found relating speed hump/table construction material to their speed or volume reduction effectiveness or compared the effectiveness of temporary devices compared to permanent installations. However, there have been some suggestions that a softer material may deform near the top of the hump and be pushed in the direction of traffic flow (ITE Traffic Engineering Council, 1997). The result of this deformation (besides a speed hump/table with a less than preferred shape) may be a higher average speed over the hump/table without an increase in driver discomfort.

When constructing speed humps, regardless of the material used, it is important that the proper vertical dimensions and transitions are attained. The ITE guidelines suggest that tolerances of ±0.5 inch are acceptable as long as the height of the hump does not exceed four inches (ITE Traffic Engineering Council, 1997). Templates have also been designed and may be used to assure that the proper dimensions are achieved (ITE Traffic Engineering Council, 1997). By constructing permanent speed hump/table in two separate lifts, the accuracy of the hump/table shape can be greatly improved and tolerances of ±0.25 inches are attainable (ITE Traffic Engineering Council, 1997; Clement, 1983).

Placement and Spacing

One of the first steps in the design process is to determine where the speed hump/table is to be located along the roadway. Speed humps/tables are typically placed on local and/or collector residential streets, and many of the speed hump/table installations are on streets with a posted speed limit of 25 or 30 mph.

There are several general guidelines related to the placement of speed humps/tables according to ITE (ITE Traffic Engineering Council, 1997). These guidelines are related to the existing alignment, cross section, and intersection design of the roadway. Horizontal and vertical sight distance should be considered when determining the installation location. A speed hump/table should be placed in a location where vehicles will not unexpectedly encounter it at a high rate of speed but cannot accelerate to an undesirable speed prior to encountering the speed hump. ITE guidelines suggest that the first speed hump in a series be placed a distance of 200 feet or less from a stop sign or a short horizontal curve (ITE Traffic Engineering Council, 1997). However, it is also suggested that speed hump not be located within 250 feet of a traffic signal. The guidelines also state that if a significant downgrade exists, the first speed hump in a series should be located near the crest. Additionally, sight distance needs to be considered. When sight distance may be an issue, especially during nighttime hours, the placement of speed humps should be compared to the existing or planned lighting of the street (ITE Traffic Engineering Council, 1997).

Speed humps/tables should also be constructed downstream of storm sewer inlets and have a tapered edge along the curb line to facilitate drainage (ITE Traffic Engineering Council, 1997). In areas in which no curb is present, delineator posts or other treatments are suggested to discourage drivers from driving around the hump. The placement of the speed humps should also consider cross streets and other points of access. Speed humps/tables are intended for mid-block locations and are typically not placed within an intersection or other point of access. Speed humps/tables should also not be located near or over manhole covers or next to fire hydrants. On-street parking is not greatly affected by the use of speed humps/tables. Table 1 lists guidelines implemented by individual jurisdictions for the location of a speed hump/table or the first speed hump/table in a series.

A series of speed humps/tables are often more effective in reducing speeds than single installations since it prevents a vehicle from speeding up after negotiating a single device (ITE Traffic Engineering Council, 1997). The number and spacing of speed humps/tables often depend on the implementing jurisdiction and tend to be project specific. For example, Gwinnett County, Georgia specifies a spacing of 350 to 500 feet with a series of speed humps extending no more than 0.75 mile (Urban et al., 1999). Table 2 summarizes some of the speed hump/table spacing policies used in the United States.

Table 1. Jurisdiction Speed Hump Placement Guidelines*

Jurisdiction	Guideline
Fairfax, Virginia	200' from an intersection
Thousand Oaks, California	50' to 200' from intersections, STOP signs, and “tight turns”
	5' to10' from driveways
Fort Worth, Texas	300' from traffic signals, STOP signs, or YIELD signs
	75' from uncontrolled intersections
Pennsylvania DOT	Prohibited on horizontal curves with radius less than 300'
	Prohibited on grades greater than 8%
	150' from unsignalized intersections
	250' from signalized intersections
Gwinnet County, Georgia	Prohibited on grades greater than 8%
	100' to 200' from STOP signs or “small” geometric curvatures

Sources: Urban et al., 1999; Pennsylvania DOT, 2001; Clement, 2001; Vazquez, 2000; City of Fairfax, 2001.

Table 2. Spacing Values Currently Used in Speed Hump Installations*

Jurisdiction	Spacing (ft)
Fairfax, Virginia	No less than 500
Kuna, Idaho	600 minimum
Thousand Oaks, California	150 to 400
Fort Worth, Texas	300 to 1600
Pennsylvania DOT	250 to 600
Atlanta, Georgia	200 to 700
Cobb County, Georgia	300 to 500
Gwinnett County, Georgia	350 to 500
San Antonio, Texas	300 to 890
Seattle, Washington	326 to 553
Austin, Texas	300 to 500
Bellevue, Washington	200 to 300
Berkeley, California	150 to 400
Boulder, Colorado	150 to 800
Howard County, Maryland	400 to 600
Montgomery County, Maryland	400 to 600
Phoenix, Arizona	No more than 500
Portland, Oregon	300 to 600

* Sources: Ewing, 1999; Urban et al., 1999; Pennsylvania DOT, 2001; Clement, 2001; Vazquez, 2000; City of Fairfax, 2001; Marek and Walgren, 1998; Ballard, 1998; Szplett and Fuess, 1999; City of Austin, 2001.

The factor that may have the greatest impact on the effectiveness of a speed hump/table installation is the spacing of the slow points. The maximum acceptable operating speed for the area should be determined. The impact or design speed of the speed hump/table and the typical operational capabilities of the vehicles in the traffic flow may help determine the spacing of the devices (Ewing, 1999). For example, it has been suggested that "speeds increase approximately 0.5 to 1.0 mph for every 100 feet of separation for hump spacing up to 1000 feet" (Ewing, 1999). Therefore, if the speed humps are spaced too far apart, vehicle speeds between the hump locations may not be effectively reduced, and resources are wasted if the speed humps are spaced too close together (plus local residents may feel the devices are an unnecessary nuisance and comfort levels unacceptable). For example, early speed hump installations at 500-foot spacing in Phoenix, Arizona, did not significantly reduce mid-block speeds, and 150-foot spacing in Bellevue, Washington, led to complaints from adjacent residents leading to removal of every other hump leaving a spacing of 300 feet (Ewing, 1999).

As demonstrated in Table 2, a wide range of spacing guidelines is used. This may be due to the fact that many speed hump/table installations are retrofits into existing roadways (Wainwright, 1998). A special Subcommittee of the California Traffic Control Devices Committee, however, has developed an approximate equation for the spacing of 3-inch-high speed humps (ITE Traffic Engineering Council, 1997). The equation is as follows (ITE Traffic Engineering Council, 1997):

$$H_s = 0.5[2(V_{85})^2 - 700]; \tag{1}$$

where H_s is the optimal spacing between 3-inch speed humps (feet) and V_{85} is the desired 85th percentile speed between humps (mph).

The document that discusses the use of Equation 1 does not state whether it applies to a parabolic and/or trapezoidal profile. Nor does the expression account for the length measured in the direction of travel of the speed hump. It is speculated that the exiting speeds and acceleration rates will differ between a 22-foot speed table and a 12-foot speed hump.

Geometric Design

In 1975, the Transport and Road Research Board of Great Britain determined that the ideal design shape for a speed hump was parabolic, 12 feet wide in the direction of travel, and four inches high (Clement, 1983). It was determined that at or below the design speed of this type of hump, a driver would experience no discomfort, but above the design speed drivers would experience increasing levels of discomfort as speed increases (Clement, 1983). However, drivers intentionally traversing the hump at excessive speeds would still be able to maintain control of their vehicle (Clement, 1983). On average, these speed humps were shown to lower the prevailing maximum speed by 30 percent (Clement, 1983). Common design shapes are shown in Figure 3.

In the United States, the design guidelines developed by ITE were based on the Watts speed hump profile (ITE Traffic Engineering Council, 1997). These guidelines suggested that a parabolic shape, 12 feet long, with a height of three to four inches be used. Experience in the United States since 1993 has resulted primarily in the use of 3.5-inch speed humps (Wainwright, 1998). This design typically results in an 85th percentile speed between 15 and 20 mph (Ewing, 1999). The Watts style hump, however, has been modified in several jurisdictions. For example, Portland, Oregon, has developed a 14-foot parabolic speed hump that is three inches in height. The 85th percentile speed for the 14-foot parabolic speed hump is about 3 mph higher than the standard 12-foot Watts hump (Ewing, 1999). This 14-foot speed hump design has gained national acceptance and is currently used in a number of jurisdictions (Wainwright, 1998).

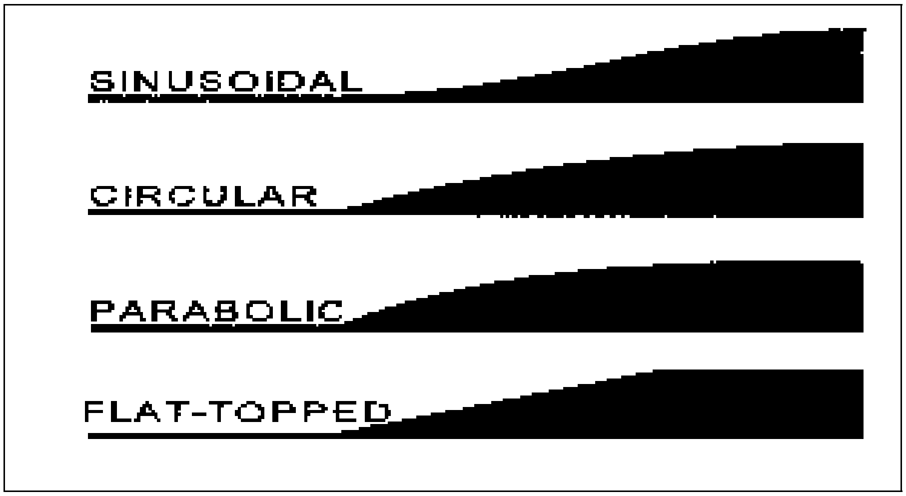


Figure 3. Commonly Used Speed Hump Profiles (Ewing, 1999)

Another commonly used design shape in the U.S. is that of the Seminole County speed hump. This speed hump is a flat-topped undulation, 22 feet in length, and three to four inches in height (Ewing, 1999; ITE Traffic Engineering Council, 1997). The design is sometimes referred to as a speed table (Ewing, 1999). This design has become very common in the state of Florida and is used in Maryland, Oregon, Georgia, Texas, and Washington (Ewing, 1999; Knapp, 2000; Marek and Walgren, 1998; Urban et al., 1999). The ramps of the Seminole County speed hump are circular in shape and six feet long (Ewing, 1999; ITE Traffic Engineering Council, 1997). However, ramps used in Gwinnett County, Georgia, have a constant slope and a height of 3 and 5/8 inches (Ewing, 1999; Urban et al., 1999).

Speed humps/tables may also have a non-parabolic or trapezoidal shape (i.e., sinusoidal or circular), as shown in Figure 3. This type of speed hump/table can be installed in combination with other traffic calming devices such as chokers (Ewing, 1999; LaRosa, 2001; Transportation Association of Canada, 1998). Boca Raton, Florida, and Bellevue, Washington, commonly install enhanced speed humps, which combine a choker with a speed hump resulting in both vertical and horizontal deflection (LaRosa, 2001). Boca Raton's enhanced speed hump design utilizes a four-inch speed table hump measuring 22 feet in length and a choker constructed to reduce the roadway width to 18 feet (LaRosa, 2001).

Signing and Marking

Signing and marking is another key design feature of speed hump/table installations. The *Manual of Uniform Traffic Control Devices* (MUTCD) provides some guidelines and suggestions for traffic control along streets with speed humps/tables (FHWA, 1988). Section 2C.22 of the MUTCD states the following:

> Guidance:
> The SPEED HUMP (W17-1) sign should be used to give warning of a vertical deflection in the roadway that is designed to limit the speed of traffic…If used,

the SPEED HUMP sign should be supplemented by an Advisory Speed plaque (see Section 2C.42).

Option:
If a series of speed humps exists in close proximity, an Advisory Speed plaque may be eliminated on all but the first SPEED HUMP sign in the series. (FHWA, 1988)

Although the MUTCD recommends the use of the W17-1 SPEED HUMP sign (Figure 4), the most commonly used sign with speed hump installation is the W8-1 BUMP sign as shown in Figure 5 (ITE Traffic Engineering Council, 1997). Other signs that have been used by agencies include HUMP and ROAD HUMP. The ITE design guidelines also recommend the use of advisory speed plaques as shown in Figure 6. Some agencies also include a supplemental plaque with the legend Next XX Feet for a series of speed humps, and others install special attention flags or flashing lights.

Figure 4. Typical W17-1 SPEED HUMP Warning Sign (FHWA, 1988)

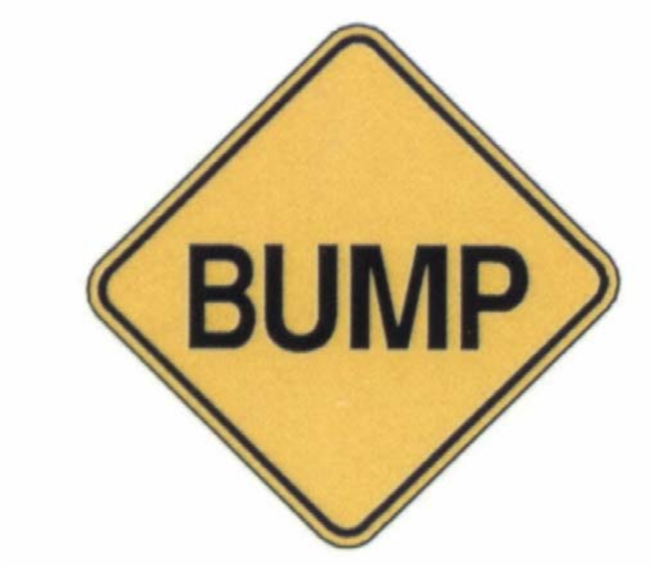


Figure 5. Typical W8-1 BUMP Warning Sign (FHWA, 1988)

Figure 6. Typical W13-1 Advisory Speed Plaque (Moeur, 2001)

Other jurisdictions have also developed their own speed hump sign. The speed hump sign used in San Antonio, Texas, is provided in Figure 7. Boca Raton, Florida, developed a special regulatory sign that combines a "20 MPH" speed limit sign with a TRAFFIC CALMED AREA warning sign as shown in Figure 8 (LaRosa, 2001). This sign is placed at the entrances to traffic-calmed neighborhoods.

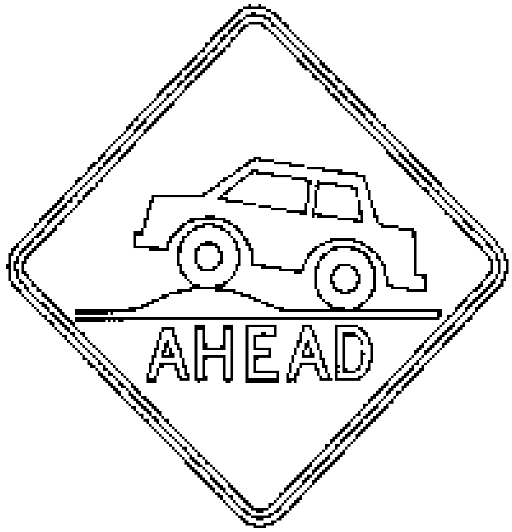


Figure 7. Speed Hump Sign Used in San Antonio, Texas (Ballard, 1998)

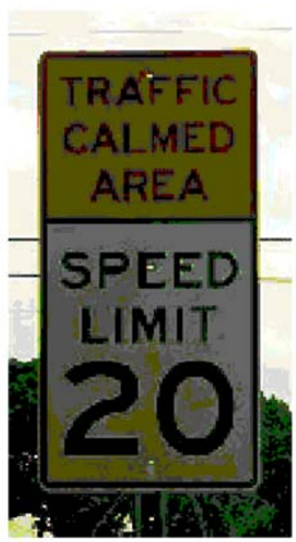


Figure 8. Sign Placed at All Access Points to a Traffic-Calmed Neighborhood in Boca Raton, Florida (LaRosa, 2001)

Pavement markings are also typically used with speed humps and speed tables. Again, the MUTCD does not require or provide required layouts for these pavement markings. However, if pavement markings are used with a speed hump/table, the markings must be white and located on the hump/table (FHWA, 1988). MUTCD suggested pavement markings for speed humps and speed tables are shown in Figures 9 and 10 respectively. A suggested layout for advanced speed hump/table pavement markings is also provided in the MUTCD as indicated in Figure 11.

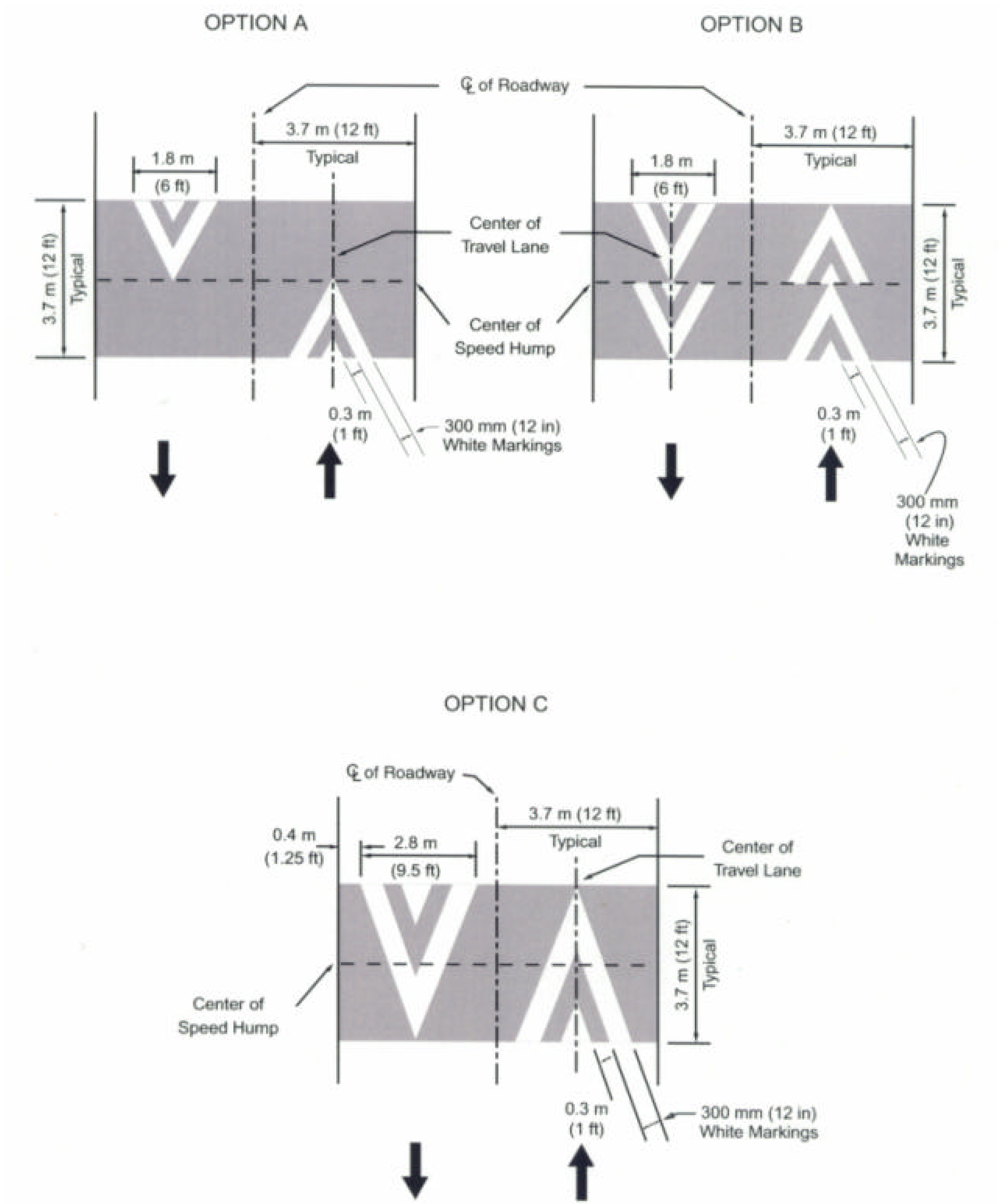


Figure 9. Typical Speed Hump Pavement Markings Shown in the MUTCD (FHWA, 1988)

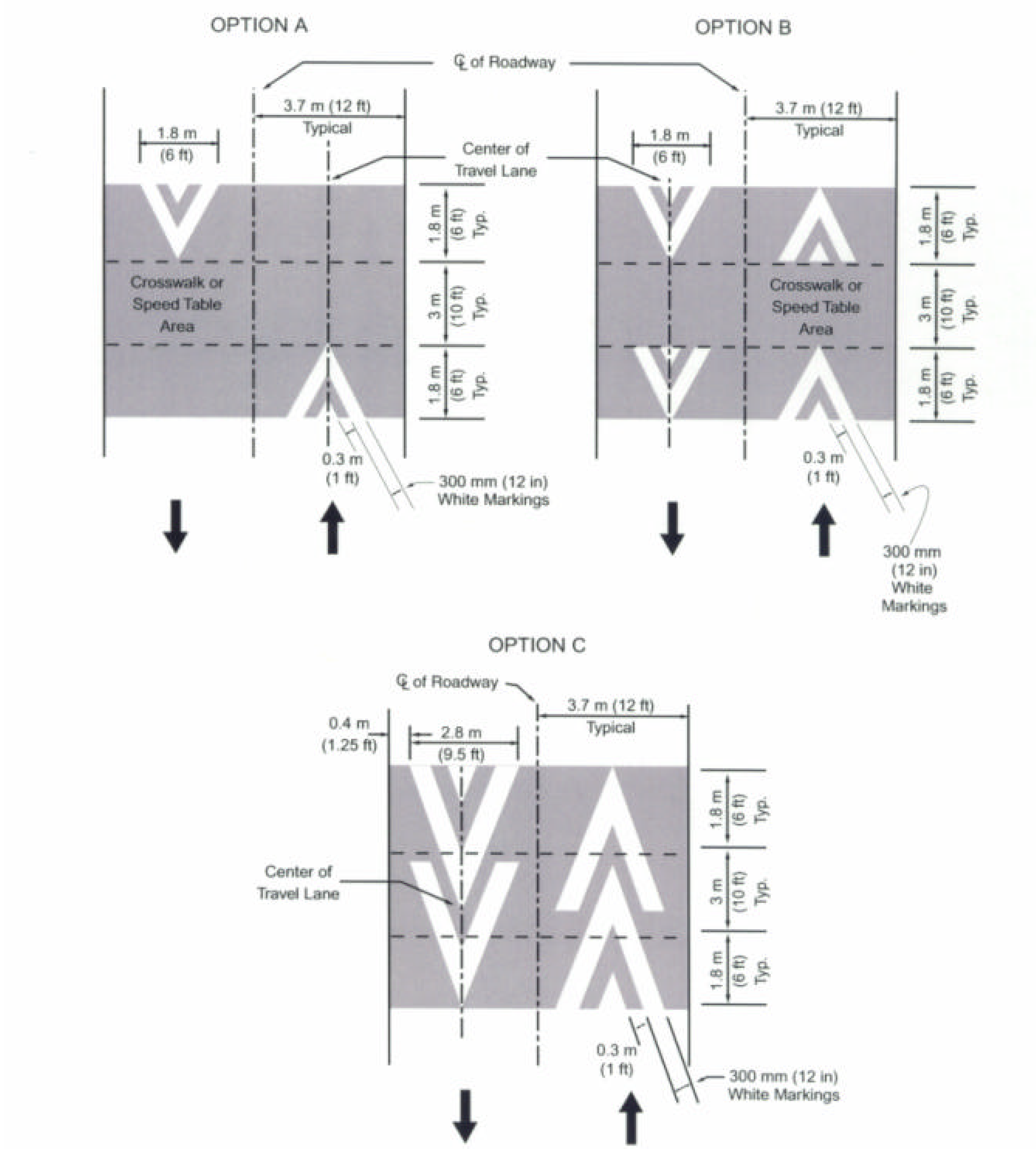


Figure 10. Typical Speed Table Pavement Markings Shown in the MUTCD (FHWA, 1988)

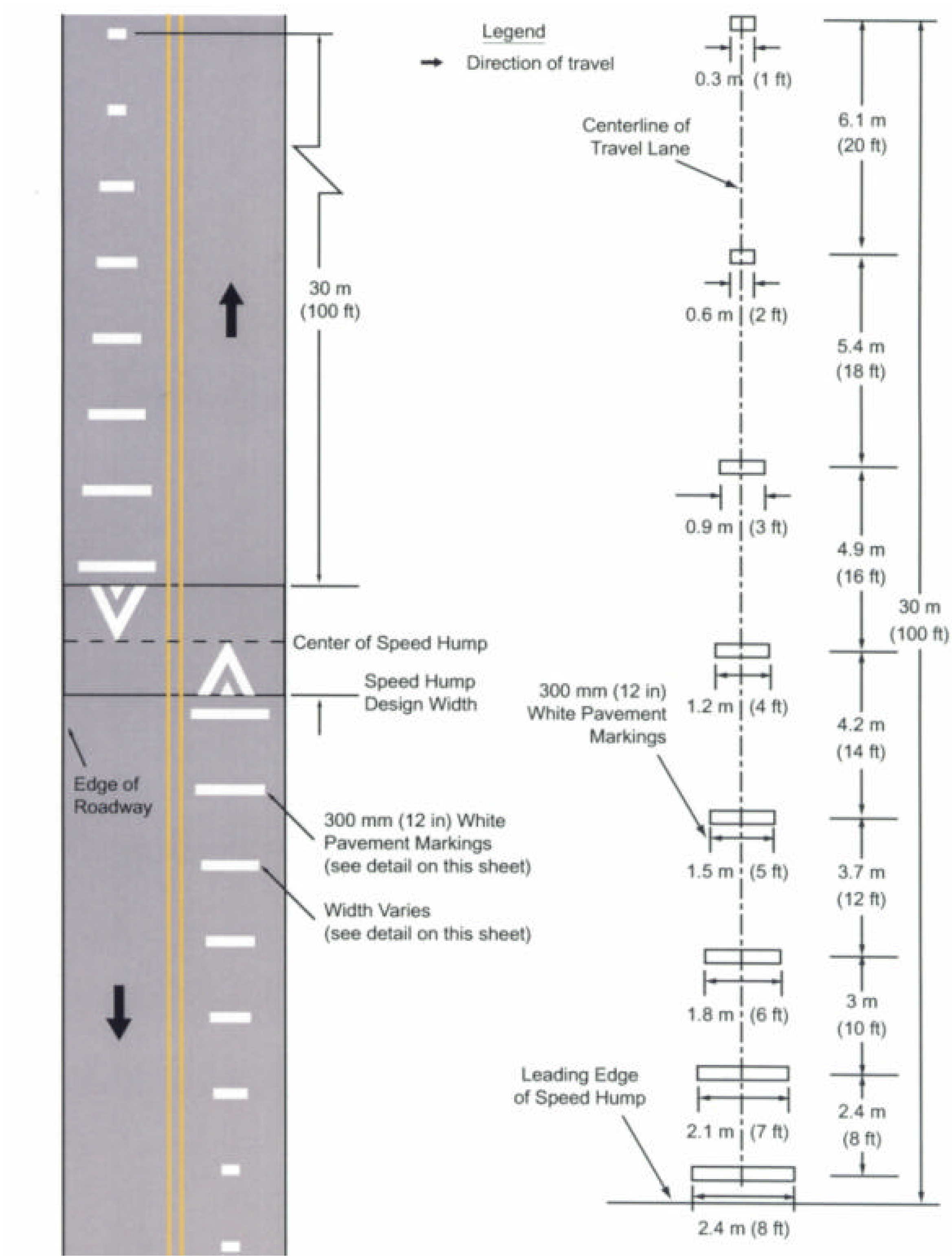


Figure 11. Typical Advanced Speed Hump/Table Pavement Markings Shown in the MUTCD (FHWA, 1988)

Speed Hump/Table Impacts

Both advantages and disadvantages, summarized in Table 3, have been observed with the use of speed humps/tables as a traffic calming device. The main advantage is speed reduction. Reductions in cut-through traffic are also an advantage of the devices. A more in-depth discussion on speed and volume reduction is provided in the following sections. Additionally, Portland, Oregon; Howard County, Maryland; Montgomery County, Maryland; Omaha, Nebraska; San Diego, California; San Jose, California; and Tampa, Florida, have all reported reductions in the number of crashes after speed humps/tables (Ewing, 1999; Transportation Association of Canada, 1998; Kittelson and Associates, Inc., 2000; Gorman et al., 1989). Speed humps and speed tables were installed in Berkeley and San Jose, California, and Palm Beach, Florida, to discourage criminal activity (ITE Traffic Engineering Council, 1997; Lockwood and Stillings, 1998).

Table 3. Advantages and Disadvantages of Speed Humps/Tables

Advantages	Disadvantages
Speed reduction	Emergency response delays
Volume reduction	Traffic diversion
Accident frequency reduction	Liability concerns
Accident severity reduction	Aesthetics
Crime reduction	Snow removal/maintenance difficulty
	Noise

Various disadvantages have also been noted. Lawsuits have been brought against several jurisdictions in response to speed hump installations including Sarasota, Florida; Seattle, Washington; Charlotte, North Carolina; Howard and Montgomery County, Maryland; and San Diego, California (Ewing, 1999; Knapp, 2000; Ewing and Kooshian, 1997; Ewing, 1998). However, lawsuits filed against jurisdictions claiming damage due to speed humps/tables are usually unsuccessful (Ewing, 1999), concerns about liability may limit the installation of speed humps/tables in some jurisdictions. Another disadvantage is aesthetics (Ewing, 1999). Residents in Bellevue, Washington, Gwinnet County, Georgia, and Orlando, Florida, complained that speed humps/tables blemished the appearance of their neighborhoods, driving away prospective homebuyers and thus reducing property values (Ewing, 1999; Edwards and Bretherton, 1998). Maintenance is another concern, especially in areas where snow removal is required (Ewing, 1999). However, several jurisdictions have made improvements to their snow removal equipment and report little if any additional complications (Ewing, 1999; ITE Traffic Engineering Council, 1997; Knapp, 2000; Pennsylvania DOT, 2001; Ripley and Klingaman, 1998; Gorman et al., 1989). Another disadvantage is that noise may be generated by vehicles braking while approaching and then accelerating away from speed humps. Residents in San Antonio, Texas, Seattle, Washington, and Omaha, Nebraska, voiced complaints of increased noise levels following installation of speed hump/table. However other studies in the U.S. have shown that actual noise levels remain unchanged and in some cases decrease with use of the devices (Ewing, 1999; Marek and Walgren, 1998; Transportation Association of Canada, 1998; Ballard, 1998; Gorman et al., 1989; Department of the Environment, Transport, and the Regions, 2000). However, drivers intentionally honking their horns in protest were reported in Boulder, Colorado, and Colwood, British Columbia (Transportation Association of Canada, 1998).

Impact on Emergency Response Vehicles
Although speed humps and speed tables are effective in reducing traffic speeds, they may adversely reduce speeds of emergency response vehicles and consequently increase service time (Ewing, 1999; Knapp, 2000; Transportation Association of Canada, 1998; Ripley and Klingaman, 1998; Atkins and Coleman, 1997; Atkins and Wilson, 1998; Gutschick, 1998; Montgomery County, 2001). In some jurisdictions, the emergency response services (EMS) have been the most vocal opponents of speed humps/tables (Ewing, 1999; Gorman et al., 1989; Ewing and Kooshian, 1997). Several studies have evaluated the impact of speed humps/tables on emergency response times as shown in Table 4. The amount of delay that is incurred depends on the type of emergency vehicle tested and the desired operating speed (Ewing, 1999; Transportation Association of Canada, 1998; Atkins and Coleman, 1997; Atkins and Wilson, 1998; Gutschick, 1998; Montgomery County, 2001). For example, in the Montgomery County EMS study, the crossing speeds for a tiller style ladder truck, a pumper fire engine, an ambulance, and an aerial tower truck were 6.1, 9.1, 8.7, and 10.8 mph, respectively (Montgomery County, 2001). Additionally, the emergency equipment tested in Montgomery County was only able to attain an operating speed of about 20 mph while traveling through the test section compared to normal operating speeds of 35 to 40 mph (Gutschick, 1998; Montgomery County, 2001).

Table 4. Speed Hump/Table Design and Emergency Response Time*

Jurisdiction	Speed Hump/Table Design	Delay per Hump/Table (Seconds)
Portland, Oregon	14' humps	1.0 to 9.4
	22' tables	0.0 to 9.2
Austin, Texas	12' humps	2.3 to 9.7
Montgomery County, Maryland	12' humps	2.8 to 7.3
Sarasota, Florida	12' humps	4.7
Boulder, Colorado	12' humps	2.8 to 6.0

*Sources: Ewing, 1999; Knapp, 2000; Transportation Association of Canada, 1998; Atkins and Coleman, 1997; Montgomery County Fire and Rescue Commission, 1997; Gutschick, 1998.

Speed Reduction
Speed reduction is the primary purpose of speed humps and speed tables. A number of studies have evaluated differences in speeds at a location before and after a speed hump or table was installed. Review of the various studies indicate that the magnitude of speed reduction depends on a number of factors including the design and spacing, where the speed difference was collected in relationship to the traffic calming device, the surrounding environment, and vehicle mix. However, information provided in the documentation of many before and after studies is not always consistent. For example, many of the studies did not indicate the type or number of speed humps/tables used, and the location at which speeds were measured in relationship to the devices was often not clear. Of the studies that do report

the location of the speed measurements, many indicate only that measurements are taken "between the humps." Lack of consistent information makes it difficult to compare results among studies.

Reduction in 85th Percentile Speeds

A summary of the results of several studies comparing the 85th percentile speeds before and after speed humps or tables were implemented, is provided in Table 5. In most cases, speeds decreased. However, no change or even a slight increase in 85th percentile speeds was reported for some locations (Ewing, 1999; Ripley and Klingaman, 1998; City of Charlotte, 2001). Not only does the change in speed vary between jurisdictions, they also vary between individual sites within each jurisdiction (Ewing, 1999; Clement, 1983; Dittberner, 1999; Knapp, 2000; Marek and Walgren, 1998; Urban et al., 1999; Transportation Association of Canada, 1998; Ballard, 1998; City of Charlotte, 2001; Aburahmah and Al Assar, 1998; City of Bloomington, 2000). This variation may be partly due to the lack of formal design standards and spacing requirements and the different roadway environment of each retrofit installation. Results in Table 5 demonstrate that the speed reduction between speed humps and speed tables is comparable. For 12-foot speed humps, changes in the 85th percentile speeds varied from +1 mph to –16 mph [4 percent to –42 percent] (Ewing, 1999; Clement, 1983; Dittberner, 1999; Knapp, 2000; Marek and Walgren, 1998; Urban et al., 1999; Transportation Association of Canada, 1998; Ballard, 1998; City of Charlotte, 2001; Aburahmah and Al Assar, 1998; City of Bloomington, 2000). For speed tables, changes in the 85th percentile speeds vary from 0 to –17 mph [0 percent to –41 percent] (Ewing, 1999; Marek and Walgren, 1998; Urban et al., 1999; City of Charlotte, 2001).

Reduction in High-End Speeders

Along with reduction in the 85th percentile speeds, there is some evidence that speed humps/tables reduce high-end speeders. For example, prior to the installation of the 14-foot speed humps in Portland, 60 percent of the traffic typically exceeded the 25 mph posted speed limit with 14.5 percent of the traffic exceeding the posted speed limit by at least 10 mph (Kittelson and Associates, Inc., 2000). After 14-foot speed humps were installed, only 20 percent of the traffic exceeded the 25 mph speed limit and only 1 percent was in excess of 10 mph over the speed limit. The use of 22-foot speed tables in Portland had a similar effect, decreasing the percentage of drivers exceeding the speed limit from 77 percent to 43 percent (Kittelson and Associates, Inc., 2000). Drivers exceeding the speed limit by more than 10 mph also decreased from 22 percent to 3 percent with the 22-foot speed tables (Kittelson and Associates, Inc., 2000). Figures 12 and 13 show the speed frequency distributions for the 14-foot speed humps and 22-foot speed tables, respectively, in Portland. As shown, the distribution of speeds following the installation of the 14-foot speed humps and the 22-foot speed tables is left of the distribution of speeds before. The distributions also indicate that fewer speed observations are noted in the speed ranges that are significantly higher than the 25-mph speed limit.

Table 5. Changes in 85th Percentile Speed*

Jurisdiction	Design	Before (mph)	After (mph)	Difference (mph)	Change (%)
Austin, Texas**	12' humps	36 to 40	26 to 31	-5 to -12	-14 to -32
	22' tables	35 to 40	28 to 31	-6 to -9	-17 to -24
Bellevue, Washington**	12' humps	33 to 39	25 to 27	-6 to -12	-18 to -31
	22' tables	34 to 35	29 to 31	-3 to -6	-9 to -17
Berkeley, California**	12' humps	25 to 36	20 to 28	-3 to -11	-12 to -34
	22' tables	31	25	-6	-19
Boulder, Colorado**	12' humps	28 to 31	25	-3 to -8	-11 to -24
Charlotte, North Carolina**	22' tables	31 to 40	27 to 37	0 to -9	0 to -23
Dayton, Ohio**	12' humps	32 to 34	25 to 32	0 to -9	0 to -26
Eugene, Oregon**	14' humps	32 to 34	27	-5 to -7	-16 to -21
Ft. Lauderdale, Florida**	12' humps	35	25	-10	-29
	22' tables	36 to 38	29 to 33	-4 to -9	-11 to -24
Gwinnett County, Georgia**	22' tables	35 to 47	26 to 34	-6 to -14	-15 to -32
Howard County, Maryland**	12' humps	38 to 40	28	-10 to -12	-26 to -30
	22' tables	35 to 43	28 to 36	0 to -14	0 to -33
Montgomery County, Maryland**	12' humps	32 to 43	25 to 34	-3 to -12	-9 to -30
	22' tables	33 to 40	29 to 34	-1 to -8	-3 to -22
Omaha, Nebraska**	12' humps	34 to 45	27 to 37	0 to -11	0 to -27
San Diego, California* *	12' humps	34 to 38	25 to 30	-6 to -13	-17 to -34
San Jose, California**	12' humps	32 to 36	20 to 26	-10 to -13	-28 to -39
Sarasota, Florida**	12' humps	29 to 35	21 to 28	-5 to -9	-17 to -27
	22' tables	42	25	-17	-41
Tucson, Arizona**	12' humps	26 to 45	19 to 33	+1 to -7	+4 to -42
Boca Raton, Florida**	12' humps	34 to 39	31 to 35	-3 to -4	-9 to -10
Kirkland, Washington**	12' humps	32 to 35	24 to 27	-7 to -10	-22 to -30
	14' humps	34 to 35	25 to 28	-7 to -9	-20 to -26
	22' tables	35	27	-8	-23
Las Vegas, Nevada**	12' humps	29 to 38	22 to 27	-6 to -16	-21 to -42
Minneapolis, Minnesota**	32' tables	31 to 33	29 to 31	0 to -4	0 to -12
Tampa, Florida**	12' humps	38 to 42	28 to 34	-6 to -12	-15 to -30
Thousand Oaks, Calififornia**	12' humps	27 to 43	23 to 32	-4 to -11	-15 to -29
Sherbrooke, Quebec	—	47	37	-10	-21
Toronto, Ontario**	—	27 to 29	24	-4 to -6	-11 to -17
Ottawa, Ontario**	—	27 to 28	21	-6 to -7	-22 to -25
Victoria, British Columbia	—	35	23	-12	-34
Seattle, Washington**	12' humps	35 to 38	29 to 31	-4 to -7	-11 to -18
	22' tables	40	36	-4	-10
Cobb County, Georgia	22' tables	43	34	-9	-21
San Antonio, Texas**	12' humps	35 to 40	26 to 37	-3 to -12	-7 to -31
Manatee County, Florida**	—	27 to 45	19 to 32	-1 to -11	-2 to -40

Table 5. Changes in 85th Percentile Speed *Continued*

Jurisdiction	Design	Before (mph)	After (mph)	Difference (mph)	Change (%)
Portland, Oregon**	14' humps	29 to 37	23 to 28	-3 to -10	-9 to -30
Phoenix, Arizona**	12' humps	26 to 29	20	-6 to -9	-23 to -31
Iowa City, Iowa**	—	32 to 33	27 to 34	+1 to -5	+3 to -16
Bloomington, Ilinois**	—	21 to 40	18 to 26	-3 to -14	-14 to -35
Virginia DOT	—	33	21	-12	-35
	—	36	23	-13	-37

* Sources: Ewing, 2000; Clement, 1983; Urban et al., 1999; Marek and Walgren, 1998; Ballard, 1998; Knapp, 2000; Transportation Association of Canada, 1998; Ripley and Klingaman, 1998; City of Charlotte, 2001; Dittberner, 1999; Aburahmah and Al Assar, 1998; City of Bloomington, 2001; Arnold and Cottrell, 1999.

** Values were summarized from a table of projects within that jurisdiction.

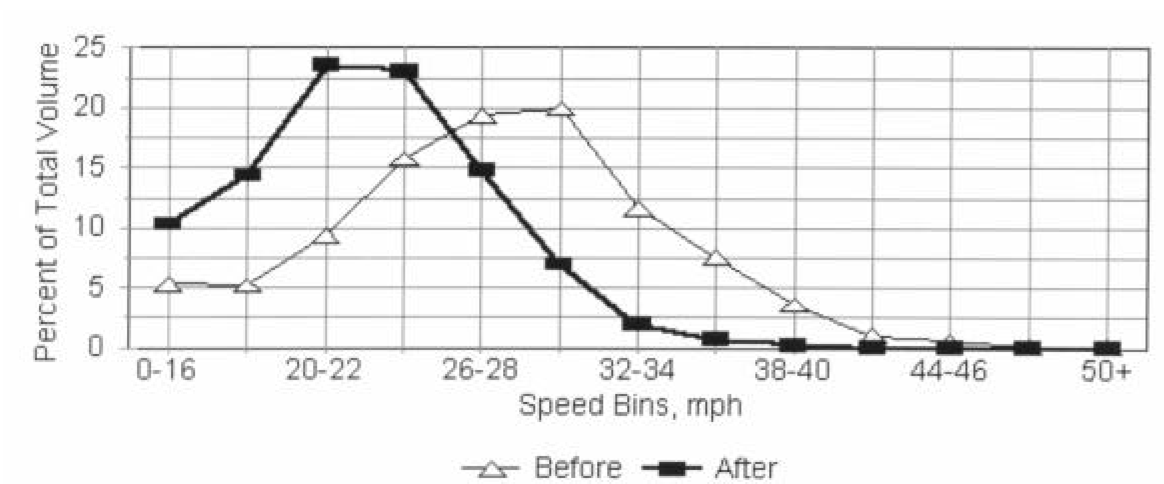


Figure 12. Portland 14-Foot Speed Hump Speed Distribution (Kittelson and Associates, Inc., 2000)

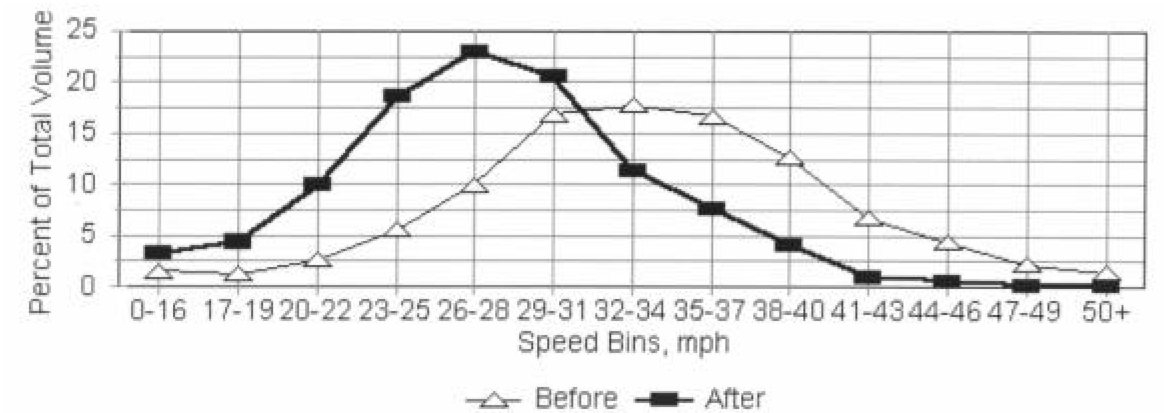


Figure 13. Portland 22-Foot Speed Hump Speed Distribution (Kittelson and Associates, Inc., 2000)

Height Versus Speed Reduction

A study by Mak (1986) attempted to develop a relationship between undulation height and speed reduction. In the study, two series of 13-foot parabolic speed humps 3-4 inches in height and spaced 300 feet apart were evaluated. The free-flow speed prior to the speed hump installations was between 30 and 35 mph. Speed profiles were collected for each of the two test sites and a linear regression performed to obtain the following two equations:

Crossing Speed = 35.03 – (5.13 x Undulation Height) (2)

Speed Change = 16.89 – (5.92 x Undulation Height) (3)

Crossing speed is the speed at which a vehicle traverses a speed hump, while the speed change is the difference between before and after speeds (Mak, 1986). In these equations, crossing speed and speed change are given in mph and undulation height is in inches (Mak, 1986). Based on these equations, as undulation height increases, the crossing speed decreases and the speed change increases in the negative direction indicating larger speed reductions (Mak, 1986). These equations developed did not take into account possible impacts due to speed hump spacing because the speed humps that were studied had a uniform 300-foot separation. The equations may not be appropriate estimation tools for installations with spacing other than 300 feet. These equations were also only developed for 13-foot parabolic speed humps and may not be appropriate for other speed hump designs or for speed tables. Additionally, the equations were based on a sample set of only three.

Evaluating Speed Profiles

Most studies used to evaluate speed reduction used spot speed studies. Several studies report the use of speed profiles to evaluate speed hump/table effectiveness (Clement, 1983;

Kittelson and Associates, Inc., 2000; Clark, 2000; Mak, 1986; Barbosa et al., 2000). Speed profiles plot speed as a function of distance. The speed profiles used in these studies were produced by plotting a series of speed measurements taken at particular locations along a section of roadway (i.e., at the speed hump/table, at points between humps/tables, at intersections, etc.) (Clement, 1983; Kittelson and Associates, Inc., 2000; Clark, 2000; Mak, 1986; Barbosa et al., 2000). For example, a study in Thousand Oaks, California, reported that speed measurements were recorded at the speed hump and mid-way between humps. After plotting the measured speeds by distance, accelerations were calculated and speed and acceleration were studied to determine "optimal" spacing. An optimal spacing of 300 feet resulted (Clement, 1983).

In a 2000 study by Barbosa, Tight, and May, speed profiles and acceleration profiles were developed for several traffic calming devices, including speed humps and tables, to determine which traffic calming devices were more effective. The study found that speed humps and speed tables had the greatest impact on reducing the speeds.

Speed profiles from Athens-Clarke County, Georgia, were used to compare sections of roadway with speed humps to sections of roadway with four-way stop signs (Clark, 2000). The speed profiles showed that speed humps produced more constant speeds over the section of roadway than the four-way stop signs and that the four-way stop signs were not able to slow traffic at mid-block locations (Clark, 2000). In a study by Mak in 1986 and in studies from Portland, Oregon, speed profiles were created to evaluate speeds and acceleration/deceleration as vehicles approached, traversed, and exited speed humps. Results are shown in Table 6. The Portland study stated that acceleration/deceleration rates were more abrupt for the 4-foot speed humps when compared to the 22-foot speed tables (Kittelson and Associates, Inc., 2000).

Table 6. Mak and Portland Speed Profile Evaluation Results*

Measure	Mak Study	Portland Study	
	13' Speed Hump	14' Speed Hump	22' Speed Table
Average approach speed in mph (50 feet from speed hump)	20.9	—	—
Crossing speed in mph	15.9	20 to 22	26 to 30
Average exit speed in mph (speed hump to 50 feet after hump)	18.6	—	—
Approach in mph (50 feet in advance to speed hump)	-5.0	—	—
Exit in mph (speed hump to 50 feet after hump)	+2.7	—	—
Approach in ft/sec^2 (50 feet in advance to speed hump)	-3.6	—	—
Exit in ft/sec^2 (speed hump to 50 feet after hump)	+1.5	—	—
Speed midway between adjacent humps in mph	—	25 to 28	29 to 33

*Sources: Ewing and Kooshian, 1997; Mak, 1986.

As discussed, the studies that used speed profiles to evaluate spacing and compare different traffic calming devices created speed profiles by collecting spot speeds at various locations and then plotting spot speeds versus distance. This method does not account for speed variations for individual vehicles. With this method, it is difficult to determine how individual vehicles behave in the vicinity of speed humps/tables, such as whether they brake abruptly and then speed up between devices. Additionally, without subsequent speed measurements for the same vehicle, it is not possible to calculate actual acceleration or deceleration.

Volume Reduction

Some speed hump installations have also been shown to reduce traffic volumes along the treated roadway (Ewing, 1999; Dittberner, 1999; Transportation Association of Canada, 1998; Ballard, 1998; Kittelson and Associates, Inc., 2000; Ripley and Klingaman, 1998; City of Charlotte, 2001; Clark, 2000; Aburahmah and Al Assar, 1998; City of Bloomington, 2001; Arnold and Cottrell, 1999). Speed reductions produced by speed humps/tables discourage but do not restrict through traffic from using a calmed street. The use of a speed hump/table (or other traffic calming device) may discourage cut-through traffic from using the traffic calmed roadway, therefore providing the added benefit of traffic volume reduction (Ewing, 1999; Transportation Association of Canada, 1998). A number of traffic calming studies has been conducted, resulting in varying results for volume reductions as shown in Table 7.

In areas where a high volume of cut-through traffic is present or the availability of parallel alternate routes is greater, the magnitude of the volume reduction due to a speed hump/table installation has the most potential. Following the installation of speed humps in 1998 along Clarendon Street in Phoenix, Arizona, traffic volumes decreased by 41 percent (Dittberner, 1999). Another street in Phoenix, 77th Avenue, experienced only a 7 percent reduction in traffic volume (Dittberner, 1999). The authors speculate that the difference in volume reduction may have been primarily due to the fact that Clarendon Street had a high volume of cut-through traffic created by a discontinuity of a nearby collector street (Dittberner, 1999). As presented in Table 7, the magnitude of a reduction in traffic volume can also depend on the type of vertical traffic calming measure implemented. For example, studies in Portland, Oregon, suggest that 14-foot speed humps effectively divert more traffic than the 22-foot speed tables (Ewing, 1999; Kittelson and Associates, Inc., 2000). In Portland, average traffic volumes decreased 33 percent on streets with 14-foot speed humps and 22 percent on streets with 22-foot speed tables (Kittelson and Associates, Inc., 2000).

Ideally the “displaced” through traffic would divert to a collector or arterial street, but this is not always the case. If parallel alternate local residential routes are available, the traffic may divert to parallel residential streets and simply shift the problem to another location. Resident surveys from Portland indicated that residents living along parallel but untreated streets perceive deterioration in traffic conditions and safety following installation of speed humps (Kittelson and Associates, Inc., 2000). For this reason, if traffic volumes on a parallel street(s) increase by more than 400 vehicles per day, Portland transportation officials decided to try to solve the situation by redesigning the device or incorporating traffic calming devices on the negatively impacted parallel street(s) (Ewing, 1999). Portland has converted many 14-foot speed hump installations into 22-foot speed table installations in an attempt to mitigate unwanted diversion.

Table 7. Changes in Volume*

Jurisdiction	Speed Hump Design	Change (%)
Austin, Texas**	12' humps	+20 to –36
	22' tables	+9 to –19
Bellevue, Washington**	12' humps	+14 to –27
	22' tables	-19 to –24
Boulder, Colorado**	12' humps	-13 to –28
Charlotte, North Carolina**	22' tables	+5 to –26
Dayton, Ohio**	12' humps	+121 to –46
Eugene, Oregon**	14' humps	-41 to –43
Ft. Lauderdale, Florida**	12' humps	-30
Gwinnett County, Georgia**	22' tables	+27 to –48
Howard County, Maryland**	22' tables	-11 to –35
Montgomery County, Maryland**	12' humps	+43 to –72
	22' tables	+46 to –41
Portland, Oregon**	14' humps	+19 to –65
San Diego, California**	12' humps	+29 to –65
Sarasota, Florida**	12' humps	-10 to –62
	22' tables	-21
Tucson, Arizona**	12' humps	+26 to –55
Boca Raton, Florida**	12' humps	-10 to –42
Kirkland, Washington**	12' humps	+5 to –50
	14' humps	+25 to –6
	22' tables	-5
Las Vegas, Nevada**	12' humps	+9 to –50
Minneapolis, Minnesota**	32' tables	+20 to +53
Tampa, Florida**	12' humps	-18 to –43
Phoenix, Arizona**	12' humps	-15 to –41
Toronto, Ontario*	—	-18
Iowa City, Iowa*	—	-18 to –21
Seminole County, Florida	22' tables	-9
San Antonio, Texas**	12' humps	+13 to –17
Athens-Clarke County, Georgia	—	0
Manatee, Florida**	—	+30 to –200
Virginia DOT	—	-4
Bloomington, Illinois**	—	+8 to –21

* Sources: Ewing, 1999; Dittberner, 1999; Transportation Association of Canada, 1998; Ballard, 1998; Kittelson and Associates, Inc., 2000; Ripley and Klingaman, 1998; City of Charlotte, 2001; Clark, 2000; Aburahmah and Al Assar, 1998; Arnold and Cottrell, 1999; City of Bloomington, 2000.

** Values were summarized from a table of projects within that jurisdiction.

Speed Hump/Table Public Opinion

A major contributor to the success of a traffic calming program is public acceptance (Ewing, 1999). Speed humps are generally supported by the public (Ewing, 1999; Clement, 1983; Knapp, 2000; Marek and Walgren, 1998; Ballard, 1998; Kittelson and Associates, Inc., 2000; Ripley and Klingaman, 1998; Gorman et al., 1989). Portland, Oregon, has installed over 500 speed humps and only two sets of humps have ever been removed, and Berkeley, California, a city with one of the oldest traffic calming programs in the United States, has never had to remove a speed hump (Ewing, 1999; Kittelson and Associates, Inc., 2000). The success and history of speed humps in these two cities are indications of the public support for these devices. Local resident and driver surveys from several jurisdictions also indicate support for speed humps/tables. A summary of several resident surveys reported in literature is shown in Table 8. As shown, overall speed humps/tables are supported by local residents (Ballard, 1998; Kittelson and Associates, Inc., 2000; Ripley and Klingaman, 1998; Gorman et al., 1989).

Table 8. Results of Resident Survey on Speed Humps/Tables*

Jurisdiction	Response Rate	Favor	Disfavor	No Opinion
San Antonio, Texas	40%	75%	21%	4%
Omaha, Nebraska	56%	82%	18%	0%
Iowa City, Iowa	63%	68%	32%	0%

* Sources: Ballard, 1998; Ripley and Klingaman, 1998; Gorman et al., 1989.

The resident survey in San Antonio, Texas, asked residents to comment on several different aspects of speed humps (Ballard, 1998). When asked what the best thing was about the speed humps, 67 percent of the respondents stated that they thought the speed humps slowed traffic, and 5 percent believed that the humps improved safety (Ballard, 1998). When asked what the worst thing was about the speed humps, 13 percent of the respondents felt the speed humps were ineffective, 10 percent felt the humps were too noisy, and another 5 percent responded that the humps caused vehicle damage (Ballard, 1998). Another 9 percent and 6 percent, respectively, responded that the worst thing about the speed humps was that they were too low/short and that there were not enough of them (Ballard, 1998).

Residents in Seattle, Washington, living along First Avenue NE, which contained a speed table, and Fremont Avenue N, which contained a speed hump, were surveyed to compare the public's view of the two devices (Marek and Walgren, 1998). The results of the Seattle survey are provided in Table 9. As shown, the speed table received a higher approval rating than the speed hump. However, the public did perceive the speed hump as being more effective. These results may indicate that the public prefers the decreased discomfort levels associated with speed tables and are willing to sacrifice effectiveness for a more comfortable ride.

Table 9. Results of a Resident Survey on Speed Table vs. Speed Hump*

Survey Item	Speed Table	Speed Hump
Reduced speeds	60%	94%
Reduced volumes	20%	41%
Increased safety	65%	75%
Increased noise	5%	19%
Decreased noise	10%	47%
Favor of keeping the device	80%	48%

* Source: Marek and Walgren, 1998.

DATA COLLECTION METHODOLOGY

The scope of the project included rural cities in Iowa. A description of the project was advertised in Iowa DOT and Center for Transportation Research and Education (CTRE) newsletters and asked for interested cities. Originally, it was expected that three or four Iowa cities with acceptable test locations would volunteer and participate in this project. Potential test locations had to be local streets located within a residential area with a posted speed limit of 25 or 30 miles per hour (mph). Streets classified as primary emergency response routes or transit routes would not be considered. The study locations also needed to be straight relatively flat sections of roadway due to constraints of the laser range finder (LRF) used for data collection. A total of eight jurisdictions responded to the Iowa DOT and CTRE newsletters and requested additional information on the project. They included

- City of Atlantic
- City of Shenandoah
- City of Denison
- City of Le Claire
- City of Newton
- City of Orchard
- City of Packwood
- Calhoun County

The City of Orchard could not be contacted after showing initial interest in the project and was dropped from consideration. The Shenandoah City Council decided additional police enforcement was a better solution and indicated they were no longer interested. The Calhoun County Sheriff also decided that speed humps/tables were not the best solution for the Twin Lakes State Park area. He felt that the county would receive criticism from area residents for installing and then removing a temporary device a short time later.

Meetings with city officials, local law enforcement, local fire and rescue agencies, and interested residents or citizen groups were held with the five remaining jurisdictions. The city meetings included a brief presentation about speed humps/tables, a description of the project, and the responsibilities of the participating parties (CTRE, Iowa DOT, and the jurisdiction). Residential streets that the cities felt would be good candidates for the project were visited as part of the city meeting. The site visits were used as an opportunity to gather information on the surrounding area and of the roadway itself. After the meetings, the cities of Denison and Newton indicated they were no longer interested in participating in the project. The City of Denison may have withdrawn over concerns of liability raised by the city attorney and/or maintenance concerns from the street department. The City of Newton, at the time of the city meeting, was in the process of hiring a new city engineer and new police chief and did not want to commit these new officials to any additional obligations. The City of Packwood was still interested after the meeting. However, they were dropped from consideration by the study team due to low volumes on the street in question; these low volumes would have required a number of site visits to collect a sufficient sample size and would have required more resources than was reasonable. The City of Atlantic and the City of Le Claire also remained interested after city meetings. Two sites in Atlantic and one site in Le Claire met the criteria and were selected for the project.

Site Descriptions

The city of Atlantic (population 7,432) is located in west central Iowa approximately 80 miles west of Des Moines (Iowa DOT, 1999*)*. The City of Le Claire (population 2,734) is located in east central Iowa approximately 20 miles northeast of Davenport (Iowa DOT, 1999). Descriptions of the three sites selected for the temporary speed hump/table installations are provided in the following sections. Each street was located in a residential area and had a posted speed limit of 25 mph.

Roosevelt Drive—Atlantic, Iowa

An aerial view of Roosevelt Drive and the surrounding area is shown in Figure 14. The Roosevelt Drive test section has a northwest-southwest orientation. Roosevelt Drive is a 30-foot wide, flat, residential, asphalt street with curb and gutter. Stop signs are located on Roosevelt Drive at the intersections with Olive Street and with 14th Street. No stop control exists on either Olive or 14th Street at those intersections. On-street parking is allowed on Roosevelt Drive but is only occasionally utilized. A total of 27 households have property adjacent to Roosevelt Drive between Olive Street and 14th Street.

Brookridge Circle, 12th Street, and 13th Street also intersect Roosevelt Drive. Stop signs are located at each of the three minor streets. Traffic on Roosevelt Drive is not required to stop at any of the three intersections. Of the three minor streets, Brookridge Circle has the highest volume of traffic. The Heritage House, a retirement community consisting of an assisted living center and several apartment buildings, is located on Brookridge Circle, east of Roosevelt Drive. The main access to the Heritage House is from Roosevelt Drive, so many of the residents, staff, and visitors use Roosevelt Drive. Thirteenth Street east of Roosevelt Drive is a 500-foot section of roadway that dead ends and has several houses located along it. Twelfth Street is also a dead end street, approximately 500 feet long, which serves as an accessway to two houses located on Roosevelt Drive.

Atlantic High School, Washington Elementary School, and Schuler Elementary/Atlantic Middle School are located near Roosevelt Drive. The intersections of Olive Street with 14th Street and Olive Street with 10th Street are both four-way stop controlled. During the city meeting in Atlantic, the city administrator stated that the two intersections become "congested" before and after school causing drivers, particularly high-school-age drivers, to use Roosevelt Drive as a "shortcut" to avoid the intersection of Olive and 14th Streets. City officials and residents of Roosevelt Drive felt that this cut-through traffic was the main contributor to the speeding problem on Roosevelt Drive. It was noted during the data collection process that a significant number of vehicles entered Roosevelt Drive from 11th Street, particularly during the hours of peak morning traffic. Not all of these drivers appeared to be high school age. It was speculated that many were parents dropping their children off at the nearby Schuler Elementary/Atlantic Middle School.

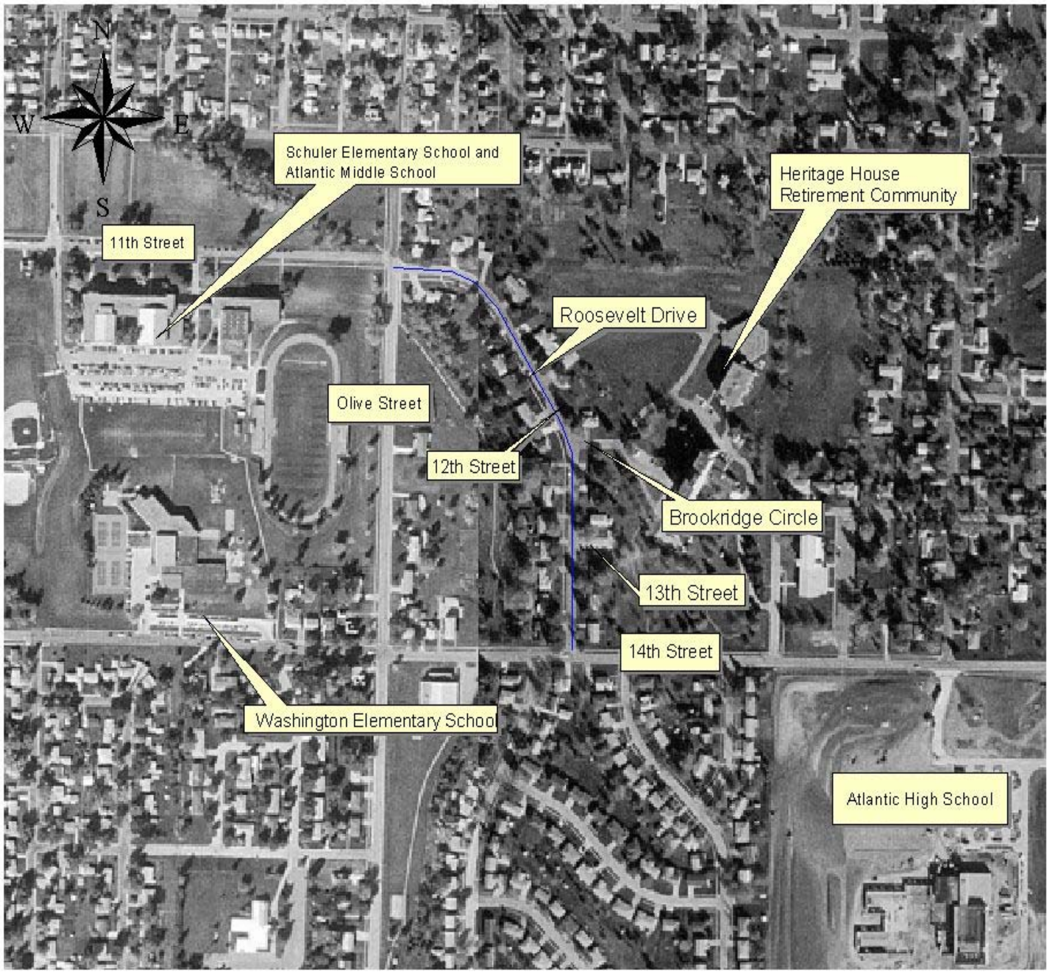


Figure 14. Roosevelt Drive in Atlantic, Iowa
(USDA Natural Resources Conservation Service, 2001)

As shown in Figure 14, no parallel alternate routes exist for this section of Roosevelt Drive. As a result, cut-through traffic diverted from Roosevelt Drive following a speed hump and/or speed table installation would be diverted back to the streets intended to carry the traffic, Olive Street and 14th Street.

Redwood Drive—Atlantic, Iowa

An aerial view, taken in 1994, of the area surrounding Redwood Drive is shown in Figure 15. The Redwood Drive test section is located in a new residential housing development and is bounded by 17th Street to the north and 22nd Street to the south. It is a 30-foot wide concrete residential street with curb and gutter. The intersection of Redwood Drive and 17th Street has four-way stop control, and the intersection of Redwood Drive and 22nd Street is a T-intersection, controlled by a stop sign on Redwood Drive. On-street parking is permitted but is rarely utilized. A crest vertical curve was located on the south end of the section under study, and a large radius horizontal curve was present in the vicinity of the 19th Street intersection. Neither is in the vicinity of the data collection location.

Figure 15 shows the study area as farmland since the only available aerial photograph was taken prior to development along Redwood. Consequently, Redwood Drive and three intersecting minor streets, 17th Street, 18th Street, and 19th Street, were drawn on the aerial photograph to show location. Currently, ten houses have been built adjacent to Redwood

Figure 15. Redwood Drive in Atlantic, Iowa
(USDA Natural Resources Conservation Service, 2001)

Drive between 17th Street and 22nd Street, and several other lots are for sale and ready for development. Both 18th Street and 19th Street are dead-end streets approximately 500 feet in length, with residential developments along each street. In addition, a nursing home (the Allen House) is located along 19th Street. Undeveloped land still exists on both sides of Redwood Drive, and farmland is located south of 22nd Street. The sparse amount of development combined with the 30-foot wide paved roadway, with little or no actual on-street parking, was believed to have induced higher vehicle speeds.

City officials felt that speeds were a problem along this section of Redwood Drive throughout the day but specifically during the morning and afternoon commute hours. A grade separated interchange at U.S. Highway 71 and 22nd Street is located to the east of Redwood Drive. City officials felt that commuters exiting U.S. Highway 71 at 22nd Street use Redwood Drive while traveling to the business and industrial areas of Atlantic. Also, due to the proximity of the Atlantic High School, city officials felt that high school students traveling to and from school used Redwood Drive. Atlantic city officials feel that these commuters and high school students using Redwood Drive as a cut-through route are part of the speeding problem along Redwood Drive. As shown in Figure 15, there are no adjacent parallel streets to Redwood Drive. Therefore, no unwanted traffic diversion to other local roads was expected after the installation of the speed hump/table at this location.

Canal Shore Drive—Le Claire, Iowa

As shown in Figure 16, Canal Shore Drive is located between the Mississippi River and U.S. Highway 67 in Le Claire, Iowa. Canal Shore Drive is a 21-foot wide asphalt street without curb and gutter. The land along Canal Shore Drive is used both for residential and recreational purposes. The area of interest for the speed hump/table installation was the section of Canal Shore Drive near Captain's Quarters (a local boat marina) and two adjacent residential areas. This section of Canal Shore Drive is flat with a minor horizontal curve located east of Captain's Quarters marina. City officials had received numerous complaints from both the owner of Captain's Quarters and nearby residents, especially those on the western end of Canal Shore Drive, about traffic traveling at excessive speeds.

Captain's Quarters is a dry dock marina and has property on both sides of Canal Shore Drive. The majority of the boats and the parking area for marina patrons are located on the north side of Canal Shore Drive. During the boating season boaters are required to cross Canal Shore Drive from the parking and boat storage areas to access the marina office, vending machines, and the river. Many of the boats must also be transported via a forklift across Canal Shore Drive to be launched. According to the owner of the marina and the Le Claire Police Chief, several near incidents between speeding traffic and pedestrians or marina equipment have occurred. Many of the homes along Canal Shore Drive have boat docks and property on the south side of Canal Shore Drive as well. It is not uncommon to see pedestrians crossing Canal Shore Drive at these locations. Canal Shore Drive does not have any side streets or parallel residential streets. The only street parallel to Canal Shore Drive is U.S. Highway 67, which is a major roadway. Therefore, traffic diversion to other local roads due to speed hump/table installation was not a concern.

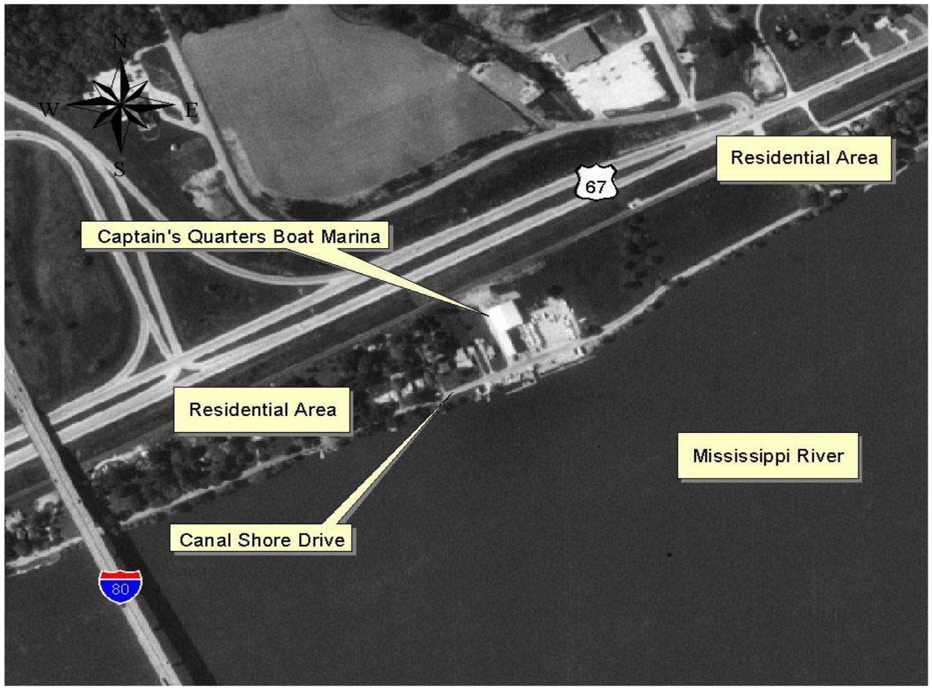


Figure 16. Canal Shore Drive in Le Claire, Iowa (USDA Natural Resources Conservation Service, 2001)

Speed Hump/Table Installations

Two different temporary traffic calming devices, a speed hump designed for a crossing speed of 25 mph and a speed table designed for a crossing speed of 30 mph, were purchased from *Recycled Technologies* for this research. The temporary devices are made of recycled rubber and can be installed for any length of time and then removed and installed in another location. Both devices were installed and evaluated at each of the three chosen test sites. The 25 mph speed hump was installed first and then converted to the 30 mph speed table at all three test locations. The 25 mph speed hump measured 14 feet in the direction of travel, three inches in height, and had parabolic seven-foot ramps. The temporary 30 mph speed table measured 18 feet in the direction of travel, three inches in height, and had seven-foot parabolic ramps on either side of a four-foot wide plateau. A side view of a temporary 25 mph speed hump and a temporary 30 mph speed table are shown in Figures 17 and 18, respectively. The temporary devices consist of recycled rubber mats anchored to the existing pavement through the use of anchor plates and 5/8-inch lag bolts. The anchor plates are metal plates with pre-punched holes for the lag bolts and threaded studs extending upward and are available in lengths of six or eight feet.

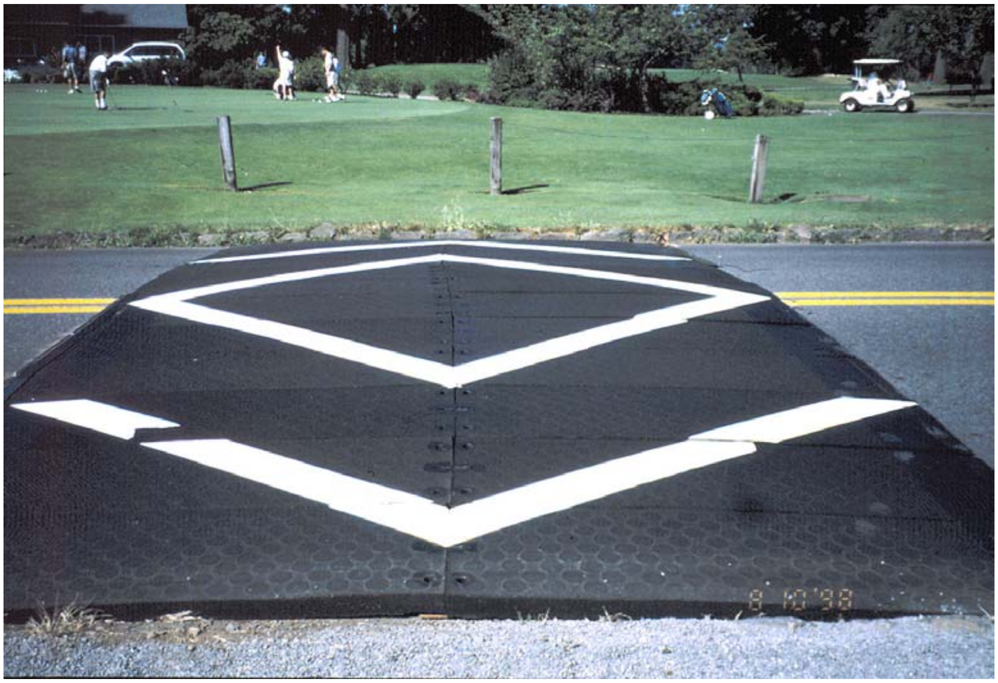


Figure 17. 14-Foot Temporary 25 mph Speed Hump (City of Portland, 2001)

Figure 18. 18-Foot Temporary 30 mph Speed Table

Installation Process

Before the devices were installed, the exact location of speed hump/table along the study location was determined. The installation location was chosen based on several factors. First, the speed humps/table had to be located so a vehicle would encounter it at a 90-degree angle and with enough sight distance to allow drivers to see and react to the device, so that those traveling at excessive speeds could maintain control of the vehicle when traversing the device. Second, the speed hump/table could not interfere with existing drainage or obstruct any drainage structures. Third, the speed hump/table could not hinder utility work or interfere with emergency equipment. Thus, the devices were not placed near or over manholes or adjacent to fire hydrants. Fourth, the speed hump/table could not interfere with points of access. Therefore, the devices were not placed within driveways, intersections, or other points of access. In addition, an attempt was made to leave at least one car length between the edge of the speed hump/table and the nearest driveway to avoid interference with exiting vehicles.

The speed humps/tables were installed at or near mid-block of the street under consideration. A mid-block location provided the opportunity to observe vehicles as they approached, traversed, and exited the speed hump/table. Also, higher vehicle speeds can be expected at mid-block locations. The location of the devices with respect to the data collection equipment will be discussed in more detail later.

In each participating jurisdiction, the city street department with the help of CTRE staff installed the temporary devices. The installation of the 25 mph speed hump was completed in approximately two hours with a four-person crew. The conversion of the 25 mph speed hump to the 30 mph speed table also took approximately two hours with a four-person crew. One lane of traffic was open during the installation process. Once half of the speed hump/table had been installed it was opened to traffic and the remaining side of the hump/table was installed. Specific details on the actual installation and removal of the temporary speed humps/tables are provided in Appendix B.

Speed Hump/Table Site Locations

The locations of the installations on each of the three test streets are illustrated in Figures 19 through 21.

The section of Roosevelt Drive used for this research was the tangent section located between the Brookridge Circle intersection and the beginning of a minor horizontal curve. This section of Roosevelt Drive is approximately 450 feet in length and appeared to carry the largest volume of vehicles along Roosevelt Drive. The temporary devices were installed at approximately the midpoint of this road segment. This location made it possible to observe vehicles approaching, traversing, and exiting the speed hump/table. The closest driveway to the installation was approximately 25 feet from the nearest edge of the device. The centerline of the closest intersecting side street, 12th Street, was located approximately 270 feet from the nearest edge of the device. The warning signs in advance of the temporary device for northbound traffic and southbound traffic were located 220 feet and 170 feet from the nearest edge of the speed hump/table, respectively.

Figure 19. Data Collection and Installation Locations on Roosevelt Drive (USDA Natural Resources Conservation Service, 2001)

On Redwood Drive, the speed hump/table was installed on the section of roadway located between 18th Street and 19th Street. The vertical curve on the southern end of Redwood Drive restricted placement of the speed hump/table due to inadequate sight distance. The section of Redwood Drive used for the speed study was bounded by 17th Street on the north and 19th Street on the south and was approximately 750 feet in length. Like Roosevelt Drive, the devices were installed on Redwood Drive approximately at a mid-block location so vehicles could be observed approaching, crossing, and exiting the speed hump/table. The closest driveway was located approximately 45 feet from the nearest edge of the speed hump/table while the centerline of the closest side road, 19th Street, was approximately 180 feet from the nearest edge of the device. The warning signs in advance of the temporary device for the northbound and southbound traffic on Redwood Drive were located 150 feet and 115 feet from the nearest edge of the speed hump/table, respectively.

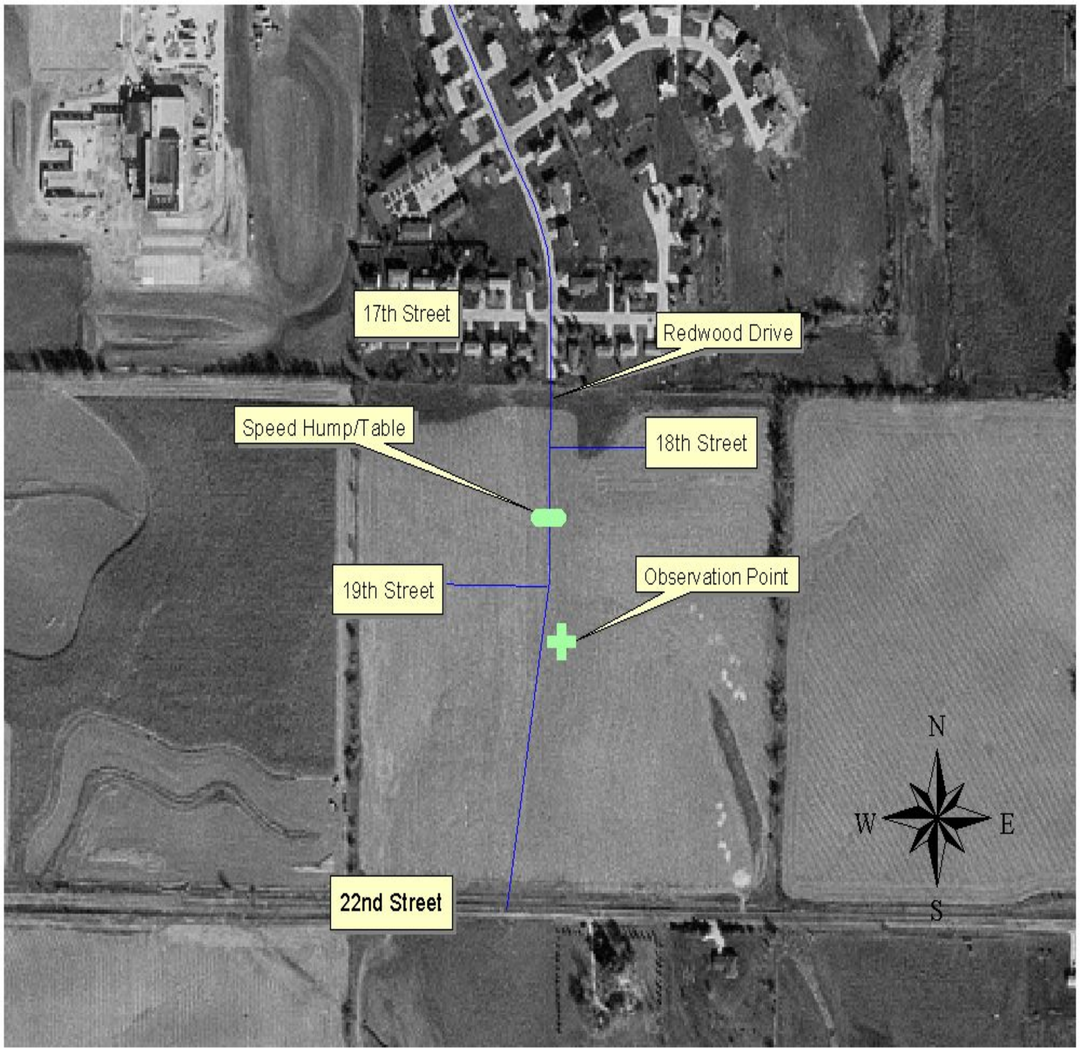


Figure 20. Data Collection and Installation Locations on Redwood Drive (USDA Natural Resources Conservation Service, 2001)

On Canal Shore Drive, the speed hump/table was installed just west of Captain's Quarters boat marina. The speed hump/table was located on a straight segment approximately 575 feet in length, making it possible to observe vehicles as they approach, traverse, and exit the speed hump/table. The closest driveway to the speed hump/table was approximately 20 feet from the nearest edge of the device. The nearest edge of the speed hump/table was located approximately 105 feet from the entrance to the dry dock storage area and approximately 200 feet from the marina office building. The nearest edge of the speed hump/table was also approximately 300 feet from the entrance to the marina parking area located on the north side of Canal Shore Drive. The advanced warning sign for the eastbound and westbound traffic on Canal Shore Drive were located approximately 30 feet and 300 feet from the nearest edge of the speed hump/table respectively.

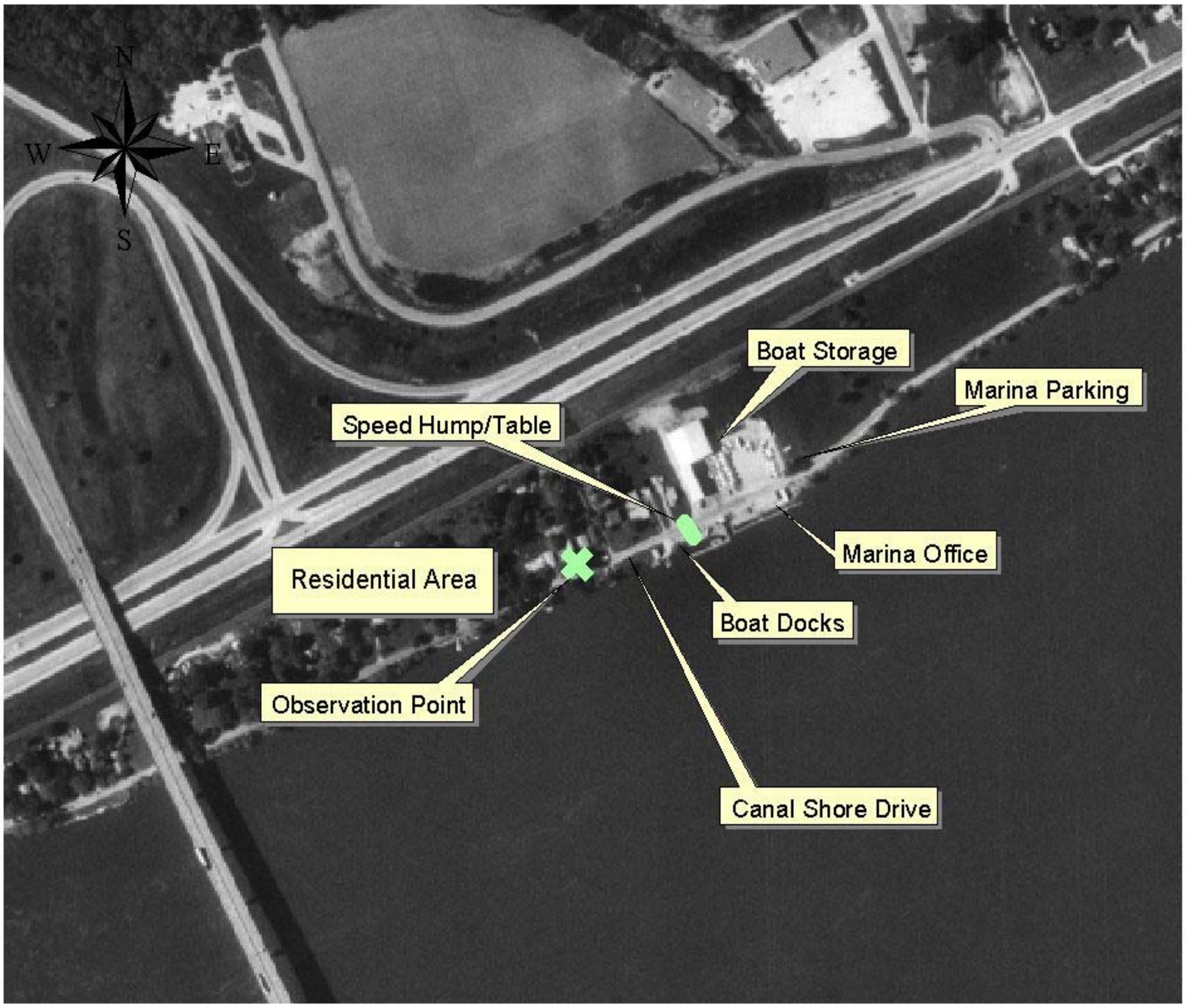


Figure 21. Data Collection and Installation Locations on Canal Shore Drive (USDA Natural Resources Conservation Service, 2001)

Signing and Markings

Warning signs and pavement markings were used while the devices were in place. Standard W17-1 warning signs were placed in advance of the speed hump/table in each direction. The yellow warning signs used were 30-inch by 30-inch diamonds with a black border and legend reading SPEED HUMP AHEAD as shown in Figures 4 and 22. Placement of the warning signs was left to the participating cities, but it was specified that the warning signs should be placed at least 100 feet in advance of the speed hump/table. The 100-foot distance meets the placement requirements of warning signs set forth by the 2000 MUTCD (FHWA, 2000). The warning signs were either mounted on signposts or banded to existing utility poles.

Figure 22. Speed Hump Warning Sign

Pavement markings were applied to the ramps of the speed hump/table. A triangular pattern on the approach sides of the speed hump/table was used as illustrated in Figure 23. The solid inner triangles were 20 inches in width and 14 inches in height. The outer triangles had a base of 48 inches, a height of 53 inches, and were 8 inches wide. The same markings were used at each test site. It should be noted that the markings had begun to wear, as shown in Figure 24, by the end of the research project, a period of approximately six months. These markings would need to be periodically reapplied if the devices are to be used as permanent installations or rotated between sites.

Figure 23. Pavement Markings on Speed Hump/Table

Figure 24. Pavement Markings After Approximately Six Months

Data Collection Methodology

Speed and volume data were collected at each of the three test locations during four time periods:

- at least one week before installation (before)
- while the 25 mph speed hump was in place
- while the 30 mph speed table was in place
- at least one week after the devices were removed (after)

"Before" data were collected and used to determine existing traffic characteristics prior to the installation of the temporary devices and data were then collected while the devices were in place to determine their impacts on vehicle speed profiles, vehicle speeds, the frequency of speeders, and traffic volumes. The data collected while the temporary speed hump and speed table were in place were compared to determine differences in impacts of the two devices. "After" data were collected following the removal of the devices to measure short-term impacts on the driving public that may be associated with the temporary speed humps/tables. A timeline of the data collection process is shown in Table 10.

Table 10. Data Collection Timeline

Site	Date	Task
Roosevelt Drive	May 16, 2001	Before data collected (Northbound only)
	May 22, 2001	Before data collected (Southbound only)
	May 29, 2001	25 mph speed hump installed
	June 5, 2001	Last day of school for Atlantic Community Schools
	June 5, 2001	Week 1 of 25 mph speed hump data collected
	June 13, 2001	Week 2 of 25 mph speed hump data collected
	June 18, 2001	Speed hump converted to 30 mph speed table
	June 20, 2001	Week 1 of 30 mph speed table data collected (all data lost due to equipment malfunction)
	July 3, 2001	Week 2 of 30 mph speed table data collected (Southbound only)
	July 10, 2001	Week 3 of 30 mph speed table data collected (Southbound data lost equipment malfunction)
	July 12, 2001	30 mph speed table removed
	July 18, 2001	After data collected
Redwood Drive	June 7, 2001	Before data collected
	June 18, 2001	25 mph speed hump installed
	June 21, 2001	Week 1 of 25 mph speed hump data collected
	July 3, 2001	Week 2 of 25 mph speed hump data collected
	July 12, 2001	Speed hump converted to 30 mph speed table
	July 17, 2001	Week 1 of 30 mph speed table data collected
	July 25, 2001	Week 2 of 30 mph speed table data collected
	July 27, 2001	30 mph speed table removed
	July 31, 2001	After data collected
Canal Shore Drive	July 19, 2001	Before data collected (weekday)
	July 21, 2001	Before data collected (weekend)
	July 29, 2001	Before data collected (weekend)
	August 2, 2001	25 mph speed hump installed
	August 12, 2001	Week 1 of 25 mph speed hump data collected
	August 26, 2001	Week 2 of 25 mph speed hump data collected
	Sept. 13, 2001	Speed hump converted to 30 mph speed table
	Sept. 29, 2001	Week 1 of 30 mph speed table data collected
	October 6, 2001	Week 2 of 30 mph speed table data collected
	October 23, 2001	30 mph speed table removed
	Nov. 3, 2001	After data collected
	Nov. 4, 2001	After data collected

Speed Data Collection
Speed profiles were collected for individual vehicles using a laser range finding device (LRF or laser gun). The laser gun emits an invisible laser that measures the distance to an object 238.4 times per second and has an accuracy of ± 0.5 feet (Laser Atlanta, 2000). The laser gun was used to record distance and time measurements for each vehicle in a separate file on a 2MB SRAM Type I PC card that inserts into the rear of the gun.

The data were downloaded from the PC cards to a desktop computer. Speed and acceleration were calculated from the distance and time measurements output by the guns using an executable program written in C. The program calculated speed and acceleration at one-second intervals. This information allowed a speed profile for each vehicle to be plotted.

A pair of crosshairs is visible to the operator of the laser gun when looking through a sight window on top of the gun. The operator places the crosshairs at a particular location on a vehicle, such as the license plate, and "locks onto" or follows that point as the vehicle travels away from the data collection equipment as shown in Figure 25. Operators found that tracking vehicles moving away from the laser gun was easier than tracking approaching vehicles. The rear of most vehicles tends to be more flat and square than the front and provides a larger area for the laser to lock onto than the front of the vehicle. This allowed more leeway if the vehicle or the data collector moved suddenly. Although the laser beam is fairly safe, pointing the laser gun at the rear of the vehicle also prevented the laser beam from being directed into an oncoming driver's eye.

The laser gun requires a clear sight distance between the laser gun and the vehicle being observed to obtain accurate data. The laser gun was positioned so that the line of sight of the laser gun was clear of tree branches, bushes, utility poles, traffic signs, parked cars, and other obstructions.

Figure 25. Data Collection on Redwood Drive

Figures 26, 27, 28, and 29 show the line of sight of the laser gun for Roosevelt Drive northbound, Roosevelt Drive southbound, Redwood Drive, and Canal Shore Drive, respectively. An attempt was made to locate the laser gun in a position that allowed observation of vehicles in the main direction of travel. From preliminary field observations, the directional traffic movements on Roosevelt Drive were nearly even throughout a typical day. Thus, data were recorded for both the northbound and southbound lanes. Southbound vehicles were collected in the morning hours and the northbound traffic was collected during the afternoon hours. On Redwood Drive, the majority of the traffic on Redwood Drive appeared to be in the northbound direction so data were collected in that direction for Redwood Drive. The majority of traffic appeared to travel in the eastbound direction along Canal Shore Drive. Thus only eastbound vehicles were observed on Canal Shore Drive.

In the experimental design, a sample size of 100 vehicles was intended for each day of data collection. An original sample size of 100 vehicles would allow a number of vehicle profiles to be discarded due to problems with the laser gun, turning vehicles, etc. and still result in a sample size large enough for statistically significant conclusions to be reached. However, due to the amount of traffic at the test sites and equipment limitations (e.g., battery life) the goal of 100 vehicles was not always attained.

Figure 26. Northbound Data Collection View on Roosevelt Drive

Figure 27. Southbound Data Collection View on Roosevelt Drive

Figure 28. Northbound Data Collection on Redwood Drive

Figure 29. Eastbound Data Collection View on Canal Shore Drive

Volume Data Collection

Volume data were collected during the same periods as the speed data: (1) before the devices were installed, (2) while the 25 mph speed hump was in place, (3) while the 30 mph speed table was in place, and (4) after the devices were removed. Traffic volumes were collected using tube counters. Volumes were counted for one to two weeks during each of the four data collection time periods.

The counting equipment was placed near the speed hump/table to assure that every vehicle traversing the speed hump/table was counted. Due to the lack of parallel streets at all three test locations, traffic diversion to other residential streets was not a concern and thus volumes were only collected on the test streets.

Resident Survey

A resident survey was also performed to determine the perception of local residents to the speed hump/table. A brief survey consisting of eight questions was distributed door-to-door along the three test streets, with a cover letter and self-addressed stamped envelope. On Roosevelt Drive, surveys were distributed to a total of 25 houses between Olive Street and 14th Street. All houses with property adjacent to Redwood Drive between 17th Street and 22nd Street, 10 in total, were also given a survey. In Le Claire, surveys were distributed to a total of eight homes that were within approximately one city block of the speed hump/table along Canal Shore Drive. Each survey was numbered so the location of the responding resident with respect to the speed hump/table could be referenced. A copy of the cover letter and survey are provided in Appendix C.

DATA ANALYSIS AND RESULTS

Speed and volume data were collected on Roosevelt Drive, Redwood Drive, and Canal Shore Drive during the study period. Data were collected before the speed hump/table was installed, while the speed hump was in place, while the speed table was in place, and shortly after the speed table was removed as discussed in Data Collection Methodology. Once collected, the speed and volume data were analyzed to determine the impacts of the temporary speed hump and temporary speed table on vehicle speed profiles, vehicle speeds, speeders traveling significantly above the speed limit, and traffic volumes. The speed and volume data were evaluated and tested statistically to determine the impacts.

Vehicle speed data collected during the before period were compared to the data collected while the speed hump was in place and while the speed table was in place to determine the impact of each device. The data collected while the speed hump was in place and while the speed table was in place were also compared to determine if one device was more effective at speed reduction. Finally, the before data was compared to the after data to determine if any short term speed impacts were present following the removal of the speed table. The speed reduction results were also compared to previous studies from other jurisdictions. The speed profiles and the acceleration/deceleration data were used to estimate the spacing required for a series of temporary speed humps and temporary speed tables.

Data Preparation

A description of data collection is provided in Data Collection Methodology. A laser gun was used to collect changes in distance between the device and vehicle tracked. Distance measurements per unit time were converted using a C program to a second-by-second profile of speed and acceleration for each vehicle studied.

Once data were collected and processed, erroneous datapoints were removed from the datasets. Although the laser gun is an accurate instrument, a number of factors can cause inaccurate data to be recorded. The laser gun records distance from the gun to the nearest object in it's path. As a result, if the operator loses lock on the vehicle being tracked or an object, such as a pedestrian, moves between the operator and vehicle, false distances are recorded. Most errors of this type are easy to detect since they typically result in unrealistic values. Significant changes in speed or acceleration between instantaneous readings, negative speeds, or extremely high speeds or accelerations are indications that inference occurred. Errors of this type were identified in the datasets and removed.

Comparison of Mean Speeds

Mean speeds were compared at various locations along the test sections. Drivers are expected to behave differently upstream or downstream of traffic calming devices than they do at the devices themselves. The vehicle's location in relationship to the midpoint of the speed hump/table (or the location where the speed hump/table would be located) was also calculated and reported instantaneously for each vehicle. Consequently vehicle speeds at different locations in the study area could be evaluated.

Mean vehicle speeds were evaluated at various locations along each test segment. Data were analyzed upstream of the speed hump/table, at the location of the speed hump/table, and downstream of the speed hump/table. Figure 30 illustrates the different locations. The upstream section included the distance from 200 to 100 feet upstream of the midpoint of where the speed hump/table was or would be located. This section was nearest to the laser gun. Only 100 feet of data were available since some distance between the laser gun and the vehicle is necessary for the operator to establish lock. The next section represented a two-hundred foot section of vehicle activity shortly before, while crossing the speed hump/table, and exiting the device. The section began 100 feet upstream from the midpoint of where the device was located to 100 feet downstream of the device. The next section was the immediate downstream section. This represented a 200-hundred foot section of roadway from 100 to 300 feet downstream of the midpoint of the location of the speed hump/table. The final section was the downstream section. The farther vehicles were away from the laser gun the more likely it was that the operator had lost lock on the vehicle. Consequently, this section represented the last section of the study area with enough vehicle samples to be included for analysis. The downstream section included vehicle data collected from 300 to 400 feet downstream of the midpoint of the speed hump/table location.

Sample sizes varied between the sections for the same data collection period due to the dynamic nature of data collection with the laser gun. Operators were not able to “lock” onto vehicles at the same locations. Additionally, the distance that an operator followed individual vehicles varied. One vehicle may have been followed for 800 feet while another was only tracked for 200 feet before interference occurred with the line of sight. As a result more data may have been available for one section than another.

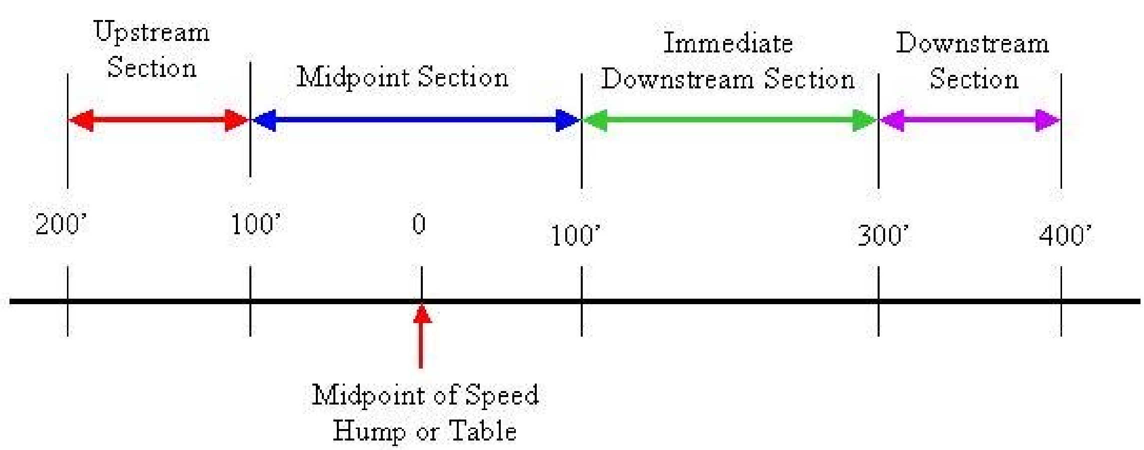


Figure 30. Schematic of Section Locations

Mean speeds were calculated for each data collection period for each section. If a vehicle had multiple datapoints (instantaneous speed and acceleration) for a specific location, speed was averaged for the vehicle providing a single value for the section. For example, if a single vehicle had three datapoints (3 seconds of data), mean speed for the vehicle for the section was equal to the sum of the 3 instantaneous speeds divided by 3. Mean speed for the section was the average of all vehicles over the section. Mean speeds were calculated for each section and then compared for the periods before, during, and after the temporary devices were in place.

A two-sample t-test was to be used to evaluate differences in mean speed between scenarios. A two-sample t-test assumes that samples are independent, are drawn from a normal population, and have equal variance. An F-test was used to test whether each pair of datasets tested had equal variance. The F-test also assumes that the populations are normally distributed. The null hypothesis used for the F-test was $\sigma_1 = \sigma_2$ where σ_1 and σ_2 are the variances of the two populations with σ_1 being the larger variance. The alternate hypothesis used was $\sigma_1 \neq \sigma_2$. If the calculated test statistic fell outside of the determined rejection range, the statistical test failed to reject the null hypothesis and the population variances were considered equal and the two sample t-test could be used to compare mean vehicle speed. However, if the test statistic for the F-test fell within the rejection range, the variances of the two populations were not considered equal resulting in the rejection of the null hypothesis. If the F-test indicated that the sample variances were not equal, an approximate two-sample t-test (which uses the variance of each sample in calculating the test statistic as opposed to the two-sample t-test which uses a pooled sample variance) was used to test the mean vehicle speeds. The approximate two-sample t-test also assumes the samples are independent and are collected from a normal population.

The null hypothesis and test procedure were the same for the two-sample t-test and the approximate two-sample t-test. The null hypothesis used was $\mu_1-\mu_2=0$ where μ_1 and μ_2 are the means of the two populations while the alternate hypothesis was $\mu_1-\mu_2\neq0$. If the absolute value of the test statistic calculated was within the rejection range, the null hypothesis was rejected and the means are assumed to be unequal. Otherwise, the statistical test fails to reject the null hypothesis, and the means are considered equal, or no statistically significant change in mean vehicle speed occurred. All the tests were evaluated at a confidence level of 95 percent. The test statistics calculated for the F-Test and the two sample t-tests are presented in Tables E1-E4 of Appendix E along with the critical values that indicate the rejection ranges.

Comparison of Mean Speeds Before and While Speed Hump Was In Place

Table 11 compares mean vehicle speeds before the speed hump was installed with the data collected while the 25 mph temporary speed hump was in place for all three test sites. Overall, mean vehicle speeds decreased while the speed hump was in place. Statistically significant decreases in mean vehicle speed occurred at the midpoint section at for all three test sites. Mean speeds decreased by 7.3, 5.7, 8.2, and 4.3 mph on Roosevelt Drive northbound, Roosevelt Drive southbound, Redwood Drive, and Canal Shore Drive, respectively.

Upstream of the speed hump, Roosevelt Drive northbound mean vehicle speeds decreased by 4.3 mph. There was no statistically significant change in mean speeds for Roosevelt Drive southbound and Canal Shore Drive. Not enough vehicles were available for the upstream section for Redwood Drive, so no comparison was made.

Significant decreases in mean vehicle speed did occur at the immediate downstream section (100 to 300 feet downstream of the speed hump) at all test sites except Canal Shore Drive. Mean vehicle speeds decreased by 6.1, 2.6, and 3.4 mph on Roosevelt Drive northbound, Roosevelt Drive southbound, and Redwood Drive, respectively. The mean speed on Canal Shore Drive 100 to 300 feet downstream of the device was only 14.3 mph prior to the installation of the speed hump, which was already well below the posted speed limit, thus little change in vehicle speed would be expected.

On Redwood Drive and Canal Shore Drive, it was possible to track vehicles over a distance of 300 to 400 feet downstream of the temporary speed hump. Sufficient vehicles were not tracked at this distance on Roosevelt to include. Statistically significant decreases in mean vehicle speed did not occur for this section of the study segment. This indicated that vehicles accelerated back to a level of speed approximately equal to those prior to installation.

Comparison of Mean Speeds Before and While Speed Table Was In Place

Table 12 compares the mean vehicle speeds calculated for the study period before the speed hump or table were installed and the period while the speed table with a design speed of 30 mph was in place. As noted in Table 12, the Roosevelt Drive northbound dataset was fairly small for the period of time when the speed table was present. Unfortunately a significant amount of data was lost due to mechanical error and limited resources, and a rigid data collection schedule did not allow time to collect additional data. The City of Le Claire was expecting the devices by a certain date.

Results are similar to those for the temporary speed hump as listed in Table 11. Overall, statistically significant changes in mean vehicle speed occurred when the speed table was in place when compared to mean vehicle speeds before installation of the devices. A significant reduction of 7.1 mph occurred on Roosevelt Drive northbound for the upstream section (100 to 200 feet upstream of the midpoint of the speed table). No significant change occurred on Roosevelt Drive southbound or Canal Shore Drive for the upstream sections. A significant decrease in mean vehicle speed occurred at the section where the speed table was located for all three sites. Decreases of 8.6 mph, 5.3 mph, 3.6 mph, and 3.4 mph were noted on Roosevelt Drive northbound, Roosevelt Drive southbound, Redwood Drive, and Canal Shore Drive, respectively. In addition, decreases in mean vehicle speed of 5.1 mph, 3.2 mph, and 3.6 mph occurred at the immediate downstream section (100 to 300 feet downstream of the midpoint of the speed table) on Roosevelt Drive northbound, Roosevelt Drive southbound, and Redwood Drive respectively. No significant changes in mean vehicle speed were observed for the immediate downstream section of Canal Shore Drive, which is not

Table 11. Comparison of Mean Speeds Before and While Speed Hump Was In Place

Sections	Before (mph)	After Hump Installation (mph)	Change (mph)	Statistically Significant	p value	Before Sample Size	Sample Size After Installation
Roosevelt Drive – NB*							
100 to 200' upstream	27.0	22.7	-4.3	Yes	0.0005	21	30
At the device	27.4	20.1	-7.3	Yes	0.0000	26	42
100 to 300' downstream	25.2	19.1	-6.1	Yes	0.0000	24	35
Roosevelt Drive – SB*							
100 to 200' upstream	22.0	20.1	-1.9	No	0.1232	11	20
At the device	25.0	19.3	-5.7	Yes	0.0000	47	41
100 to 300' downstream	25.8	23.2	-2.6	Yes	0.0048	43	39
Redwood Drive							
At the device	25.9	17.7	-8.2	Yes	0.0000	40	63
100 to 300' downstream	25.8	22.4	-3.4	Yes	0.0005	39	57
300 to 400' downstream	25.7	24.2	-1.5	No	0.1486	27	27
Canal Shore Drive							
100 to 200' upstream	17.9	17.2	-0.7	No	0.4387	40	39
At the device	17.2	12.9	-4.3	Yes	0.0000	49	50
100 to 300' downstream	14.3	13.6	-0.7	No	0.4004	46	49
300 to 400' downstream	18.5	17.3	-1.2	No	0.3778	18	25

* NB = northbound; SB = southbound

Table 12. Comparison of Mean Speeds Before and While Speed Table Was In Place

Section	Before (mph)	After Table Installation (mph)	Change (mph)	Statistically Significant	p value	Before Sample Size	Sample Size After Installation
Roosevelt Drive – NB*							
100 to 200' upstream	27.0	19.9	-7.1	Yes	0.0030	21	4
At the device	27.4	18.8	-8.6	Yes	0.0000	26	8
100 to 300' downstream	25.2	20.1	-5.1	Yes	0.0031	24	7
Roosevelt Drive – SB*							
100 to 200' upstream	22.0	22.7	+0.7	No	0.6132	11	15
At the device	25.0	19.7	-5.3	Yes	0.0000	47	18
100 to 300' downstream	25.8	22.6	-3.2	Yes	0.0012	43	18
Redwood Drive							
At the device	25.9	17.5	-8.4	Yes	0.0000	40	82
100 to 300' downstream	25.8	22.2	-3.6	Yes	0.0001	39	82
300 to 400' downstream	25.7	23.1	-2.6	Yes	0.0038	27	59
Canal Shore Drive							
100 to 200' upstream	17.9	18.2	+0.3	No	0.7777	40	45
At the device	17.2	13.8	-3.4	Yes	0.0002	49	50
100 to 300' downstream	14.3	16.2	+1.9	No	0.0601	46	46
300 to 410' downstream	18.5	19.8	+1.3	No	0.3419	18	26

* NB = northbound; SB = southbound

unexpected due to the initial low speeds. Unlike the temporary speed hump, mean vehicle speed on Redwood Drive for the downstream section (300 to 400 feet downstream of the midpoint of the temporary speed table) decreased by 2.6 mph. Data were not available for this section for the other sites. However without being able to detect the same pattern for the other sites, it is difficult to determine whether the speed table was actually more effective in reducing speeds downstream than the speed hump.

Comparison of Mean Speeds for Speed Hump Versus Speed Table

Mean vehicle speeds observed while the speed hump was in place are compared to mean vehicle speeds while the speed table was in place in Table 13. Overall, there is no statistically significant difference in mean vehicle speeds between the two devices throughout the study sections. On the upstream section of Roosevelt Drive southbound, the study showed statistically significant higher speeds for the speed table as opposed to the hump (2.6 mph). On Canal Shore Drive higher speeds for the hump were also statistically significant for both downstream sections. Speeds were 2.6 mph higher for the immediate downstream section and 2.4 mph higher for the downstream section. While other studies have shown speed humps to have a greater impact on vehicle speeds, results of this study showed no significant changes in mean vehicle speed along any section between the temporary speed hump and the temporary speed table (Ewing, 1999, Kittelson and Associates, Inc., 2000*)*.

Comparison of Mean Speeds Before and After Speed Hump and Table Were Installed

Table 14 compares mean vehicle speeds before the speed hump/table was installed and shortly after the device was removed. Results were mixed as to whether the devices had a short-term impact on mean vehicle speeds. Speeds on Roosevelt Drive northbound had lower speeds after the devices were removed than before. For the upstream section, mean speeds were 5.1 mph lower; for the section at the device, speeds were 4.4 mph lower; and for the section immediately downstream, speeds were 2.8 mph lower. Speeds were not significantly different after the devices were removed for all sections of the Roosevelt Drive southbound segment, all sections of the Redwood Road segment, and most of the Canal Shore Drive sections. The immediate downstream section of Canal Shore Drive experienced a slight increase in mean vehicle speeds (3.5 mph).

Reduction of Top Vehicle Speeds

Transportation officials are often most concerned with reducing the number of high-end speeders (those traveling significantly over the speed limit), and less concerned with those slightly exceeding the speed limit. The objectives of the research were not to just look at whether speed humps or tables reduce vehicle speeds, as has been done in a other studies, but also to evaluate whether they both have similar impacts on vehicles who are traveling significantly over the speed limit. If the speed table could be shown to be as effective in reducing top speeds, its use may be recommended over the hump since it is more comfortable for drivers to traverse, due to the flatter surface, and may provide less impact to ambulance or fire services. To evaluate the impact of both devices on high-end speeders, changes the number of vehicles traveling in specific speed ranges over the speed limit and changes in 85th percentile speeds were evaluated.

Table 13. Comparison of Mean Speeds for Speed Hump Versus Speed Table

Section	Speed Hump (mph)	Speed Table (mph)	Change (mph)	Statistically Significant	p value	Speed Hump Sample Size	Speed Table Sample Size
Roosevelt Drive – NB*							
100 to 200' upstream	22.7	19.9	-2.8	No	0.2056	30	4
At the device	20.1	18.8	-1.3	No	0.5560	42	8
100 to 300' downstream	19.1	20.1	+1.0	No	0.6961	35	7
Roosevelt Drive – SB*							
100 to 200' upstream	20.1	22.7	+2.6	Yes	0.0377	20	15
At the device	19.3	19.7	+0.4	No	0.7571	41	18
100 to 300' downstream	23.2	22.6	-0.6	No	0.5936	39	18
Redwood Drive							
100 to 200' upstream	20.7	20.6	-0.1	No	0.9200	29	31
At the device	17.7	17.5	-0.2	No	0.7425	63	82
100 to 300' downstream	22.4	22.2	-0.2	No	0.7897	57	82
300 to 400' downstream	24.2	23.1	-1.1	No	0.2304	27	59
Canal Shore Drive							
100 to 200' upstream	17.2	18.2	+1.0	No	0.3301	39	45
At the device	12.9	13.8	+0.9	No	0.2332	50	50
100 to 300' downstream	13.6	16.2	+2.6	Yes	0.0022	49	46
300 to 400' downstream	17.4	19.8	+2.4	Yes	0.0443	25	26

* NB = northbound; SB = southbound

Table 14. Comparison of Mean Speeds Before and After Speed Hump and Table Were Installed

Section	Before (mph)	After (mph)	Change (mph)	Statistically Significant	p value	Before Sample Size	After Sample Size
Roosevelt Drive – NB*							
100 to 200' upstream	27.0	21.9	-5.1	Yes	0.0005	21	14
At the device	27.4	23.0	-4.4	Yes	0.0009	26	16
100 to 300' downstream	25.2	22.4	-2.8	Yes	0.0315	24	15
Roosevelt Drive – SB*							
At the device	25.0	26.8	+1.8	No	0.3490	47	14
100 to 300' downstream	27.8	25.8	-2.0	No	0.2865	43	13
Redwood Drive							
At the device	25.9	24.7	-1.2	No	0.3290	40	30
100 to 300' downstream	25.8	25.7	-0.1	No	0.9585	39	29
300 to 400' downstream	25.7	25.0	-2.7	No	0.5584	27	22
Canal Shore Drive							
100 to 200' upstream	17.9	17.9	0	No	0.9765	40	18
At the device	17.2	18.7	+1.5	No	0.1460	49	40
100 to 300' downstream	14.3	17.8	+3.5	Yes	0.0033	46	39
300 to 400' downstream	18.5	19.6	+1.1	No	0.5028	18	21

* NB = northbound; SB = southbound

Changes in Speed Ranges
Changes in peak vehicle speeds were evaluated to determine whether the temporary speed hump and/or the temporary speed table influenced drivers who traveled at speeds that were significantly above the speed limit. The peak speed was determined for each vehicle in each dataset by selecting the highest instantaneous speed for that vehicle regardless of location along the link. Data for the northbound and southbound directions of travel for Roosevelt Drive were combined.

Table 15 provides a breakdown of the vehicle speed ranges for Roosevelt Drive, Redwood Drive, and Canal Shore Drive. The percentage of vehicles traveling in the following speed ranges are shown:

- below 20 mph
- from 20 to 25 mph
- 26 to 30 mph
- 31 to 35 mph
- greater than 35 mph

The percentage of vehicles observed exceeding the speed limit (> 25 mph) decreased on Roosevelt Drive, Redwood Drive, and Canal Shore Drive after the speed hump was installed. As shown in Table 15, 68.1 percent, 65.0 percent, and 7.8 percent of the vehicles on Roosevelt Drive, Redwood Drive, and Canal Shore Drive, respectively, exceeded the posted speed limit of 25 mph prior to the installation of the temporary speed hump. In addition, 18.1 percent, 20.0 percent, and 2.0 percent of the vehicles observed on Roosevelt Drive, Redwood Drive, and Canal Shore Drive, respectively, exceeded 30 mph. While the temporary speed hump was in place on Roosevelt Drive, Redwood Drive, and Canal Shore Drive, the percentage of vehicles exceeding 25 mph decreased to 41.4 percent, 44.4 percent, and 3.9 percent respectively while the percentage exceeding 30 mph dropped to 13.4 percent, 7.9 percent, and zero respectively. The percentage of vehicles exceeding the 25 mph speed limit decreased while the temporary speed table was in place on Roosevelt Drive and Redwood Drive but increased on Canal Shore Drive. On Roosevelt Drive after the table was installed the number of vehicles observed traveling above the speed limit decreased to 33.3 percent and on Redwood Drive that number also decreased to 33.3. After installation of the temporary speed hump no vehicles were observed traveling higher than 30 mph on Roosevelt and only 2.1 percent of vehicles on Redwood were traveling faster than 30 mph. On Canal Shore Drive the percentage of vehicles exceeding the speed limit was actually higher than before the device was installed with 19.3 percent traveling above the speed limit and 3.8 percent traveling more than 30 mph.

Table 15. Vehicle Activity by Speed Range

Speed Range (mph)	Before Devices	With Speed Hump	With Speed Table	After Devices
Roosevelt Drive				
<20	0.0%	11.0%	14.8%	13.3%
20-25	31.9%	47.6%	51.9%	36.7%
26-30	50.0%	28.0%	33.3%	30.0%
31-35	13.9%	11.0%	0.0%	10.0%
>35	4.2%	2.4%	0.0%	10.0%
Total > 25 mph	68.1%	41.4%	33.3%	50.0%
Redwood Drive				
<20	2.5%	15.9%	14.0%	0.0%
20-25	32.5%	39.7%	52.7%	37.0%
26-30	45.0%	36.5%	31.2%	50.0%
31-35	15.0%	6.3%	2.1%	13.0%
>35	5.0%	1.6%	0.0%	0.0%
Total > 25 mph	65.0%	44.4%	33.3%	63.0%
Canal Shore Drive				
<20	41.2%	68.6%	51.9%	31.7%
20-25	51.0%	27.5%	28.8%	53.7%
26-30	5.8%	3.9%	15.5%	9.8%
31-35	2.0%	0.0%	3.8%	4.8%
>35	0.0%	0.0%	0.0%	0.0%
Total > 25 mph	7.8%	3.9%	19.3%	14.6%

Surprisingly the fraction of vehicles traveling higher than the speed limit and greater than 30 mph was lower for the speed table than the speed hump for both Roosevelt and Redwood Drives. It was expected that the speed hump would have a greater impact on speeders than the speed table. The temporary speed table was designed to be traversed comfortably at 30 mph, while the speed hump was designed to be traversed at only 25 mph. Consequently it was expected that more vehicles would travel above the speed limit for the table than for the hump. It is possible that drivers on Roosevelt Drive and Redwood Drive were more intimidated by the wider speed table and slowed further.

After the temporary speed table was removed from Roosevelt Drive, the number of drivers that exceeded 25 mph was 18.1 percent lower than that observed in the before period. Unfortunately, the number of vehicles exceeding 30 mph in the after period was 1.9 percent higher than in the before period. The number of speeders exceeding 25 mph and 30 mph on Redwood Drive in the after period were 2.0 and 7.0 percent lower, respectively, than the before period. This may indicate that a short-term lasting impact on peak speeds may be associated with the temporary speed hump and/or the temporary speed table. The number of speeders observed exceeding 25 mph and 30 mph on Canal Shore Drive in the after period were 6.8 and 2.8 percent higher, respectively, than the percentage observed in the “before” period. However, this may be more related to a change in conditions along Canal Shore Drive than a problem with the traffic calming devices. Data collected after the devices were removed occurred towards the end of the recreational season due to the problems with data collection discussed previously. If the number of vehicles and pedestrians accessing the marina had decreased during the after study period, drivers on Canal Shore may have felt more comfortable driving at higher speeds.

Changes in 85th Percentile Speed

The 85th percentile speeds were calculated for each roadway segment. A comparison of speeds for the temporary speed hump is summarized in Table 16 and Table 17 for the speed table. The 85th percentile speed for most of the sections along Roosevelt Drive northbound, Roosevelt Drive southbound, and Redwood Drive were around 30 mph before installation of the speed hump. The 85th percentile speed on Canal Shore Drive was only 20 mph indicating that a speeding problem did not exist on that segment even before the traffic calming devices were installed. After the temporary speed hump was installed, the 85th percentile speeds decreased 3.7 to 5.2 mph on the Roosevelt Drive northbound segment depending on the section. The 85th percentile speeds on Roosevelt Drive southbound decreased 2.4 mph on the upstream section, 4.9 mph at the speed hump and did not change downstream. On the Redwood Drive test segment, speeds decreased 7.1 mph at the hump and 4.0 and 1.3 mph for the downstream sections. On Canal Shore Drive, 85th percentile speeds decreased 4.7 mph at the speed hump and 2.0 mph or less on the others sections.

As shown in Table 17 after the speed table was installed, 85th percentile speeds on Roosevelt Drive northbound decreased from 4.3 to 7.2 mph depending on the section. On Roosevelt Drive southbound a slight increase of 1.5 mph was observed for the upstream section with a decrease of 4.7 at the location of the speed table and a decrease of 1 mph for the downstream section. The most significant decrease occurred at the location of the speed hump on Redwood Drive with a decrease of 9.7 in 85th percentile speeds. The downstream sections of Redwood experienced decreases of 4.2 and 1.1 mph. On Canal Shore Drive a slight increase in 85th percentile speeds was noted for all sections (1.5 to 4.0 mph) except the section at the speed hump itself which experienced a 2.5 mph decrease. As discussed previously this may have been due to seasonal changes in drivers rather than the device itself.

Table 16. Differences in 85th Percentile Speeds with Installation of Speed Hump

Roosevelt Drive – NB*	Before (mph)	After Hump Installation (mph)	Change (mph)	Percent Change	Before Sample Size	After Sample Size
100 to 200' upstream	29.8	26.1	-3.7	-12.4%	21	30
At the device	30.9	25.7	-5.2	-16.8%	26	42
100 to 300' downstream	29.4	25.5	-3.9	-13.3%	24	35

Roosevelt Drive – SB*	Before (mph)	After Hump Installation (mph)	Change (mph)	Percent Change	Before Sample Size	After Sample Size
100 to 200' upstream	24.8	22.4	-2.4	-9.7%	11	20
At the device	28.0	23.1	-4.9	-17.5%	47	41
100 to 300' downstream	28.1	28.1	0.0	0.0%	43	39

Redwood Drive	Before (mph)	After Hump Installation (mph)	Change (mph)	Percent Change	Before Sample Size	After Sample Size
At the device	30.0	22.9	-7.1	-23.7%	40	63
100 to 300' downstream	30.0	26.0	-4.0	-13.3%	39	57
300 to 385' downstream	27.7	26.4	-1.3	-4.7%	27	27

Canal Shore Drive	Before (mph)	After Hump Installation (mph)	Change (mph)	Percent Change	Before Sample Size	After Sample Size
100 to 200' upstream	21.3	20.2	-1.1	-5.2%	40	39
At the device	21.6	16.9	-4.7	-21.8%	49	50
100 to 300' downstream	19.6	17.6	-2.0	-10.2%	46	49
300 to 385' downstream	21.0	21.2	0.2	1.0%	18	25

*NB = northbound; SB = southbound

Table 17. Differences in 85th Percentile Speeds with Installation of Speed Table

Roosevelt Drive – NB*	**Before (mph)**	**After Table Installation (mph)**	**Change (mph)**	**Percent Change**	**Before Sample Size**	**After Sample Size**
100 to 200' upstream	29.8	22.6	-7.2	-24.2%	21	4
At the device	30.9	24.3	-6.6	-21.4%	26	8
100 to 300' downstream	29.4	25.1	-4.3	-14.6%	24	7
Roosevelt Drive – SB*	**Before (mph)**	**After Table Installation (mph)**	**Change (mph)**	**Percent Change**	**Before Sample Size**	**After Sample Size**
100 to 200' upstream	24.8	26.3	1.5	6.0%	11	15
At the device	28.0	23.3	-4.7	-16.8%	47	18
100 to 300' downstream	28.1	27.1	-1.0	-3.6%	43	18
Redwood Drive	**Before (mph)**	**After Table Installation (mph)**	**Change (mph)**	**Percent Change**	**Before Sample Size**	**After Sample Size**
At the device	30.0	20.3	-9.7	-32.3%	40	82
100 to 300' downstream	30.0	25.8	-4.2	-14.0%	39	82
300 to 400' downstream	27.7	26.6	-1.1	-4.0%	27	59
Canal Shore Drive	**Before (mph)**	**After Table Installation (mph)**	**Change (mph)**	**Percent Change**	**Before Sample Size**	**After Sample Size**
100 to 200' upstream	21.3	22.9	1.6	7.5%	40	45
At the device	21.6	19.1	-2.5	-11.6%	49	50
100 to 300' downstream	19.6	21.1	1.5	7.6%	46	46
300 to 410' downstream	21.0	25.0	4.0	19.0%	18	26

* NB = northbound; SB = southbound

Table 5 summarized the results of speed hump and speed table speed studies conducted in other jurisdictions. As shown, the change in speed for 12-foot speed humps varied from +1 to -16 mph, or a +4 to -42 percent (Ewing, 1999; Clement, 1983; Urban et al., 1999; Marek and Walgren, 1998; Ballard, 1998; Knapp, 2000; Transportation Association of Canada, 1998; City of Charlotte, 2001; Dittberner, 1999; Aburahmah and Al Assar, 1998; City of Bloomington, 2001). The change in vehicle speed associated with the speed tables listed in Table 5 varied from zero to –17 mph, or from zero to -41 percent (Ewing, 1999; Urban et al.; 1999; Marek and Walgren, 1998; City of Charlotte, 2001). The magnitude and percentage of speed reductions associated with speed humps and speed tables listed in Table 5 are comparable to one another in that the range of reductions are similar for the two devices. This study, however, found a larger speed reduction, both in magnitude and percentage, associated with the temporary speed table. This could be the result of small sample sizes in this study. Any outliers in the small samples could have skewed the 85th percentile calculations. This could also be the result of lingering impacts of the temporary speed hump while the speed table was in place. Drivers may have become familiar with the temporary speed hump, and this previous experience may have impacted the results of the speed table data.

Optimum Spacing

An effective speed hump(s) installation should slow traffic to the objective speed over as long a roadway segment as possible. The goal with any installation would be to slow traffic over as long a roadway segment as possible with the smallest number of speed humps. Vehicles traveling at a constant, but decreased, speed (due to proper speed hump spacing) may also decrease noise and pollution levels. This approach to speed hump installation should increase the level of safety along the roadway segment (by reducing the severity of the crashes that do occur) and use the funding available for speed hump installation more effectively. The spacing of speed humps that meets these objects needs to be quantitatively determined.

As discussed in Comparison of Means Speeds in the Data Analysis and Results section, mean vehicle speeds increased downstream of the temporary traffic calming devices. In some cases there was no statistically significant change in mean vehicle speed between conditions before installation of the speed hump/table and while the devices were in place either upstream or downstream of the temporary device location. This indicates that the effect of the speed hump/table is limited to the immediate area around the device. A series of devices may be necessary in order to obtain reductions in vehicle speed over an entire city block.

A special Subcommittee of the California Traffic Control Devices Committee developed an equation (see Equation 1 in Background) to calculate the optimal spacing for a series of speed humps (ITE Traffic Engineering Council, 1997*)*. Using this equation with the desired 85th percentile speed of 25 mph, an optimal spacing of 275 feet was calculated. Another study suggests that vehicle speeds will increase 0.5 to 1.0 mph for every 100 feet of device separation (Ewing, 1999*)*. This suggests that for an 85th percentile speed of 28 mph, the traffic calming devices should be spaced at intervals of 300 to 600 feet.

A spacing criteria was also developed based on the results of this research. Speed profiles were created from the data collected on Redwood Drive and on Roosevelt Drive southbound while the temporary devices were in place and used to quantify spacing for a series of temporary speed humps or temporary speed tables on these roadways. The speed profiles collected on Canal

Shore Drive and Roosevelt Drive northbound are presented but not considered for the spacing analysis either because very few vehicles exceeded 25 mph or because a small number of profiles were available for evaluation. Creation and comparison of the speed profiles is presented in Data Preparation in the Data Analysis and Results section and an evaluation of optimum spacing is provided in Comparison of Mean Speeds in the same section.

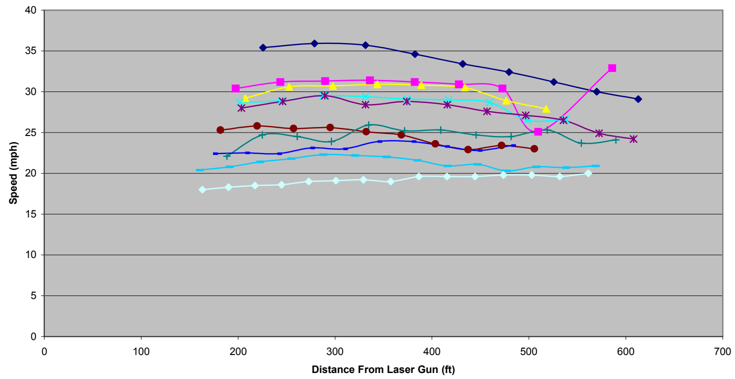
Comparison of Speed Profiles

Speed profiles of individual vehicles were created by plotting instantaneous vehicle speed versus distance from the laser gun for each of the three test sites during each data collection stage. The remaining speed profiles and their associated speed data were used in the evaluation described in the following sections of this report and are provided in Appendix D. A representative sample of speed profiles for each test street from each data collection time period were plotted to show the overall distribution and range of the speed profiles collected and are shown in Figures 31–34. The following is shown in each:

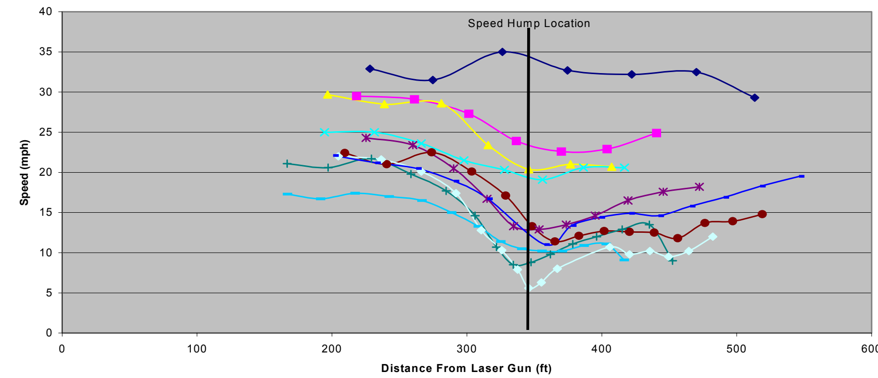
(a) speed profiles collected before the temporary devices were in place
(b) speed profiles collected while the 25 mph speed hump was in place
(c) speed profiles collected while the 30 mph speed table was in place
(d) speed profiles collected after the 30 mph speed table was removed.

As illustrated in Figures 31–34, vehicle profiles collected in the period before the traffic calming devices were installed are fairly constant with a flat slope. As shown, a number of the vehicles shown exceeded the 25 mph posted speed limit somewhere along the test street. The shape of the speed profiles collected for the periods while the speed hump and speed table were in place are noticeably different than those collected in the before period. The laser gun was located approximately 340, 305, 255, and 280 feet upstream of the midpoint of the temporary speed hump/table on Roosevelt Drive northbound, Roosevelt Drive southbound, Redwood Drive, and Canal Shore Drive, respectively. The speed profiles collected on Roosevelt Drive and Redwood Drive while the devices were in place show a dip in vehicle speeds (i.e., a deceleration and then an acceleration) in the vicinity of the temporary speed hump/table. On the other hand, many of the profiles collected along Canal Shore Drive remained relatively flat while the temporary speed hump/table was in place. This may be due to the low vehicle speeds that existed prior to installation. The after profiles at each location also have a relatively flat shape and appear to be consistent with the shape and magnitude of the before profiles. No short-term impacts associated with the temporary speed hump/tables are easily detected

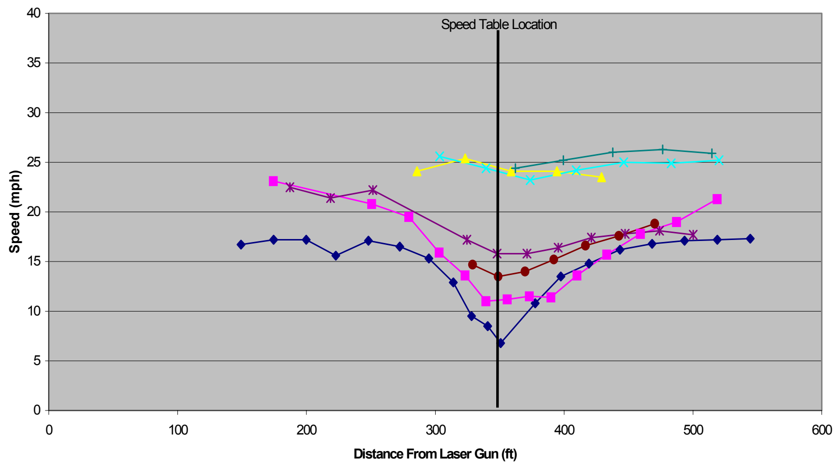
A visual analysis of the speed profiles showed no noticeable difference between the speed profiles collected while the speed hump was in place and while the speed table was in place on any of the three test streets. Additionally, the shape of the profiles collected while the temporary speed hump and temporary speed table were in place are similar in shape to those reported in other studies (Kittelson and Associates, Inc., 2000; Clement, 1983; Mak, 1986; Clark, 2000; Barbosa, et al., 2000).



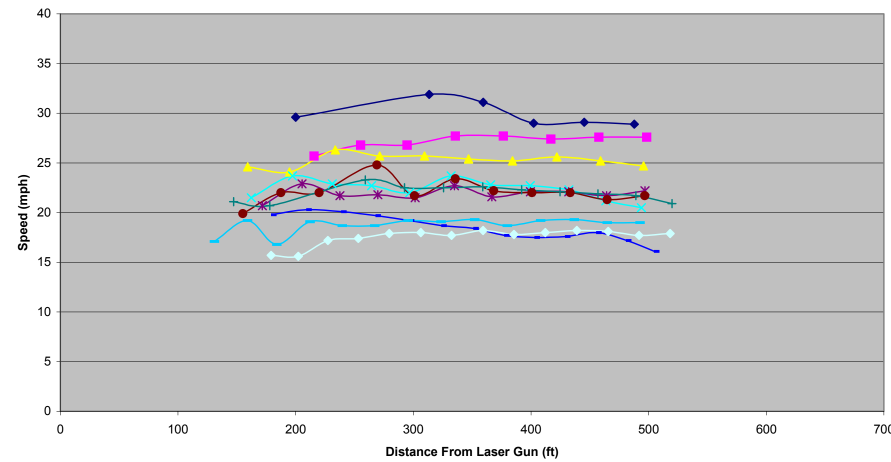
(a) Before



(b) Speed Hump

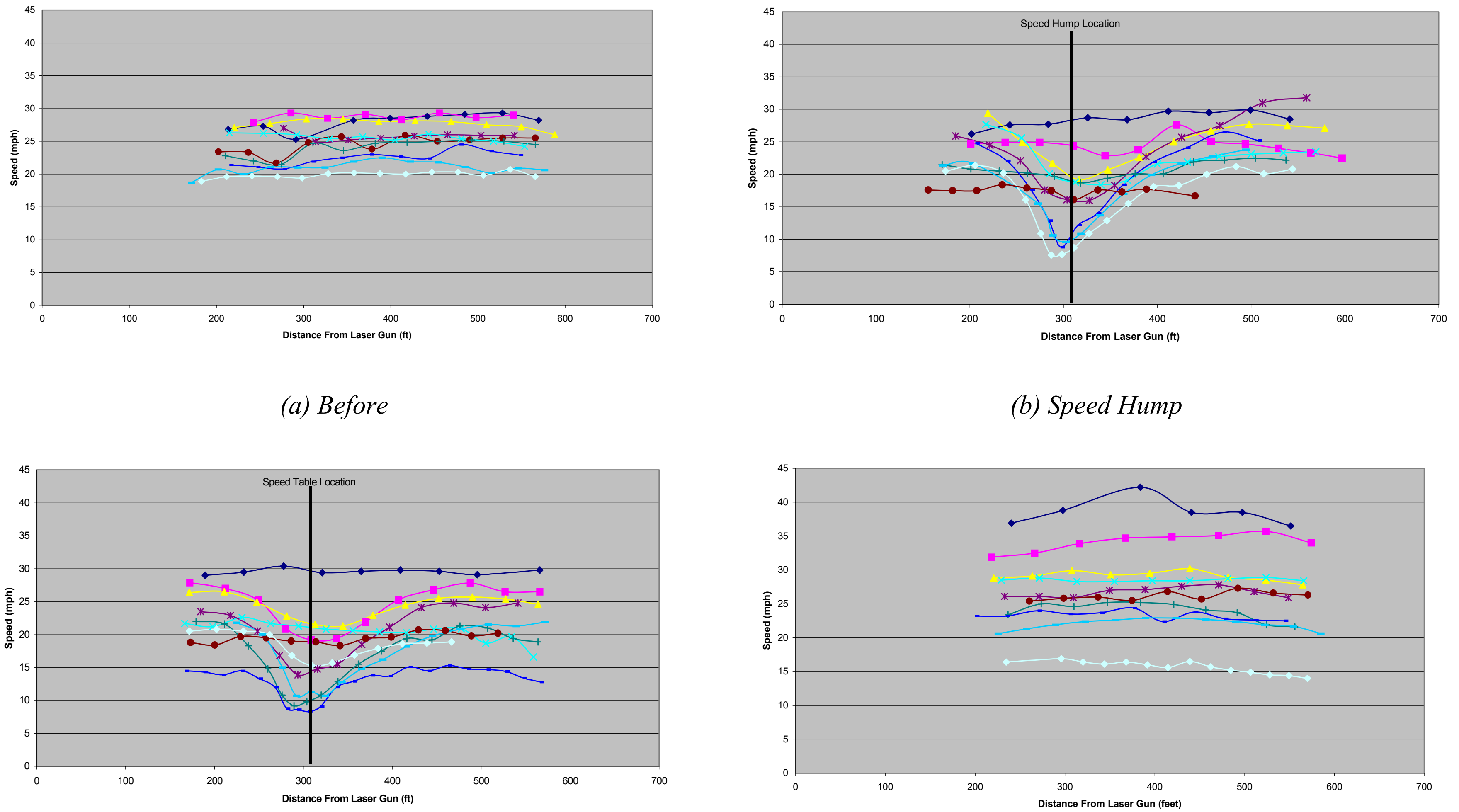


(c) Speed Table



(d) After

Figure 31. Roosevelt Drive Northbound Representative Speed Profiles



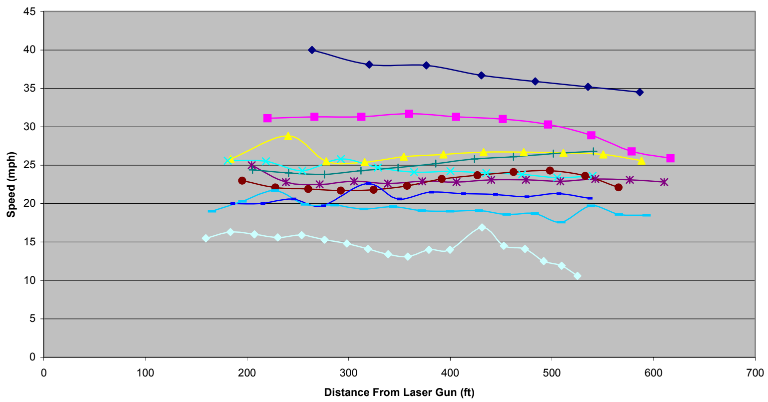
(a) Before

(b) Speed Hump

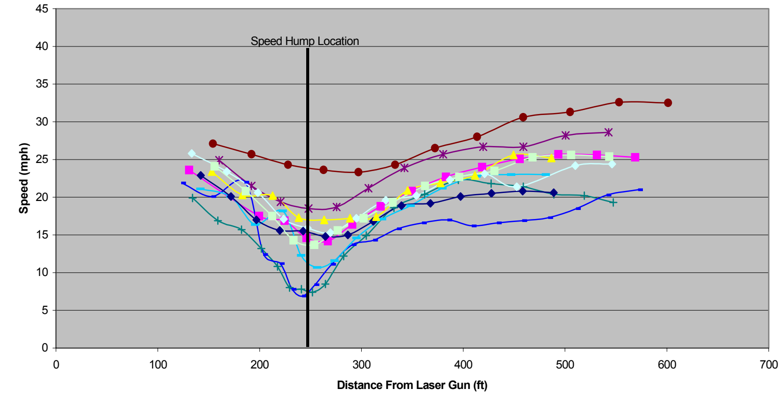
(c) Speed Table

(d) After

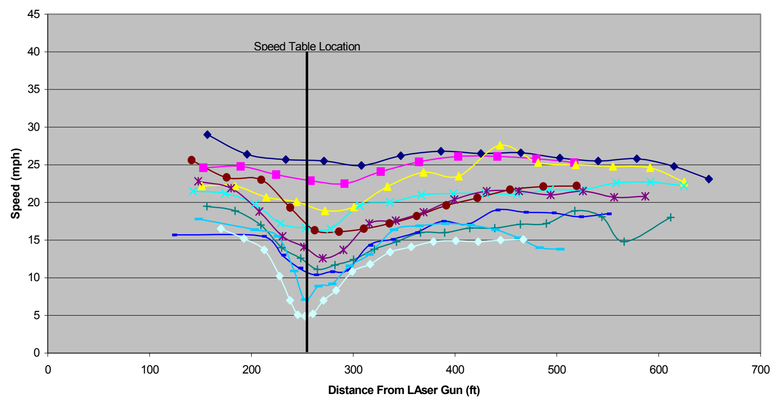
Figure 32. Roosevelt Drive Southbound Representative Speed Profiles



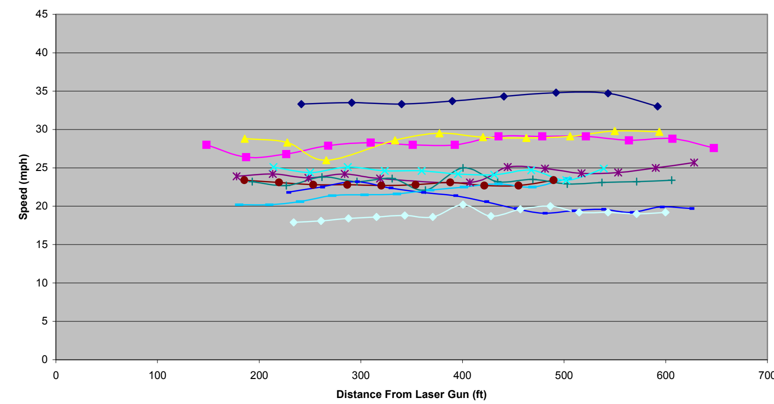
(a) Before



(b) Speed Hump

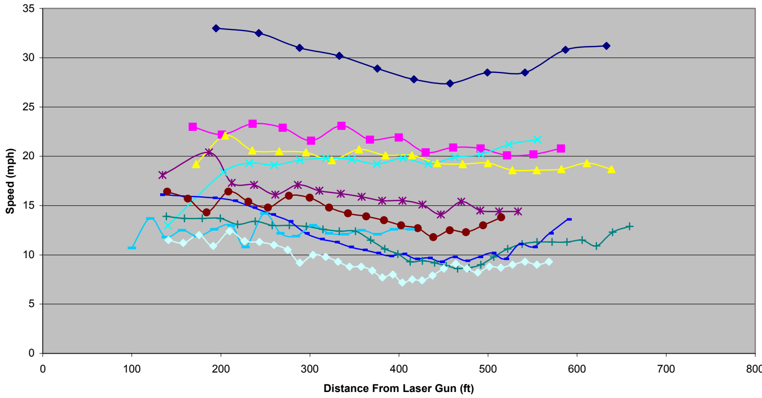


(c) Speed Table

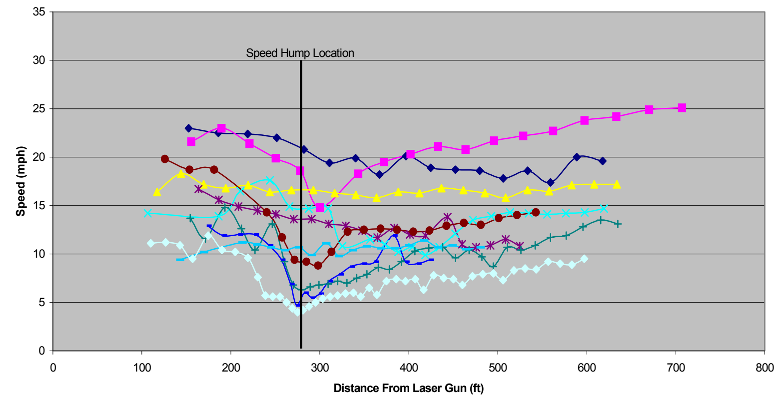


(d) After

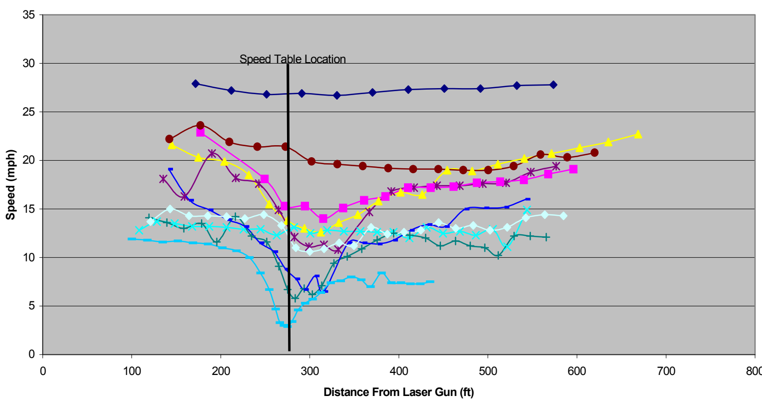
Figure 33. Redwood Drive Representative Speed Profiles



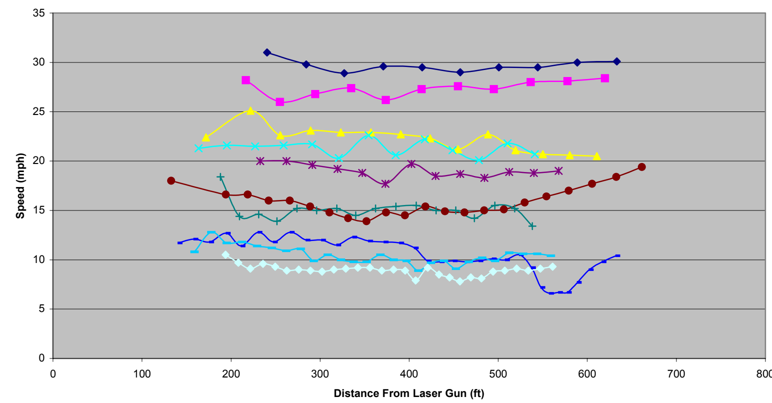
(a) Before



(b) Speed Hump



(c) Speed Table



(d) After

Figure 34. Canal Shore Drive Representative Speed Profiles

Determination of Optimum Spacing

The speed hump/tables were individual installations; Accordingly an assumption had to be made about a driver's reactions to additional downstream devices in order to estimate optimal spacing of speed hump or tables to maintain desired speeds. For the following analysis and discussion, it was assumed that the presence of another downstream device would not impact the speed choice of a driver or their acceleration or deceleration rate at the existing device. It was assumed that a driver would decelerate at the same rate as they approached a device, crossed the speed hump/table at the same speed, and accelerated away from the device at the same rate as was observed with the single installations in this study.

A spacing of slow points that allows drivers to accelerate to speeds above the speed limit is not desirable. On the other hand, spacing the devices too closely may lead to driver annoyance and loss of public support. Therefore, the speed profiles collected in this research were evaluated with respect to the locations where the decelerations began and where vehicles had accelerated to a speed of 25 mph. Using the assumptions above, it was determined that the suggested spacing for the temporary devices should be the sum of the distance used to decelerate and the distance used to accelerate to approximately 25 mph. The distance used to decelerate was defined as the distance from which approximately 75 percent of the approaching vehicles had begun braking, identified by the negative slope of the speed profile, to the approximate center of the speed hump/table. The distance used to accelerate was defined as the distance from the approximate center of the speed hump/table to the point where approximately 75 percent of the vehicles had accelerated, identified by the positive slope of the speed profile, to around 25 mph. Coincidently, this is the point where many of the slopes begin to level off indicating more constant speeds.

Figures 35 and 36 show the speed profiles collected on Roosevelt Drive southbound and Redwood Drive, respectively, while the temporary 25 mph speed hump was in place. These figures contain only those profiles associated with a vehicle traveling at or above the 25 mph speed limit at some point along the roadway sections studied. The thick black vertical lines indicate the approximate position where most vehicles began to decelerate, the approximate center point of the temporary speed hump, and the approximate location of where speeds reached 25 mph. The deceleration distance on Roosevelt Drive southbound was about 60 feet, and the acceleration distance was about 160 feet. The sum of the deceleration distance and acceleration distance, or the suggested spacing for temporary speed humps along Roosevelt Drive, was approximately 220 feet. Figure 36 indicates that the deceleration and acceleration distances for Redwood Drive were approximately 80 feet and 205 feet, respectively, resulting in a suggested spacing on Redwood Drive of approximately 285 feet. Therefore, the results of the evaluation on Roosevelt Drive southbound and Redwood Drive suggest a spacing of between 220 and 285 feet for a series of 25 mph temporary speed humps. The optimal spacing of 275 feet, calculated from Equation 1, is in the upper end of the spacing range suggested for temporary speed humps along Roosevelt Drive and Redwood Drive. However, the 220 feet and 285 feet spacings are smaller than the 300 to 600 feet suggested by some researchers (Ewing, 1999; Urban et al., 1999; Pennsylvania DOT, 2001; Clement, 1996; Vazquez, 2000; City of Fairfax, 2001; Marek and Walgren, 1998; Ballard, 1998; Szplett and Feuss, 1999; City of Austin, 2001).

The procedure described above was also followed for the evaluation of temporary speed tables on Redwood Drive. As shown in Figure 37, the deceleration and acceleration distances on Redwood Drive while the temporary speed table was in place are 85 feet and 195 feet, respectively. This equates to a suggested spacing of 280 feet for a series of 30 mph temporary speed tables along Redwood Drive. Unfortunately, not enough data were available to evaluate the potential spacing issues of the temporary speed table at any of the other two test sites for comparison. This spacing criteria is in the range of that suggested for the temporary speed humps. However, this was expected since no significant difference in vehicle speeds was found between the two devices and that the vehicle acceleration and deceleration distributions for the two devices were very similar. The range of suggested spacings from the previous calculations and Table 2 may imply that optimal or ideal spacing criteria for speed humps and/or speed tables may not be practical. Speed choices on a street fitted with speed humps/tables are not always necessarily determined by the location, size, or spacing of the devices. Instead, a driver's choice of speed may be influenced more by the width of the roadway, the roadside environment, the horizontal and/or vertical curvature, the presence of parked vehicles, traffic control devices (signing and pavement markings), or the purpose of a particular trip.

Volume Reduction

Traffic diversion to other parallel residential streets was not a concern for any of the three test locations. Roosevelt Drive, Redwood Drive, and Canal Shore Drive do not have any nearby parallel residential streets, thus any traffic diverted would be displaced to nearby arterial roadways as intended. Traffic volumes were collected during the study periods for each of the sites using tube counters in the data collection section.

Volume counts were compiled and compared for each data collection period for each test segment. Volumes collected before installation of the speed hump/table were compared to the volume counts collected while the temporary speed hump and temporary speed table were in place to determine if any diversion occurred. The volume counts collected while the temporary speed hump was in place were also compared to the counts collected while the temporary speed table was in place to determine if any new or additional diversion took place after the speed hump was converted to the speed table.

It was expected that any traffic that was using the test sites as a cut-through route would occur during weekdays between the hours of 7 AM and 7 PM. These are the hours and days of the week when drivers would be expected to travel to or from work or school and may chose to cut through a residential neighborhood. It was felt that traffic in these residential neighborhoods between the hours of 7 PM and 7 AM and on the weekend would likely be local residential traffic only. Therefore this period of time was used as the analysis period.

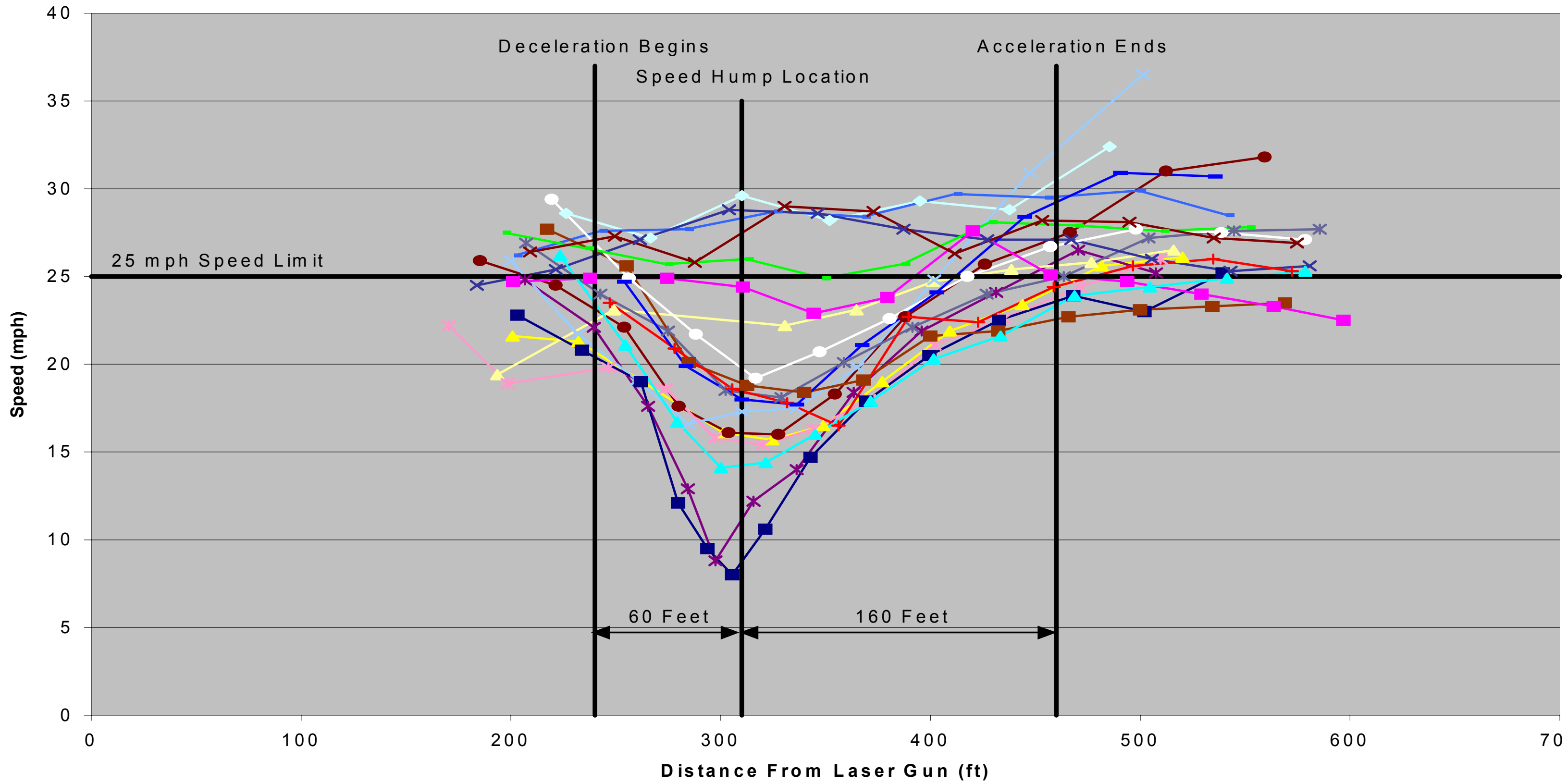


Figure 35. Roosevelt Drive Southbound Speed Hump Spacing Analysis

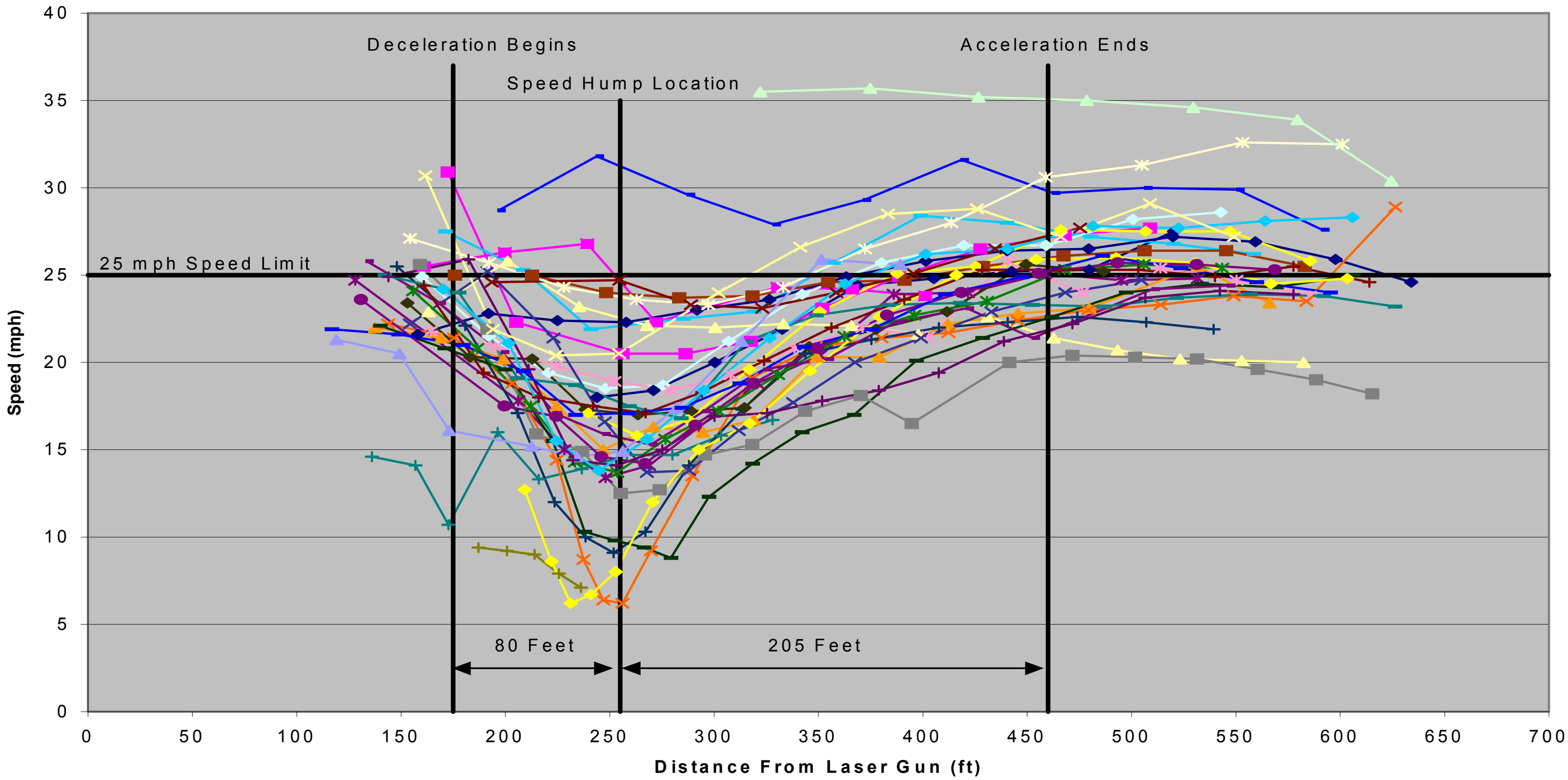


Figure 36. Redwood Drive Speed Hump Spacing Analysis

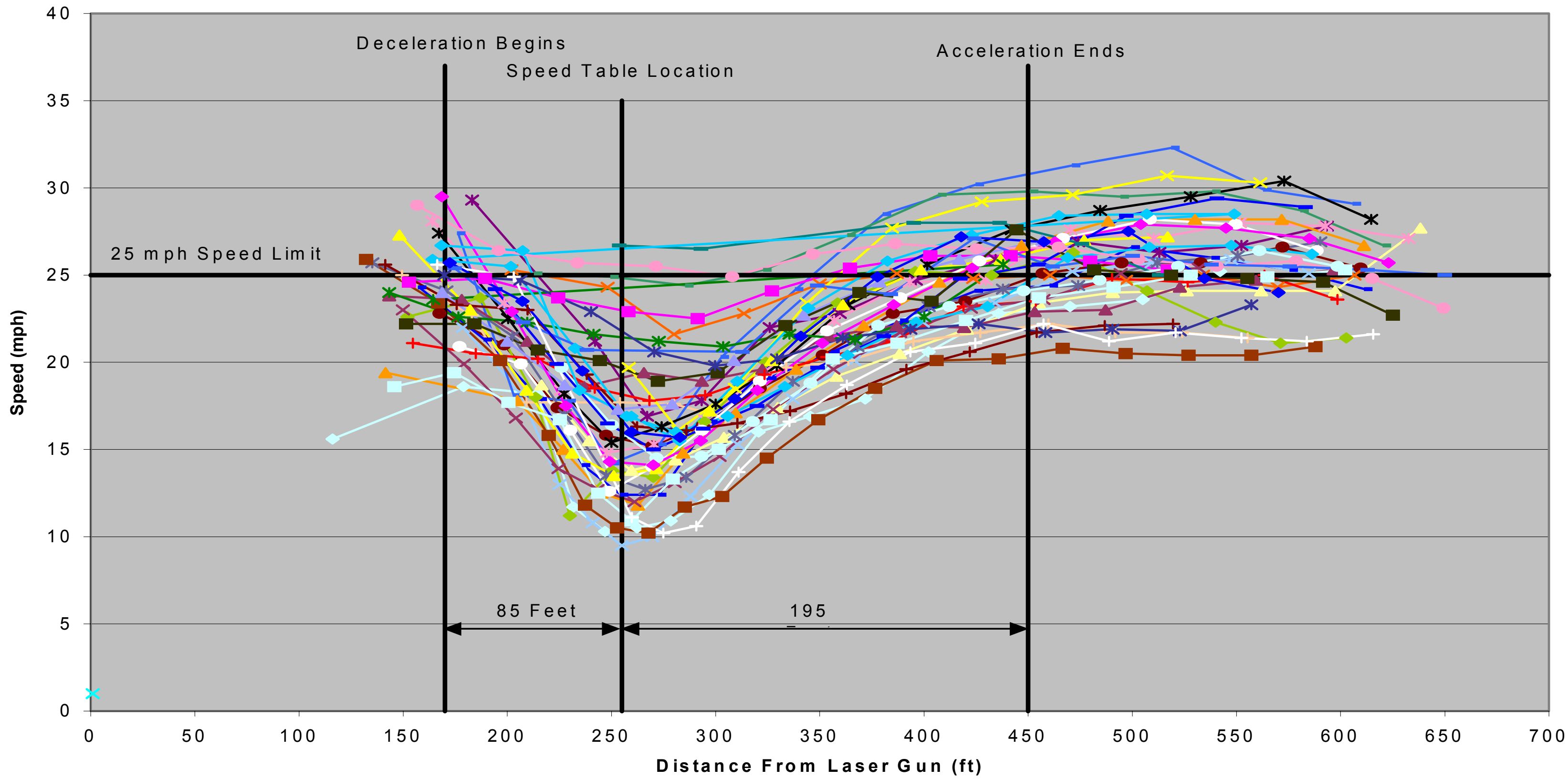


Figure 37. Redwood Drive Speed Table Spacing Analysis

Description of Mann-Whitney Test

The volume data were evaluated statistically to determine if any significant changes occurred. Typically, traffic volumes are not normally distributed. Therefore, the Mann-Whitney test, a nonparametric counterpart of the t-test, was used in the evaluation (Conover, 1980). This test determines whether two populations are equal and has three assumptions (Conover, 1980). When using the Mann-Whitney test, it is assumed that both samples are random samples taken from their respective populations, that there is mutual independence between the two samples, and that the measurement scale is at least ordinal (Conover, 1980). The null hypothesis is that the volume counts of one data collection period are equal to the volume counts from another data collection period (i.e., the volume counts from the before period are equal to the volumes collected while the temporary speed hump was in place). The alternate hypothesis is that the two volume counts are not equal.

When using the Mann-Whitney Test, sample one is the sample with the smallest number of values. The two samples are combined and then sorted in ascending order. Once sorted, the values are ranked with the lowest value receiving a rank of one. If several values are equal, each is assigned a rank of the average of the ranks that they would have been assigned assuming no ties in values. For example, if a sample contained two equal data values that would have received ranks of four and five had they been different in magnitude, both data values would be assigned a rank of 4.5. If few or no ties occur in the data set, the test statistic is simply the sum of the ranks of sample one. If a significant number of ties do occur, a new test statistic is calculated by subtracting the mean of the ranks from the original test statistic and dividing by the standard deviation of the ranks. The null hypothesis is rejected at a level of significance of α if the test statistic is less than the $\alpha/2$ quantile or greater than the $1-\alpha/2$ quantile. These quantiles can be found in a table of the quantiles for the Mann-Whitney test statistic, and the tests were done to a 95 percent level of significance (Conover, 1980).

Volume Results

The results of the volume analysis are presented in Table 18. The test statistics and rejection ranges calculated for the volume data are provided in Table E5 of Appendix E. Redwood Drive was the only test site to show no significant change in traffic volumes while the temporary devices were in place. Along Canal Shore Drive, traffic volumes increased after the temporary speed hump was installed and then decreased to initial (before) levels following the installation of the temporary speed table. Both changes were statistically significant. The results indicate that the temporary speed hump may have diverted traffic from Canal Shore Drive, but the speed table did not. Unfortunately, the conflicting factors discussed previously (e.g., weather, the time of the year) played a leading role in the traffic patterns and characteristics at this location and do not allow this conclusion to be drawn conclusively.

Traffic volumes on Roosevelt Drive did significantly decrease while the temporary speed hump and temporary speed table were in place. However, as shown in Table 18, the volume counts collected when the devices were in place were not significantly different.

Table 18. Volume Analysis Summary

Test Site	Daily Range Volume Counts		Sample Size		Statistically Significant
Before vs. Speed Hump					
	Before	**Speed Hump**	**Before**	**Speed Hump**	
Roosevelt Dr.	638 to 854	474 to 714	3	10	Yes
Redwood Dr.	308 to 446	309 to 398	6	9	No
Canal Shore Dr.	196 to 239	209 to 421	4	6	Yes
Before vs. Speed Table					
	Before	**Speed Table**	**Before**	**Speed Table**	
Roosevelt Dr.	638 to 854	471 to 609	3	8	Yes
Redwood Dr.	308 to 446	342 to 400	6	5	No
Canal Shore Dr.	196 to 239	142 to 233	4	6	No
Speed Hump vs. Speed Table					
	Speed Hump	**Speed Table**	**Speed Hump**	**Speed Table**	
Roosevelt Dr.	474 to 714	471 to 609	10	8	No
Redwood Dr.	309 to 398	342 to 400	9	5	No
Canal Shore Dr.	209 to 421	142 to 233	6	6	Yes

Study Limitations

Several potential sources of error were introduced during the data collection phase. The first and possibly the most significant source of error was the location of the data collection equipment and personnel. The clear line of sight needed for the laser gun required the data collection equipment as well as the data collectors to set up near the traveled way. This may have influenced vehicle speeds if drivers realized their speed was being measured. However, this could not be avoided. Figures 38–41 show the view that approaching drivers had of the data collection equipment. As shown in Figures 40 and 41, the data collection equipment was somewhat hidden from approaching drivers along Redwood Drive and Canal Shore Drive. Nonetheless, numerous drivers at all three test sites were noted observing the data collection equipment and personnel. Some motorists stopped to ask what was being surveyed or photographed. The impact may have lessened as motorists became used to the equipment. However, it is speculated that this may have had some impact on vehicle speeds.

A second source of error that may have been introduced at each location was related to the type of driver observed. Ideally, all data collected along Roosevelt Drive would have occurred prior to the end of the school year in Atlantic, since city officials and residents attributed the speeding problem to school age drivers. Unfortunately, this data collection timeline was not possible due to delays encountered in the shipping of the temporary devices and weather conditions. The before data and the first week of data while the 25 mph speed hump was in place occurred while school was in session; The remainder of the data along Roosevelt Drive was collected after school was dismissed. Accordingly, the driver population along Roosevelt Drive changed. A similar problem was also encountered in Le Claire. Since Canal Shore Drive serves both residential and recreational traffic, two different groups of drivers were observed. An attempt was made to collect data during the week while the majority of the traffic on Canal Shore Drive was speculated to be residential. However, as it turned out, residential traffic volumes were so small it was feared that a significant sample size could not reasonably be collected in a timely manner. Therefore, data were collected during the weekend when recreational traffic was prevalent on Canal Shore Drive. During the boating season, many sightseers and boaters were observed along Canal Shore Drive on the weekends. However, once the weather began to cool, only residential drivers with a few recreational drivers were observed on the weekends. The data collected before and while the 25 mph speed hump was in place occurred during warm weather and consisted of what was felt to be mostly recreational traffic. Data collected while the 30 mph speed table was in place and the after period extended into the fall, meaning that the majority of traffic observed was residential. This may have impacted not only the speed data, but the volume data as well. Even during the boating season, weather conditions greatly impacted the volume of traffic observed on Canal Shore Drive due to its recreational nature.

It should also be noted that the speed data collected along Canal Shore Drive, especially during the boating season, may have yet another source of error associated with it. The area being studied along Canal Shore Drive passes through the Captain's Quarters boat marina as shown in Figure 42. Therefore, the speed of a vehicle traveling through the area may have been influenced by the operations of the marina. It was not uncommon to have pedestrians walking around the marina and crossing Canal Shore Drive. Many vehicles also stopped along Canal Shore Drive within the marina area to unload picnic baskets, fishing gear, and coolers before parking in the designated area shown in Figure 42. Also, some vehicles were required to stop or slow while boats were being transported across Canal Shore Drive with a forklift from the dry dock storage to the river as shown in Figure 43.

Figure 38. Approaching Driver's View of Data Collection Equipment on Roosevelt Drive Northbound

Figure 39. Approaching Driver's View of Data Collection Equipment on Roosevelt Drive Southbound

Figure 40. Approaching Driver's View of Data Collection Equipment on Redwood Drive

Figure 41. Approaching Driver's View of Data Collection Equipment on Canal Shore Drive

Figure 42. Marina Patrons Along Canal Shore Drive

Figure 43. Typical Marina Operations

RESIDENT SURVEY ANALYSIS AND RESULTS

A resident survey was distributed at all three test locations approximately one week following the removal of the temporary speed table. Responses from the resident survey were compiled, tabulated, and evaluated to determine how the residents of Roosevelt Drive, Redwood Drive, and Canal Shore Drive perceived the temporary devices. The results of the resident survey were compared to similar surveys conducted in other jurisdictions within the United States.

Surveys were distributed door-to-door to all residents living along the sections of Roosevelt Drive and Redwood Drive observed in the study and within approximately one city block of the speed hump/table on Canal Shore Drive. The resident survey and cover letter are provided in Appendix C. As shown in Table 19, the response to the resident survey was 76.6 percent. This response rate was larger than other speed hump/table resident surveys reviewed (Ballard, 1998; Gorman et al., 1989; Ripley and Klingaman, 1998*)*. A summary of the findings for each question in the resident survey follows.

Table 19. Resident Survey Response Rate

Area	Surveys Distributed	Surveys Returned	Response Rate
Roosevelt Drive	25	21	84.0%
Redwood Drive	10	8	80.0%
Canal Shore Drive	12	7	58.3%
Overall	47	36	76.6%

Question One: Familiarity

Question one of the resident survey asked about the familiarity each resident had with the temporary devices. Residents were asked how often they had to drive over the temporary speed hump/table. A summary of the responses for question one is shown in Figure 44. The majority of residents crossed the devices at least several times a day.

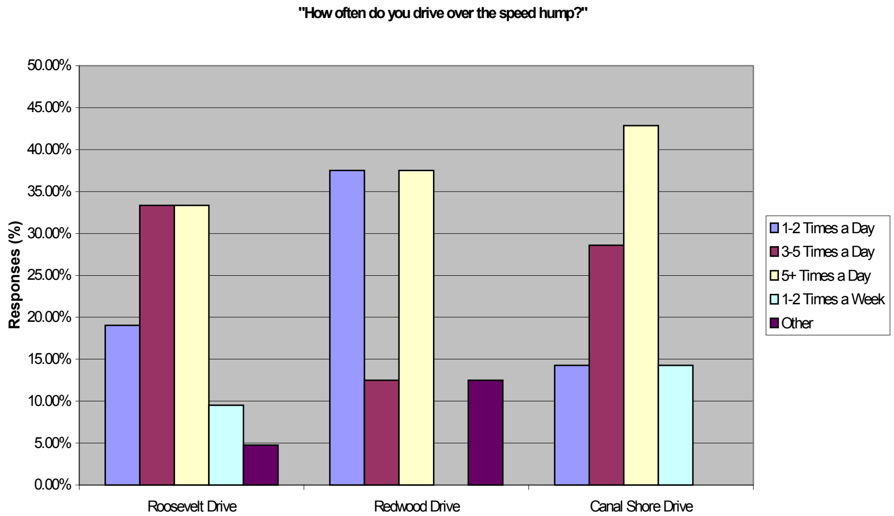


Figure 44. Question One Response (Familiarity)

Question Two: Perceived Speed Change

Question two of the resident survey asked whether residents perceived a reduction in traffic speeds following the installation of the temporary speed hump/table. As presented in Figure 45, 16.7 percent of the residents living along Roosevelt Drive thought speeds had increased following the installation of the temporary speed hump/table. None of the Redwood Drive or Canal Shore Drive residents reported an increase in traffic speed. A decrease in traffic speeds was reported by 50.0 percent, 62.5 percent, and 57.1 percent of the respondents from Roosevelt Drive, Redwood Drive, and Canal Shore Drive, respectively. The responses to question two are similar to the responses reported by other jurisdictions that have performed resident surveys (Clement, 1983; City of Fairfax, 2001; Transportation Association of Canada, 1998*)*.

For example, resident surveys conducted in San Antonio and Portland indicated that 67 percent and 69 percent of the respondents respectively reported a decrease in traffic speeds following installation of speed humps (Kittelson and Associates, Inc., 2000; Ballard, 1998*)*. Also, 94 percent of the residents of Fremont Avenue N polled in Seattle felt speeds decreased after speed humps were installed while 60 percent of the residents of First Avenue NE reported speeds decreased after speed tables were installed (Marek and Walgren, 1998*)*.

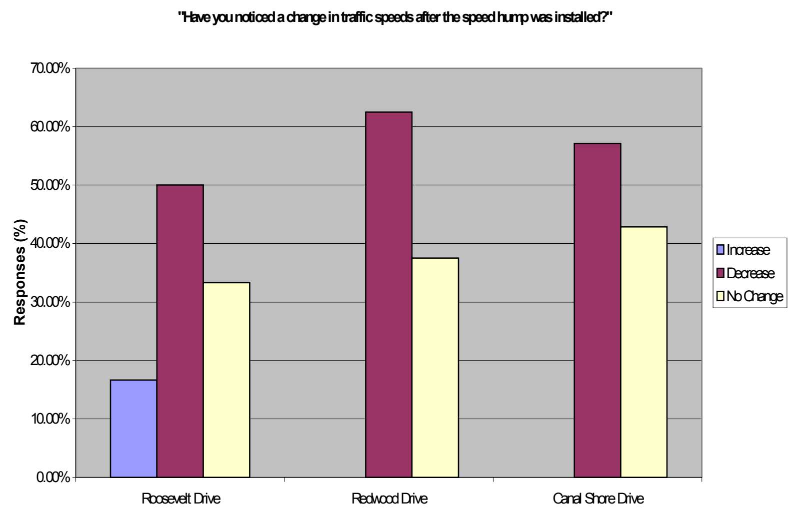


Figure 45. Question Two Response (Perceived Speed Change)

Question Three: Perceived Volume Change

Question three of the resident survey asked whether residents perceived a change in traffic volumes after the temporary speed hump/table was installed. As shown in Figure 46, the residents of Roosevelt Drive, Redwood Drive, and Canal Shore Drive reported no changes in traffic volumes. Only 14.3 percent and 12.5 percent of the respondents from Roosevelt Drive and Redwood Drive, respectively, reported a perceived decrease in traffic volumes. No residents of Redwood Drive or Canal Shore Drive reported a perceived increase in traffic volume, but 4.8 percent of the respondents from Roosevelt Drive believed this did occur.

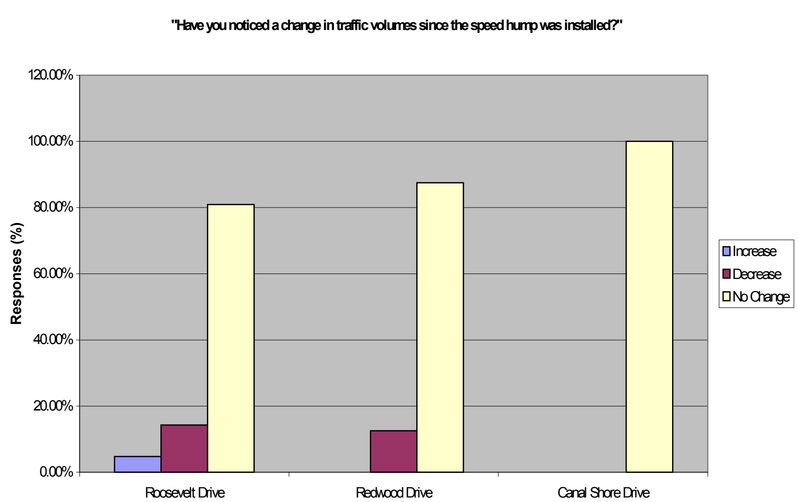


Figure 46. Question Three Response (Perceived Volume Change)

Question Four: "What do you like most about the speed hump"?

Question Four asked about residents what they liked the most about the temporary speed hump/table. A summary of the findings is shown in Table 20. Overall, the most common response to Question Four, with a total of 15 responses, was that the speed hump/table slowed traffic. Four of the respondents, at least one from each test location, also commented on how the speed hump/table was gradual and not as severe as a speed bump.

Three respondents from Roosevelt Drive and Redwood Drive felt that safety had increased following the installation of the speed humps/tables and that they worried less about the children in the area. Two of the respondents from Roosevelt Drive and Redwood Drive also stated that the speed hump/table required greater attention from drivers. These responses are consistent with those from other resident surveys conducted in other jurisdictions within the United States (Ewing, 1999; Ballard, 1998; Ripley and Klingaman, 1998).

While the majority of the residents responding to Question Four seemed to be in favor of the temporary devices, two residents from Roosevelt Drive stated that the devices were totally ineffective. Another resident from Roosevelt Drive and two residents from Canal Shore Drive did not like anything in particular about the speed hump/table. Also, a total of nine respondents from the three test locations did not reply to Question Four, which may indicate that these residents are indifferent to the devices and/or may not support their use.

A total of three residents from Redwood Drive and Canal Shore Drive also responded to Question Five by stating that they wished the devices were still in place and that more devices had been installed. A total of 12 residents stated that they had no notable dislikes toward the devices. These comments indicate support for temporary speed humps/tables and are also consistent with responses of other resident surveys (Ballard, 1998).

Table 20. Question Four: "What do you like most about the use of the speed hump?"

Comment	Number of Responses		
	Roosevelt Drive	Redwood Drive	Canal Shore Drive
Speeds were reduced	9	3	3
Required greater attention from drivers	1	1	
Is a gradual bump/not as severe as a speed bump	2	1	1
Increases safety levels/worry less about children in the area	1	2	—
The devices were ineffective	2	—	—
Decreases drag racing	—	1	—
Easily moved for snow removal	—	—	1
Liked nothing in particular	1	—	2
No response	6	2	1

Question Five: "What do you like least about the speed hump"?

Question Five asked residents what they disliked about the speed hump/table. A variety of comments were received, and a summary is provided in Table 21. Common responses to Question Five were that the devices were ineffective, were a nuisance, or caused wear and tear on vehicles. Other responses indicated that some drivers (particularly high school age drivers) would accelerate and attempt to ramp the devices. One resident commented that the devices were a waste of taxpayers' money. Some residents also disliked the fact that they had to slow down. Similar negative comments were also reported in surveys from other jurisdictions within the United States (Ballard, 1998; Ripley and Klingaman, 1998).

Table 21: Question Five: "What do you like least about the speed hump"?

	Number of Responses		
Comment	**Roosevelt Drive**	**Redwood Drive**	**Canal Shore Drive**
Causes wear and tear to vehicles	1	—	1
The devices were ineffective	2	—	1
Makes on-street parking less desirable	1	—	—
The devices were a nuisance/annoying	3	1	—
Some drivers tried to speed up or ramp the device	2	2	—
Devices not big enough	1	—	—
Having to slow down	3	—	—
Waste of tax-payers money	1	—	1
Some drivers come to a complete stop before crossing	1	—	—
Fire trucks and ambulances are delayed	1	—	—
Maintenance/snow removal problems	1	—	—
Wish the devices were still installed/more devices	—	1	2
The fact that they are needed to slow vehicles down	—	—	1
Used for convenience of marina only	—	—	1
Just don't like	—	1	—
No dislikes	2	3	2
No Response	5	1	—

Question Six: Whether Speed Humps/Tables Should Be Installed

Question Six of the resident survey asked whether permanent speed humps/tables should be installed. The results are presented in Figure 47. The majority of the residents from all three test sites were in favor of future use of permanent speed humps/tables. More specifically, 47.6 percent, 50.0 percent, and 57.1 percent of the respondents from Roosevelt Drive, Redwood Drive, and Canal Shore Drive, respectively, showed this support. Overall, 18 of the 36 respondents, or 50.0 percent, were in favor of the use of speed humps/tables on their streets. However, 38.1 percent, 25.0 percent, and 42.9 percent of the residents along Roosevelt Drive, Redwood Drive, and Canal Shore Drive, respectively, opposed their use. Overall, thirteen of the 36 respondents, or 36.1 percent, were not in favor of using speed humps/tables. The residential support was lower and the residential opposition higher in this study than other resident surveys conducted within the United States (Ballard, 1998; Gorman et al., 1989; Ripley and Klingaman, 1998).

Those surveys from Roosevelt Drive, Redwood Drive, and Canal Shore Drive that indicated a response of "no" to Question Six were evaluated to determine if a cause for their opposition was related to their exposure response in Question One. A summary of this evaluation can be seen in Table 22. No relationship was found, although most of the non-support came from residents that traversed the devices more than three times a day.

The location of the residences in relation to the speed hump/table was also evaluated to determine if this may have had an influence on the support or non-support of the devices. It was speculated that residences adjacent to the speed hump/table may be more likely to oppose the use of the devices due to the aesthetics of the device or possible increased noise levels. The analysis of a resident's location and response to Question Six did not reveal any overall trends, but along Roosevelt Drive most of the disapproval came from residents living close to the devices.

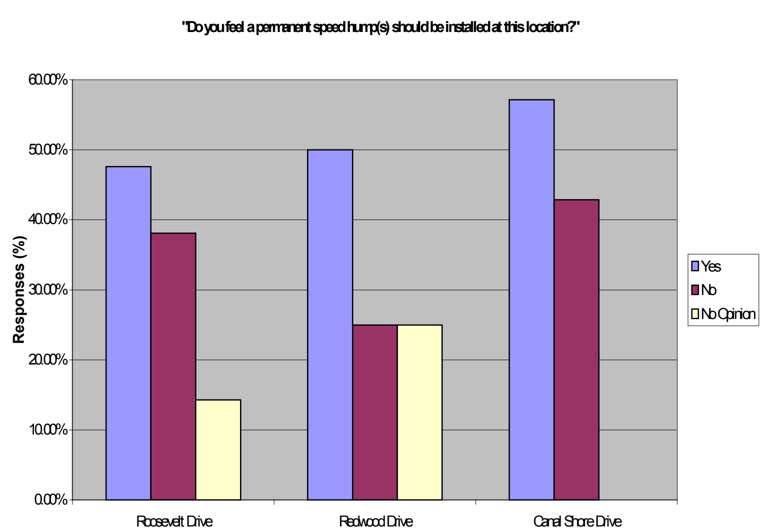


Figure 47. Question Six Response (Whether Speed Humps/Tables Should Be Installed)

Table 22. Driver Exposure Versus Speed Hump/Table Support

Driver Exposure to Speed Hump/Table	In Favor of Speed Hump/Table?		
	Yes	No	No Opinion
Roosevelt Drive			
1–2 times a day	2	1	1
3–5 times a day	3	4	—
5+ times a day	5	2	—
1–2 times a week	—	1	1
Other	—	—	1
Redwood Drive			
1–2 times a day	2	—	1
3–5 times a day	1	—	—
5+ times a day	—	2	1
1–2 times a week	—	—	—
Other	1	—	—
Canal Shore Drive			
1–2 times a day	1	—	—
3–5 times a day	1	1	—
5+ times a day	2	1	—
1–2 times a week	—	1	—
Other	—	—	—

Question Seven: Preferred Device

Question Seven asked which of the devices, the speed hump or the speed table, was preferred. A summary of the responses to Question Seven is shown in Figure 48. The results of Question Seven varied between the three test streets. The residents of Redwood Drive and Canal Shore Drive preferred the temporary speed hump, but the residents of Roosevelt Drive preferred the temporary speed table. Also, 42.9 percent and 37.5 percent of the respondents from Roosevelt Drive and Redwood Drive, respectively, indicated they had no preference between the two devices, and 42.9 percent of the respondents from Canal Shore Drive did not answer Question Seven. Several respondents, however, did indicate that they were unaware two devices had been tested. Also, several residents stated that they were supportive of the device installed on their street (i.e., “the one that was on Redwood Drive”). It is felt that since the two temporary devices were very similar in appearance, a number of residents (and drivers) may not have been aware two different devices were installed. This may explain why a large percentage of the residents did not indicate a preference or did not respond Question Seven.

Figure 49 shows the relationship between the preference indicated for a device and the level of residential support for that device. Of those who responded that they were in favor of using speed humps/tables, the temporary speed hump was preferred over the temporary speed table. The opposite was true for those respondents who are against the use of speed humps/tables. If speed control measures were to be used in future, these residents preferred the temporary speed table. This response was expected due to the profile of the temporary speed table being less severe than that of the temporary speed hump.

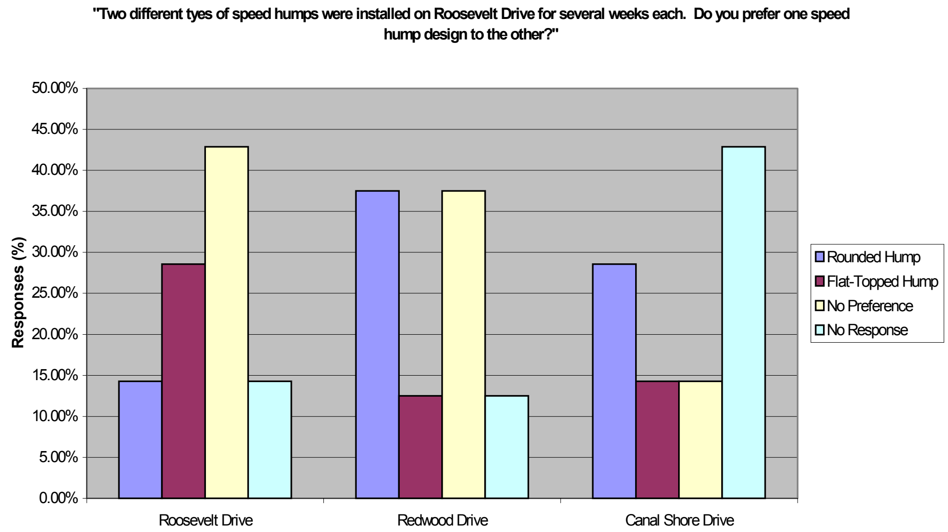


Figure 48. Question Seven Response (Preferred Device)

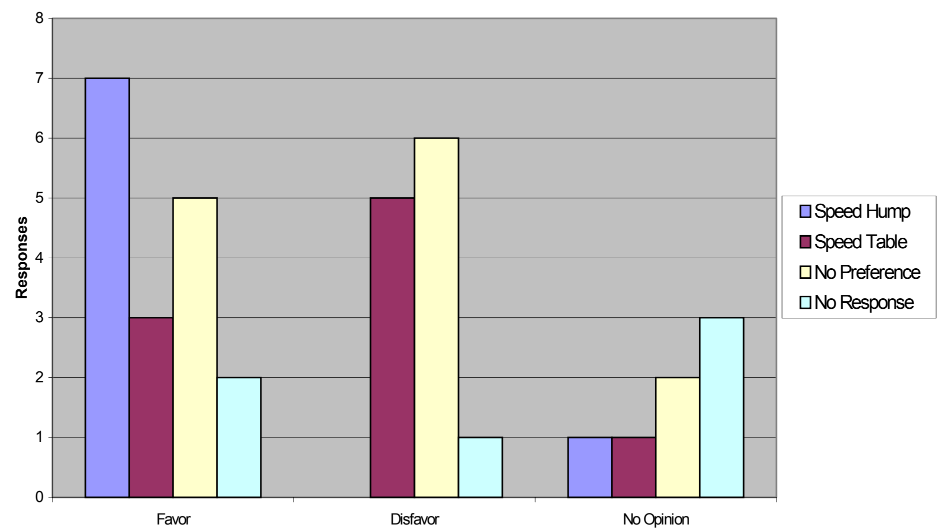


Figure 49. Public Support Versus Device Preference

Question Eight: Additional Comments

Question Eight asked residents to list any additional comments they might have regarding the use of the temporary traffic calming devices. For the most part, the comments did not contribute any new information. Common responses were related to the tendency of younger drivers attempting to ramp the devices, a suggestion that several be used as opposed to single installations, suggestions for other locations that may benefit from speed humps/tables, and that the devices were ineffective and should not be considered. A complete list of the comments received from the residents of Roosevelt Drive, Redwood Drive, and Canal Shore Drive is provided in Appendix F.

CONCLUSIONS AND RECOMMENDATIONS

The main objective of this research was to evaluate the impact of temporary speed humps and speed tables on the vehicle speeds, vehicle speed profiles, and traffic volumes along local and/or collector streets in several rural Iowa cities. More specific objectives follow:

- Determine whether speed humps and/or speed tables can be used effectively to reduce vehicle speeds in small Iowa cities
- Evaluate the effectiveness of temporary speed humps in reducing top vehicle speeds
- Evaluate the use of temporary speed humps in reducing average vehicle speeds and top vehicle speeds as compared to speed humps
- Evaluate the optimum spacing of speed humps/tables
- Evaluate the short-term impacts of temporary devices
- Evaluate changes in traffic volumes during the study period
- Evaluate the response of rural residents to speed hump/tables and compare their attitudes with those of urban areas

Two cities volunteered and asked for the devices. Test streets included Roosevelt Drive and Redwood Drive in Atlantic, Iowa, and Canal Shore Drive in Le Claire, Iowa. A 25-mph temporary speed hump and a 30-mph temporary speed table, both made of recycled rubber, were purchased and installed on the three residential streets. The speed hump was installed first and then converted to a speed table. Each device was installed for a period of at least two weeks at the same location. Speed, volume, and resident opinion data were then collected and evaluated. A summary of the results, conclusions, and recommendations are presented in the following sections.

In general, the devices were shown to be effective with the temporary speed table performing as well or better than the speed hump. However, it should be noted that neither Roosevelt Drive nor Redwood Drive had a significant speeding problem before the devices were installed. Canal Shore Drive was not experiencing a speeding problem at all. As a result the study is not able to address the impact of the temporary devices on excessive speeds.

Average Vehicle Speeds

Both the speed hump and the speed table were effective in reducing mean speeds at the device and immediately downstream. Although no significant speeding problem existed at any of the test sites, the mean speed after the speed hump/table was installed were below the 25 mph speed limit in the immediate vicinity of the device. The two-sample t-test or the approximate two-sample t-test was used to compare differences in mean speeds. Statistically significant decreases in mean vehicle speeds occurred at the midpoint section for all study segments. For the upstream section, Roosevelt Drive northbound, mean vehicle speeds decreased, but no statistically significant change occurred for either Roosevelt Drive southbound or Canal Shore Drive. Significant decreases in mean vehicle speed in the immediate downstream section occurred for all segments except Canal Shore Drive. Data were available for the 300- to 400- foot downstream sections of Redwood Drive and Canal Shore Drive, but no difference in mean speeds were noted for this section.

Results comparing mean vehicle speeds for the speed table are similar to those for the hump. Reductions in mean speed occurred at the location of the speed table and immediately downstream for all segments except Canal Shore Drive. Decreases in mean speed were observed upstream for Roosevelt Drive northbound and Redwood Drive but not Roosevelt Drive southbound or Canal Shore Drive. Decreases resulted for the 300- to 400-foot downstream section of Redwood Drive but not Canal Shore Drive.

Reduction of Top Vehicle Speeds

The results of the peak speed analysis indicated that the temporary speed hump and temporary speed table both effectively reduced vehicles traveling at higher speeds. Both appeared to impact speeds equally well. The speed data collected on Roosevelt Drive and Redwood Drive indicated that the temporary speed hump effectively reduced the percentage of vehicles exceeding the speed limit, but that the percentage of vehicles traveling at speeds greater than 25 mph decreased more after the temporary speed hump was converted to the temporary speed table. While the temporary speed hump was in place the percentage of vehicles exceeding 25 mph decreased by 26.7, 20.6, and 3.9 percent and vehicles traveling over 30 mph decreased by 4.7, 11.1 and 2 percent for Roosevelt Drive, Redwood Drive, and Canal Shore Drive respectively. After the speed tables was installed vehicles traveling faster than 25 mph and 30 mph decreased by 24.8 and 18.1 percent on Roosevelt and 31.7 and 17.9 percent on Redwood. The percentage of vehicles traveling over the speed limit and over 30 mph increased on Canal Shore Drive by 11.5 and 1.8 percent.

In addition, the 85th percentile speeds were calculated for each roadway segment. The 85th percentile speed on Canal Shore Drive was only 20 mph prior to the installation of the devices indicating that a speeding problem did not exist on that segment even before the traffic calming devices were installed. The existing 85th percentile speed for most of the sections for the other sites was around 30 mph. An evaluation of the 85th percentile speeds indicated that both the temporary speed hump and temporary speed table effectively reduce 85th percentile speeds at the location of the device and for at least the length of data collection downstream (about 400 feet). However, 85th percentile speeds upstream of the device were not significantly influenced by the presence of either device, which suggests that a single speed hump or table is only effective in the immediate vicinity of the device. Additionally the speed table appeared to decrease downstream speeds more than the speed hump although the opposite was expected. Finally, comparison of the results with results from other studies indicates that speed humps and speed tables both reduce the 85th percentile vehicle speeds as effectively in small rural communities as they do in larger urbanized areas.

Optimum Spacing

As discussed, mean vehicle speeds increased at the last downstream section from the temporary traffic calming devices. In some cases, there was no statistically significant change in mean vehicle speed between conditions before installation of the speed hump/table and while the devices were in place either upstream or at the last downstream section, indicating that the effect of the speed hump/table is limited to the immediate area around the device. In order to obtain reductions in vehicle speed over an entire city block, a series of devices may be necessary. Vehicle speed profiles were analyzed to evaluate the point where vehicles began to decelerate before traversing the speed table or hump and the point at which they had completed acceleration after the device. This information was used to develop a suggested spacing for a series of temporary speed humps or temporary speed tables on these roadways. Spacing values of 220 feet to 285 feet were calculated for temporary speed humps on Roosevelt Drive and Redwood Drive. This range of spacing is similar to the values used by other jurisdictions but is shorter than most.

It may not be possible to develop a single spacing value for speed humps and speed tables. A range of values may be more appropriate based on the results of this research, and it may be more practical because speed humps/tables are often used in a retrofit situation. Speed choices may be influenced more by the roadway width, roadside environment, roadway geometrics, neighboring land use, and type of trips being performed. In other words, the optimal spacing for devices may vary from street to street.

Speed Hump Versus Speed Table

One research objective was to evaluate the use of temporary speed tables in reducing average vehicle speeds and top vehicle speeds as compared to speed humps. If the speed table could be shown to be as effective in reducing top speeds, its use may be recommended over the hump since it is more comfortable for drivers to traverse (due to the flatter surface) and may provide less impact to ambulance or fire services. One of the main conclusions is that the speed table appears to function as effectively as the speed hump in reducing both average and top vehicle speeds.

Mean vehicle speeds while the speed hump was in place were compared to mean vehicle speeds while the speed table was in place. Differences of less than 3.0 mph resulted for all sections. While other studies have shown speed humps to have a greater impact on vehicle speeds, results of this study showed no significant changes in mean vehicle speed between the temporary speed hump and the temporary speed table.

The speed data collected on Roosevelt Drive and Redwood Drive indicated that the temporary speed hump effectively reduced the percentage of vehicles exceeding the speed limit, but the percentage of vehicles traveling at speeds greater than 25 mph decreased more after the temporary speed hump was converted to the temporary speed table. The temporary speed table appeared to be more effective than a speed hump in reducing the number of speeders. However, this conclusion contradicts the results of other jurisdictions. For example, a study in Portland showed that speed humps reduced the number of speeders more effectively than the speed table (Kittelson and Associates, Inc., 2000). While the temporary speed hump was in place the percentage of vehicles exceeding 25 mph decreased by 26.7, 20.6, and 3.9 percent and vehicles traveling over 30 mph decreased by 4.7, 11.1 and 2 percent for Roosevelt Drive, Redwood Drive, and Canal Shore Drive respectively. After the speed table was installed vehicles traveling faster than 25 mph and over 30 mph decreased by 24.8 and 18.1 percent on Roosevelt and 31.7 and 17.9 percent on Redwood. The percentage of vehicles traveling over the speed limit and over 30 mph increased on Canal Shore Drive by 11.5 and 1.8 percent.

An evaluation of the 85th percentile speeds indicated that both the temporary speed hump and temporary speed table effectively reduce 85th percentile speeds at the location of the device and for at least the length of data collection downstream (about 400 feet). However, 85th percentile speeds upstream of the device were not significantly influenced by the presence of either device, which suggests that a single speed hump or table is only effective in the immediate vicinity. Additionally, the speed table appeared to decrease downstream speeds more than the speed hump although the opposite was expected.

Short-Term Impact of Temporary Devices

There has been some speculation that it may be possible to slow speeds and/or reduce traffic volumes for a period of time after a temporary speed hump has been removed. If true, the installation of temporary speed humps on different roadways within a neighborhood (on a rotating but irregular time period basis) may decrease the overall neighborhood speeds and/or traffic volumes. This would produce impacts similar to the multiple speed hump installations that are part of a neighborhood speed hump program, but in a temporary manner. Unfortunately there were no definitive conclusions as to whether the speed hump or table were able to impact speeds short-term.

Mean vehicle speeds before the speed hump/table was installed and shortly after the device was removed were compared. Results were mixed as to whether the devices had a short-term impact on mean vehicle speeds. Speeds on Roosevelt Drive northbound were after the devices were removed than before the devices were installed. Speeds were not significantly different after the devices were removed for all sections of the Roosevelt Drive southbound segment, all sections of the Redwood Road segment, and most of the Canal Shore Drive sections. The immediate downstream section of Canal Shore Drive experienced a slight increase (3.5 mph) in mean vehicle speed.

After the temporary speed table was removed from Roosevelt Drive, the number of drivers that exceeded 25 mph was 18.1 percent lower than the number observed in the before period. However, the number of vehicles exceeding 30 mph in the after period was slightly higher (1.9 percent higher). The number of speeders exceeding 25 mph and 30 mph on Redwood Drive in the after period were 2 and 7 percent lower, respectively. This may indicate that a short-term lasting impact on peak speeds may be associated with the temporary speed hump and/or the temporary speed table. The number of speeders observed exceeding 25 mph and 30 mph on Canal Shore Drive in the after period were 6.8 and 2.8 percent higher, respectively, than the percentage observed in the before period. However, it is believed that this is due to a change in conditions along Canal Shore Drive rather than being a problem with the traffic calming devices.

Changes in Traffic Volumes

Overall, an analysis of the volume data collected did not indicate any reductions in traffic volumes along Roosevelt Drive, Redwood Drive, or Canal Shore Drive that would suggest traffic diversion occurred. Thus, it can be concluded that the temporary devices did not divert traffic for the three test sites. This was expected because the primary function of speed humps and speed tables is their impact on vehicle speed and not traffic volumes. In addition, there were no parallel streets for volume diversion to occur. Small sample size, however, limits the strength of this conclusion.

Public Acceptance

The results of the resident survey in this study were consistent with those reported in other jurisdictions. Overall more respondents were supportive of the use of the temporary speed hump/table than opposed. Many of the residents who participated in the resident survey perceived reduced traffic speeds but no change in traffic volume. A number of positive comments were also received about increased safety levels, greater attention from drivers, and the less severe profile of the speed hump/table when compared to the more familiar speed bump. However, the responses from the resident survey related to the preference of temporary device were not conclusive. Temporary speed humps were preferred on Redwood Drive and Canal Shore Drive and temporary speed tables were preferred on Roosevelt Drive. The majority of the respondents, however, indicated they had no preference or did not respond to question seven.

Recommendations

Based on the results of the data analysis, the limitations associated with some of the data collected, and the conclusions that were reached, several recommendations for future research and implementation are appropriate. The following sections discussed these recommendations.

Limitations and Suggestions for Future Research

The temporary devices installed in this research were in place for a relatively short period of time. Some studies have suggested that, as time passes, drivers become accustomed to the devices, and speeds will once again increase (Ripley and Klingaman, 1998). Since speed humps and speed tables are relatively new in this part of the country, drivers may be unfamiliar with the devices and may require more time to adjust to the devices. Therefore, future research efforts should install these devices for a period greater than one to two months and evaluate the impacts of the devices throughout this extended period. For example, these temporary devices could be installed on residential streets in early spring and removed in late fall. The effectiveness of the devices should be evaluated throughout the spring, summer, and fall months to determine if any changes in vehicle speed, traffic diversion, etc. take place as time passes.

Another recommendation for future study is related to spacing criteria. In this study, it was assumed that a speed and/or acceleration/deceleration would not be affected by the presence of additional downstream devices. The appropriateness of this assumption should be analyzed by installing a series of devices along a residential street and collecting and evaluating speed profiles. The location of the peak speeds can also be evaluated. The spacing of the temporary devices might also be changed along the same roadway, and the speed profiles re-examined.

The impacts of temporary speed humps and temporary speed tables could also be explored further. The results of the resident survey indicated that some residents were unaware that two different temporary devices were tested. If the residents of Roosevelt Drive, Redwood Drive, and Canal Shore Drive did not realize different devices were used, it can be reasonably assumed that drivers were also unaware. Installing the temporary speed hump and later converting it to the temporary speed table may have been a poor experiment design. To more accurately measure the difference in the impact of the two temporary devices, it is suggested that temporary speed humps be installed on some residential streets and temporary speed tables installed, ideally in the same jurisdiction, on separate but similar residential streets. Data should be collected for all installations and then compared to determine any differences in vehicle speeds, traffic volumes, acceleration/deceleration rates, and public acceptance.

The additional acceleration and deceleration rates that resulted from the speed hump/table should be investigated as a source of additional vehicle emissions and increased noise levels. Previous research on vehicle emissions associated with speed hump/table installations has not been well documented. In addition, a common complaint from residents in other jurisdictions regarding speed hump/table use is increased noise levels following installation. It may be possible that the “softer” rubber material of the temporary devices in this study reduced typical speed hump/table noise levels, and this should be explored.

Future Implementation

The results of this research in Atlantic and Le Claire have shown the effectiveness of temporary speed humps and temporary speed tables and the effectiveness of traffic calming in small rural cities. It is recommended that small rural jurisdictions should consider temporary speed humps and/or temporary speed tables as a possible solution to concerns of speeding traffic on residential streets.

The temporary speed hump and temporary speed table used in this study were easily installed and removed with little damage to the existing pavement. These temporary devices provide jurisdictions with a valuable opportunity to test the use of speed humps and/or speed tables on residential streets and determine if they are an effective solution to a particular traffic problem. They also provide an opportunity to evaluate the public’s opinion of the devices. Although up-front costs of the temporary devices may be higher than installing a permanent device, should a permanent device be rejected by the public or not function effectively, additional costs are incurred in the removal process, especially if a number of devices are installed. These temporary devices may also be ideal for jurisdictions who have concerns of snow removal or those that experience unwanted traffic characteristics during certain times of the year only (i.e., recreational areas).

Further, a series of devices may be needed to reduce speeds. However, if a jurisdiction does install these temporary devices, it should consider sight distance, the traffic control devices incorporated into the design, utility work, and access to side streets, driveways, alleyways, and business entrances. In addition, speed humps and speed tables should only be installed on residential streets, and residents along these streets should be informed of the decision to install devices in advance. The devices should also be evaluated to assure they are functioning properly, and parallel residential streets should be monitored for significant traffic diversion and/or increased vehicle speeds. Additional speed humps/tables may be needed on parallel streets or the original installations removed if significant diversion occurs. Should a network of parallel streets be fitted with speed humps and/or tables, local fire and rescue agencies should be consulted to assure emergency response times are not impacted significantly.

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APPENDIX A. TRAFFIC CALMING DEVICES

Many jurisdictions use traffic calming devices to reduce traffic speeds and/or traffic volumes on residential streets. The goals and objectives of traffic calming programs vary from jurisdiction to jurisdiction and from project to project. A number of different devices are used in an attempt to decrease traffic speed and/or volume. Traffic calming devices are often grouped as a volume control device or a speed control device depending on its intended function. The following schematics are volume control and speed control traffic calming devices commonly used.

Volume Control Devices

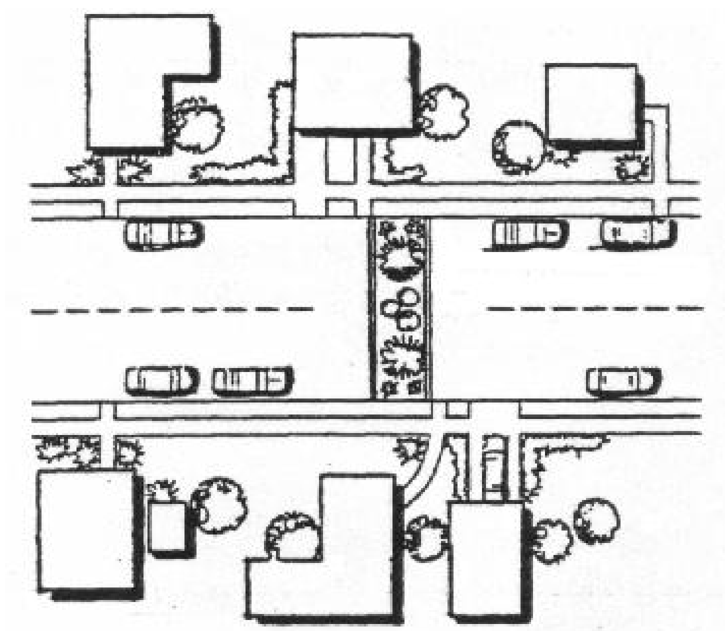

Figure A1: Full Street Closure *(4)*.

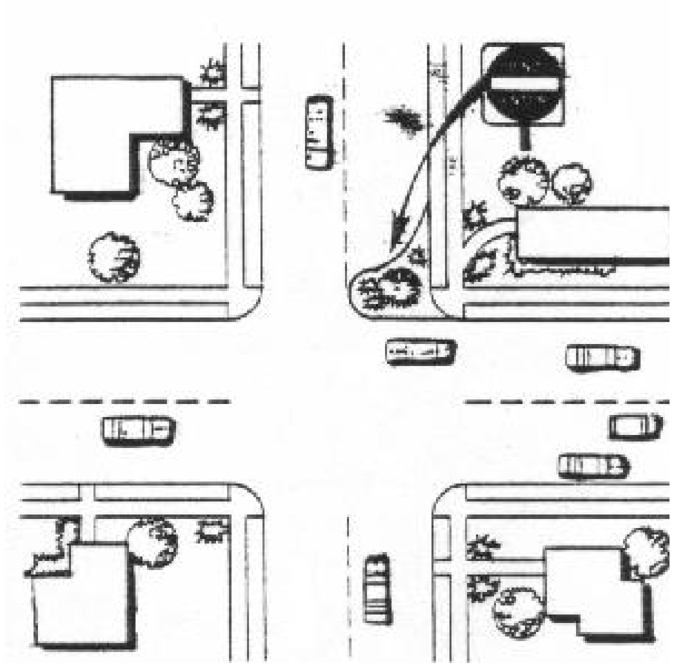

Figure A2. Half- or Partial Street Closure *(4)*.

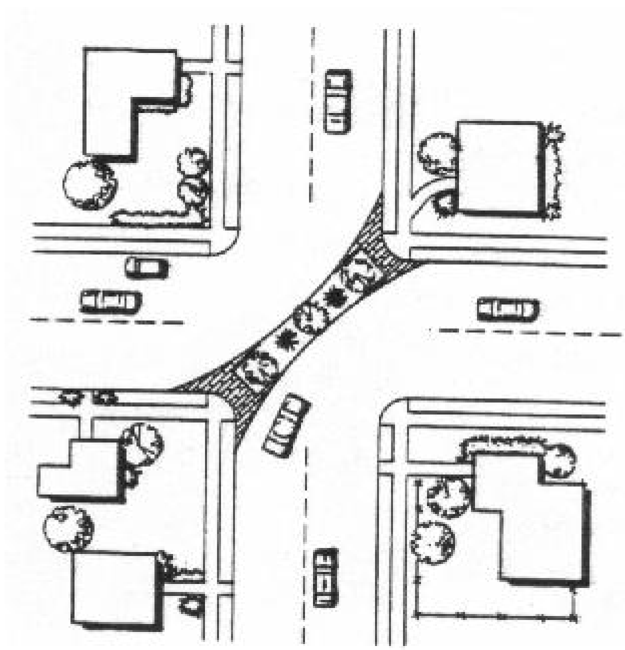

Figure A3: Diagonal Diverter *(4)*.

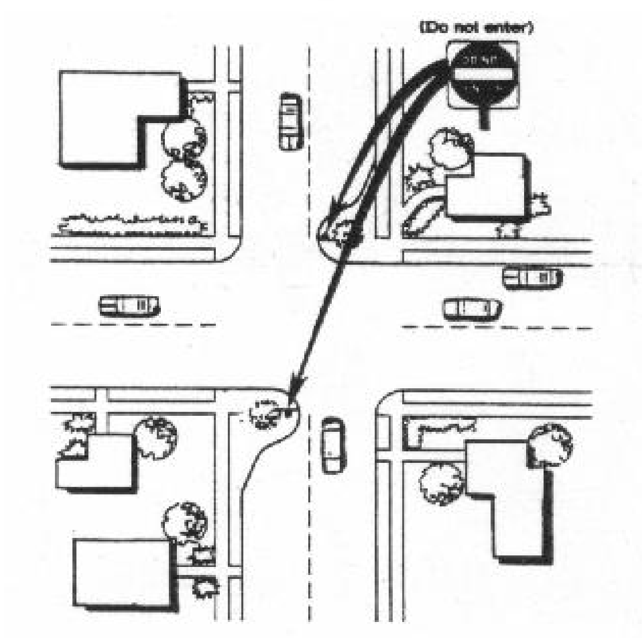

Figure A4: Semi-Diverter *(4)*.

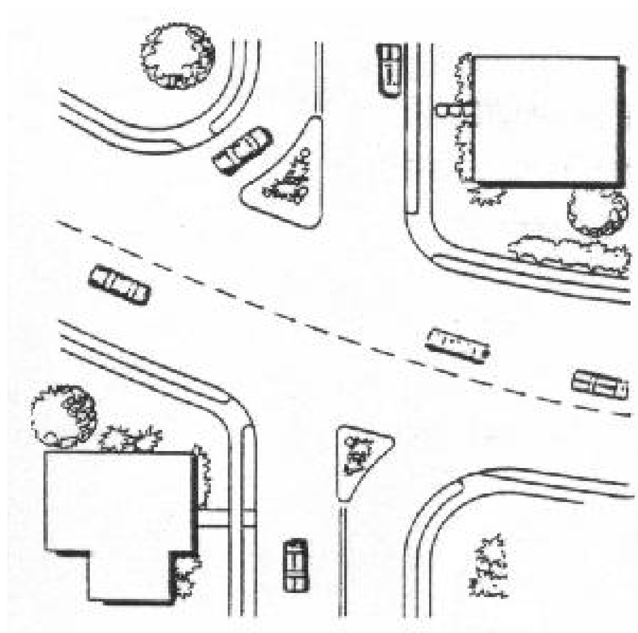

Figure A5: Forced Turn Islands *(4)*.

Speed Control Devices

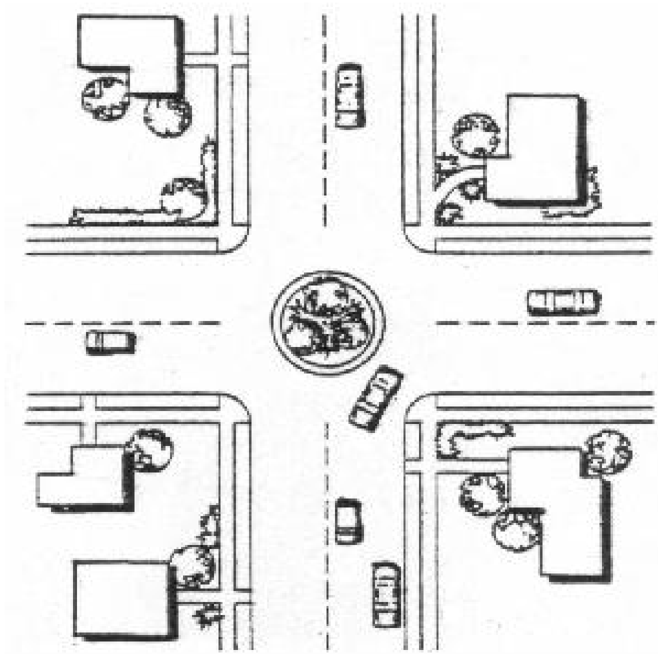

Figure A6: Traffic Circle *(4)*.

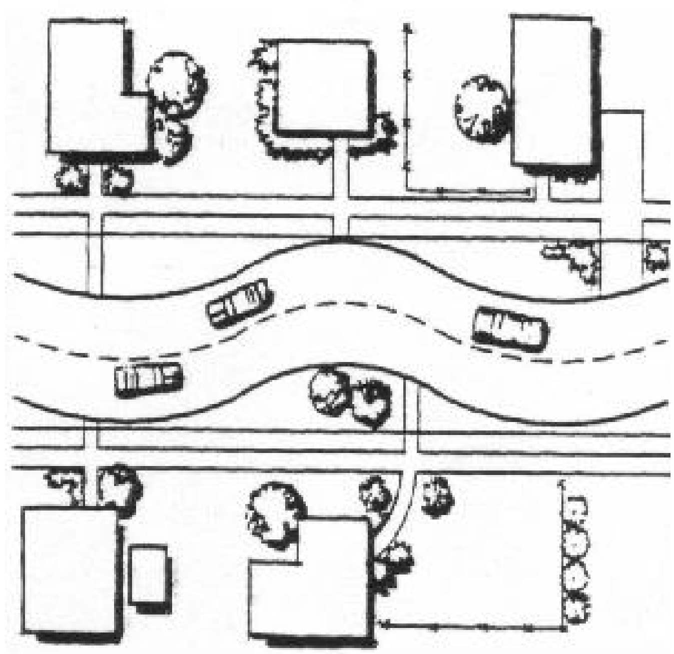

Figure A7: Chicane *(4)*.

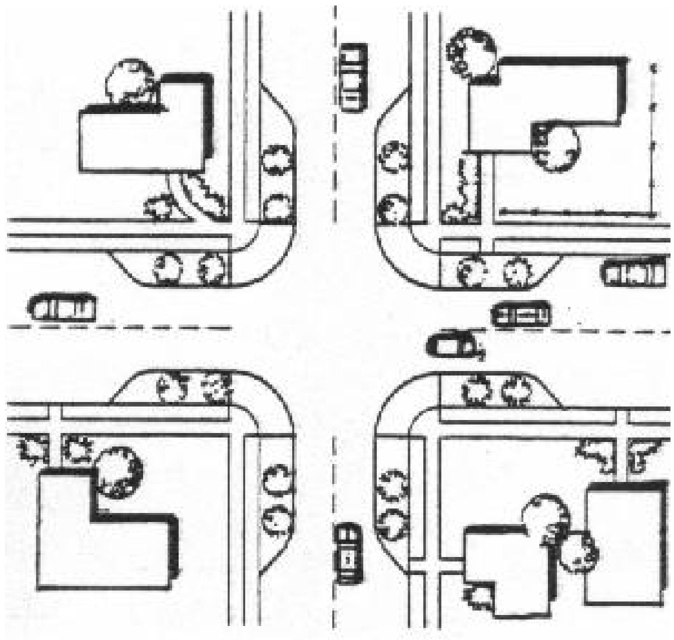

Figure A8: Neckdown *(4)*

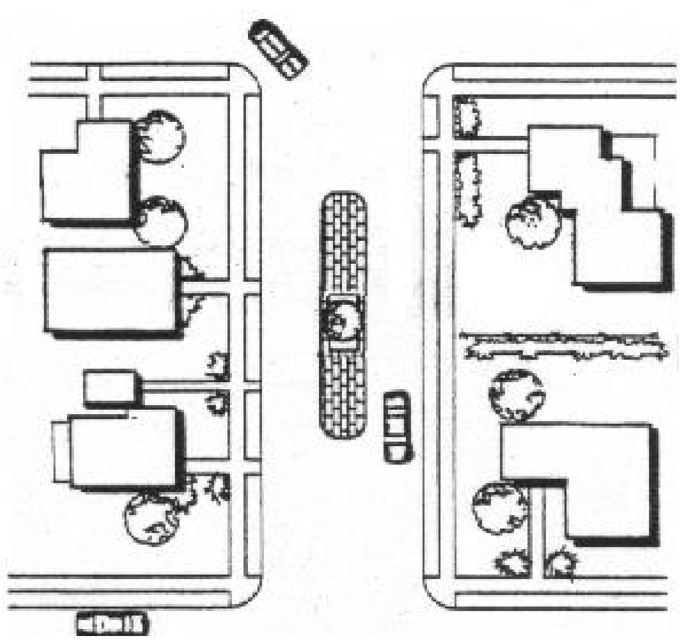

Figure A9: Center Island Narrowing *(4)*

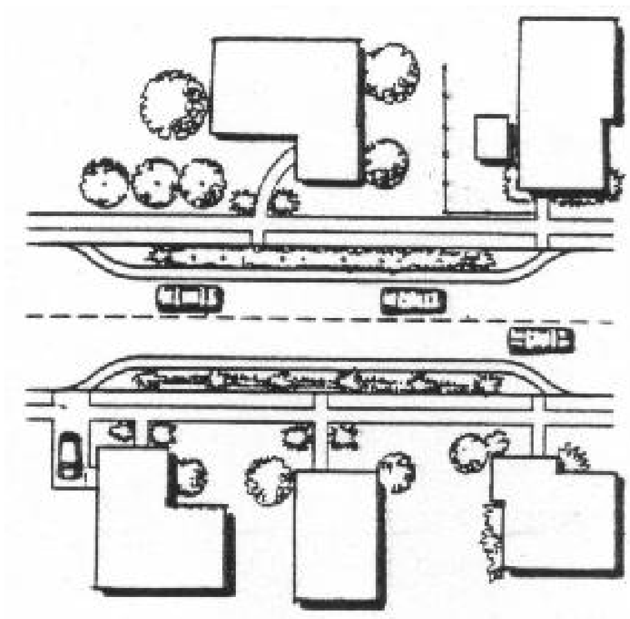

Figure A10: Choker *(4)*

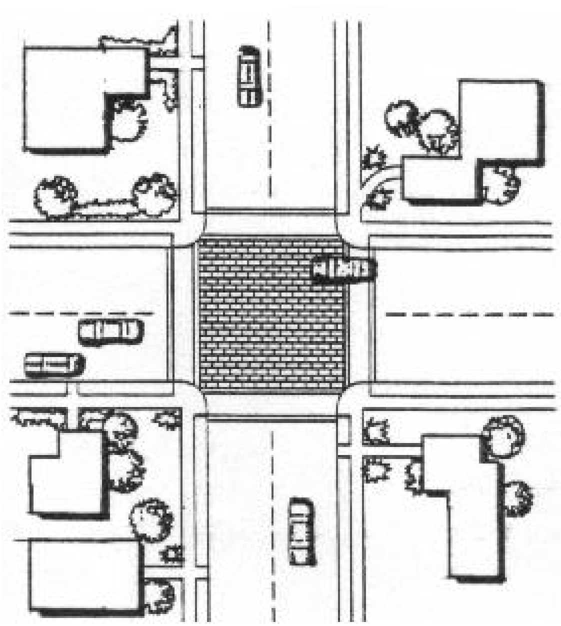

Figure A11: Raised Intersection *(4)*

APPENDIX B. TEMPORARY SPEED HUMP/TABLE INSTALLATION AND REMOVAL

The temporary devices used in this project are made of recycled rubber and anchored into the existing pavement. The installation and removal process is relatively easy and can be completed by a four-person crew in two to four hours depending on which device is being installed. A chalk line, a hammer drill, a ¾ inch masonry bit, an impact wrench, a ½ inch socket drive, paper cups, and stir sticks are needed to complete an installation. It was also found helpful to have an air compressor, sledge hammer, and crowbar on hand during the installation and removal process. The following is a detailed description of temporary speed hump and temporary speed table installation procedure.

B.1 Temporary Speed Hump Installation

Once the location of the speed hump is chosen, a chalk line is snapped across the roadway perpendicular to the curb and gutter or edge of shoulder as shown in Figure B1a. Next, the number and combination of 6-foot and 8-foot anchor plates has to be determined. For the installations on Roosevelt Drive and Redwood Drive, one foot was left between the edge of the outside anchor plates and the curb face to facilitate drainage. On Canal Shore Drive, the outside anchor plates were placed at the edge of the pavement since drainage was not a concern due to the lack of curbing. The first anchor plate is placed on the pavement with the threaded studs up and the edge of the plate even with the snapped chalk line as seen in Figure B1b. Once in place, holes are drilled into the pavement to a depth of approximately six inches with a hammer drill and ¾ inch masonry bit as shown in Figure B1c. Weight should be applied to both ends of the anchor plate as the holes are being drilled to prevent the anchor plate from moving. *Recycled Technologies* recommends that all the holes in the anchor plate be drilled into the pavement *(52)*. However, no significant problems were encountered when only half of the holes were drilled. The streets fitted with the temporary speed hump/table in this study did not carry a significant volume of heavy vehicles. In situations where significant heavy vehicle volumes are present or where the devices are being used as permanent installations, it may be beneficial to drill all holes to prevent the device from shifting under repeated traffic loading.

As the holes are being drilled, it is helpful to occasionally insert a lag bolt into the drilled hole to assure adequate depth. After the holes are drilled, a two-part resin is poured into the holes to seal the pavement and prevent future chemical and frost damage. To activate the resin material, equal parts of resin part A and resin part B are mixed in a paper cup. Once mixed, the drilled holes are filled ¾ full with resin and the lag bolts with washers are placed in the drilled holes as shown in Figures B1d and B1e. A sledgehammer may be necessary to tap the lag bolts into the holes. Weight should be applied to each end of the anchor plate to assure the anchor plate remains flush with the pavement until the resin has set. Typically, set up times for the resin was three and five minutes.

Once the resin has set, the ramp mats can be placed on the threaded studs of the anchor plate. The 25 mile per hour (mph) speed hump consists of a series of two-foot wide by seven-foot long mats. The first mat should be placed on the curbside of the anchor plate with the first hole in the mat fitting over the second threaded stud from the edge of the anchor plate as shown in Figure B1f. Tie straps, small metal plates with two studs extending upward, are used to prevent the mats from shifting with respect to one another. The studs on the tie straps may or may not be threaded. The threaded tie straps are placed under the mats nearest the curb line or edge of travel way to accommodated the tapered edge panels, which will be discussed shortly. As the mats are being placed, unthreaded tie straps should be inserted in pre-drilled holes on the underside of each mat prior to the adjacent mat being installed as shown in Figure B1g. The placement of the threaded tie strap can be seen in Figure B1h**.** As the mats are being placed, ½ inch nuts and washers are placed on the threaded studs as shown in Figure B1i. Mats on the other side of the speed hump can be placed at this time using the exposed treaded anchor plate studs as shown in Figure B1j. Once all the mats are in place, the nuts should be tightened with the impact wrench as shown in Figure B1k. Rubber plugs are then placed over the holes in the mats to prevent water from accumulating around the exposed threaded studs, nuts, and washers. The last stud on the end of the anchor plate should still be exposed. The second anchor plate in the series is then placed on the roadway with the long edge along the chalk line. Before any holes are drilled for the next anchor plate, a ramp mat should be placed on the remaining stud of the previous anchor plate and the first stud of the new anchor plate as shown in Figure B1l. This is done to assure that the anchor plates remain square each other and so the device remains perpendicular to both curb lines. This mat should not be tightened down at this time. Once the second anchor plate is in line, the unbolted mat can be removed and the holes drilled. The same process is followed across the roadway.

Tapered edge panels are used to help facilitate drainage. To install the tapered edge panel, a hole must be drilled in the pavement through the threaded tie strap with the hammer drill and ½ inch masonry bit to a depth of six inches as shown in Figure B1m. Once the hole is drilled, two-part resin is poured in the hole until the hole is approximately ¾ full and a 5/8-inch lag bolt and washer are inserted. Once the resin has set, the tapered edge panel is placed on the threaded stud of the tie strap and the exposed threaded stud of the anchor plate as shown in Figure B1n. Once the tapered edge panels are in place, ½ inch nuts and washers are placed on the studs and tightened with the impact wrench and rubber plugs placed over the holes. Due to the slope of the tapered edge panel, the rubber plugs may have to be cut for a flush.

(a)

(b)

Figure B1: Temporary 25 mph Speed Hump Installation.

(c)

(d)

Figure B1 (Continued)

(e)

(f)

Figure B1 (Continued)

(g)

(h)

Figure B1 (Continued)

(i)

(j)

Figure B1 (Continued)

(k)

(l)

Figure B1 (Continued)

(m)

(n)

Figure B1 (Continued)

B.2 Temporary Speed Table Installation

The installation procedures for the temporary 30 mph speed table are very similar to that of the 25 mph speed hump. The only difference is that two series of anchor plates are required. The first series of anchor plates are secured to the pavement following the procedure outlined above with only one side of two-foot by seven-foot rubber mats being installed. Next, the two-foot by four-foot flat mats are placed on the remaining set of studs. The location of the second row of anchor plates is determined by finding the location where the threaded studs line up with the holes of the flat section mats. The two-foot by four-foot mats should be placed on the both ends of both series of anchor plates to assure the anchor plates remain parallel. The location of the second set of two anchor plates are determined in the same manner as in the 25 mph speed hump installation. This procedure can be seen in Figures B2a-B2c. Tie straps are not used with the flat sections. Also, four-foot tapered edge panels are used for drainage purposes but do not require a threaded tie strap. They are simply placed over the exposed outside studs of the anchor plates and tightened down with ½ inch nuts and washers.

In this study, the 25 mph speed humps were installed first and later converted to the 30 mph speed tables. The conversion process is no different than the installation procedures described above except one set of anchor plates is already in place. One problem was encountered during the conversion process. The tolerance used in the manufacturing of the four-foot by two-foot mats was large enough to cause the holes in the flat mats and the threaded studs of the anchor plates not match directly. When the installation process reached the centerline of the roadway, the threaded studs could not be inserted into the holes of the four-foot flat mats. Several of the flat mats had to be cut with a masonry blade in order to get the holes and studs to align properly.

B.3 Temporary Speed Hump/Table Removal

Removal of the temporary speed hump is as straightforward as the installation. A four-man crew can remove a temporary 30 mph speed table in about one hour. It is speculated that the temporary 25 mph speed hump can be removed in about half that time. The ½ inch nuts are loosened and removed with the impact wrench. It was found useful to have a magnet on hand to remove the nuts and washers from the holes in the ramp mats. Once the nuts are removed, the mats can be lifted off. Once the mats are removed, the impact wrench is used to remove the 5/8-inch lag bolts as shown in Figure B3 and the anchor plates can be simply lifted off the pavement. The exposed holes in the pavement are completely filled with two-part resin to protect the pavement from chemical and frost damage.

(a)

(b)

Figure B2. Temporary 30 mph Speed Table Installation.

(c)

Figure B2. (Continued)

Figure B3. Lag Bolt and Anchor Plate Removal.

APPENDIX C. RESIDENT SURVEY AND COVER LETTER

A resident survey was performed as part of this project to determine how the residents of Atlantic and Le Claire, Iowa perceived the temporary traffic calming devices. A copy of the cover letter and resident survey distributed on Roosevelt Drive is shown in Figures C1 and C2 resectively. The same cover letters and surveys were also distributed to the residents of Redwood Drive and Canal Shore Drive.

CTRE

Center for Transportation Research and Education

August 17, 2001

Dear Atlantic Resident,

My name is Dan Smith and I am a graduate student at Iowa State University and the Center for Transportation Research and Education. The City of Atlantic has participated in an Iowa Department of Transportation (IDOT) funded project to determine if speed humps can be used effectively in Iowa. This summer, a speed hump was in place on Roosevelt Drive. I am interested in how the residents living along Roosevelt Drive feel about the speed hump. Enclosed you will find a short resident survey form. If you could please take a few minutes to complete the survey and return it to me by August 31, it would be greatly appreciated. A postage paid envelope is also enclosed for your convenience. Your opinions and comments are important to the success of this project, and will help determine the overall benefit and public acceptance of the speed hump. This information will also help city officials determine whether or not installation of more traffic calming devices should be evaluated in Atlantic. If you have any questions please feel free to contact me at (515) 296-6686 or email me at djsmith@iastate.edu.

I would like to thank you for allowing us to perform this study in your neighborhood and thank you for your time.

Sincerely,

Daniel J. Smith
Graduate Research Assistant
Center for Transportation Research and Education
Iowa State University

IOWA STATE UNIVERSITY

ISU Research Park • 2901 S. Loop Drive, Suite 3100 • Ames, Iowa 50010-8632
Phone 515-294-8103 • Fax 515-294-0467 • Web site www.ctre.iastate.edu/

Figure C1: Resident Survey Cover Letter

Center for Transportation Research and Education

Temporary Speed Hump Residents Survey

1. How often do you drive over the speed hump?
   - ❑ 1-2 times a day
   - ❑ 3-5 times a day
   - ❑ 5+ times a day
   - ❑ 1-2 times a week
   - ❑ Other _______________
2. Have you noticed a change in traffic speeds after the speed hump was installed?
   - ❑ Speeds have increased
   - ❑ Speeds have decreased
   - ❑ No noticeable changes in speed
3. Have you noticed a change in traffic volumes since the speed hump was installed?
   - ❑ Volumes have increased
   - ❑ Volumes have decreased
   - ❑ No noticeable change in traffic volume
4. What do you like most about the use of the speed hump?

5. What do you like least about the use of the speed hump?

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Figure C2: Resident Survey

Center for Transportation Research and Education

6. Do you feel a permanent speed hump(s) should be installed at this location?

- ❑ Yes
- ❑ No
- ❑ No opinion

7. Two different types of speed humps were installed on Roosevelt Drive for several weeks each. Do you prefer one speed hump design to the other?

- ❑ I prefer the rounded hump (first installation)
- ❑ I prefer the flat-topped hump (second installation)
- ❑ I have no preference

8. Please list any other comments you may have.

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Figure C2 (Continued)

APPENDIX D. BEFORE, DURING, AND AFTER SPEED PROFILES

Speed profiles were plotted from the output of an executable program written in C, which calculated vehicle speed from the distance measurements collected using the laser gun. Speed profiles were plotted for each data collection period for each test site. Figures D1, D2, D3, and D4 show the profiles collected on Roosevelt Drive northbound in the “before”, while the temporary 25 mph speed hump was in place, while the temporary 30 mph speed table was in place, and “after” data collection periods respectively. Figures D5, D6, D7, and D8 show the profiles collected on Roosevelt Drive southbound in the “before”, while the temporary 25 mph speed hump was in place, while the temporary 30 mph speed table was in place, and “after” data collection periods respectively. Figures D9, D10, D11, and D12 show the profiles collected on Redwood Drive in the “before”, while the temporary 25 mph speed hump was in place, while the temporary 30 mph speed table was in place, and “after” data collection periods respectively. Figures D13, D14, D15, and D16 show the profiles collected on Canal Shore Drive in the “before”, while the temporary 25 mph speed hump was in place, while the temporary 30 mph speed table was in place, and “after” data collection periods respectively.

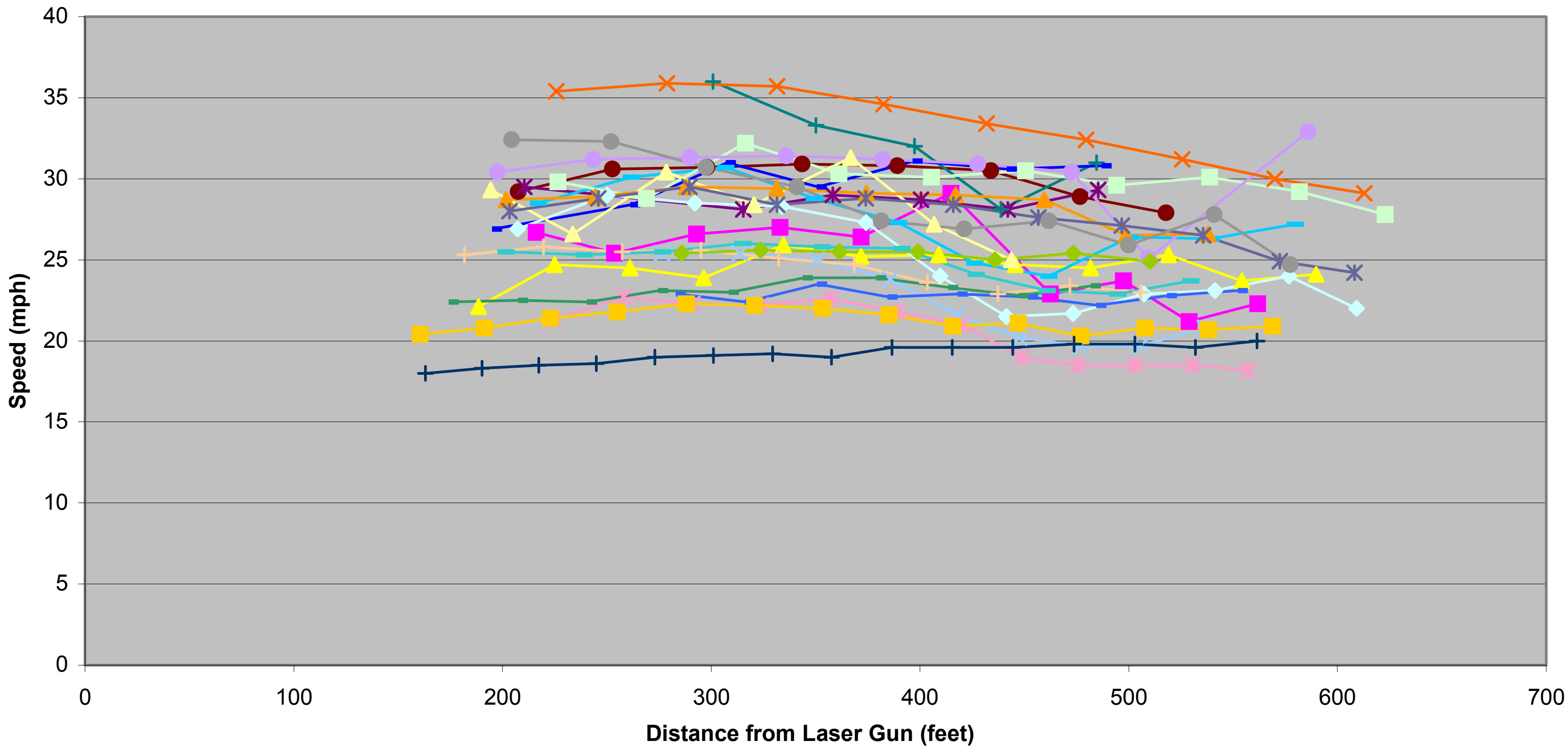

Figure D1: Roosevelt Drive Northbound "Before" Speed Profiles

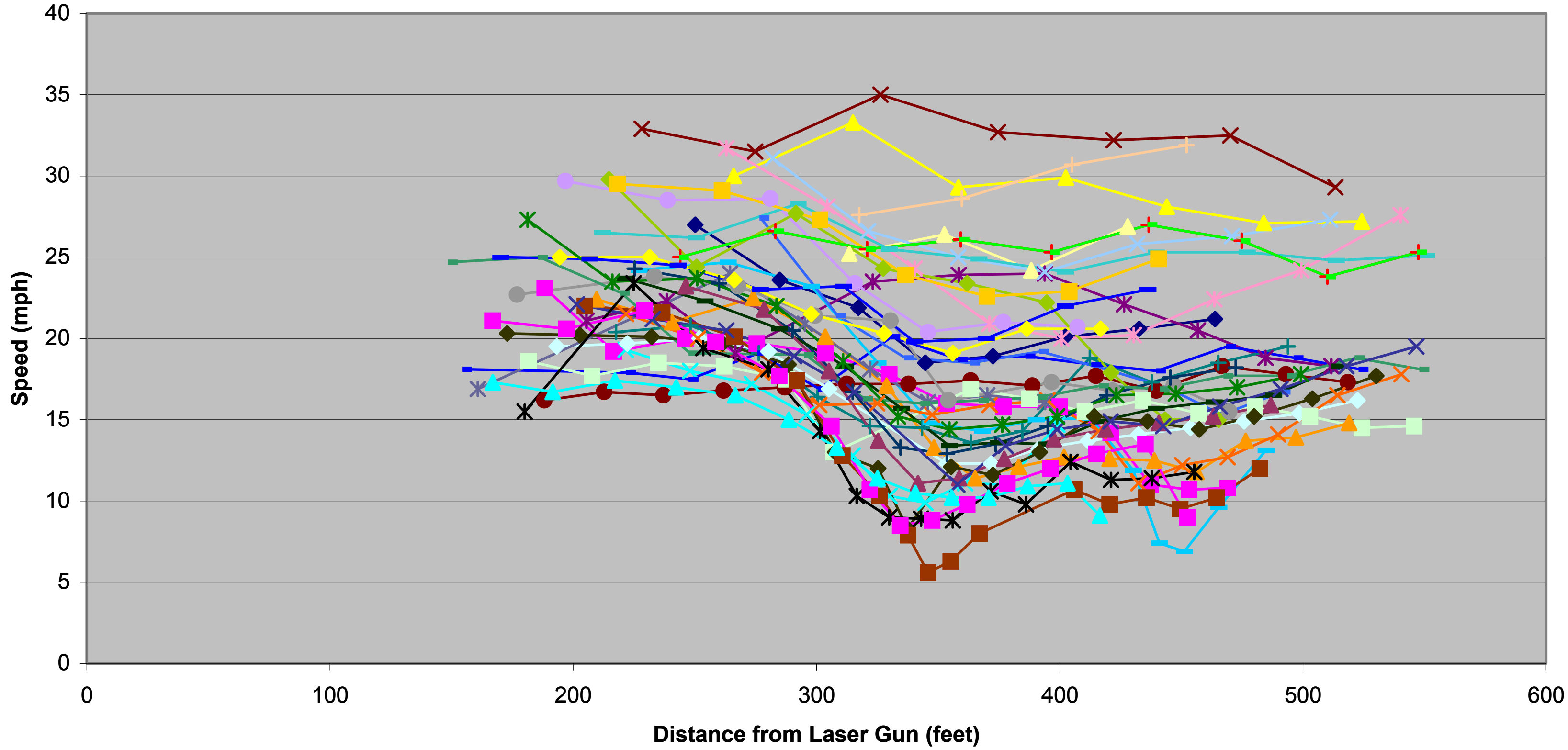

Figure D2. Roosevelt Drive Northbound Temporary 25 mph Speed Hump Speed Profiles.

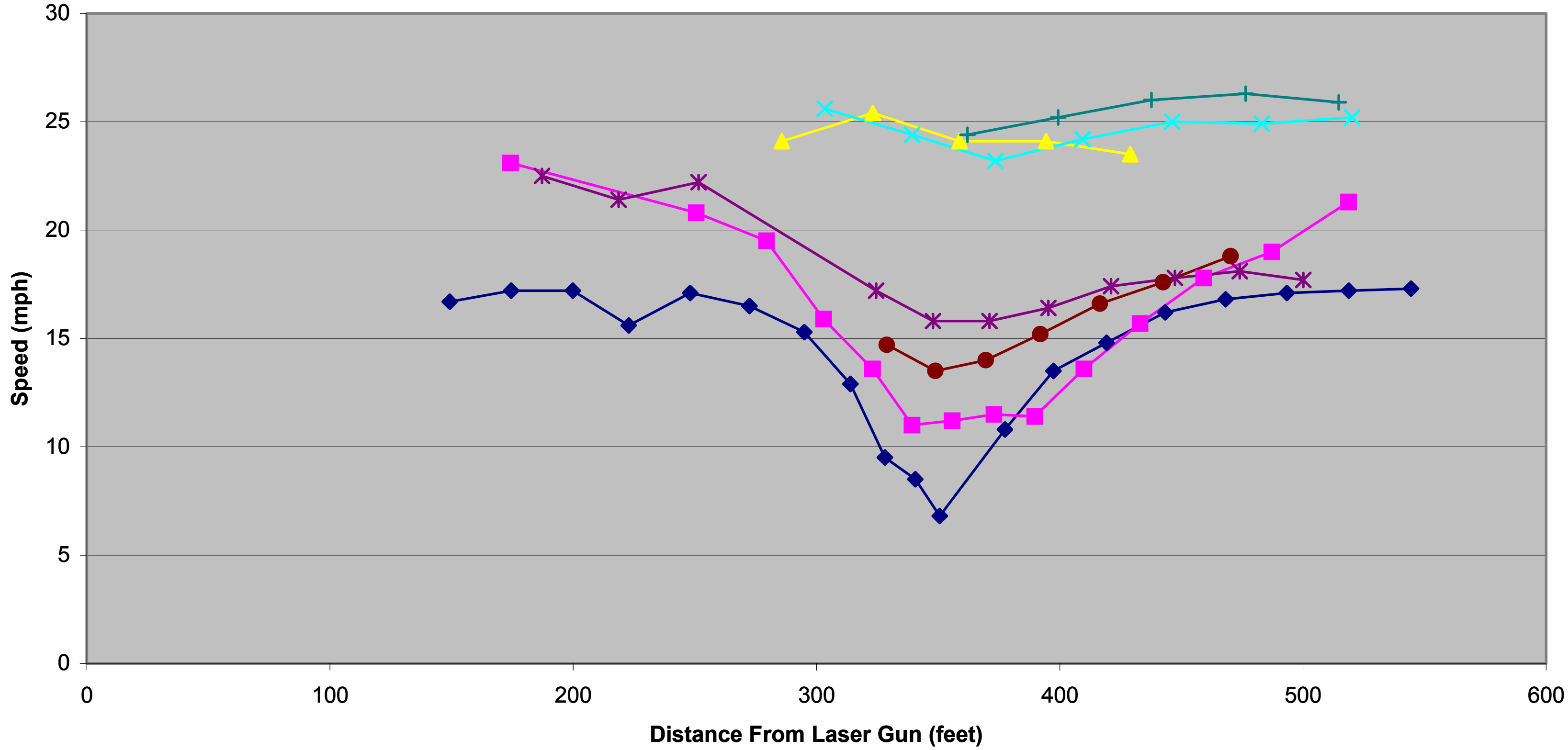

Figure D3. Roosevelt Drive Northbound Temporary 30 mph Speed Table Speed Profiles.

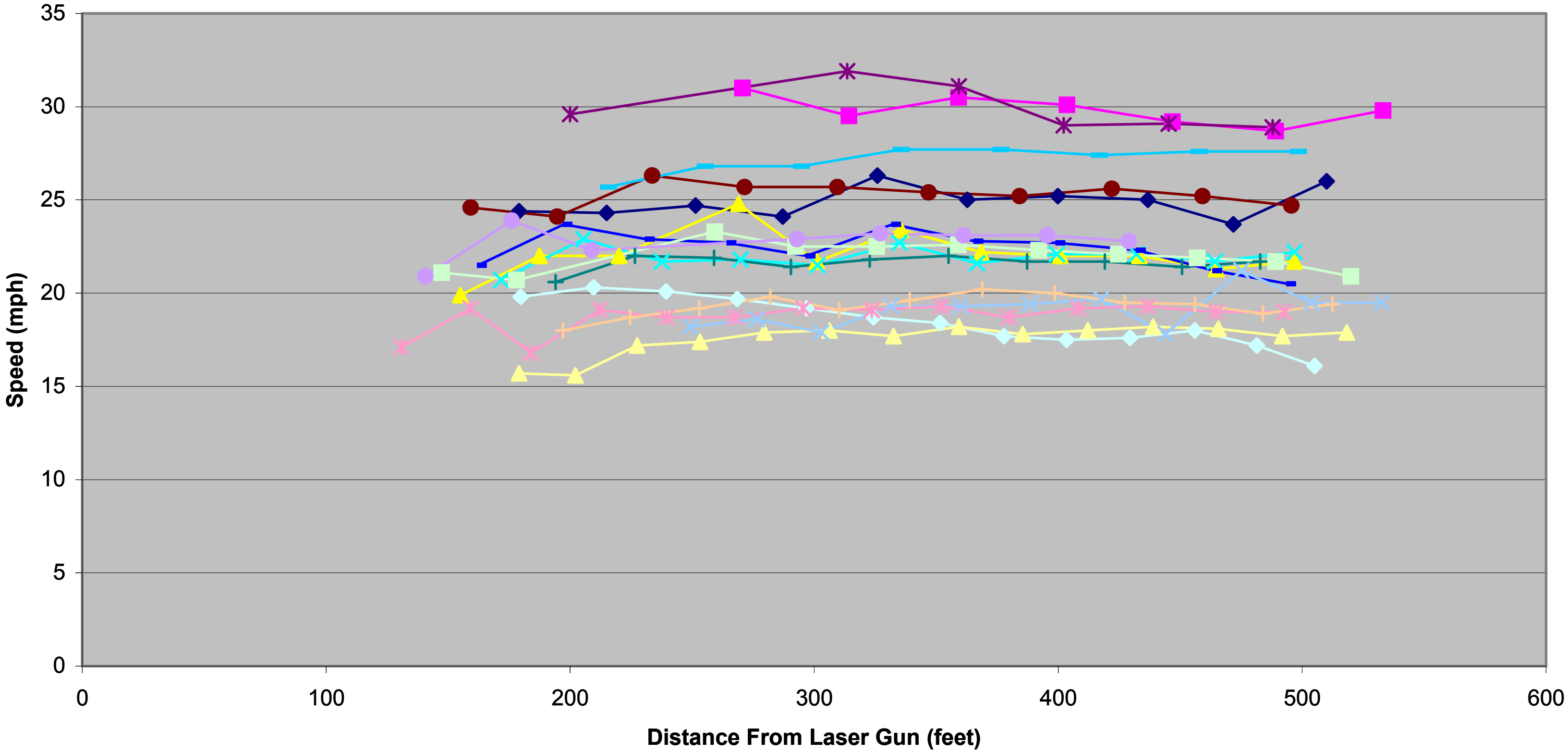

Figure D4: Roosevelt Drive Northbound "After" Speed Profiles

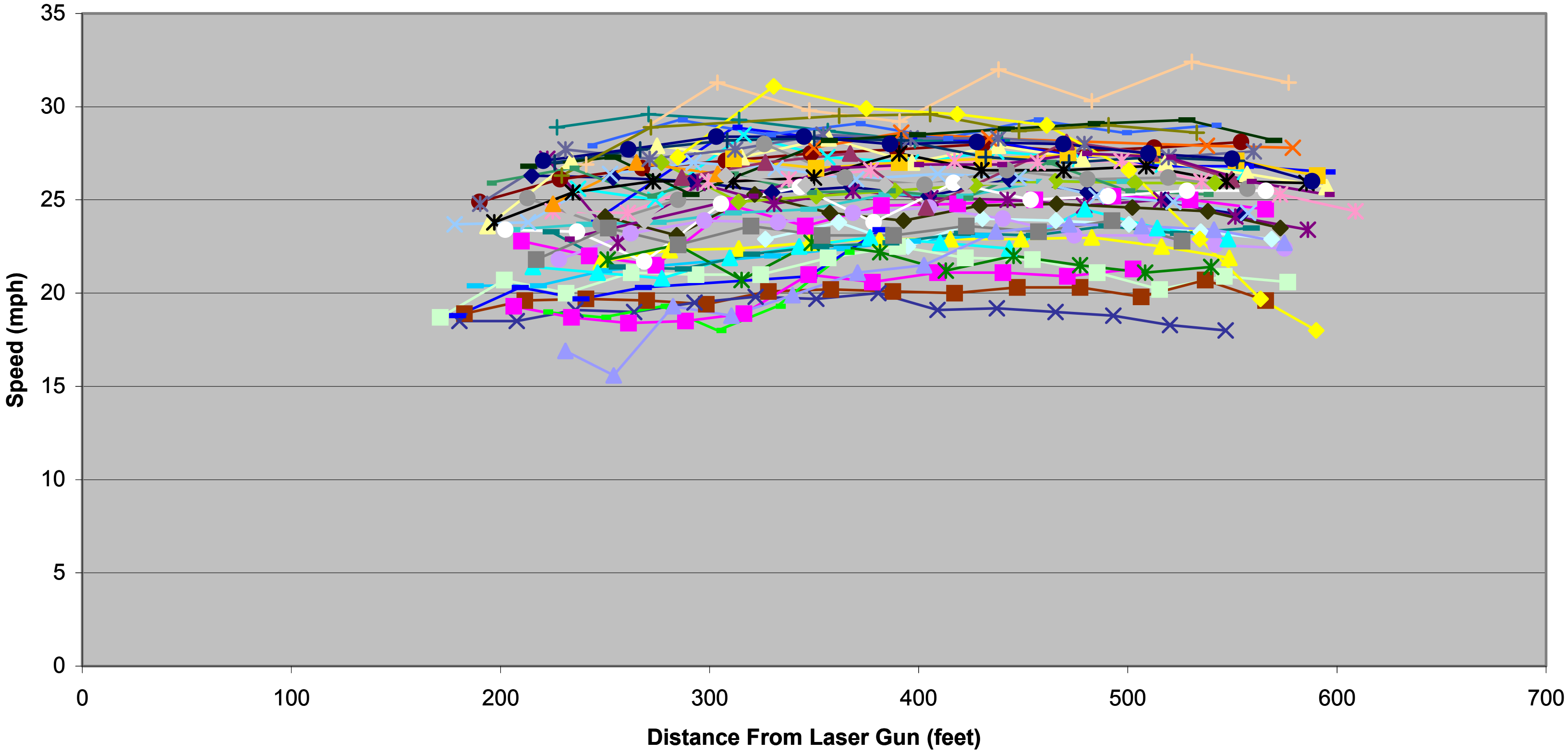

Figure D5: Roosevelt Drive Southbound "Before" Speed Profiles

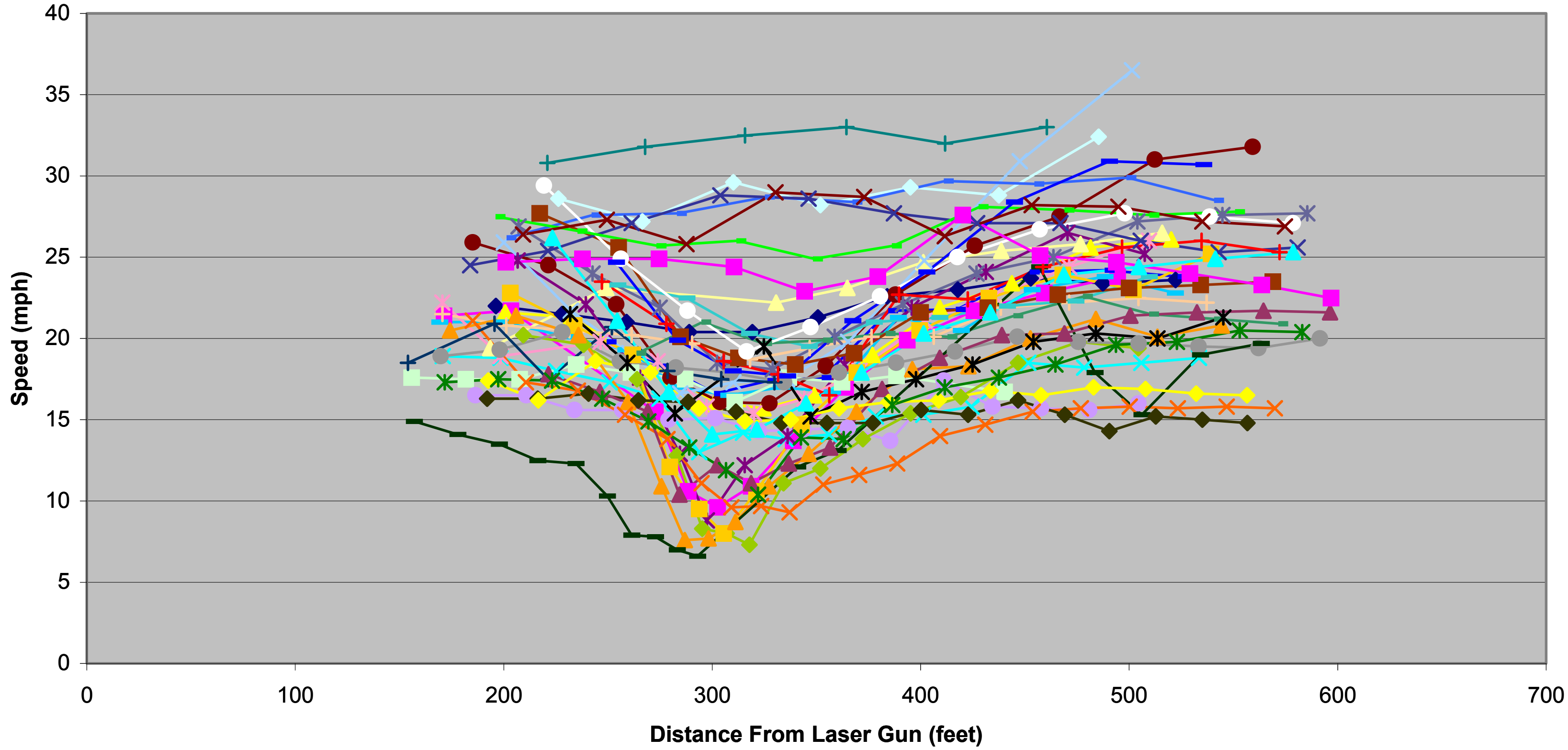

Figure D6: Roosevelt Drive Southbound Temporary 25 mph Speed Hump Speed Profiles

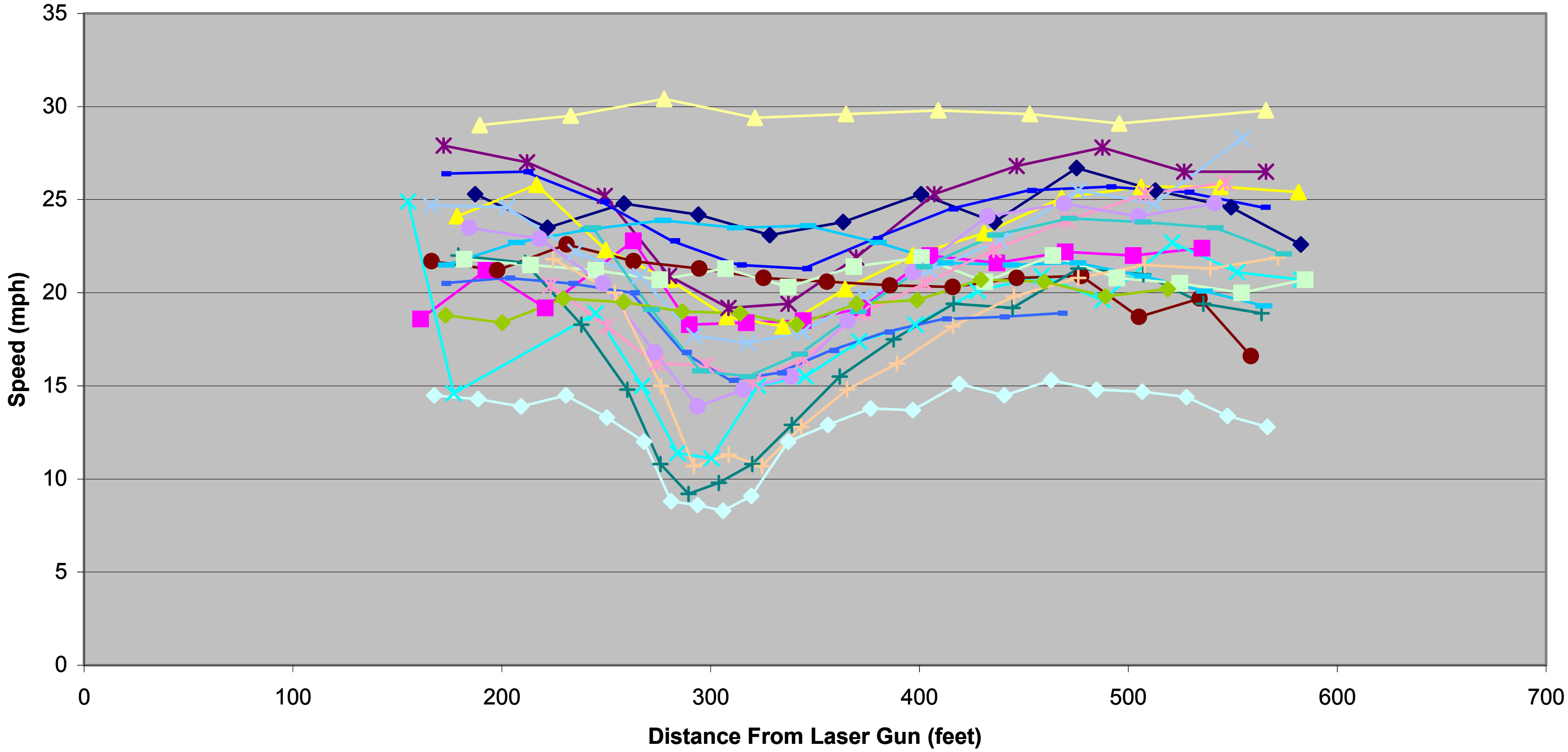

Figure D7: Roosevelt Drive Southbound Temporary 30 mph Speed Table Speed Profiles

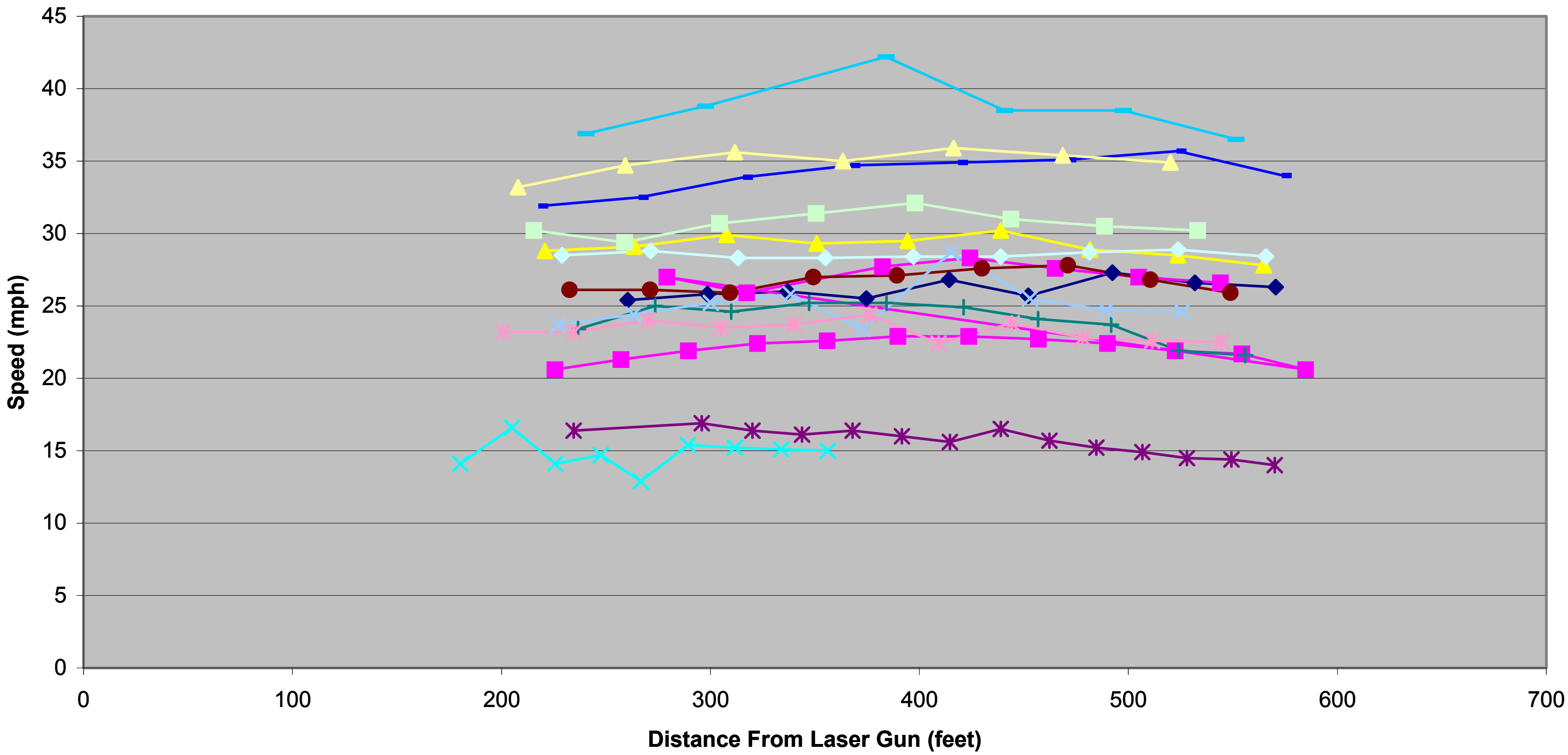

Figure D8: Roosevelt Drive Southbound "After" Speed Profiles

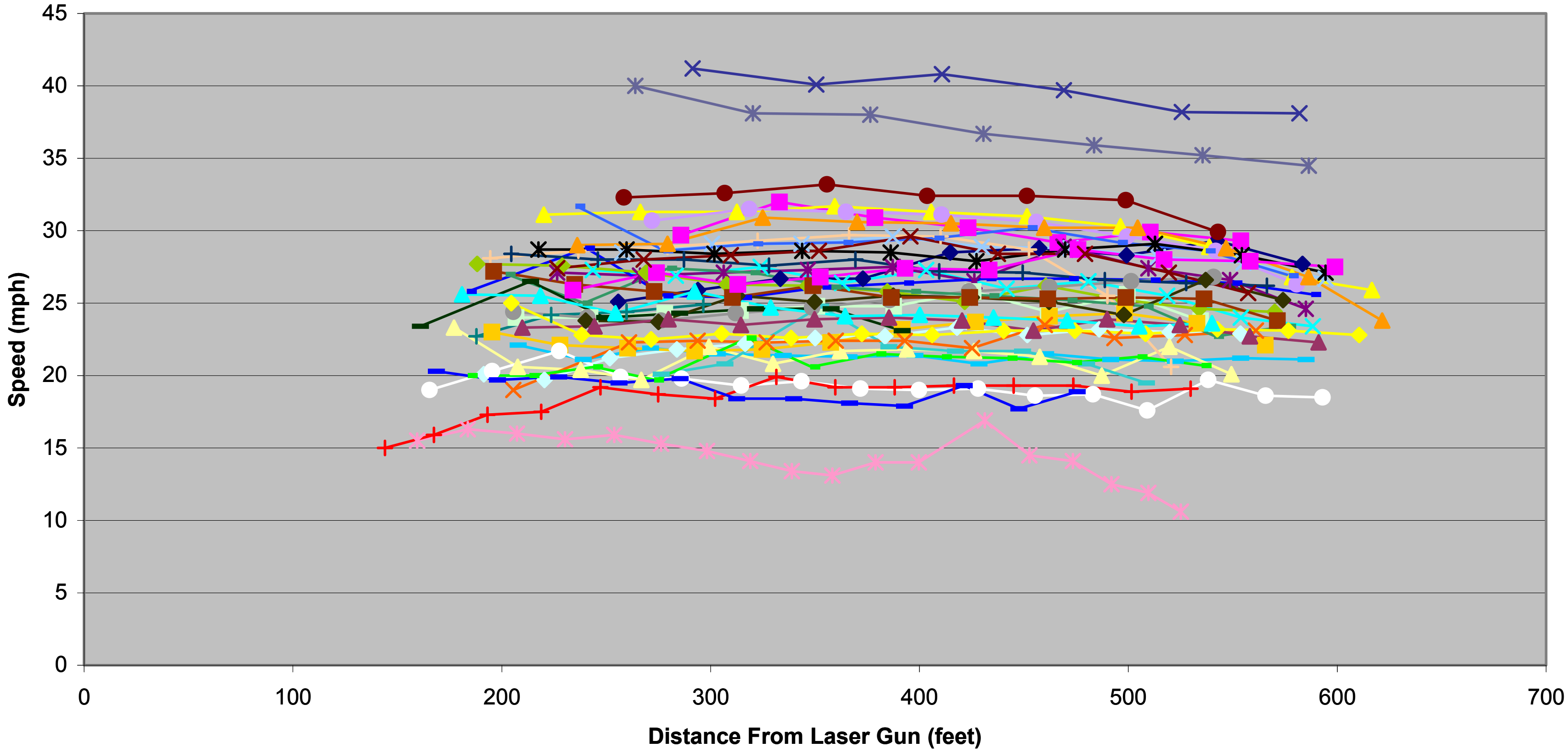

Figure D9: Redwood Drive "Before" Speed Profiles

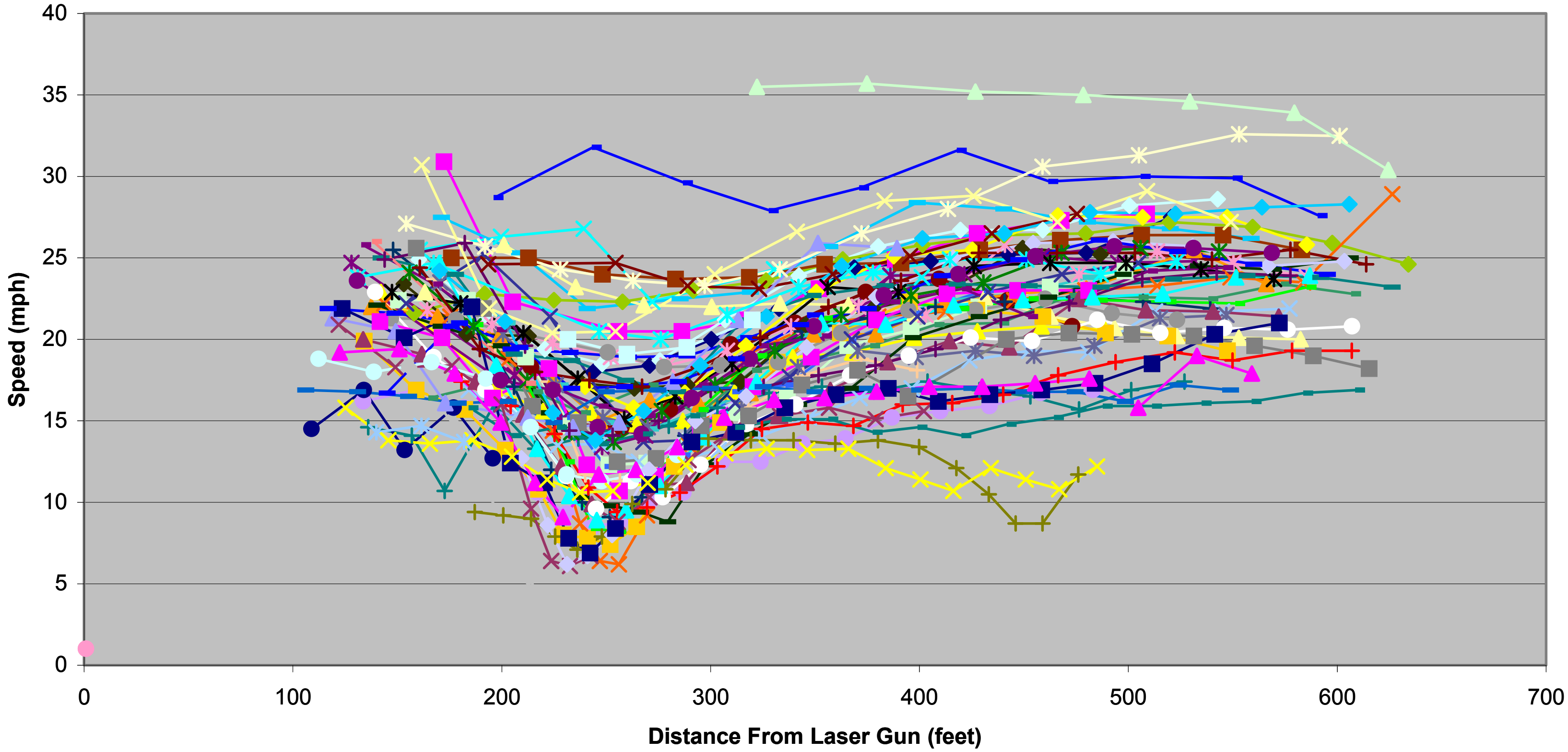

Figure D10: Redwood Drive Temporary 25 mph Speed Hump Speed Profiles

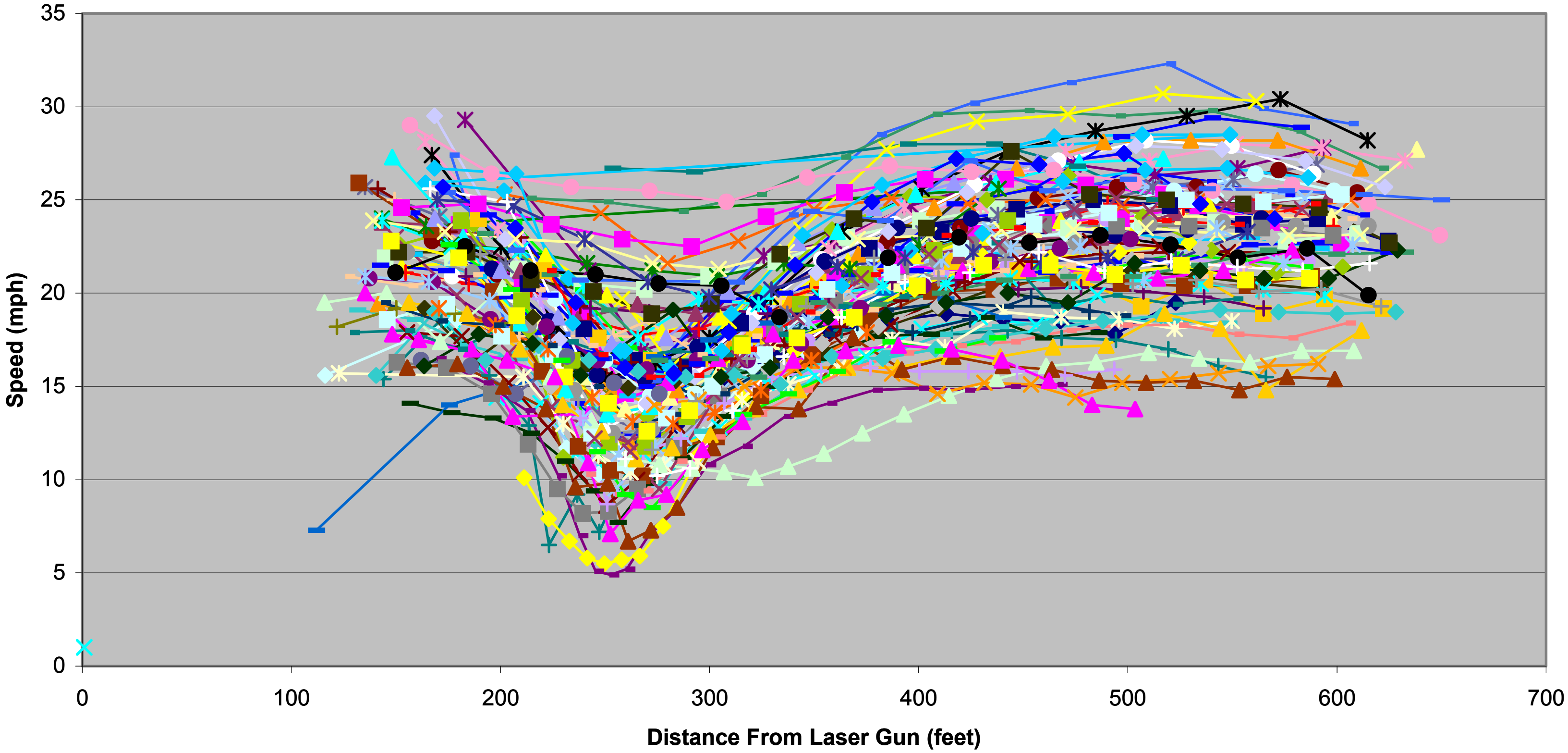

Figure D11: Redwood Drive Temporary 30 mph Speed Table Speed Profiles

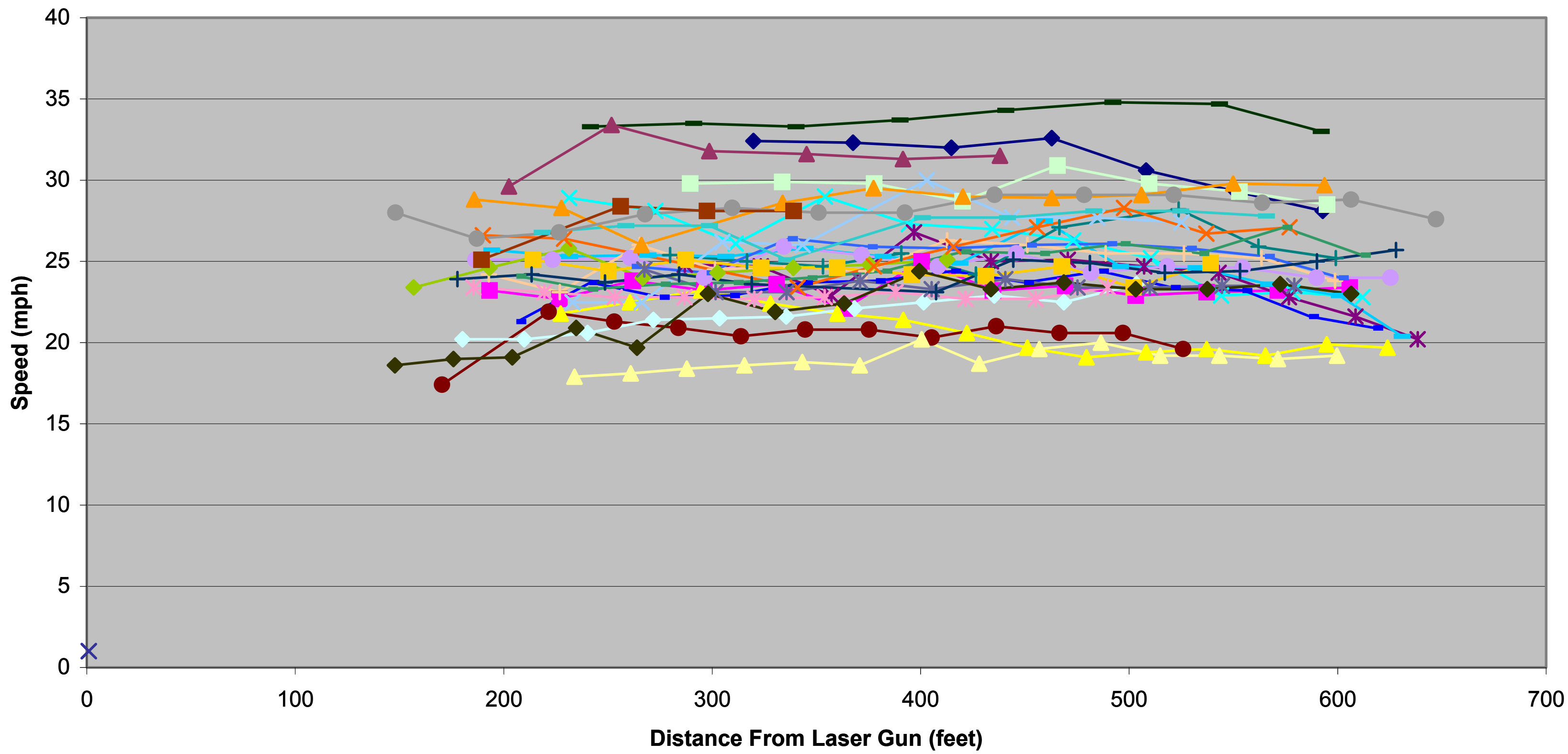

Figure D12: Redwood Drive "After" Speed Profiles

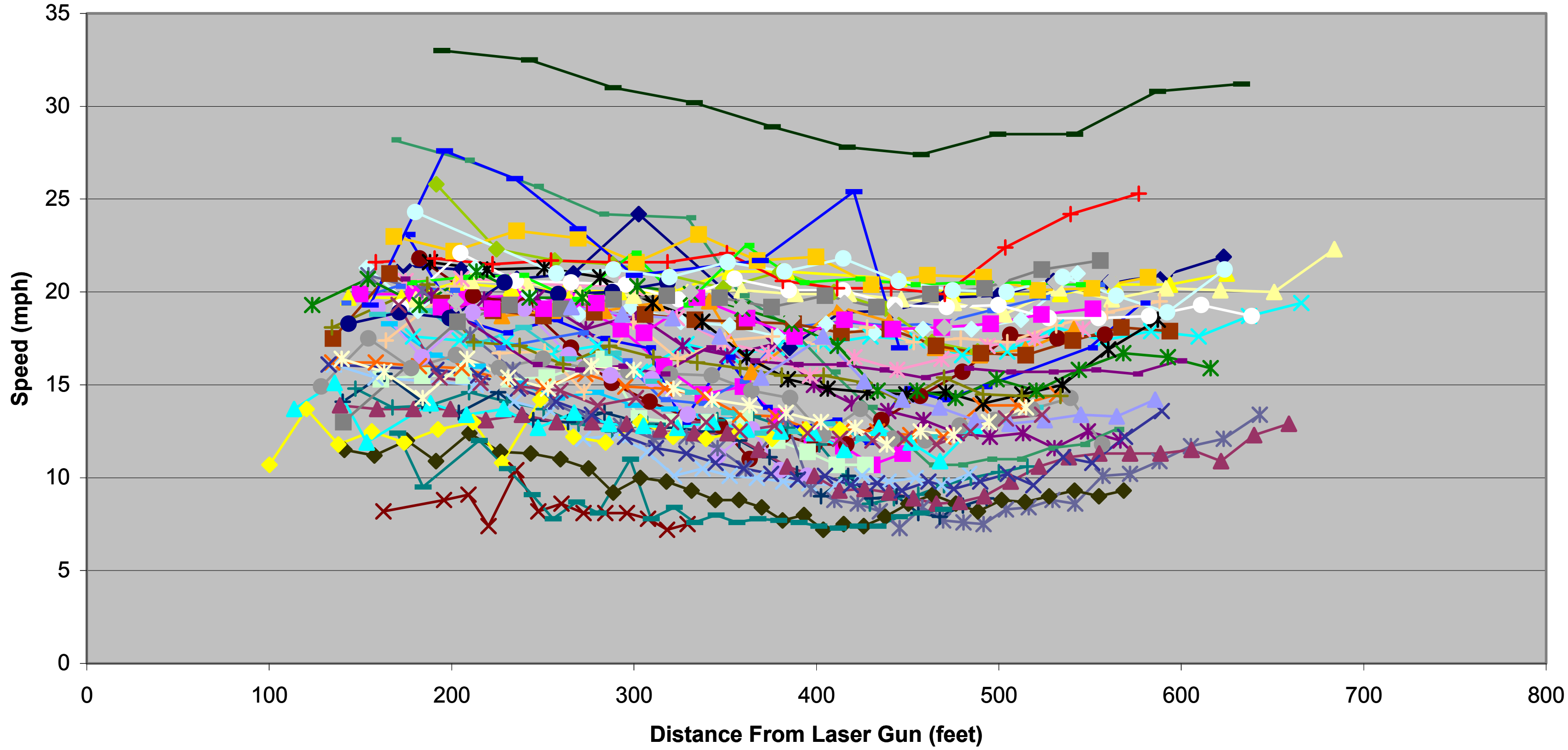

Figure D13: Canal Shore Drive “Before” Speed Profiles

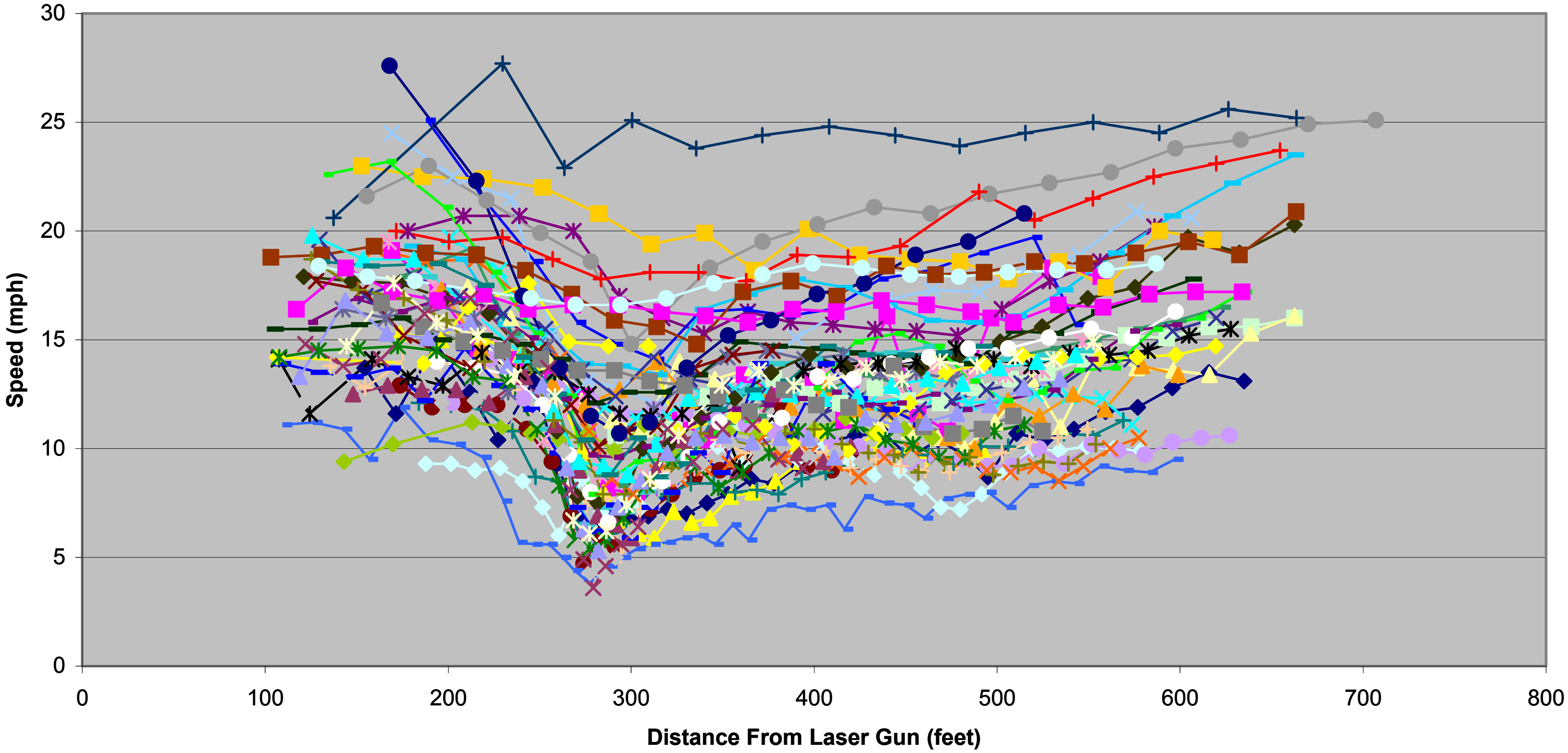

Figure D14: Canal Shore Drive Temporary 25 mph Speed Hump Speed Profiles

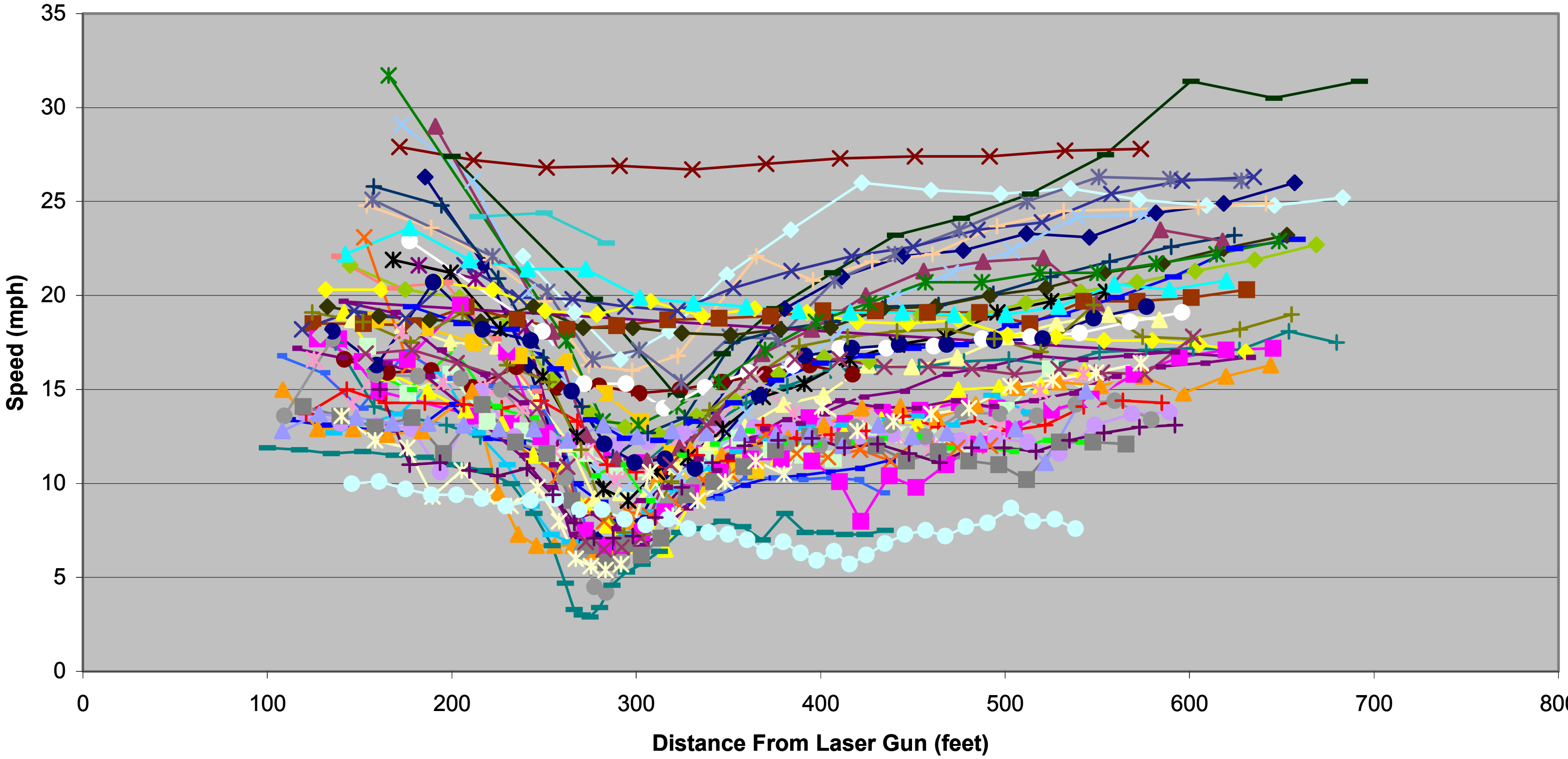

Figure D15: Canal Shore Drive Temporary 30 mph Speed Table Speed Profiles

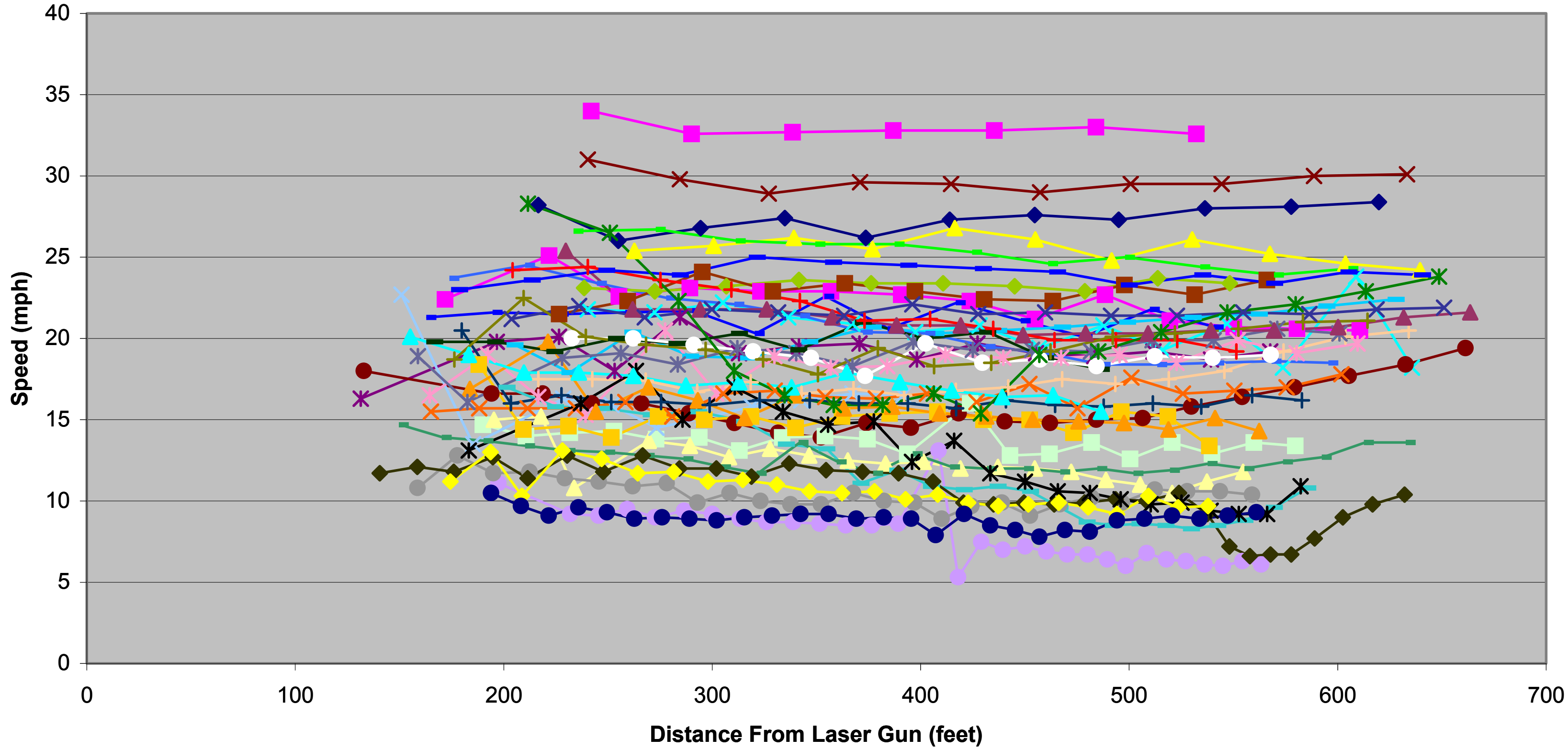

Figure D16: Canal Shore Drive "After" Speed Profiles

APPENDIX E. SPEED AND VOLUME TEST STATISTICS

The following tables summarize the test statistics and critical rejection values calculated in the statistical evaluation of the speed and volume data. The F-test and two sample t-tests were used to evaluate mean vehicle speeds while the Mann-Whitney Test was used to evaluate the collected volume data.

Table E1: "Before" Versus Speed Hump Test Statistics

Roosevelt Drive - NB	"Before"	Speed Hump	F-Test		Two Sample t-Test	
Section	Sample Size	Sample Size	Test Statistic	F Critical	Test Statistic	t Critical
100 to 180' upstream	21	30	1.0295	2.3569	3.7452	2.0096
At the device	26	42	2.1143	2.1135	6.3417	1.9971
100 to 300' downstream	24	35	3.0021	2.2098	4.6603	2.0032

Roosevelt Drive – SB	"Before"	Speed Hump	F-Test		Two Sample t-Test	
Section	Sample Size	Sample Size	Test Statistic	F Critical	Test Statistic	t Critical
100 to 150' upstream	11	20	1.2534	3.4351	1.5878	2.0452
At the device	47	41	2.0318	1.8236	6.6039	1.9944
100 to 300' downstream	43	39	1.8619	1.8674	2.899	1.9901

Redwood Drive	"Before"	Speed Hump	F-Test		Two Sample t-Test	
Section	Sample Size	Sample Size	Test Statistic	F Critical	Test Statistic	t Critical
At the device	40	63	1.1784	1.7413	8.2256	1.9837
100 to 300' downstream	39	57	1.2787	1.7742	3.5847	1.9855
300 to 385' downstream	27	27	1.0955	2.1943	1.4664	2.0066

Canal Shore Drive	"Before"	Speed Hump	F-Test		Two Sample t-Test	
Section	Sample Size	Sample Size	Test Statistic	F Critical	Test Statistic	t Critical
100 to 200' upstream	40	39	1.0358	1.9014	0.7784	1.9912
At the device	49	50	1.4084	1.7660	5.4594	1.9847
100 to 300' downstream	46	49	1.9138	1.7852	0.8453	1.9893
300 to 385' downstream	18	25	1.2038	2.3865	0.8916	2.0195

Table E2. "Before" Versus Speed Table Test Statistics.

Roosevelt Drive - Northbound

	"Before" Sample Size	Speed Table Sample Size	F-Test		Two Sample t-Test	
			Test Statistic	F Critical	Test Statistic	t Critical
100 to 200 feet upstream	21	4	1.6917	14.1674	3.3132	2.0686
At the device	26	8	1.6325	2.8478	5.1391	2.0369
100 to 300 feet downstream	24	7	1.0630	3.0232	3.2276	2.0452

Roosevelt Drive - Southbound

	"Before" Sample Size	Speed Table Sample Size	F-Test		Two Sample t-Test	
			Test Statistic	F Critical	Test Statistic	t Critical
100 to 200 feet upstream	11	15	1.6563	3.5504	-0.5122	2.0639
At the device	47	18	1.6606	2.0812	5.4367	1.9983
100 to 300 feet downstream	43	18	1.0346	2.4335	3.4134	2.0000

Redwood Drive

	"Before" Sample Size	Speed Table Sample Size	F-Test		Two Sample t-Test	
			Test Statistic	F Critical	Test Statistic	t Critical
At the device	40	82	2.0434	1.6825	9.2610	2.0017
100 to 300 feet downstream	39	82	1.9033	1.6886	4.0860	2.0017
300 to 400 feet downstream	27	59	1.1985	1.8652	2.9746	1.9886

Canal Shore Drive

	"Before" Sample Size	Speed Table Sample Size	F-Test		Two Sample t-Test	
			Test Statistic	F Critical	Test Statistic	t Critical
100 to 200 feet upstream	40	45	1.5834	1.8662	-0.2833	1.9990
At the device	49	50	1.0038	1.7690	3.9652	1.9847
100 to 300 feet downstream	46	46	1.1497	1.8073	-1.9035	1.9867
300 to 410 feet downstream	18	26	1.0409	2.5484	-0.9612	2.0181

Table E3. Speed Hump Versus Speed Table Test Statistics.

	Speed Hump Sample Size	Speed Table Sample Size	F-Test		Two Sample t-Test	
			Test Statistic	F Critical	Test Statistic	t Critical
Roosevelt Drive - Northbound						
100 to 200 feet upstream	30	4	1.7416	14.0865	1.2921	2.0369
At the device	42	8	1.2952	4.3049	0.5929	2.0106
100 to 300 feet downstream	35	7	2.8242	5.0405	-0.3934	2.0211
Roosevelt Drive - Southbound						
100 to 200 feet upstream	20	15	1.3215	2.6469	-2.1655	2.0345
At the device	41	18	1.2235	2.4423	0.3108	2.0025
100 to 300 feet downstream	39	18	1.9264	2.4518	-0.5367	2.0040
Redwood Drive						
100 to 150 feet upstream	29	31	1.3722	2.1121	0.1008	2.0017
At the device	63	82	1.7339	1.5906	0.3294	1.9814
100 to 300 feet downstream	57	82	1.4884	1.6082	0.2672	1.9774
300 to 400 feet downstream	27	59	1.0940	1.8652	1.2081	1.9886
Canal Shore Drive						
100 to 180 feet upstream	45	39	1.6401	1.8770	-0.9798	1.9893
At the device	50	50	1.4138	1.7622	-1.1995	1.9845
100 to 300 feet downstream	49	46	1.6646	1.7852	-3.1415	1.9858
300 to 430 feet downstream	25	26	1.2530	2.2574	-2.0639	2.0096

Table E4. "Before" Versus "After" Test Statistics.

Roosevelt Drive - Northbound

	"Before" Sample Size	"After" Sample Size	F-Test		Two Sample t-Test	
			Test Statistic	F Critical	Test Statistic	t Critical
100 to 170 feet upstream	21	14	1.4019	2.9477	3.8709	2.9477
At the device	26	16	1.0229	2.4110	3.5802	2.0211
100 to 300 feet downstream	24	15	1.1160	2.4966	2.2357	2.0262

Roosevelt Drive - Southbound

	"Before" Sample Size	"After" Sample Size	F-Test		Two Sample t-Test	
			Test Statistic	F Critical	Test Statistic	t Critical
At the device	47	14	4.0403	2.2008	-0.9667	2.1314
100 to 300 feet downstream	43	13	3.1488	2.2709	-1.1081	2.1448

Redwood Drive

	"Before" Sample Size	"After" Sample Size	F-Test		Two Sample t-Test	
			Test Statistic	F Critical	Test Statistic	t Critical
At the device	40	30	1.2214	2.0327	0.9831	1.9955
100 to 300 feet downstream	39	29	1.9819	2.0580	0.0522	1.9966
300 to 400 feet downstream	27	22	1.2938	2.3450	0.5894	2.0117

Canal Shore Drive

	"Before" Sample Size	"After" Sample Size	F-Test		Two Sample t-Test	
			Test Statistic	F Critical	Test Statistic	t Critical
100 to 200 feet upstream	40	18	1.1621	2.1388	-0.0296	2.0032
At the device	49	40	1.5952	1.8149	-1.4669	1.9877
100 to 300 feet downstream	46	39	1.3301	1.8424	-3.0273	1.9890
300 to 400 feet downstream	18	21	1.3484	2.6158	-0.6767	2.0262

Table E5. Speed and Volume Test Statistics and Rejection Ranges.

"Before" vs. Speed Hump Volume Counts

Test Site	"Before" Sample Size	Speed Hump Sample Size	Test Statistic	Lower Quartile Limit	Upper Quartile Limit
Roosevelt Drive	3	10	33.0	10.0	32.0
Redwood Drive	6	9	46.0	32.0	64.0
Canal Shore Drive	4	6	12.0	13.0	31.0

"Before" vs. Speed Table Volume Counts

Test Site	"Before" Sample Size	Speed Hump Sample Size	Test Statistic	Lower Quartile Limit	Upper Quartile Limit
Roosevelt Drive	3	8	30.0	9.0	27.0
Redwood Drive	6	5	32.0	19.0	41.0
Canal Shore Drive	4	6	27.0	12.0	28.0

Speed Hump vs. Speed Table Volume Counts

Test Site	"Before" Sample Size	Speed Hump Sample Size	Test Statistic	Lower Quartile Limit	Upper Quartile Limit
Roosevelt Drive	10	8	57.50	54.00	98.00
Redwood Drive	9	5	37.50	22.00	48.00
Canal Shore Drive	6	6	56.00	27.00	51.00

APPENDIX F. RESIDENT SURVEY RESPONSES TO QUESTION EIGHT

The following are the comments received in response to Question Eight of the resident survey from respondents of Roosevelt Drive, Redwood Drive, and Canal Shore Drive.

Roosevelt Drive

- "As far as slowing traffic down, it might have for some but for others it was something to have fun with. One person that I know of hit the speed bump at speeds above the speed limit and hit some gravel where a water main was repaired and lost control of his car and ended up in my yard almost striking a tree."
- "The students seemed to view the hump as a challenge. See how fast we can go over them! Older drivers who were already driving reasonably seemed frightened by them."
- "The speed humps did slow some vehicles but it did not appear to slow down the drivers that were driving the fastest. Young drivers (16-25) appeared to view the humps as a challenge. Some would take the hump at higher speeds to see what would happen or as a thrill."
- "For residents on Roosevelt Dr., it would be my choice to have speed humps farther south where there are several younger children. During the school year, high school students race on our street, so speed humps might slow traffic some. Others seemed to see how fast they could drive over the humps!"
- "Need sharper speed bumps."
- "I think it should be more aggressive."
- "We feel this should have been tried during the school year, rather then the summer months. The traffic is much less during the summer months."
- "I would like to see two placed on Roosevelt Dr. Thank you for any help you could give us."
- "I'd be in favor of two installed on either end of the street. If only one is to be installed, I'd be in favor of a more central location. At this time in the life of the neighborhood, the children live at the south end of the neighborhood."
- "Most of the speeding cars were high school students before or after school. You could determine the effectiveness of the speed humps during the school year."
- "I did not see a need for it in the first place."
- "I wish it could have been done while school was still in session, they are the speeders. Thanks for doing this for us."
- "I am not sure the high school students do use or will use Roosevelt Dr. with the new building but speed bumps will decrease that use and probably require their use on Plum St."
- "I never realized there was more than one."
- "It doesn't really make a lot of difference to me. A hump is needed more at the plaza where McDonalds and HyVee are. People come straight in headed for Alco driving too fast."
- "Three times I was backing out of my driveway, I looked south toward the bump, saw no one-proceeded to back out and found a car behind me who had stopped at the hump then proceeded into my backing path. Locate these as far between driveways as possible."

- “The speed hump is worthless. Kids use it as a ramp. It is a waste of taxpayers money. We don’t need to pay for someone to count cars either.”

Redwood Drive

- “Appreciate effort to slow traffic.”
- “I don't think it made much difference, therefore don't feel putting one in would be worthwhile.”
- “Maybe a second hump further south, closer to 22nd on Redwood would slow traffic effectively.”
- “We noticed a huge slow-down of the traffic and would love to see it come back. Is there anything our neighborhood can do to get it back?”
- “This was not a safety issue as I never knew which vehicles were going to increase speed to ramp the installation.”
- “The traffic on Redwood needs to be slowed down! Put hump back on Redwood.”

Canal Shore Drive

- “I was surprised about this, the school buses were probably not going faster than the posted speed limit, but they did not seem to slow down for the hump and gave me the impression of more bounce and impact than the other vehicles.”
- “We'd like to see several placed at regular intervals on the street-they do help.”
- “I feel that this is an ineffective way to control traffic speed. If there is a speed problem, why is the police not patrolling and writing tickets. My opinion is that it's a waste of tax payers money.”
- “I think effective speed humps should be installed.”
- “I think there should be more of these humps on Canal Shore. The street is like a race track and anything to slow down the cars/trucks is welcome.”
- “Upper 1/3-1/2 of Canal Shore Dr. is desperately in need of resurfacing. The present surface is badly packed and very dusty. This job was, I believe, scheduled to be done years ago and postponed. Other streets have been/are being resurfaced instead. With 3 school buses, city-owned vehicles, large garbage trucks, and lots of marina traffic, the speed hump has been a blessing, especially since the drive is home to many children and some elderly. Furthermore, walkers, bikers, and tourists use Canal Shore Dr. for recreational purposes. Not only safety but environmental concerns such as dust control should be addressed. Canal Shore Dr. is one of LeClaire's front doors. Why not help the neighborhood be an asset?