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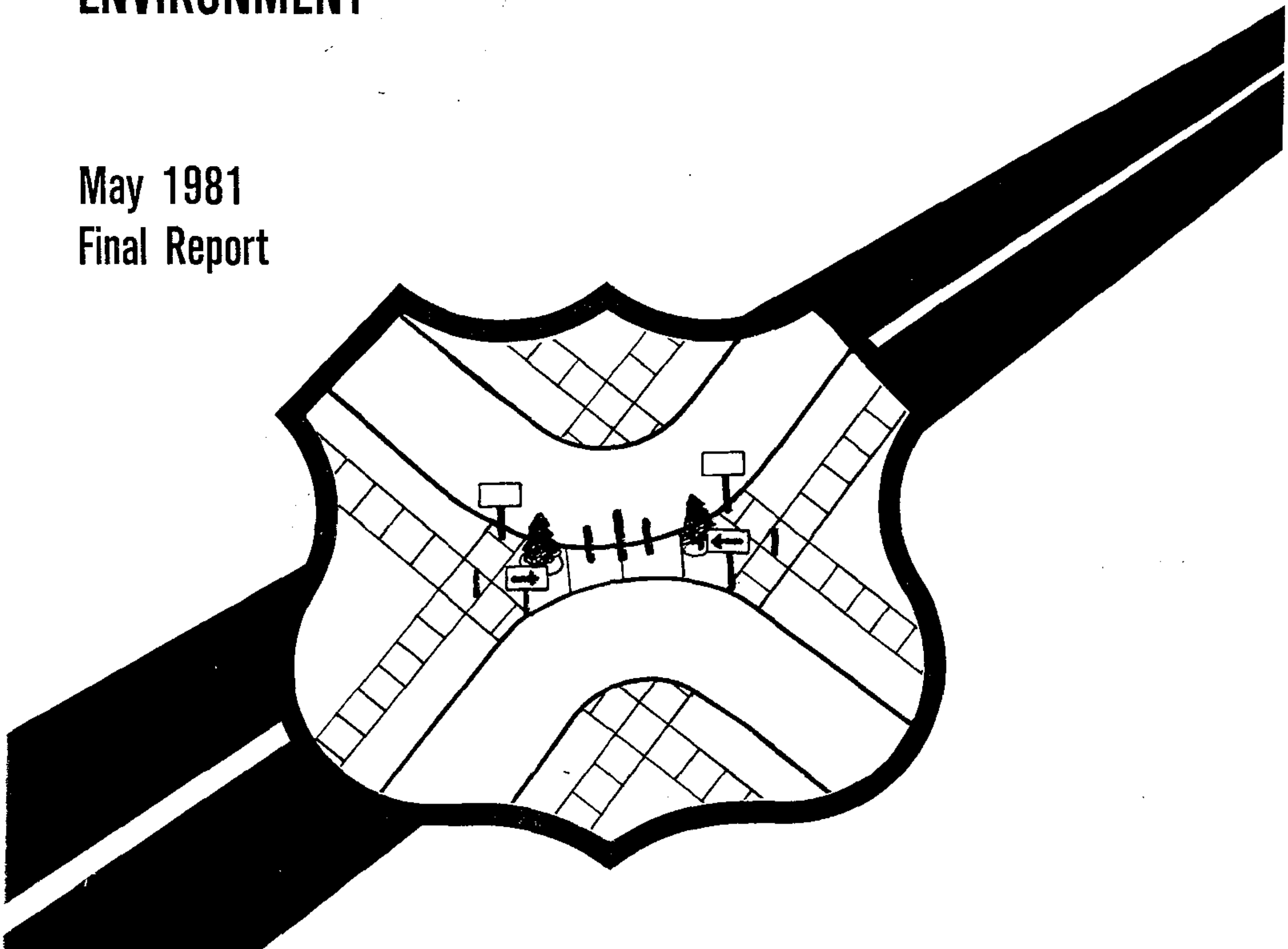
IMPROVING THE RESIDENTIAL STREET ENVIRONMENT

May 1981
Final Report



DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
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Washington, D.C. 20590

FOREWORD

This report capsulizes the results of state-of-the-art research on a broad range of techniques for residential traffic control or traffic management and specific case study research on applications of the Transportation and Road Research Laboratory (TRRL) developed "road hump" on United States residential streets. It also summarizes finding of original research on resident preferences regarding traffic speed and volume on residential streets, and on factors which affect drivers' speed choice on residential streets, and reviews legal consideration in neighborhood traffic management.

This study was initiated as a result of problem statements submitted for FCP Project 1A by engineers in Berkeley, California; Mesa, Arizona; Anne Arundel County, Maryland; Sacramento, California and Santa Ana, California.

Sufficient copies of the Executive Summary are being distributed to provide two copies to each regional office, two copies to each division office, two copies to each State highway agency, and one copy to each Metropolitan Planning Organization (MPO). One copy of the full report is being sent to each regional office, division office, State highway agency, and Metropolitan Planning Organization (MPO). The State, division office, and MPO copies of both reports are being sent directly to each division office.

for D. Solomon
Charles F. Scheffey
Director of Research
Federal Highway Administration

NOTICE

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16. Abstract

This final report summarizes state of the art research on a broad range of techniques for Residentail Street Traffic Control or Traffic Management and specific case study research on applications of the TRRL-developed "road hump" on U.S. residential streets. It also summarizes findings of original research on resident preferences regarding traffic speed and volume on residential streets, on factors which affect drivers' speed choice on residential streets and reviews legal considerations in neighborhood traffic management.

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ACKNOWLEDGMENTS

Several officials in local jurisdictions made contributions which were vital to the success of this program. Messers. Bill Wilson and Earl Ray of the City of St. Louis, Warren Siecke of the City of Brea, Bob Drummond of the City of Boston and Dick Folkers of the City of Sacramento were instrumental in the case study research on road humps. Others too numerous to cite here individually shared information and insights which comprised the fundamental data base for the State-of-the-Art Report. Their contributions are gratefully acknowledged.

CHAPTER I
INTRODUCTION

REPORT AND PROJECT SCOPE

This final technical report is one of three documents resulting from Contract Number DOT-FH-11-9309, Improving The Residential Street Environment, sponsored by the Federal Highway Administration. It details current practice and new techniques for control of traffic on residential streets. The word "control" is used here in a broader sense than the traffic engineer's strict definition. Many of the devices considered herein may more properly be termed geometric features of the road. In the context of this study, the traffic controls of interest are ones which guide, warn or regulate traffic for purposes of improving the quality of the residential environment along streets having the predominant intended function of providing access to residential properties in the immediate local area. The study is concerned with responses to problems experienced on existing residential streets; design of new residential streets is not within its scope.

The initial phase of the study involved a review of current practices in residential street traffic control or residential street traffic management. The review concentrated on activities in the United States but also scanned overseas experience and practices on the subject matter. Findings of this review were thoroughly documented in a report entitled Improving the Residential Street Environment, State-of-the-Art. The State-of-the-Art report identifies devices currently in use for residential area traffic control and presents data on their performance. It also provides an extensive guide to the process of planning and design for residential area traffic control and for community involvement in that process. Chapter 2 of this final report details procedures followed in the state-of-the-art search and highlights significant portions of the State-of-the-Art report.

The state-of-the-art search led to focusing a significant portion of the second phase of the research project on testing and field application of a form of speed control hump developed by the Transportation and Road Research Laboratory (TRRL) in Great Britain. The TRRL "undulation" differs from "conventional speed bumps" in both its physical shape (12 feet (3.65m) long in the direction of vehicle travel versus 1.5 - 3 feet (.46-.92m) for conventional bumps) and in performance characteristics (apparently both safer and more effective in controlling speeds than conventional humps). Field testing of the device was conducted in St. Louis, Missouri, and public street case studies were conducted in Boston, Massachusetts and Brea, California. Additional field tests and public street case studies were observed in Sacramento, California. Chapter 3 details study procedures and findings of the research on undulations.

As an outgrowth of the state-of-the-art search findings, the research team was requested to conduct an exploratory probe of what traffic speeds and volumes on residential streets met resident expectations or achieved broad acceptance. That is to say, what should the speed limit be on a local residential street? This inquiry stemmed from the finding in the first phase of the research that objective traffic measures traditionally relied-upon by traffic engineers to identify problem conditions frequently do not coincide with resident perceptions of problem thresholds or conditions. This is particularly true with respect to traffic speed and traffic volume. Chapter 4 presents an Implementation Plan for applications of the TRRL Road Humps. The plan stresses carefully monitored applications rather than providing blanket approval for use of the device.

Chapter 5 of this report details research methodology utilized in the probe of resident sensitivity to traffic speed and volume, details findings of the research and suggests directions for further research on this subject. Chapter 5 also presents the results of pilot research relating driver speed on residential streets to roadside environmental factors. This research, if carried further, may be assistive in development of "psychological controls" on residential street speeding.

Chapter 6 presents a review of legal considerations in neighborhood traffic management.

SUMMARY OF KEY FINDINGS

State-of-the-Art Research

The state-of-the-art search included review of residential traffic management installations or attempts in over 250 local jurisdictions in the U.S., extensive review of applications overseas and direct contacts with leading practitioners in the field. Major findings of the state-of-the-art phase of the project are summarized below.

- Employment of special traffic control measures intended to mitigate the impacts of traffic on the quality and liveability of residential streets is extremely pervasive in local jurisdictions across the U.S. Even those jurisdictions which have not actually resorted to employment of such devices have almost universally experienced some problems or pressures related to conflicts between local street traffic and residential liveability.

- There has been considerable communication of techniques through professional journals, professional society work and informal jurisdiction to jurisdiction contacts. However, at the time of the state-of-the-art search, the most extensive publications on the subject matter (Appleyard - Liveable Urban Streets: Managing Auto Traffic in Neighborhoods and Buchanan - Traffic in Towns) had not reached the implementation-level professionals in most local jurisdictions. Furthermore, even these works lack the specificity regarding device design, location criteria and planning process guidance which the action-level professionals need.

  As a result, actions taken to date at the local level reflect the efforts of individual professionals operating largely on their own judgment and initiative with limited knowledge of parallel experiences and without knowledge of the full range of options open to them. This has produced a wide variation in both methods of control attempted and in the design treatments of fundamentally similar devices. It has also led to repetitions of similar unsatisfactory experiences in several communities and to wasted efforts reinventing solutions which have already proven satisfactory somewhere else.

- The lack of guidance and heavy reliance on individual judgment has led to numbers of installations involving peculiar geometrics and choices of materials and absence of signs and markings such that the research team felt concern for the functionality and safety of these particular installations. The need for authoritative guidance on the subject seemed clear.

- Many of the techniques utilized in neighborhood traffic control have not yet been clearly addressed in the Manual on Uniform Traffic Control Devices (MUTCD), parallel state manuals and basic traffic engineering reference texts. There is need for a means of improving techniques and fostering conformity of design practices with respect to geometrics, materials, signing and marking of residential street traffic control devices as well as to official recognition of residential street traffic management as legitimate traffic control activity. It appears desirable that the subject of residential street traffic control receive more direct treatment in the MUTCD and complimentary design guides.

- Objective measures customarily used by traffic engineers sometimes do not measure, or relate to problem conditions perceived by residents. For instance, traffic engineers consider the 85th percentile speed in evaluating conformity to speed limits while resident perceptions of speeding tend to be shaped by the speeds of the few fastest drivers. As a result of this difference, professionals and residents frequently disagree as to whether a problem existed and whether a particular device really changed conditions or not.

- Engineers face many obstacles to becoming actively involved in traffic management schemes. Obstacles include the lack of official or quasi-official design guidance, conflicts between traditional objective traffic engineering measures and resident perceptions of problem conditions, a partial knowledge of attempts-gone-wrong in other communities and the inherent conflict between the philosophy of neighborhood traffic management and the traditional role of the traffic engineer to facilitate and improve accessibility. As a consequence, some traffic engineers, public works and planning officials have staunchly opposed residential street traffic control measures.

- A variety of traffic control devices* have been utilized in the U.S. for residential street traffic control or traffic management purposes with some degree of success. Different devices respond best to differing types of problems and differing site circumstances. No single device can be tabbed the universal solution to residential street traffic problems.

  Many of the devices are physical in the sense that they physically induce or preclude specific patterns of driver behavior. Physical devices are normally successful in bringing about the desired change in traffic. But they usually involve fairly substantial engineering and construction costs and can have substantial secondary impacts, some positive and others adverse in nature.

  Other devices are passive in the sense that they simply command or suggest a driver behavior pattern but depend on driver choice to comply to achieve their intended effect. Since they are more easily violated than physical controls, they tend to be less effective in achieving their objective. Passive controls generally involve low cost installations and usually

* Throughout this report, the words "traffic control devices" are used in a broad context rather than in the traffic engineer's specific definition. Some of the devices of interest (i.e.: diagonal diverters, undulations, culs-de-sac) might more properly be termed "geometric features of the road" rather than "control devices". However, since these features are introduced for purposes of controlling the amount and behavior of traffic which uses the streets in the same way as turn prohibition signs, stop signs or speed limits might be, the term traffic control devices is used in a broad context throughout the report.

have fewer secondary impacts than physical controls but do require some degree of enforcement for success. An ideal form of control would be one which operates on inherent driver response patterns to particular stimuli to induce desired driver behavior patterns. Such psychological controls might avoid the cost and heavy-handed secondary impacts associated with physical controls and the dependence on drivers' voluntary compliance of the passive controls. Some attempts at developing such controls have been made but few have proven effective.

- A key problem with physical devices is the need to preserve essential accessibility for emergency vehicles.

- Overseas attempts at residential area traffic management have generally employed the same types of control devices as are being employed by local jurisdictions in the U.S. However, there are two major foreign developments which deserve further consideration in the U.S. One of these is a form of speed control hump or undulation developed by TRRL in Great Britain. The device is a hump of circular-arc cross-section raising to a maximum of four inches (10cm) above the normal pavement surface and having a chord distance of 12 feet (3.65m) in the direction of vehicular travel. TRRL's test track and public street experiments indicated its speed control performance and safety characteristics were sufficiently different from (improved over) those of "conventional speed bumps" to warrant consideration of U.S. applications of the TRRL device. Case studies of such U.S. applications became a major element of the Phase Two research program.
  In the Netherlands, extensive efforts have been devoted to development of "woonerven" (residential precincts). Woonerven involve changes in both the physical characteristics of the street and in the regulations governing vehicular operation. The physical changes involve elimination of any features which suggest a separation of different types of traffic (and hence, priority for motorized traffic). Features suggesting pedestrians have complete access to the entire street area are emphasized. Other physical changes introduced to slow traffic include humps, changes in alignment, changes in pavement texture, narrowings and use of bollards, planters, trees, street furniture and parking areas to reinforce the alignment changes and narrowings. The special "rules of the road" which apply in a woonerf restrict drivers to speeds no faster than "a walking pace," orders that drivers not hinder pedestrians and that pedestrians not unnecessarily hamper the progress of drivers.
  A woonerf can be a single block or an area of several blocks. Over 800 woonerven have been constructed in the Netherlands over the past decade. The concept is also being applied extensively in Germany.

- Although neighborhood traffic problems usually manifest themselves through site specific conditions and complaints, the fundamental problems are as often systemic as they are site specific. Attempts at site specific traffic management actions in many of the communities observed were not entirely satisfactory because of failure to recognize the systemic nature of the problems. Effective solutions to systemic problems involve a group of control devices treating an entire area or neighborhood. For this reason, the State-of-the-Art report emphasizes systemic approaches to planning for neighborhood traffic management.

- Peoples' feelings about their home environment, particularly with respect to traffic and street appearance issues, are extremely strong and often emotionally charged. Residential traffic management actions often benefit some residents at the expense of inconveniences or disbenefits to others (mostly drivers). For these reasons, residential traffic management actions are usually controversial.

  Successful planning for residential traffic management requires consideration of many fine-grained details involving residents' perceptions of the problems, people's behavior in using the street and precise physical conditions and constraints. Because of the inherently controversial nature of the actions and the importance of resident perceptions and of minute details of usage and behavior known only to residents, community involvement is an essential element in planning for residential traffic management. For this reason, the State-of-the-Art report presents extensive guidance on community involvement in the planning process.

- Attempts at residential traffic management were hampered by shortcomings in understanding how to conduct a planning process for this purpose as frequently as they were hindered by incomplete knowledge relating to the specific control devices. Shortcomings were noted involving virtually every step of planning: what data to collect, how and where to collect it, how to interpret data and identify the existence, nature and extent of problems, how to involve the community and how to utilize community input, how to develop alternative plans and how to choose among them and how to evaluate what actually happened after the plan was implemented. For this reason, the State-of-the-Art report included an extensive guide to planning for residential traffic management.

Research on TRRL Road Humps

As noted above, findings in the State-of-the-Art search led to interest in the potential for applying the TRRL road hump to U.S. streets. The Phase Two research on this subject included the following activities.

Further direct contacts were made with TRRL researchers and details of their installation, site selection and monitoring procedures not covered in published reports were conveyed. Most recent reports on TRRL's public street tests of the device were obtained and reviewed.

Tests of the device on a closed site were conducted in St. Louis, Missouri. Case studies involving application of the device on two public streets in Boston, Massachusetts and one public street in Brea, California, were conducted. Further tests on a closed site and a case study application on a public street conducted independently by the City of Sacramento, California were monitored by the research team. An additional case study application in Washington, D.C. was prepared. However, implementation did not take place at a date early enough for monitoring in this program.

Principal findings of the research on undulations are summarized as follows:

- The humps appear to be extremely effective in reducing traffic speed to levels reasonable for local residential streets. For example, 85th percentile speeds on the Brea and Boston test segments were at or just below the 25 mph (46 kmph) speed limit after hump installation while beforehand the 85th percentive speed profile ranged to 38 mph (70 kmph) on the Brea street and to 35 mph (65 kmph) on the two Boston streets. Speeds of the fastest drivers are affected as well as those of "average" drivers. This speed behavior modification occurs even though drivers who wish to travel fast over the humps could do so at the cost of a modest level of nuisance discomfort without experiencing severe discomfort or vehicle damage. Figure 3 illustrates the speed behavior changes induced by the humps.

- Patterns of modification of speed behavior established immediately after the humps were installed appeared to remain fairly constant over the seven months the case study sites were monitored. There is no evidence of drivers losing respect for the control and traveling faster nor of them becoming more acquiescent and traveling slower as the test period wore on.

- The humps induced some motorists who had convenient alternate routes available to avoid the test streets. Reductions in traffic volume ranged from 20 to 23 percent of the previously experienced traffic on the case study streets.

- No incidents were observed or reported which would suggest the humps posed a serious hazard to traffic safety. In responding to questionnaires, a few drivers blamed the need to replace shock absorbers or alignment problems on their vehicles to wear and tear of repeatedly crossing the humps. However, there were no accidents or incidents of vehicle damage observed or reported in which the humps were clearly a direct causal factor.

- The humps do have more severe effect on long wheelbase vehicles than on passenger cars and pick-up trucks, motorcycles and bicycles. Most of the intensified impact is experienced toward the rear of the long wheelbase vehicles. This more pronounced impact on long wheelbase vehicles would suggest that the humps not be used on major fire and ambulance access routes, routes necessarily used frequently by heavy trucks or on transit routes. It also suggests that personnel operating emergency and service vehicles (like garbage trucks) be informed of the location of all humps and trained to drive over them safely.

- In the U.S. case studies, the humps were terminated short of the gutter line to maintain gutter flow drainage (by contrast, TRRL carried the humps to the face-of-curb, building drainage provisions in to the humps. These were elaborate, costly and ultimately proved to be functionally troublesome). Many U.S. drivers attempted to partially avoid the impact of the humps by driving with one set of wheels in the open gutter pan. This was apparently done for purposes of comfort or caution rather than to go faster - speeds of drivers "running the gutter" differed only marginally from those traveling straight over the humps. But gutter running affected resident perceptions of speed and satisfaction with the device's performance. In future installations, it is suggested that drivers be discouraged from running the gutters by placement of raised "jiggle-bars" on the gutter approaches to the humps.

- If used individually, the humps will act only as a "point" speed control, similar to a stop sign in effect. A series of humps is needed to change speed pattern along an entire segment of a street. Humps spaced between 160 and 750 feet (49 to 228m) apart will act as a "segment control" with drivers speeding up only marginally between humps and with midpoint speeds substantially lower than before the humps were installed. However, at some spacing above 750 feet (228m), drivers begin to regard the humps as "point controls" and acclerate back to their normal speeds for most of the distance between humps. Precise threshold separation distance of this transition from "segment" to "point" control has not been determined. However, in the Sacramento case the humps, separated by distances of 1200 to 1500 feet (365 to 455m) clearly functioned as point controls.

- Exact separation distance specifications (i.e., precisely 400 feet or 500 feet (122 or 152m) or whatever) should not be used as a rigid criterion in locating the humps on a street. Location to take into account positions of existing features (i.e., drainage inlets, manholes and gate valves, driveways, fire plugs, street lighting and the like) is more important than spacing on a precise pattern.

- Humps should be positioned so that drivers do not approach the first hump in a series at high speed. The first hump should be placed relatively close to an intersection where vehicles must stop but far enough away for drivers to see and react to the humps and related warning signs and markings. Humps located near any curvature of horizontal or vertical alignment should always be placed so as to allow adequate sight distance for perception and reaction.

- The steepest slope on which humps were placed in the U.S. case studies was 3 percent. TRRL offers no guidance as to the maximum slope on which the humps can be safely employed. Further testing seems desirable before humps are placed on any substantial gradients.

- Adequate signing and marking of each hump is essential.

- As a rule of thumb for cost estimating purposes, an allowance of $500 per hump (1980 dollars) appears reasonable for engineering design and construction. This cost does not include preliminary planning (i.e., community involvement, establishing justification for the measure).

- No snowplowing difficulties were reported at the Boston study sites which were subject to winter snowfall conditions.

- Residents thought the humps weren't severe enough and that they didn't completely solve perceived traffic problems. They were irritated by drivers' gutter-running and a few complained about the appearance of the warning signs. But 79 to 88 percent felt the humps served a useful purpose, 73 to 88 percent felt they should be made permanent or at least kept for more testing and 77 to 92 percent thought they should be used or tested on other streets.

- Drivers tended to regard the humps as too severe (52 percent rated them too severe versus 44 percent rating them "about right" and 4 percent calling them too gentle). But 66 percent of drivers thought the humps on served a useful purpose, 62 percent thought they should be made permanent or kept there for more testing and 75 percent thought they should be used or tested on other streets as well.

- The humps are not a cure-all for residential street traffic problems. They should be applied with prudence only where sound justification warrants their use.

- Noise emitted by individual vehicles near the humps tended to increase due to braking and accleration - not due to sounds of vehicles striking the humps. But traffic reductions resulting from hump installation tend to have a cancelling effect. Some 75 percent of residents thought noise levels had decreased.

- The reasons the TRRL undulations appear to work as satisfactorily as they do while conventional speed bumps have unsatisfactory characteristics are as follows. In the undulation, the gradually applied vertical force produced by the four inch (10cm) height and 12 foot (3.65m) length is transmitted to the driver compartment through the suspension and is just enough to produce a nuisance level of discomfort which makes drivers want to slow down. But the force transmitted is not so severe as to cause loss of control or suspension damage and the four inch height is just low enough to avoid damage due to vehicles bottoming out.
  The short length of conventional humps causes vertical forces to be transmitted abruptly. Abruptly transmitted forces tend to be absorbed in tire and suspension system deformation rather than causing disconfort.

- Drivers and passengers in vehicles of differing wheelbase and suspension characteristics inevitably experience differing degrees of discomfort in passing over the humps of any given speed. The TRRL undulation shape appears to provide a reasonable range of performance for the range of vehicle types which pass over it. In the research team's judgment, it appears doubtful that significant improvements in performance for the range of vehicles in use in the U.S. can be achieved by modifying the TRRL shape.

Speed and Volume Studies

Residents' tolerance levels of traffic speed and volume were measured by subjecting panels of residents to vehicles traveling at varying speeds and to platoons of vehicles simulating varying volume levels. Residents then rated the acceptability or unacceptability of the conditions they witnessed. Principal conclusions of this pilot research are as follows:

- The methodology appears to produce results promising enough to warrant more extensive application involving more streets and panels and more rigorous selection procedures relative to panel composition.

- Resident opinion of speed acceptability shifts from almost total acceptance to almost total non-acceptance over a relatively narrow range of speeds - from 20 to 30 mph (32 to 48 kmph).

- Even if the vast majority of drivers conformed to a 25 mph (40 kmph) speed limit, nearly half the residents might not be satisfied.

- Speeds which would be considered acceptable by nearly all residents are several miles per hour slower than most drivers choose to drive on typical residential streets. Achieving speeds uniformly acceptable to residents probably requires establishment of Woonerf-like conditions rather than just enforcing current speed limits.

- Volume levels tested in the pilot study appeared to be above the crucial range where resident opinion shifts from acceptance to non-acceptance. Future studies should concentrate on rates in the 0 to 4 vehicles per minute range (vpm) rather than the 2 to 12 vpm range used in the pilot study.

Studies of the effects of elements of the residential street environment on driver speed choice gave some indication that the visual "walls" of the street created by building setbacks, curbside trees and similar features can exert subtle influences on driver behavior. However, far more extensive study is required to produce statistically significant results.

Legal Considerations In Residential Traffic Restraint

Residential traffic control plans have led to a number of court challenges as to the "authority" and "reasonability' of the acting jurisdiction's programs. In addition, as a relatively new and not fully defined aspect of engineering practices, residential area traffic controls may introduce special nuances to negligence-liability claims in accident cases.

Relative to the authority and reasonability issues, jurisdictions should understand from the outset what specific legal authority it has to control traffic in this fashion and should tailor its planning process and the controls it employs to the provisions of that legal authority. To demonstrate reasonableness of actions, the jurisdiction should document evidence of the need for action - harm to residents resultant from existing traffic conditions. It should also document the volume, composition and percent of through traffic on affected streets and contrast these with conditions which might be expected considering the designated function of the street according to the jurisdiction's Master Plan. Furthermore, it should demonstrate that less severe traffic control measures were attempted or considered, take into consideration the circuity of routing for area residents and demonstrate a scheme of reasonable routings for through traffic around the protected area and consider access needs of emergency vehicles and demonstrate involvement of the public in the planning process.

Inclusion of neighborhood traffic control practices and devices in the MUTCD and/or authorative geometric design references, whichever is most appropriate, will give engineers a basis for demonstrating conformance to standards and recommended practices and exercise of reasonable care in liability cases involving allegations of negligence.

CHAPTER 2

RESEARCH ON THE STATE OF THE ART IN RESIDENTIAL AREA TRAFFIC CONTROL

The initial phase of this research program was an extensive review of current practices in residential street traffic control or restraint. The review concentrated on activities in the United States but also scanned experiences in other countries. Findings of this research are thoroughly documented in a report entitled Improving the Residential Street Environment, State of the Art. In addition to reviewing control devices in use, the report evaluates the effectiveness of these techniques. The report also provides an extensive guide to the process of planning and design for residential area traffic control and community involvement in that process. This chapter outlines research methodology followed in the state of the art search and summarizes key portions of the report. For full details on the state of the art, the reader is referenced to the subject report which is available through the National Technical Information Service.

Search Approach

The principal researchers on this program had previously performed major projects in the field of residential traffic management. As the direct result, the research team were already in command of the vast bulk of the literature on the subject. They were also already in contact with the key researchers, innovators and implementors in the field and were already aware of the major projects implemented. The initial data base was expanded through an international literature search and direct contacts with the key innovators to obtain latest documentation or reports of progress in their work and references to other relevant projects and individuals of whom these contacts were aware. In addition, the attention focused on the research team's prior work had drawn literally hundreds of requests for information from professionals in local jurisdictions across the U.S. and abroad. Reasoning that there was a high probability that many of the individuals who had contacted us for information had subsequently taken or attempted some form of traffic management actions, we recontacted them. From them we elicited not only information on their own traffic management experiences or attempts; we also obtained reference to literature and projects in other communities which had influenced their actions or of which they were aware. In cases where the research team was not already cognizant of the references thus obtained, further direct follow-up was undertaken. Reports, informal documents, raw data and personal insights obtained from all of these contacts vastly expanded the data base available through the published literature.

In addition to this data obtained through secondary sources, members of the research team inspected countless individual neighborhood traffic management devices in over 60 cities across the U.S. to photograph the installations and observe and evaluate performance. While in Europe, members of the team also took the opportunity to observe and photograph important European developments as well as to meet directly with key European officials in the field.

As a result of the nature of this approach, the State of the Art search is not a census or statistically rigorous survey of ongoing traffic management actions in the United States. However, the sheer numbers of individuals contacted and the geographic distribution of jurisdictions sharing data and experiences lend confidence that the information presented herein reasonably represents the current State-of-the-Art. The depth, breadth, and consistency of data and experiences reported by widespread and independent sources support this conclusion. As an indication of the extensiveness of the search, Table I presents a summary of North American cities and devices considered in the search.

In its initial intent, the State-of-the-Art report was to have focused on the control devices and their performance. However, as the search progressed the research team became aware that lack of knowledge about how to conduct the process of planning for neighborhood traffic management effectively was at least as big if not a bigger problem for implementation-level professionals in the local jurisdictions than was the knowledge about control devices and how they perform. For this reason, research on the planning process and community involvement in it was acclerated. An extensive chapter on the process of planning neighborhood traffic management and community involvement in it is included in the State-of-the-Art report. This guide to planning is the authors' response to the particular planning needs of a neighborhood traffic managment program and to the planning pitfalls encountered by communities observed in the state of the art review. It draws heavily on the most current literature on process planning and community involvement as well as techniques that worked in other communities observed in the state of the art search and on the authors' own professional experiences.

NEIGHBORHOOD TRAFFIC MANAGEMENT - A DEFINITION

The terms "neighborhood traffic management" "residential area traffic control" and "traffic restraint" embrace the wide range of treatments intended to improve the residential environment by directly affecting traffic, thereby cutting off undesired impacts at the source. The treatments do this by limiting the amount of traffic on the residential streets, usually by restricting accessibility and street system continuity or by affecting the behavior of drivers. The predominant behavioral control attempted relates to traffic speed.

Neighborhood traffic management devices are normally employed on local residential streets- -streets which are predominantly residential in character and which have the sole intended traffic function of providing accessibility to limited numbers of immediately tributary properties. The rationale for neighborhood traffic management lies in the recognition of the breadth and limitations of a local residential streets function's. Local residential streets are meant to provide accessibility to limited areas directly dependent upon them, not to all travelers who find it convenient to use them. And serving traffic, even the local traffic which "belongs" there, is only a part, not the whole of their purpose. The neighborhood street is a place where children play, where neighbors meet, an extension of the front yard, a feature which affects the appearance of homes along it and the quality of life within them. Neighborhood traffic management is an attempt to control streets so as to meet real accessibility needs yet keep the traffic service function of these streets in perspective with the other considerations noted above.

Traffic management should not be confused with two alternatives to it, protection and amelioration. Residential protection measures shield residents from the adverse impacts of traffic without attempting to affect traffic itself. Noise buffers, double glazed windows and view screens are examples of protection measures located on streets intended to carrry substantial volumes of traffic, usually at moderate to fairly high speeds. Amelioration measures compensate residents for

TABLE 1
SUMMARY OF CITIES AND DEVICES REVIEWED
IN STATE OF THE ART SEARCH

Jurisdiction	Diagonal Diverters	Semi-Diverters	Cul-de-Sac/Street Closures	One-way Streets/Do Not Enter	Improve Major Streets	Rumble Strips	Bumps, Undulations	Stop Signs	Chokers/Narrowing	Traffic Circles	Traffic Signals	Turn Prohibitions	Forced Turns	Special Parking Restrictions	Median Barriers	Enforce Speed Laws	Truck Prohibitions	Special Signs/Speed Limit Signs
Fort Worth, Texas								●								●		
St. Joseph, Michigan								●										
Boston, Massachusetts							●		●								●	
Pittsburgh, PA								●			●							●
Inglewood, CA	●							●										
Traverse City, Michigan								●										
Claremont, CA																	●	●
Campbell, CA			●													●		●
Dartmouth, Canada							●	●										●
Omaha, Nebraska			●															
Davis, CA	●		●					●										
Akron, Ohio								●										
Torrance, CA			●	●			●					●			●			●
Beverly Hills, CA								●										
Detroit, Michigan												●						
Oklahoma City, OK				●			●											●
Simi Valley, CA			●															
Santa Cruz, CA								●										
Buena Park, CA								●							●			
Redondo Beach, CA			●															
Alexandria, VA			●															
Halifax, Nova Scotia			●					●				●	●					●
Oakville, Canada								●										
Littleton, Colorado			●												●			●
Tampa, Florida			●															
Jacksonville, Florida								●										●
Dallas, Texas			●					●										●
Dayton, Ohio	●		●	●					●									
Cambridge, MA				●				●						●			●	
San Luis Obispo, CA								●										
Sacramento, CA	●																	
New Haven, CT					●			●										
New Orleans, LA				●								●		●				●
Philadelphia, PA				●				●									●	
Rochester, NY				●				●										
Toledo, OH	●																	
St. Petersburg, Florida								●										
Washington, D.C.	●			●			●	●				●		●				●

Jurisdictions reporting neighborhood traffic control devices

TABLE 1 (CONTINUED)
SUMMARY OF CITIES AND DEVICES REVIEWED
IN STATE OF THE ART SEARCH

Jurisdiction	Diagonal Diverters	Semi-Diverters	Cul-de-Sac/Street Closures	One-way Streets/Do Not Enter	Improve Major Streets	Rumble Strips	Bumps, Undulations	Stop Signs	Chokers/Narrowing	Traffic Circles	Traffic Signals	Turn Prohibitions	Forced Turns	Special Parking Restrictions	Median Barriers	Enforce Speed Laws	Truck Prohibitions	Special Signs/Speed Limit Signs
San Jose, CA							●											
Sacramento Co., CA										●								
Cupertino, CA								●	●									
Saratoga, CA								●		●		●	●					●
Carson, CA															●			
Covina, CA								●										
Cyprus, CA			●															
Downey, CA			●												●			
Glendale, CA								●										
Hawthorne, CA												●						
Huntington Beach, CA													●					
Irvine, CA															●			
Los Angeles, CA			●					●										
Norwalk, CA			●															
Pasadena, CA	●																	
Placentia, CA															●			
Rancho-Palos Verdes, CA															●			
South Pasadena, CA			●															
Whittier, CA			●															
Oakland, CA	●								●									
San Diego, CA									●									
Belmont, CA			●															
San Mateo, CA		●	●		●					●								
Menlo Park, CA	●		●															
Lafayette, CA								●	●			●				●		
Richmond, CA	●		●										●					
Albany, CA															●			
Redwood City, CA															●			
Walnut Creek, CA		●	●															●
Pleasant Hill, CA		●																
Skokie, Illinois																		●
Columbus, Ohio								●										
Louisville, KY	●			●														
Hartford, CT			●															
Chicago, Illinois	●		●	●				●										
Minneapolis, Minnesota	●												●					
Grand Rapids, Michigan	●		●															
Metuchen, NJ			●															

Jurisdictions reporting neighborhood traffic control devices (continued)

TABLE 1 (CONTINUED)
SUMMARY OF CITIES AND DEVICES REVIEWED
IN STATE OF THE ART SEARCH

Jurisdiction	Diagonal Diverters	Semi-Diverters	Cul-de-Sac/Street Closures	One-way Streets/Do Not Enter	Improve Major Streets	Rumble Strips	Bumps, Undulations	Stop Signs	Chokers/Narrowing	Traffic Circles	Traffic Signals	Turn Prohibitions	Forced Turns	Special Parking Restrictions	Median Barriers	Enforce Speed Laws	Truck Prohibitions	Special Signs/Speed Limit Signs
Buffalo, NY				●								●						
Concord, MA								●									●	
Flint, Michigan								●										●
Houston, Texas			●									●						
Keane, NH								●										
Memphis, Tennessee				●														●
Miami, Florida					●					●		●						
Nashville, Tennessee	●														●			●
Isla Vista, CA			●															
Aurora, CA	●		●					●			●	●						●
Charlotte, NC						●						●			●			
Cleveland, Ohio			●	●								●	●					
Berkeley, CA	●	●	●					●	●	●	●	●	●		●			●
Decatur, Illinois	●			●				●	●				●	●	●			●
El Paso, Texas			●															
Farmington, Utah			●				●	●						●	●			●
Hampton, VA	●			●					●				●					
Kalamazoo, Michigan				●				●				●	●	●				
Kansas City, MO				●														
Lake Oswego, OR	●			●														
Madison, Wisconsin	●		●	●				●	●	●	●		●	●				●
Norfolk, VA												●					●	
Palo Alto, CA	●		●					●			●				●			
Rocky Mount, NC			●	●				●			●	●	●	●	●			●
St. Louis, MO	●		●	●			●	●	●									
St. Paul, Minnesota	●		●					●						●				
Salt Lake, Utah				●														
San Francisco, CA		●			●		●		●			●	●	●			●	
Santa Ana, CA	●		●									●	●					
Seattle, WA	●	●	●				●	●		●			●	●				●
Shaker Heights, Ohio	●	●	●	●					●				●	●				●
Springfield, MA									●									
Vancouver, BC	●		●				●			●			●					
Visalia, CA									●									
Wichita, Kansas	●	●	●										●					
Toronto, Ontario							●											
Concord, CA								●							●			

Jurisdictions reporting neighborhood traffic control devices (continued)

TABLE 1 (CONTINUED)
SUMMARY OF CITIES AND DEVICES REVIEWED
IN STATE OF THE ART SEARCH

Jurisdiction	Diagonal Diverters	Semi-Diverters	Cul-de-Sac/Street Closures	One-way Streets/Do Not Enter	Improve Major Streets	Rumble Strips	Bumps, Undulations	Stop Signs	Chokers/Narrowing	Traffic Circles	Traffic Signals	Turn Prohibitions	Forced Turns	Special Parking Restrictions	Median Barriers	Enforce Speed Laws	Truck Prohibitions	Special Signs/Speed Limit Signs
Eugene, OR	●	●	●	●					●	●					●			
Joliet, Illinois	●										●							
Portland, OR	●	●	●						●									
Baltimore, MD	●		●															
Tucson, AZ	●		●															

Jurisdictions reporting neighborhood traffic control devices (continued)

Note: Table 1 is by no means a complete summary of all jurisdictions believed to be using the various devices cited. It is simply a notation of those neighborhood traffic control devices observed or reported in the above North American communities which comprise the data base for this State-of-the-Art report. Many more North American jurisdictions are believed using some of these devices for neighborhood traffic control purposes. Jurisdictions cited above may also use other devices not indicated on the table. Some devices indicated above are test installations subsequently removed.

tolerating the undesirable impacts of street traffic by providing other amenities or services. The compensation may attempt to overcome adverse traffic impacts directly (i.e., providing parks along a street on which it is unsafe for children to play because of traffic). Or it may simply offset the adverse impacts of traffic by offering some totally unrelated but desirable facility or service.

PRIMARY DEVICES FOR NEIGHBOR HOOD TRAFFIC MANAGEMENT

Three generic types of control devices for neighborhood traffic management have been identified: positive physical controls, passive controls and psycoperception controls. Performance characteristics and primary attributes of devices in these generic categories are capsuled in Table 2 and further summarized in the paragraphs which follow. The State of the Art report provides far more detailed description and specific data than can be included herein. The reader is referenced to that document for more complete information.

Physical Controls

Positive physical controls have as a common characteristic the positive enforcement or prohibition of a specific action through the direct physical presence and character of the device itself. Physical controls have the advantages of being largely self-enforcing and of creating a visual impression, real or imagined, that a street is not intended for through traffic. Their disadvantages relative to other devices are their cost, their negative impact on emergency and service vehicles, and their imposition of inconvenient access on some parts of a neighborhood. Examples of physical controls include speed bumps, rumble strips, median barriers, cul-de-sacs, semidiverters, diagonal diverters, traffic circles, chokers and other less commonly used devices. The following paragraphs briefly illustrate these devices.

Speed bumps (Figure 1) are raised bumps in the pavement surface extending across the traveled way. Their primary objective is to reduce traffic speed. But if they force traffic to go slowly enough or make drivers uncomfortable, they may cause volume reductions by diverting traffic to alternate routes. Conventional bumps normally have a height of less than 5 inches (.1 meter), a length (in the direction of vehicular travel) normally less than 3 feet (1 meter), and a variety of shapes including circular, parabolic and triangular. Conventional speed bumps have generally been rejected in the U.S. for neighborhood traffic control applications because of potential failure to control speed and vehicle damage and safety hazards. (1) In general, the faster automobiles travel, the less discomfort is felt by drivers at the bumps. Vehicular damage possibilities include oil pans cracked in "bottoming out", damages to alignment and suspension, bent wheel rims on bicycles and loss of inadequately secured gear on emergency and service vehicles. Safety hazards include loss of control (particularly for bicyclists and motorcyclists) and falls by personnel riding the exterior footboards on fire apparatus and refuse vehicles.

1. Walsh, Lawrence B., A Study of Speed Bumps, 1975

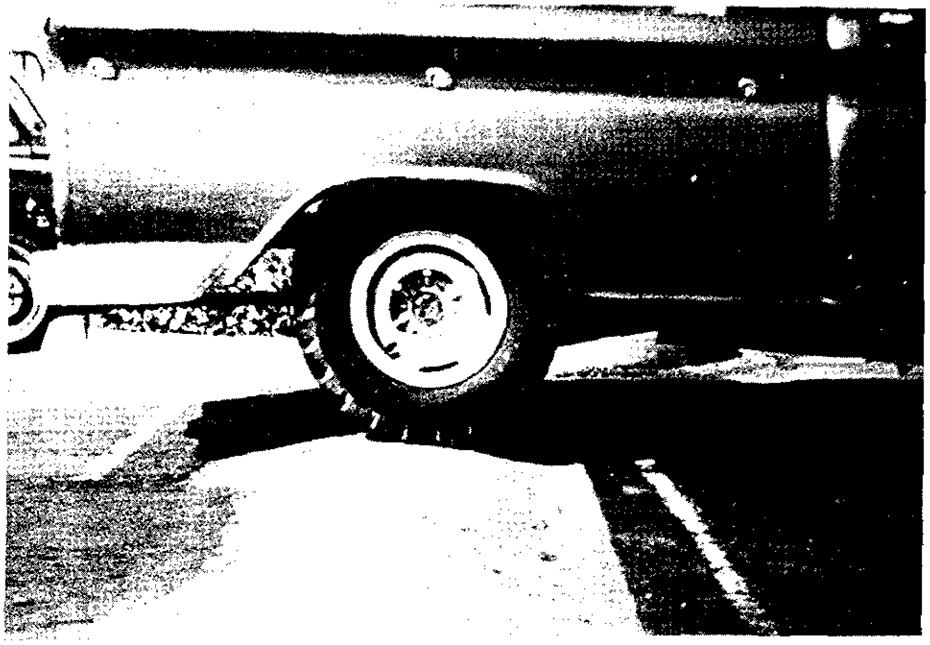
TABLE 2
NEIGHBORHOOD TRAFFIC CONTROL DEVICE CHARACTERISTICS - SUMMARY

DEVICES	DIRECT TRAFFIC EFFECTS						
	Volume Reductions	Speed Reductions	Directional Control	Change In Composition	Noise	Safety	Emergency & Service Access
Physical Controls							
Speed Bumps	Possible	Inconsistent	Unlikely	Unlikely	Increase	Adverse effects	Some problems
Undulations	Possible	Yes	Unlikely	Unlikely	No change	No problems documented	No problems documented
Rumble Strips	Unlikely	Yes	Unlikely	Unlikely	Increase	Improved	No problems
Diagonal Diverters	Yes	Likely	Possible	Possible	Decrease	Shifts accidents	Some constraints
Intersection Cul-De-Sac	Yes	Likely	Yes	Possible	Decrease	Shifts accidents	Some constraints
Midblock Cul-De-Sac	Yes	Likely	Yes	Possible	Decrease	Shifts accidents	Some constraints
Semi-Diverter	Yes	Likely	Yes	Possible	Decrease	Shifts accidents	Minor constraints
Forced Turn Channelization	Yes	Likely	Yes	Possible	Decrease	Improved	Minor constraints
Median Barrier	Yes	On curves	Possible	Possible	Decrease	Improved	Minor constraints
Traffic Circle	Unclear	Minor	Unlikely	Possible	Little change	Questionable	Some constraints
Chokers and Road Narrowing	Rare	Minor	Unlikely	Unlikely	Little change	Improved ped. crossings	No problems
Passive Controls							
Stop Signs	Occasional	Site red.	Unlikely	Unlikely	Increase	Mixed results	No problems
Speed Limit Signs	Unlikely	Unlikely	Unlikely	Unlikely	No change	No change	No effect
Turn Prohibition Signs	Yes	Likely	Yes	Possible	Decrease	Improved	No effect
One-Way Streets	Yes	Inconsistent	Yes	Possible	Decrease	Possible imp.	No effect
Psycho-Perception Controls							
Transverse Markings	No change	Yes	No effect	No effect	Possible red.	Possible imp.	No effect
Crosswalks	No effect	Unlikely	No effect	No effect	No effect	Ineffective	No effect
Odd Speed Limit Signs	No effect	No effect	No effect	No effect	No effect	No effect	No effect
Novelty Signs	No effect	Undocu-mented	No effect	No effect	Unlikely	No effect	No effect

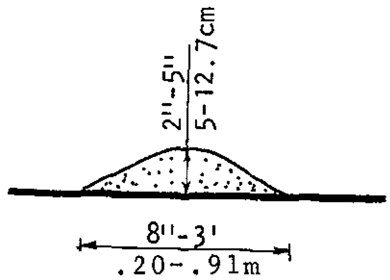
Specific details of individual applications may result in performance substantially variant from characterizations in this matrix.
See text sections on individual devices for more complete performance data, assessments and qualifications.

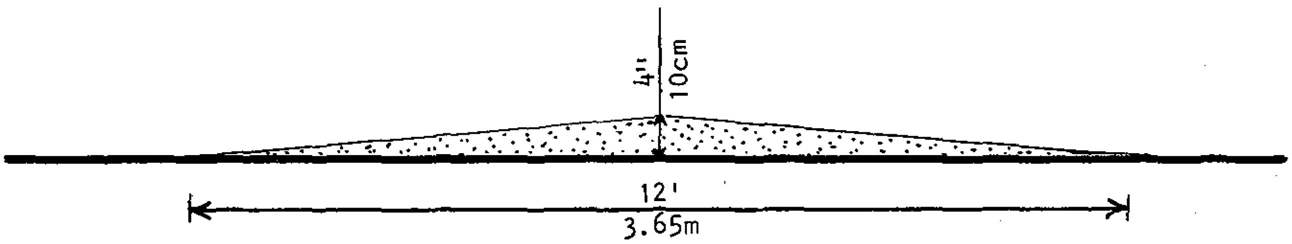
TABLE 2 (CONTINUED)
NEIGHBORHOOD TRAFFIC CONTROL DEVICE CHARACTERISTICS - SUMMARY

DEVICES	OTHER CHARACTERISTICS Construction Effort & Cost	 Landscape Opportunity	 Site or System Use	 Maintenance & Operational Effects Index
Physical Controls				
Speed Bumps	Low	None	Both	Snowplow problems
Undulations	Low	None	Both	No problems noted
Rumble Strips	Low	None	Site	Snowplow problems
Diagonal Diverters	Moderate to high	Yes	Usually system	Vandalism
Intersection Cul-De-Sac	Moderate to high	Yes	Both	Vandalism
Midblock Cul-De-Sac	Moderate to high	Yes	Both	Vandalism
Semi-Diverter	Moderate to high	Yes	Both	Vandalism
Forced Turn Channelization	Moderate	Possible	Both	No unusual problems
Median Barrier	Moderate	Possible	Both	No unusual problems
Traffic Circle	Moderate to high	Yes	Both	Vandalism
Chokers and Road Narrowing	Moderate	Yes	Both	No unusual problems
Passive Controls				
Stop Signs	Low	No	Both	No unusual problems
Speed Limit Signs	Low	No	Site	No unusual problems
Turn Prohibition Signs	Low	No	Both	No unusual problems
One-Way Streets	Low	No	Usually system	No unusual problems
Psycho-Perception Controls				
Transverse Markings	Low	No	Site	No unusual problems
Crosswalks	Low	No	Site	No unusual problems
Odd Speed Limit Sign	Low	No	Site	Vandalism
Novelty Signs	Low	No	Site	Vandalism



Conventional speed bump.





Road hump.

Figure 1. SPEED BUMPS AND ROAD HUMPS

In the U.K. the Transportation and Road Reseach Laboratory (TRRL) has developed and road-tested a quite different type of Road Hump.(2-6) Much longer (in the direction of vehicular travel) than the convential speed bump, the TRRL humps (also shown on Figure 1) have a length of 12 feet (3.6 m), a height of 4 inches (10 cm) and a circular arc cross-section. Experience in the U.K. indicates this shape, identified as an undulation in the literature performs considerably better than the conventional speed bump. Driver discomfort reportedly increases with increasing speed and vehicle damage and personal injury potential appears to be minimal. High hopes have been held for satisfactory application of this device on residential streets in the U.S., because it appeared to provide the needed restraint on drivers without the undesired secondary impacts of some of the other physical controls discussed below. Such an application comprised a major element of the second phase of research in this program. This research is documented in Chapter 3 of this report.

Rumble Strips (Figure 2), patterned sections of rough pavement normally used to alert drivers to a hazardous condition or on approach to another control device, have had some application for speed control in residential streets. While the devices have been somewhat effective in reducing speed, noise generated by traffic on the strips tends to create more resident protest than the speeding which occasioned their placement.(7-9)

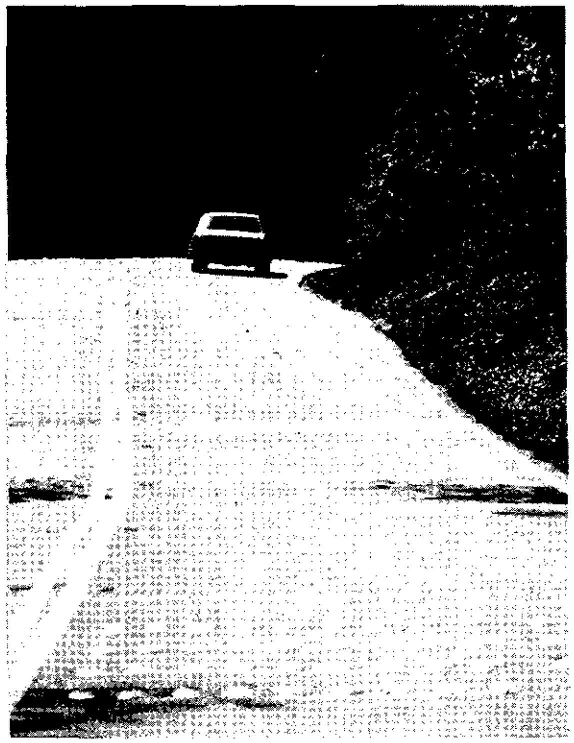


Figure 2. RUMBLE STRIP

2. Watts, G.R. "Road Humps for the Control of Vehicle Speeds, "Transport and Road Research Laboratory Report 597, 1973
3. Transport and Road Research Laboratory, "Speed Control Humps in Cudesdon Way, Cowley, Oxford, "Leaflet 617, July 1976
4. Transport and Road Research Laboratory, "Speed Control Humps in Motum Road, Norwich," Leaflet 663, September 1977
5. Transport and Road Research Laboratroy, "Speed Control Humps in Palace Road, Haringey, London," Leaflet 664, September 1977
6. Transport and Road Research Laboratory, "Speed Control Humps in Abbotsbury Road, Kensington, London," Leaflet 665, September 1977
7. Marconi, William, "Speed Control Measures in Residential Areas," Traffic Engineering, March 1977
8. Ottawa-Carleton, Regional Municipality of, Glebe Traffic Plan, the Trial Period
9. Ottawa-Carleton, Regional Municipality of, Rumble Strips for the City of Ottawa, 1973

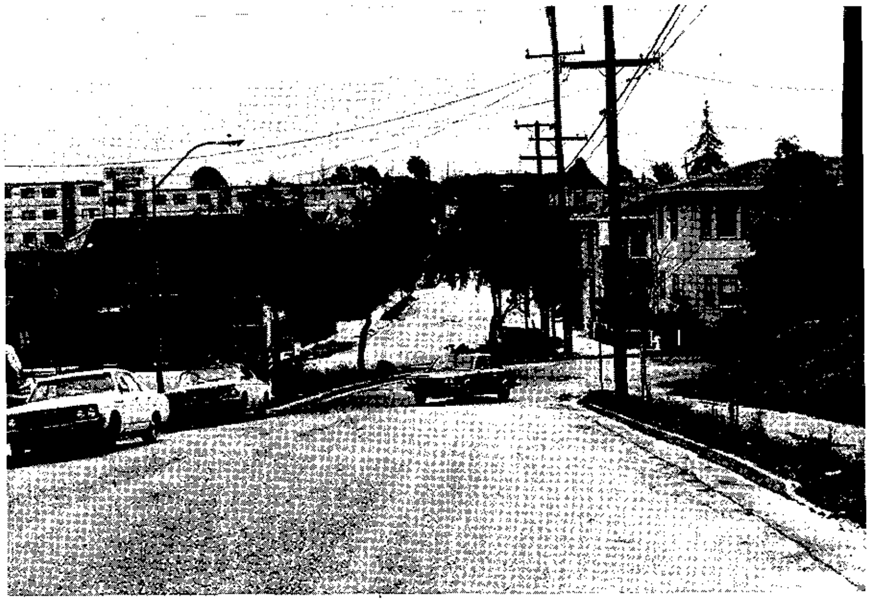
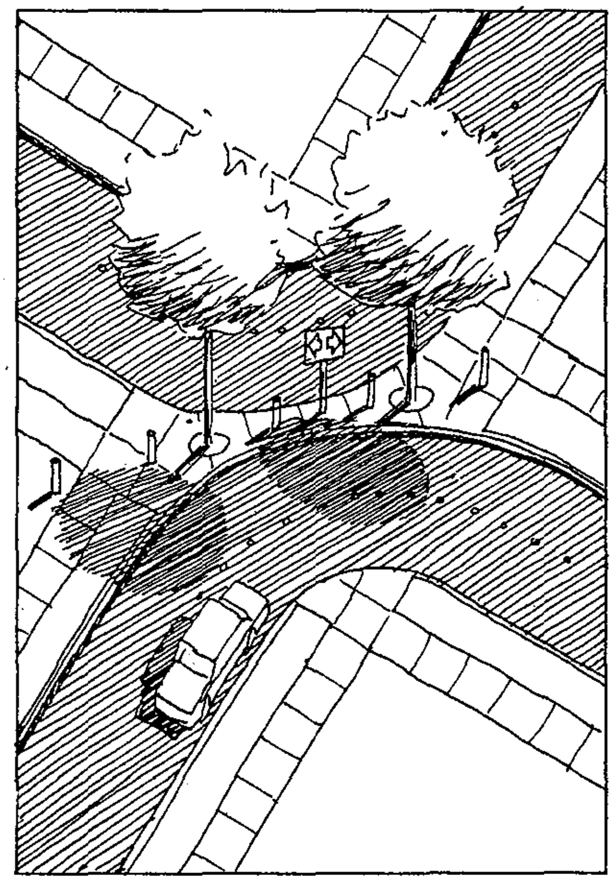


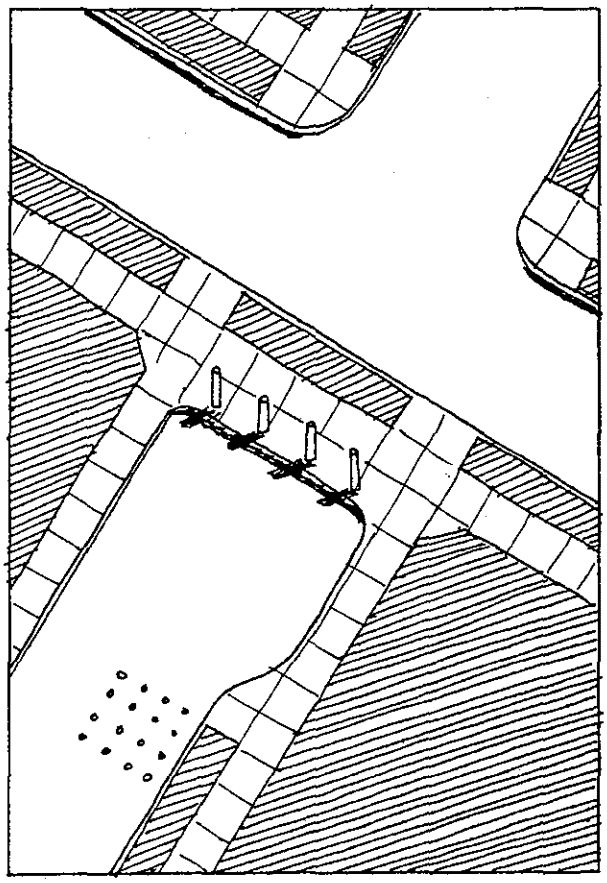
Figure 3. DIAGONAL DIVERTER



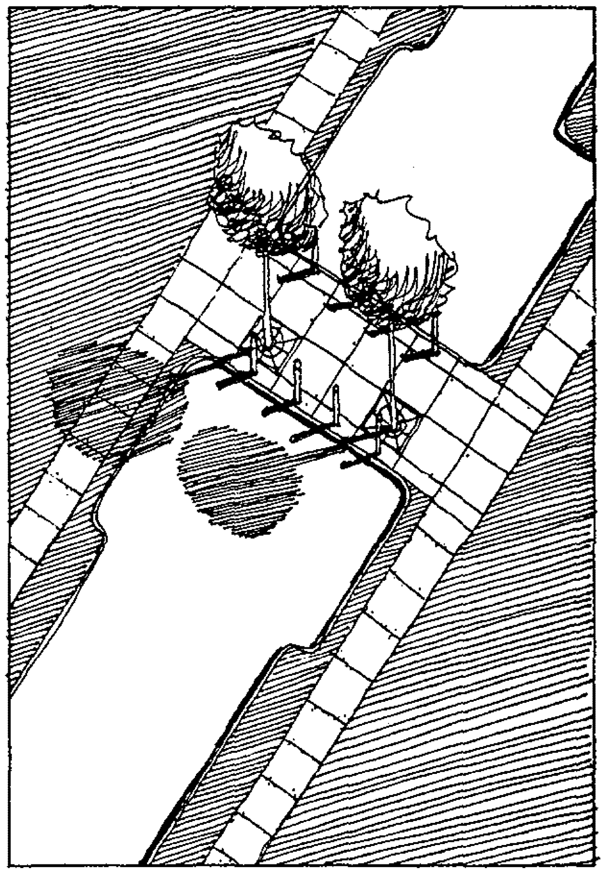
A diagonal diverter (Figure 3) is a barrier placed diagonally across a four-legged intersection to, in effect, convert it into two unconnected streets, each making a sharp turn. By interrupting street continuity in a neighborhood, a system of diverters can prevent or significantly discourage through traffic. Primary difficulties with diagonal diverters are emergency and service vehicle access, convenience for neighborhood residents, visualization of the street system by strangers, cost of construction in acceptably and 'suitable' (relative to approved engineering design practices) aesthetic materials, and the impact of the diverted traffic on whatever alternate routes exist.

A cul-de-sac (Figure 4) may be retrofitted to an existing street either at an intersection or at midblock. It provides a stronger traffic restraint than the diagonal diverter and experiences similar problem points.

Semi-diverters (Figure 5) are devices which bar traffic in one direction on a



Cul-de-sac
at intersection



Cul-de-sac
at midblock

Figure 4. CUL-DE-SAC

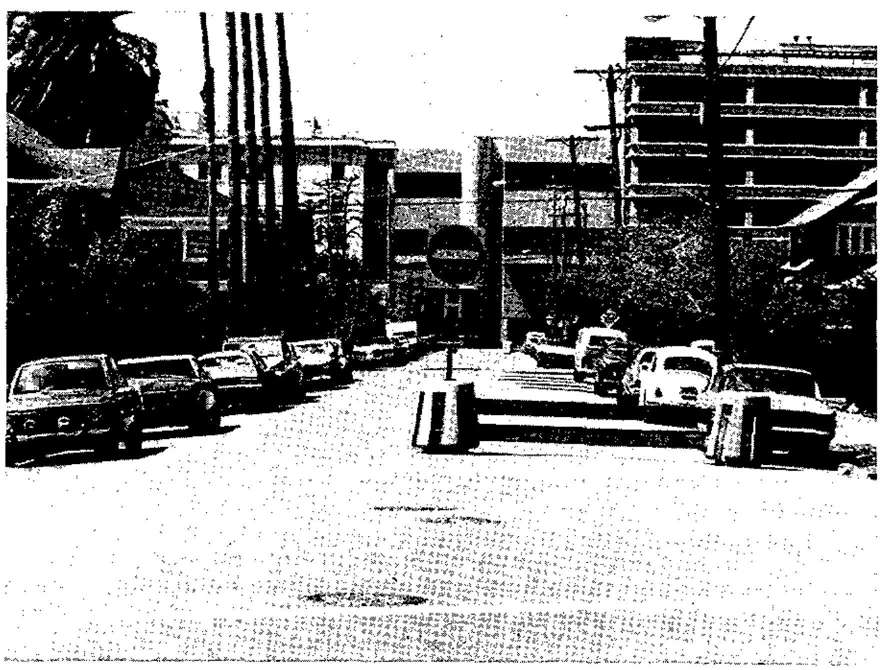


Figure 5. SEMI DIVERTER

street while permitting travel in the other direction. Because semidiverters block only half the street, they are easily violated by motorists who are so inclined. But this same property makes them a minimal impediment to emergency vehicles.

Forced turn channelization is comprised of traffic islands designed to prevent traffic from executing specific movements or to force it to execute others. This is simply an adaptation of techniques commonly used to improve traffic flows along arterial streets except that the movements prevented or forced are specifically selected to discourage through traffic on local streets.

Median barriers, standard traffic engineering devices normally used to separate and improve flows on arterial streets, can be employed to prevent left turn entries to local neighborhood streets from the arterials and to prevent through traffic flows on local streets from one neighborhood to another across an arterial.

Traffic circles (Figure 6) have been employed at low-volume, local street intersections to control speed. Not to be confused with the "mini-round-abouts" (very small traffic circles) now proliferating in the U.K.(10), which allocate right-of-way and order flows, speed control circles occupy a large central portion of the intersections, thereby forcing traffic to slow in negotiating its way around these circles. In practice, circles were found to have relatively little speed control effectiveness. (7,11,12)

A choker (Figure 7) is a narrowing of the street, either at an intersection or at midblock, to constrain the width of the traveled way. Except where the narrowing is extreme enough to limit use of the "choked" section to one direction at a time, chokers have generally not had significant effect on traffic volume or speed. Primary positive effects have been improved pedestrian safety, landscape opportunities, and definition of "neighborhood entry".

Although used to some degree in the U.K., traffic-actuated gates have not had significant application in the U.S. for purposes of through traffic restraint on residential streets.

Passive Controls

Passive controls involve the use of regulatory signs and markings to inform the driver that a specific action is not permitted, while not physically preventing the action. As such, passive controls are more easily violated than most physical controls. Their advantages include the fact that some can be in force during only portions of the day. They also impose fewer constraints on emergency vehicles, which can ignore them when necessary with little problem or hazard. Experience has shown that even with the violations, some passive controls produce a significant improvement in the level and effect of residential traffic.

Passive controls are most effective in areas where general respect for all types of traffic control is high, where there is a reasonable expectation of enforcement, or where there is little driver resentment of the specific device. Where any of these conditions do not exist, for example, where numerous stop signs are used in opposition to major traffic flows or where a turn prohibition is installed and no reasonable (from the driver's viewpoint) alternative exists, violations of the device can be expected.

10. Todd, K., Modern Rotaries, ITE Journal, Vol. 49, No. 7, July, 1979
7. Marconi, Op. Cit.
11. Yee, Kimland M., Traffic Circle Study, Sacramento Department of Traffic, undated
12. Saratoga, California, City of, De Leuw Cather Summary of Experience, 1977

Figure 6. TRAFFIC CIRCLE

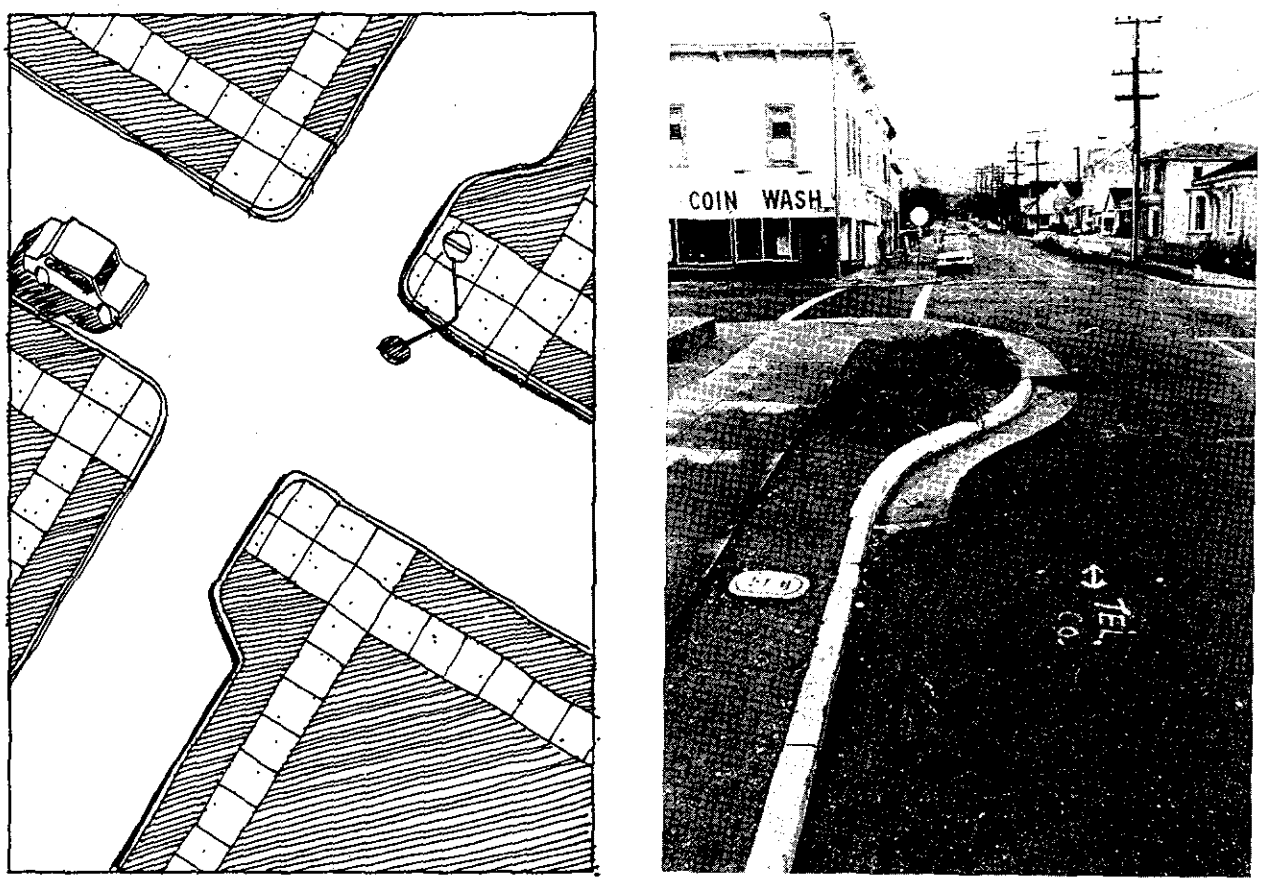


Figure 7. CHOKER

The most effective form of passive control appears to be an area system of one-way streets. Either a "full maze" system or a "limited entry" pattern (Figure 8) can substantially discourage through traffic. While one-way systems have effects on neighborhood traffic similar to a pattern of diagonal diverters, they have minimal adverse effects on emergency vehicles which can easily and fairly safely travel the "wrong way". And they tend to be more respected by motorists than other "passive" devices and than physical devices like semi-diverters which are possible to bypass, perhaps because violation takes a long time - the time to travel a whole block - or perhaps because traffic traveling in the correct direction provides a self-enforcing element.

Turn prohibitions involve the use of standard "No Right Turn" or "No Left-Turn" signs, with or without peak hour limitations. These prevent turning movements onto residential streets, thereby reducing volume. They are best used at the periphery of a neighborhood rather than within it. Turn prohibitions have the significant advantage of being effective only during specified hours of the day, if desired. If shortcutting is occurring only in one or both commute peaks, restricting turns only during these periods can allow residents full accessibility during the remainder of the day. Since turn prohibitions are clearly a passive device, their success depends on their general acceptance by the affected drivers. In areas where regulations are frequently flaunted or poorly enforced, they will have relatively little effect.

Although the basic purpose of stop signs is to assign right of way, they have frequently been used in attempts to control traffic volume and speed. Although traffic engineers have traditionally opposed use of stop signs for these latter purposes, they cannot be said to be completely ineffective. When a local street's travel time advantage over other routes

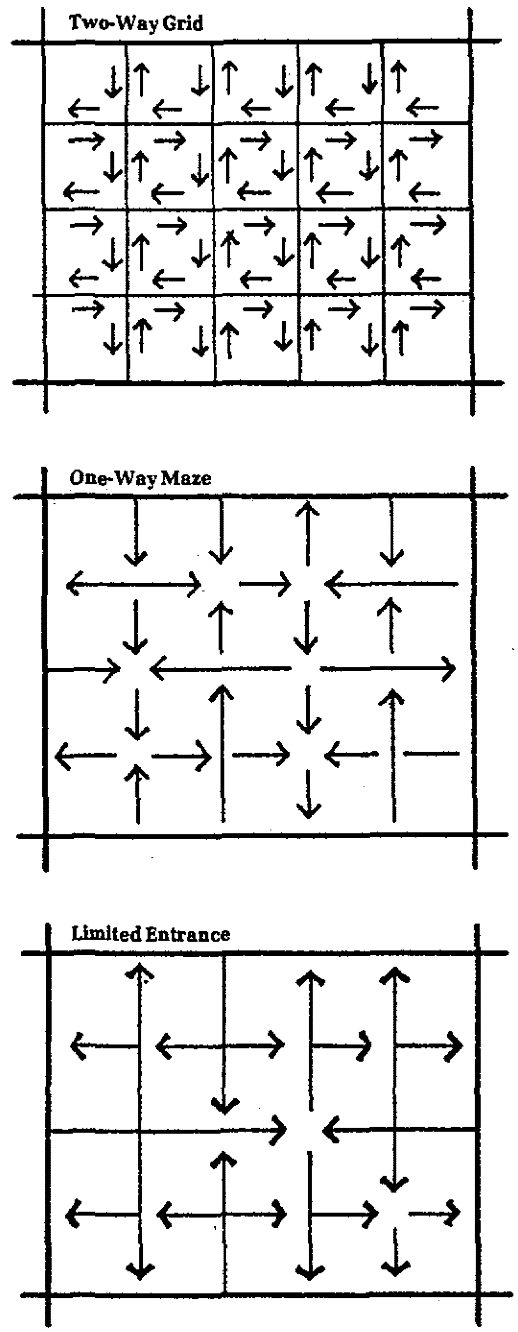


Figure 8. ONE-WAY CONTROL SYSTEMS

is marginal, stop signs may be enough to shift the balance and divert traffic. Extensive traffic engineering studies (see State of the Art Report for References) show stop signs have little impact on overall traffic speed except within about 200 feet (61m) of the signs. But if they reduce the speed of, or divert the few very fast drivers who tend to be the most disturbing to residents, residents may perceive them to have had a significant speed reduction impact. Furthermore, evidence on safety effects on STOP signs placed for volume or speed control purposes does not uniformly support the traditional traffic engineering belief that STOPs not warranted by intersection conflicts will increase accidents. The State of The Art Report cites studies in Philadelphia, Pa., St. Paul, Minn. and Concord, Calif., which show reduced accident experience following installation of "unwarranted" STOPS.

Speed limit signs have generally been found to have little effect on traffic speed or residential streets, unless constantly enforced.

Numerous other types of passive controls exist. The foregoing highlights some of the most prevalent.

Psycho-Perception Controls

Control devices described above can be classified as trying specifically to prevent, through physical and legal means, an undesired action by a driver. Another approach to the problem is to try to play upon ingrained driver responses to certain stimuli to induce or even trick them into a desired behavior pattern or to use materials and messages which heighten driver response. In concept, it might be possible to design devices which discriminate in their impacts, affecting drivers traveling "too fast" while not affecting drivers traveling at reasonable speeds.

Psycho-perception controls would appear to avoid the primary drawbacks of physical controls (too heavy-handed

Figure 9. WOONERF.

and too much interference with emergency services) and passive controls (too easy to violate). However, few effective examples have been demonstrated. Transverse lines with increasingly close spacing to give the driver the illusion of increasing speed, odd speed limit signs and unique message signs to attract attention by their novelty, and speed-actuated flashing warning or speed limit signs are examples of psycho-perception controls which have been tried, though none have enjoyed outstanding success in local residential street applications. Further development in this area of control is needed.

Woonerf

While the much publicized Woonerf treatment (Figure 9) developed in the Netherlands might be considered by some to be a physical control, we prefer to consider it as a unique category on its own.(13,14) First, it is not comprised of a single control device or discrete pattern of devices. It is a composite treatment of a street or group of streets. The changes in travelled way alignment, narrowings, constrasts in paving materials, use of planters, walls, benches, bollards, mounds, parking areas and landscape have no single set pattern; they are not designed for individual impacts on traffic but rather for the impact when the street is perceived as a whole by the driver. Second, the Woonerf is not simply a physical control though physical changes to the roadway are massive. Equally important is the concept of the street as an integrated area - a shared space for multiple uses - as constrasted to the traditional segregation of driving, parking and pedestrian activities on the ordinary street. This difference in function of the street space is explicitly recognized in unique rules of the road applicable to driving in the Woonerf. These rules essentially require drivers to operate at a walking pace and give way to pedestrians (while not allowing pedestrians to unnecessarily obstruct drivers).

SYSTEMIC PLANNING FOR NEIGHBORHOOD TRAFFIC CONTROL

While Woonerf treatments may not have broad scale applicability to residential streets typical in the U.S. and many other areas, their holistic approach serves as a useful introduction to a discussion of neighborhood traffic control as an area strategy rather than as an individual site and device application.

A common cause of failure of neighborhood traffic restraint schemes in the U.S. is attributable to a lack of systemic strategic planning - concentrating on individual sites and devices rather than controlling all traffic in a systemic way.

Most neighborhood traffic problems are area problems rather than conditions peculiar to a single limited site. Many of the devices used to treat neighborhood problems have impacts which extend well beyond the immediate site of their deployment. Some devices must be deployed in a series of installations to be effective neighborhood traffic management tools. And even if they are not dependent on the presence of other devices for inherent effectiveness, combinations of devices can have synergistic effects. For these reasons, the pattern or systemic way in which devices are deployed can be a significant determinant as to how effective the devices are in managing neighborhood traffic, in how drivers react to them, and the extent to

13. Royal Dutch Touring Club des Pays-Bas ANWB, Woonerf, 1977
14. DeJaeger, D.M., "Woonerven (Residential Yards)," ITE Compendium of Technical Papers, 47th Annual Meeting, Mexico City, 1977

which the devices pose inherent inconveniences to residents of the protected neighborhoods themselves. The various strategies pose trade-offs between the degree of protection from through traffic and compromises to resident access, internal neighborhood circulation and emergency and service access. These trade-offs and the specific nature of the individual neighborhood's problems are primary considerations in choosing a control system strategy for neighborhood traffic control.

Over and above the complex and interactive nature of problems, the fundamental concept of the residential neighborhood as a discrete area and entity to be treated in a holistic way underlies the organized approach to traffic management. The "neighborhood unit" in American planning, Buchanan's "environmental areas", "woonerven" in the Netherlands, and "traffic cells" used in Japan and other countries all define discrete residential districts where traffic behavior is to be controlled on internal streets and through traffic confined to peripheral streets. The following paragraphs expand on the concept of area-wide strategies for neighborhood traffic control.

Peripheral barrier treatments prevent traffic from entering the neighborhood by means of controls placed at local street intersections with bounding arterials and collectors. This form of boundary control can be achieved using physical devices such as cul-de-sacs, semi-diverters and median barriers, or passive devices such as turn prohibition signs and one-way streets. A primary advantage of the peripheral barrier system is that the potential intrusive traffic encounters the protective barriers while it is still on the bounding streets and still has a clear option to use these routes to its destination with little out-of-direction travel or delay. By contrast, with internal systems, drivers are first led into the neighborhood before being blocked and perhaps disoriented, trapped, certainly frustrated and possibly enraged. Another advantage of peripheral systems is that motorists are less likely to violate them along the busier streets where the perceived likelihood of enforcement is greater. Peripheral barrier treatments work best when the problematic through traffic is on a single axis of the street grid as shown in Figure 10. The treatment shown allows streets at right angles to the problem flow to be left open so that local trips can enter from the sides; entries are blocked in problem directions.

If through traffic incursions are problems on two axes of the street grid, the peripheral barrier scheme does not work quite so well because gaps must be left in the protective cordon to provide opportunities to allow neighborhood residents to return home. If this is done, the streets left open will suffer from a concentration of through and local traffic. One solution to the two axis problem is to supplement peripheral devices with internal devices to prevent the "open" streets from becoming through routes as shown on Figure 11. Even if this is done, the peripheral barrier scheme tends to be less effective in responding to biaxial through traffic problems than in the single axis situation.

Another advantage of the peripheral barrier scheme is that inconvenience to residents, while they themselves are driving, is relatively limited. Traffic flows internal to the neighborhood are unobstructed, residents have freedom of egress in any direction and reasonably convenient access in returning to the neighborhood.

Internal systems are preferred over peripheral ones in cases where problem traffic is biaxial, where boundary street oriented, office-commerical uses extend partially into the neighborhood along local streets, where traffic conditions preclude a peripheral scheme, or where a

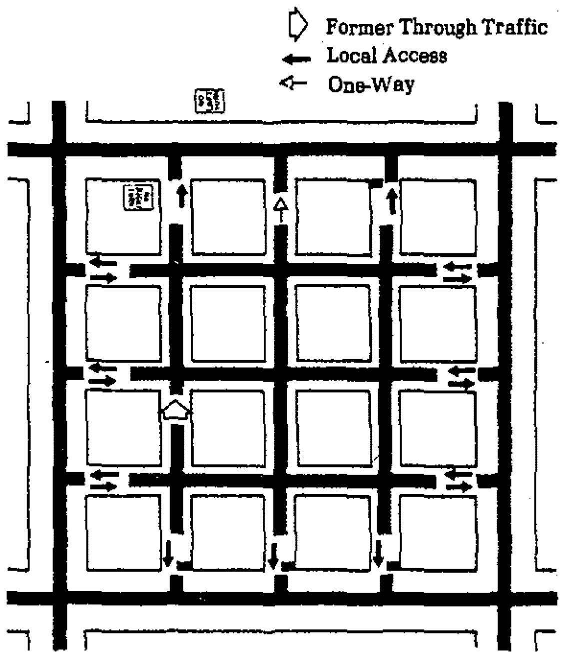


Figure 10. PERIPHERAL BARRIER
DOMINANT DIRECTION

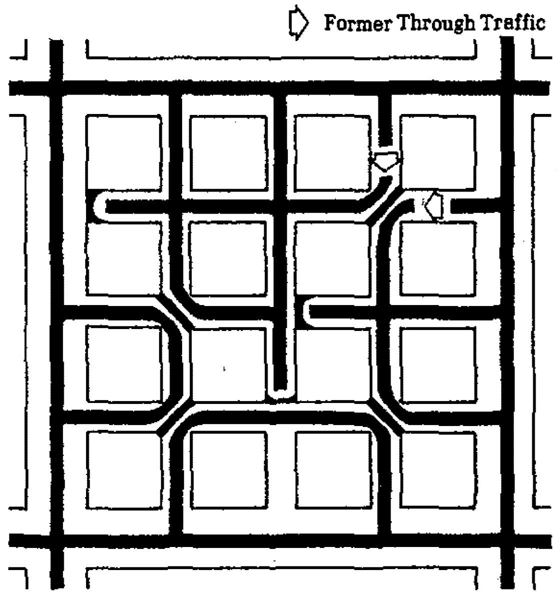


Figure 12. RETURN LOOPS
MORORISTS FORCED TO RETURN
TO BOUNDARY STREET OF ENTRY

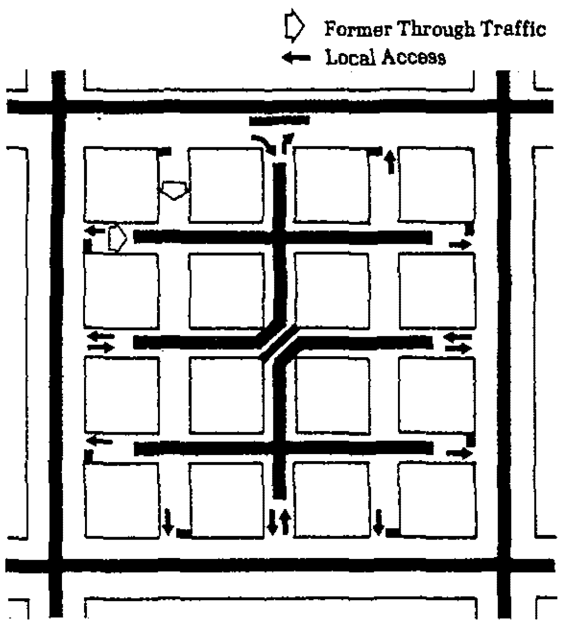


Figure 11. PERIPHERAL BARRIER
MULTI DIRECTION

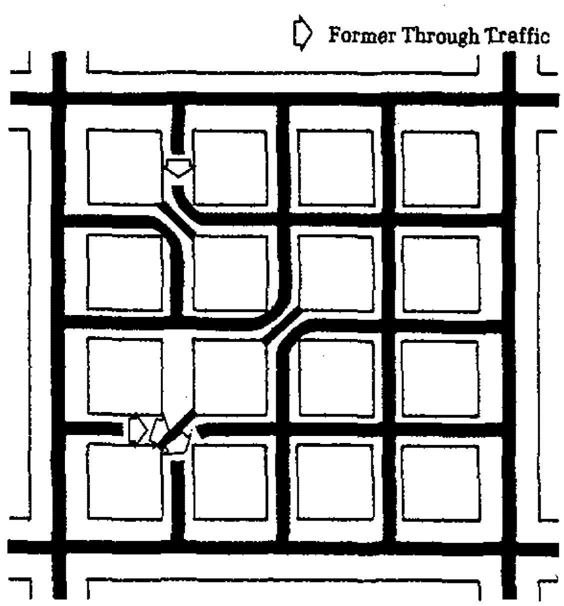


Figure 13. ANTI-THROUGH SYSTEM
TRAVEL COMPLETELY ACROSS
NEIGHBORHOOD IMPOSSIBLE

large traffic generator which requires good access, such as a hospital, is located within the neighborhood. Internal barrier systems are of three types: return loops, anti-through and maze.

As shown in Figure 12, return loops force traffic entering from any one of the streets bounding the protected neighborhood to return to the same boundary street from which it entered. Return loops are extremely effective in limiting through traffic. They are also extremely restrictive on resident travel, since each residence has access to only one boundary of the neighborhood. Internal vehicular travel in the neighborhood is virtually impossible and the system poses considerable barriers to emergency and service travel.

Figure 13 shows a typical anti-through system. It prevents traffic from traveling completely across a neighborhood to the opposite side although the motorist is not necessarily forced to return to the same boundary street from which entry was made. In anti-through systems, most residences have accessibility to two of the neighborhood boundaries. Internal neighborhood travel by automobile is still problematic. Barriers to emergency and service vehicle travel are still formidable though less so than in the case of return loop system. Return loop and anti-through systems work well to combat through traffic incursions on both axes of the residential grid. However, more limited systems of either type can be devised to respond to problems on a single axis while leaving the remainder of the neighborhood street network relatively unobstructed.

Maze systems use physical barriers or other controls in a less intensely restrictive way. In these schemes the object is to leave no street as a continuous through path across the neighborhood. As shown in Figure 14, through penetration is possible, but only by following a circuitous path. The theory behind the maze is that it will be sufficiently confusing to nonlocal travelers that they will not continue to attempt passage. For drivers familiar enough with the system to know how to get through, the out-of-direction travel and turning will make the route through the neighborhood unsatisfying as a short cut.

Of all the internal barrier systems, mazes entail the least inconvenience for residents as most residents have access to all of the bounding streets; usually only one or two blocks of out-of-direction travel are required and a fair degree of internal vehicular circulation within the neighborhood is preserved. However, this increase in resident access convenience is secured by having a system which is less positively effective against through traffic.

Figures 12, 13, and 14 show return loop, anti-through and maze systems designed to combat biaxial traffic incursions. However, all three can be designed to affect problem traffic on a single dominant axis if necessary. As noted above, the internal systems are particularly effective when a special traffic generator requiring good access is located within the neighborhood, complicating the problem of combating through traffic. Figure 15 shows a typical example of a hospital and related medical offices (hatched area) located within a neighborhood and a maze system designed to discourage through traffic. Note that the medical complex is directly accessible from all four of the bounding arterials.

Principal devices in return loop, anti-through and maze systems are diverters, semi-diverters, cul-de-sacs, median barriers and one-way streets.

The foregoing has focused upon applications in grid pattern situations. In some suburban situations, problems are analogous to those on a grid, and the peripheral or internal barrier strategies may apply as shown on Figure 16. In other situations, subdivision street patterns

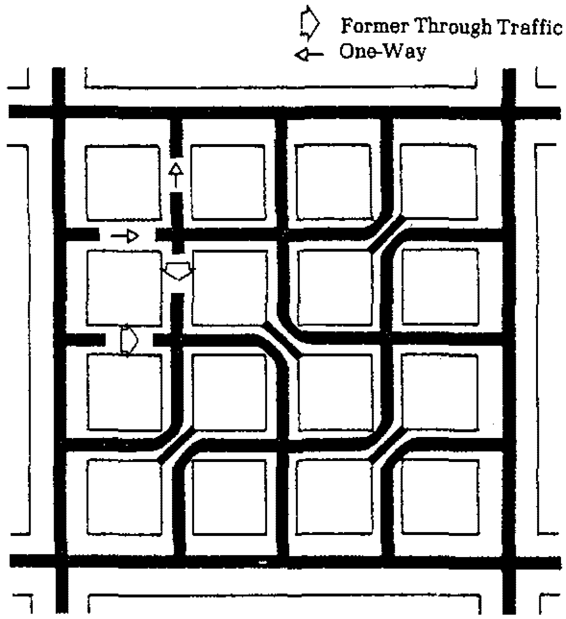


Figure 14. MAZE - NO DIRECT PATH ACROSS NEIGHBORHOOD BUT THROUGH TRAVEL IS POSSIBLE

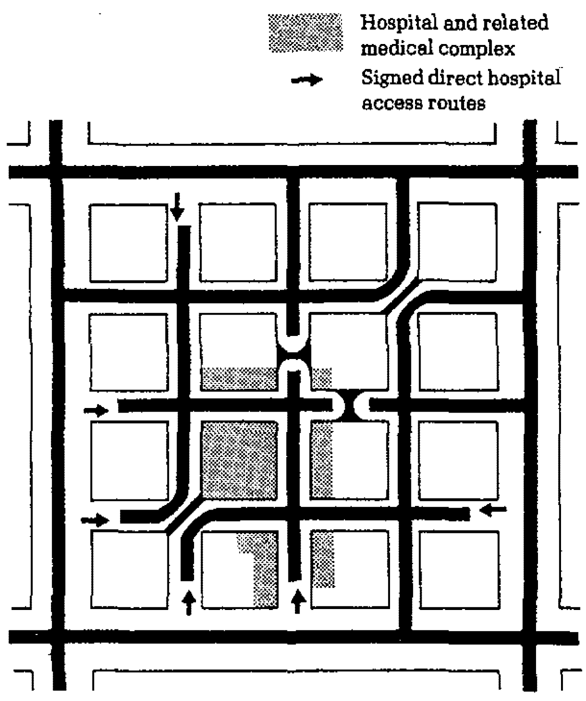


Figure 15. MAZE SYSTEM WITH INTERNAL SPECIAL GENERATOR (HOSPITAL)

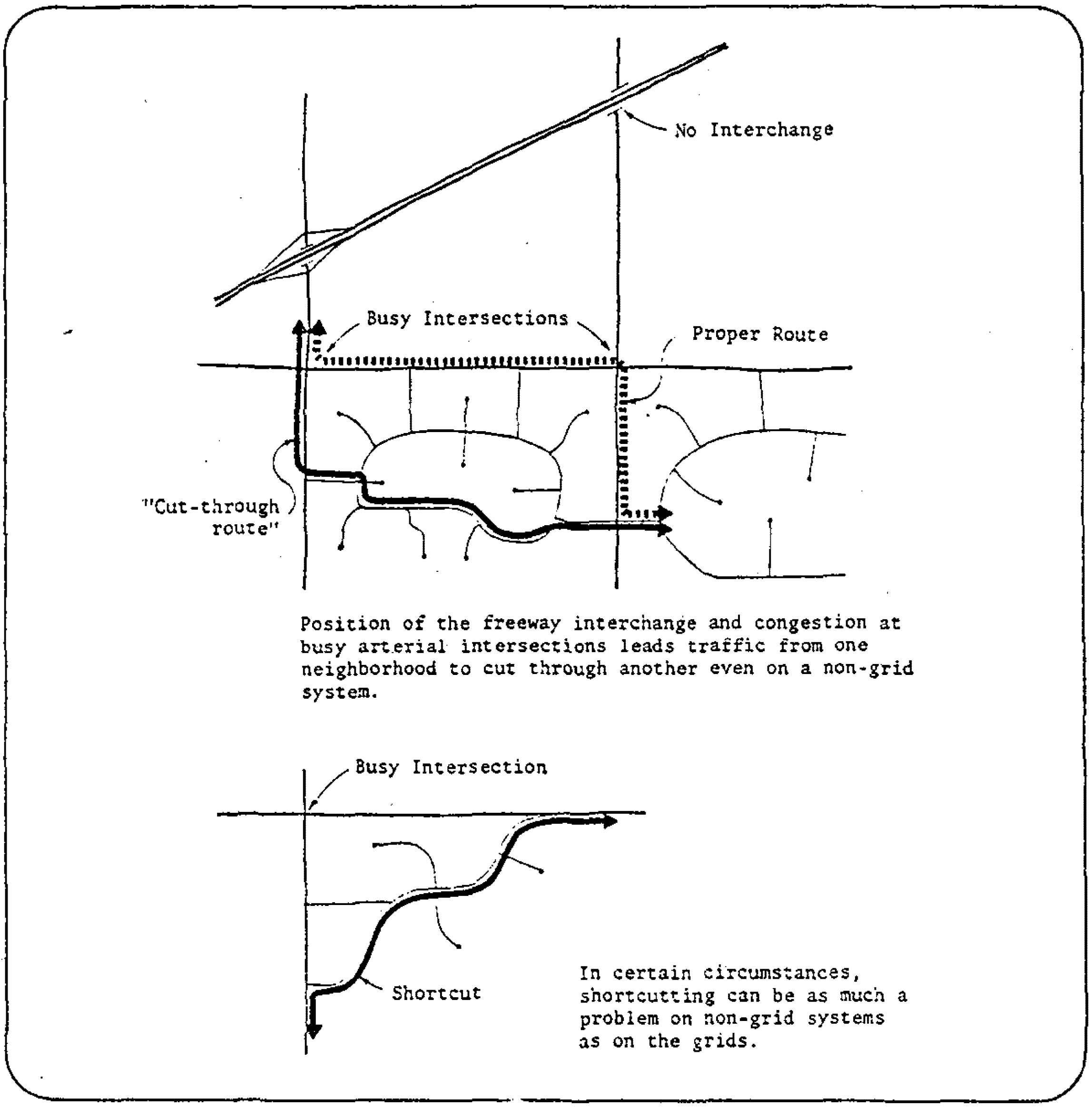


Figure 16. NON-GRID SYSTEM PROBLEMS

produce problems unique to modern suburban development.

Beyond the schematic pattern of neighborhood traffic control, overall planning philosophy of the designer can have tremendous impact on the form of a neighborhood traffic control scheme. The classical area-oriented approach set forth by Buchanan (and typical of European "traffic replanning" efforts and some U.S. urban renewal schemes) works backward from an "end-state vision" for a neighborhood or "environmental precinct" to a specific plan to achieve that state. Site-specific problems may initiate the planning process, but treatment is sought for the entire unit. While conditions which spurred action are not specifically considered, the plans produced will hopefully resolve site-specific problems initially recognized.

Application of this fairly simple concept may result in a clearly understandable scheme which generates community support and operates well in practice. The approach also eliminates need for extensive data on the specific nature of problems. However, it suffers from these drawbacks:

- There may be difficulty in defining homogeneous environmental precincts or neighborhood units. Quite often there are isolated divergent land uses withing neighborhoods such as corner stores, hospitals, and schools within the unit which require special consideration. Frequently too, neighborhoods do not have sharply defined boundaries; the transition in land use character and neighborhood identity may be rather amorphous.

- In working from a broad scale vision, this approach may fail to satisfy micro-scale needs within a planning unit, e.g., the one or two households near the device severely impacted by one device or location but not by another.

- The approach is one primarily directed to diversion of non-neighborhood traffic. It does not respond well when diversion is infeasible or when the residents themselves cause the problem - e.g., speeding on other blocks of their own neighborhood.

The problem-oriented method develops a traffic managment scheme from analysis of an array of specific conditions in an area. The focus is at a micro-scale level, a "bottom-up" approach in which attempts are made to solve identified problems individually, while still considering the systemic effects and interrelations of separate problem sites, until a set of solutions is developed for an entire area. This method requires substantial data on the specific nature of problems to determine feasible and effective alternatives. This method is common to U.S. efforts at neighborhood traffic management. The Berkeley Neighborhood Traffic Plan is perhaps the most extensive example of this assessment strategy. A chief advantage of this approach is that it works well in dealing with problem situations internal to a neighborhood such as those created by a divergent land use or by the behavior of the residents themselves.

Potential drawbacks to the problem-oriented approach become evident when large areas are being treated. They relate to difficulties in gathering and effectively using large amounts of data and a tendency toward lack of cohesion among the solutions at sites which impact one another. These potential problems can be overcome by effective data management systems and by subdividing the total study area into manageable sized units or neighborhoods for which data can be effectively organized and solutions to problems can be considered both in site context and in a cohesive neighborhood context. Then alternatives for the individual neighborhoods can be matched with one another to develop cohesive plan alternatives for the entire planning area.

This discussion of strategic planning methods is emphasized out of concern for the tendency in current practice to overlook the systemic nature of most neighborhood traffic conditions and control plans. However, it is also possible to err by being "over-comprehensive". When traffic issues in a community are few and site specific, they can be successfully addressed on an ad hoc basis. Furthermore, the broad-focused approaches above can take considerable time and resources which in many cases may not be available. In such circumstances, consideration on an individual site basis of conditions or solutions recognized to be systemic in nature can be a responsible professional approach provided no serious and irreversible damage seems likely to result. At times, treading the fine line between over-comprehensiveness on the one hand and too limited focus on the other may demand more clairvoyance than professional judgment. But it is as important to pursue ad hoc solutions when "half a loaf is better than none" as to resist incomplete scheme when well-thought out systemic approaches are indicated.

PLANNING FOR NEIGHBORHOOD TRAFFIC MANAGEMENT

Introduction

An effective planning process is the most important element in the creation of a successful neighborhood traffic management program. It is not necessarily true that the planning process is more important than selection of the "right" device; more important than design; or more important than implementation technique. Yet experiences reported in cities contacted in the state-of-the-art search include numerous failures. In virtually every case, the failure of a program can be traced directly to either a breakdown in the planning process or the failure to have a structured process at all.

For this reason, the State-of-the-Art report includes a chapter illustrating the more effective technical, political and social techniques for achieving a successful program. That chapter is summarized in the sections which follow.

Structuring an Effective Planning Process

Planning for neighborhood traffic management is normally done in cognizance of but independent from the ongoing formalized city and regional planning process structure.

An effective planning process for a neighborhood consists of the following steps:

1. Assessment of Problems and Needs
2. Development of Alternative Plans
3. Evaluation of Alternative Plans and Plan Selection
4. Implementation of Selected Plan
5. Evaluation of Selected Plan
6. Modification of Plan and Recycling the Process

Each of these steps invove technical effort by the professional and involvement of the community. The sections which follow delineate the components of each of these steps, noting necessary technical and community involvement techniques. All of the techniques have been used to some extent by State-of-the-Art cities observed, though none followed the process exactly or completely. Thus what follows is an "ideal" planning process synthesized by the research team from current successful practice.

Why Community Involvement is Necessary

Cities observed in this State-of-the-Art review provide examples where well-intentioned efforts have failed because community involvement was inadequate or non-existent. The need for an effective community participation process is evidenced not only from a technical, but also a political or social standpoint. Engineers and planners may propose a technically correct solution relative to the data they have. But the solution may not solve the real problem because it does not address the unrecorded incidents observed by and of concern to the community. Or the community, distrustful of the professionals, may use political muscle to gain implementation of a scheme which has overwhelming technical weaknesses. Community involvement allows the professionals to learn of residents' perceptions of problems, their depth of feeling about their needs, their ideas about what ought to be done and data items which only people as close to the situation as residents can observe, while professionals let residents know the physical, legal, financial and technical constraints on what can be done.

Local traffic schemes arouse powerful emotions and have widespread impact. Politically, neighborhood traffic management is controversial because inevitably some people gain and some lose. The public participation process permits assessment and exposure of potential trade-offs before implementation. Communication with potential opposition raises the possibility of working out compromises during the planning stage. And if adverse effects are not "advertised" in advance, the fact that they do occur might be used to discredit the the planning process - it will be alleged that the process and the plan were defective because of these "unplanned" and "unforeseen" adverse impacts. People are also far more likely to accept a plan or take responsibility for making it successful if they have been part of the planning or design process.

The following section summarizes reliable techniques and references for the community involvement process.

Techniques For Community Involvement

A diverse array of community involvement techniques developed for other types of planning activities is potentially adaptable to neighborhood traffic management. Community involvement usually operates at two levels:

- **participatory programs** involve community " leaders and "active citizens".

- **outreach programs** to communicate with the "silent citizens," normally the vast majority of residents.

Table 3 shows the functions of community involvement at each stage of the neighborhood traffic planning process. Naturally, different types of involvement techniques are needed to meet the disparate objectives at each stage. Figure 17 presents a range of involvement techniques and indicates which ones may be useful at each planning step. Some of the techniques shown may be more sophisticated, costly or time consuming than is appropriate in the context of the particular community and problem under consideration. The following are major factors to consider in selecting techniques most applicable to the particular situation and community.

- The intensity and pervasiveness of the community's **interest** in the traffic problem. Where strong interest is limited to a few residents, outreach approaches are indicated.

TABLE 3
COMMUNITY INVOLVEMENT PURPOSE BY PROGRAM STAGE

	Program Stage	Community Involvement Purpose
1.	Needs Assessment	Notify community that process is on-going Receive community complaints Determine problems and assets Gauge level of concern and points of conflict Familiarize community with constraints and issues Focus data gathering activities
2.	Generating Alternatives	Obtain citizen ideas and suggestions for solutions Sound out professionals' solution ideas with citizens Test strengths and weaknesses of solutions Draw out points of conflict
3.	Plan Selection	Advise public of likely effects of each alternative Obtain public's weighing of trade-offs involved in each alternative Test support for each alternative Work out compromises to potential conflicts Build a consensus and commitment for a single alternative Inform public of plan chosen
4.	Implementation	Ease acceptance of the plan Identify problems early and make responsive adjustments
5.	Evaluation and Modification	Inform the public of measured effects of the plan Learn of unforeseen problems or unexpected severity of foreseen ones Conceive and assess potential modifications

Planning Steps	Public Information Programs	Drop-in Centers	Hotlines	Meetings — Open Information	Ombudsman	Surveys	Focused Group Discussion	Delphi	Public Hearings	Meetings — Community Sponsored	Advocacy Planning	Charrettes	Community Planning Centers	Computer-Based Techniques	Design-in and Color Mapping	Plural Planning	Task Force	Workshops	Citizens Advisory Committees	Citizen Representatives	Fishbowl Planning	Interactive Cable TV Participation	Meetings — Neighborhood	Neighborhood Planning Councils	Policy Capturing	Value Analysis	Arbitrative and Mediative Planning	Citizen Referendum	Citizen Review Board	Media-Based Issue Balloting
Needs Assessment	●			●		●	●			●									●	●			●	●					●	●
Generating Alternatives	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				●
Plan Selection	●	●	●	●	●	●	●		●	●	●	●	●		●	●	●	●	●	●	●	●	●	●			●	●	●	●
Implementation	●		●														●												●	
Evaluation and Modification	●		●		●	●	●		●	●							●		●	●			●	●					●	

● Indicates a technique that may be useful at that step.

Adapted from: U.S. Federal Highway Administration, Socio-Economic Studies Division. **Effective Citizen Participation in Transportation Planning**, Volume I; Community Involvement Processes. Washington, D.C. Government Printing Office, 1976 (p. 25).

Figure 17. CITIZEN PARTICIPATION IN THE TRANSPORTATION PLANNING PROCESS

Where interest is broad based, direct participatory techniques can predominate.

- The community's **attitude,** positive, negative, or neutral, toward the traffic problem. When a community has already developed an attitude, more sophisticated techniques may be required to assure fair consideration of all alternatives.

- The community's **cohesion** which greatly determines the ease with which consensus can be reached on a proper course of action.

- The community's **expectations of its role** in the planning process, which can determine what techniques they will accept and consider legitimate.

- The community's **past experience with citizen participation** and particular techniques.

- The community's **median education level** which can influence success of techniques heavily relying on certain skills, such as reading and writing.

In general, esoteric techniques should be avoided and the simplest techniques which seem likely to produce satisfactory results should be tried.

I. PROBLEM IDENTIFICATION AND NEEDS ANALYSIS

Elements of a Community Needs Assessment

The planning processs usually begins with citizen requests for action or with the professional's perception that a problem exists. In either case, the planner must gain a thorough understanding of the problem both in technical terms and from the community's point of view. With this background, a technical evaluation of need can be made to compare perceived problems with objective data that may or may not confirm the problem. Effective analysis at this stage of the planning process requires:

- **Searching for all possible points of view.** Attempts should be made to involve merchants, residents and commuters who will be affected by any plan.

- **Outreach to silent citizens.** Although outgoing and active citizens easily become involved, the vast majority of people, even though they have strong feelings on an issue, do not write letters to the editor, petition city councils or attend public meetings. If the community involvement process is to be effective and truly representative, it must reach out to these **silent citizens.** Early use of mass media, publicity and opinion surveys are good ways of gaining silent citizens' inputs at the start of the planning process.

- **Efficient utilization of citizen involvement or input.** Early involvement is vital to assure that the process is directed to citizen needs rather than following preconceived notions of officials. Citizen involvement must be sufficiently focused to provide useful input.

- **Proper weighing of viewpoints.** Recognition of different viewpoints and needs in the neighborhood should be acknowledged, as should determination of whether a vocal majority or minority is representing interested parties at public hearings/neighborhood meetings.

- **Sensitivity to special resident groups.** Residents most vulnerable to changes in traffic patterns include the elderly, handicapped and children. These groups are usually less vocal, less organized participants in the public or political process and their needs and concerns are different than those of other residents. Similarly, recognition should be given to different residential preference or lifestyle groups, e.g., those who spend a majority of their time at home versus those working during the day and who often seeking relaxation and enjoyment outside their home.

- **Sensitivity to perceived as well as measurable problems.** Traffic engineering as it is practiced on arterial and higher order facilities relies heavily on evaluation of objective and quantifiable data. On local neighborhood streets, a different approach is needed. Driver actions which citizens on local streets perceive as problems often "measure" to be quite normal when they are evaluated by arterial standards. The key to successful assessment of neighborhood traffic problems is to understand the residents' perception of the neighborhood, and to use measures which respond to the residents' perceptions and expectations.

- **Organized analysis program and relevant observations.** Resources can easily be wasted collecting large amounts of irrelevant data or conversely, critical data may be overlooked. Once the issues and individuals involved become clear, an organized approach to the needs assessment is essential.

- **Proper staff and resource support.** In the cities observed, technically oriented professionals often assumed responsibility for performing a needs assessment. While their technical input was complete and reliable, their handling of community participation was often ineffective or virtually nonexistent. Other specialists offering guidance in community participation, techniques such as surveys, interviews, presentations and meetings, should be relied upon.

Initiating the Needs Assessment

When should a formal needs assessment be undertaken? If the objective traffic statistics available or casual direct observation present direct evidence of a problem, there is clear indication that some sort to analysis should begin. However, the absence of such direct objective evidence in an initial screening is **not** a sufficient basis for concluding that no problem exists. Data customarily collected by traffic and planning professionals or the way they customarily analyze and interpret that data may not be relevant to the actual concerns of residents and other street users.

If a sizeable minority of residents or users of a block, street or area complain about some condition, or if a majority of people in a particularly vulnerable or sensitive group (i.e., the elderly, parents with young children) complain, **then there indeed is some kind of problem.**

Techniques and Measures for Problem Identification and Needs Analysis

Community needs analysis has two points of focus, resident conditions and traffic service conditions. Resident analysis assesses the needs, problems and impacts of traffic on residents, and other institutions sensitive to it. Traffic and services analysis assesses the needs and problems of all those who wish to have access to or through the area.

The traffic analysis and resident analysis act as mutual checks, ensuring that there are grounds for community concerns, that solutions will be relevant to residents' concerns and that basic transportation needs will be met. Taken together, they generate a "before" data base upon which performance of the "solution" eventually implemented can be evaluated.

Techniques used for **resident analysis** and **traffic service analysis** fall into five main categories: citizens direct inputs, traffic/service observations, environmental observations, observations of resident acitivities, and records. Table 4 presents a range of measures in each of these categories. The large number of measures reflects the diversity of traffic impacts and the limitations of individual measures. No single measure or small group of them is sufficiently comprehensive to reasonably relate to all of the issues of possible concern. And even where measures are relevant, reliability of the measure can be a problem.* Direct inputs of citizens are usually relevant but not necessarily reliable. Direct observations and records are usually reliable but not always directly relevant. For this reason Table 4 arrays measures by resident and traffic conditions each purports to assess, and rate each for relevance and reliability. The table also demonstrates why traffic counts are the most predominant measure in current use - volume counts are a highly reliable and at least somewhat relevant indicator on virtually every need issue.

The needs assessment should not become an immense data-bound project. Table 4 provides a basis for organizing an analysis plan so that only those measure relevant to the specific problem at hand are used. But data should be assembled not just for the apparent problem site but for the full area likely to be impacted by the problem or by its solution.

2. GENERATING ALTERNATIVE PLANS

The reasoned approach to neighborhood traffic issues recognizes the potential for more than one adequate solution. It also allows for orderly assessment of a variety of inputs, e.g., neighborhood groups, businessmen, traffic engineers/planners, and public officials.

In current practice, consideration of a full range of possible solutions may be the exception rather than the rule; i.e., needs assessment, definition of a solution, and implementation often are compressed to a single line of action. A neighborhood group may petition to City Hall that diverters be installed to discourage through traffic, and a resolution may be voted on and action mandated to the traffic engineering department - all within the course of one or two city council sessions. Whether such a course of action, undertaken with little or no technical analysis or citizen input, will succeed or fail depends on good luck and good intuition. Cities studied in the State-of-the-Art review exhibited mixed results under such circumstances.

The more conventional approach for analysis of alternative traffic control plans recognizes the need to accommodate a variety of inputs through a formal, and sometimes lengthy, evaluation process. Key elements of the alternative development process are:

- Strategic considerations
- Managing and arraying available data
- Developing the alternative plans
- Community involvement in plan development

Each procedure is addressed below.

Strategic considerations and data management techniques have been discussed

* A measure is said to be reliable if different people independently evaluating a condition or event consistently coincide in rating it.

TABLE 4
TECHNIQUES AND MEASURES OF ASSESSMENT AND EVALUATION

TECHNIQUES	MEASURES	QUALITIES MEASURED: RESIDENT NEEDS										TRAFFIC/SERVICE NEEDS		
		Safety	Children's Play	Walking, Cycling, Handicapped	Parking	Noise	Air Pollution	Appearance & Maintenance	Neighboring	Social Stability	Crime	Vehicular Access	Emergency Services	Other Services
CITIZEN INPUTS	resident needs/values	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑		
	satisfaction/disturbance	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑		
	suggested improvements	○	○	○	○	○		○	○	○	○	○		
	traffic needs/values											○	◦	◦
TRAFFIC/SERVICE OBSERVATIONS	traffic volume	•	•	•		●		•	•			●	•	•
	speed	•	•	•		●		•	•			●	•	•
	parking	•	•	•	●			•				●		●
	composition	•	•	•		●		•				•		
	safety, conflicts	•	•	•								•		
	obedience	•	•	•								•		
	access											●	●	●
ENVIRONMENTAL OBSERVATIONS	traffic noise					●								
	traffic safety conditions	●												
	street access										●	●	●	●
	walking, cycling & handicapped conditions	●	●	●										
	space analysis	●	●	•								•		
	visual quality							●						
RESIDENT OBSERVATIONS	street activities	●	●	●					●					
	walking, cycling & handicapped behavior	●		●										
	parking activities				●									
RECORDS	accidents	●	●	●										
	crime statistics										●			
	existing traffic counts	•	•	•		●		•	•			●	•	•
	census data									◦				
	land use data									◦				
	assessed values									◦				
	station and route inventories												●	●

● highly relevant and reliable
○ highly relevant, somewhat reliable
• highly reliable, somewhat relevant
◦ somewhat relevant and reliable
◑ highly relevant, reliability varies

Table 8
TECHNIQUES AND MEASURES OF ASSESSMENT AND EVALUATION

previously in this summary. Key facets of the other activities are reviewed below.

Developing the Alternative Control Plans

Solution schemes do not spring miraculously from a stack of data files or overlays. Developing solutions responsive to an array of problem conditions, and constraints of any complexity demands exercise of judgment and creativity by the planner. While the control strategies discussed previously provide general guidance, each alternative must be tailored to the peculiarities of the specific study area. It is inevitable that conflicts of values and needs with each other and with constraints will occur. The responsible planner must define a set of alternatives which reflect the full range of technical possibilities and trade-off choices between benefits and undesired impacts, roughly estimating what the gains and drawbacks will be as each alternative is evolved through trial and error. Once a set of alternatives is reasonably developed, a more formalized projection of each alternative's potential effects and trade-offs is prepared as input to selection of one for action.

Community Involvement in Plan Generation

The purpose of community involvement at this stage is to guide development of schemes which seem to respond to resident perception of needs and constraints and assure that residents' schemes are addressed in the analysis. Community involvement at this stage can range from residents taking full responsibility for developing their own alternatives to simply reacting to proposals developed by professionals. Either participatory process requires immediate clarification of the relationships and roles of professionals and different kinds and groups of public participants.

Communities observed in the State-of-the-Art review exhibited the full range of citizen involvement in generation of alternative plans-from almost nil to full responsibility.

While there is a definite heirarchy in the level of citizen involvement at the alternatives generation stage - and strengths and weaknesses in each approach - the State-of-the-Art review appears to indicate that community involvement at the needs assessment and plan selection stages has far more impact than community input to the alternatives generation process. Nonetheless, involvement of a broad range of actors at those stages appears a key to success.

3. PLAN SELECTION

In neighborhood traffic issues, selection of one of several alternative plans for implementation is inevitably both a technical and social/political process. Technical analyses help clear the potential impacts each alternative might have. However, the process of placing value on these impacts and weighing trade-offs is predominantly a social and political one. It involves individual citizens, neighborhood organizations and/or public officials. How these people perceive benefits and drawbacks of the alternatives ultimately has a large effect on what plan is selected. If the selection process is not carefully structured and technical information is not convincingly presented to the public, there is a good possibility that technical considerations which should not be compromised will be cast aside.

This section first presents guidance on technical information which should be available at the evaluation stage. It then presents, through illustrations from actual application, the various types of social/political selection processes which are possible. Individual planners must determine which techniques are applicable to their local resident and political situation.

Technical Inputs

The technical inputs needed to choose a neighborhood traffic management plan are primarily estimates of what changes are likely to happen relative to those qualities used originally to determine the needs of the neighborhood. In this sense, the selection process is a formal method of determining to what degree the needs will be met. But the technical inputs to plan selection must also attempt to estimate what other possible impacts (positive or negative) each alternative might have beyond its direct objectives. The technician's role at this stage of the process is to present for each alternative the best quantified or qualitative estimates for the measures listed previously in Table 4.

The measures listed and discussed in detail in the State-of-the-Art report are quite comprehensive and may not be needed in all applications. They are presented mainly as a checklist for the planner to use in determining those issues which he believes will be important in his specific case. In large part, the importance of issues will depend on site circumstances and the concerns of those who are involved in the selection process, and at what point in the process they are involved, as illustrated below.

Community Involvement in Plan Selection

At this stage, community involvement must serve several purposes: to draw out citizens who won't participate until confronted with specific plans, eliminating the chance for "no one told me" arguments; to provide opportunity for all needs and constraints to be taken into account, to let the citizens decide the social trade-offs between alternatives, and to select a plan which has reasonable consensus or community support while meeting technical conditions and constraints. Normally, plan selection is a two phase process. In the **preparatory** phase the community develops a consensus. In the **decision** phase, officials confirm (or reject) the community's choice.

Preparatory Phase to Decision Making. Citizen participation may vary in form from **citizen review boards,** where a small number of participants represent the whole neighborhood or community, through **surveys, public meetings,** and **formal public hearings,** to, in rare cases a **citizen referendum** where the affected electorate formally votes on a plan. The key issue is the degree to which the agency, the community, and elected officials agree to be bound by the results.

A problem common to this stage of the planning process is effective dissemination of details of plan alternatives and their projected impacts. Media announcements and articles (newspapers, radio and TV), posters at prominent locations and leaflets mailed out or distributed door-to-door, can be effective.

Decision Making. Ultimately, most community decision making is finalized at the city council level (or equivalent elected body). While the council is the ultimate decision-making body, what goes on before usually has strong impact on which alternative is selected and its likely eventual success.

If the decision process is truly initiated only at the council or Planning Commission level, virtually anything can happen. A well-organized interest group with political clout can gain their way, leaving important technical considerations and the legitimate interests of the other residents and travelers ignored. Or, as more often happens, public inputs give officials nothing more than a sense of bitter conflict, leading officials to choose to do nothing or to decide issues on the basis of narrow technical findings.

Decision making by an official board works best when a consensus of citizens and technicians has beeen reached to support a single alternative prior to consideration by the council. In essence, this depends on an already established process, either formal or informal, which is recognized as having status by the board. The official body's decision-making provides both an affirmation by authority of the prior work and a point of last appeal for those who oppose the recommended alternative.

4. IMPLEMENTING DECISIONS

Once the traffic plan has been adopted by an official political body and funded, staff must proceed with physical act of installing the planned devices. While implementation may seem straightforward - most city public works or traffic departments have the resources, possibly with contractor assistance - implementation actions can have critical effect on the success or failure of the plan. This section reviews some of the significant implementation issues.

Permanent Versus Temporary Controls

There is widespread disagreement among practitioners as to whether temporary or permanent devices should be used in initial installations of diverters, semi-diverters, cul-de-sacs, circles and any other devices involving substantial construction. In complex traffic management schemes, it is inevitable that modifications will prove necessary after the schemes are implemented. Temporary devices provide flexibility for such modification. Since they normally cost less than permanent installations, an entire program can often be implemented immediatly with temporary installations even if funds are short. Individual installation can then be upgraded after they prove successful and as funds become available. On the negative side, foreknowledge of the ease of modification may lead to incomplete planning. Because of the devices' inherent impermanence, issues are never truly settled. The ready possibility of change encourages opponents to continue the controversy and leads other who might prefer limited modifications to join the agitation. In addition, use of temporary devices appears to raise greater potential for court challenges on the basis of alleged non-conformance to traffic control device standards.

As for immediate permanent installations, the very nature of their permanence seems to command more driver respect; hence better obedience and less vandalism. Residents readily accept permanent landscaped devices as enhancements to the beauty of their neighborhood whereas temporary materials are often regarded as eyesores. Because permanent installations involve sizeable funding commitments, professionals and the public hopefully ensure they have the "right answer" before deciding on a solution.

Choice between immediate permanent implementation or initial use of temporary devices should be based on the individual community's situation. In general, temporary installations might be favored in cases where plans are extensive and complex (where the possibility of some planning error is high) and/or where funds are short. Where temporary devices are selected, careful attention to their attractiveness and conformance to traffic control and design standards a must and a future committment to make permanent those devices which prove themselves should be made clear.

Incremental Versus One-Step Implementation

Devices in individual neighborhoods should be constructed or erected as nearly simultaneously as available resources permit. But if the plan encompassess a large district and involves a significant number of devices, should it be constructed as a single short-term activity? Or is an incremental neighborhood approach more realistic?

The incremental approach allows staff to devote more attention to the details of individual installations and to assure that all necessary construction materials are on hand.

With the incremental approach, lessons learned in "early action" neighborhoods can be applied citywide and repetition of mistakes avoided. Yet the incremental approach leads to a lengthy period of turmoil as traffic adjusts and readjusts to a continuing series of changes in street conditions. And public reactions to temporary adverse impacts of an early implementation increment can derail a plan at the outset even though a later staged step would have eliminated the impact. On the other hand, massive changes in traffic conditions resulting from several programs implemented at once can unite a large opposition. The planner must carefully review the individual situation to judge whether an incremental or one-step implementation approach is most appropriate.

Timing

Another helpful installation hint is to install devices at a time when the least number of drivers is likely to be around. Where possible, take advantage of the "off-season" in a summer or winter resort or tourist area and of summer vacations in a campus town. In this way, year round residents will have a chance to adjust to the changes during off-peak traffic conditions while part-time residents and visitors will be confronted with a fait ccompli when the arrive. While not all communities have the advantage of an off-season for traffic, the converse to the principle applies everywhere - avoid implementation in peak traffic seasons (like Christmas shopping season near downtown and shopping centers).

Publicity

Publicity about the adopted plan's features and its construction schedule are important components of implementation. Frequently, residents and motorists are rudely surprised by abrupt changes in their street system.

The immediate result can be erratic and illegal behavior such as dangerous driving maneuevers or out-right vandalism. In cases of large-scale plans involving barrier devices, maps showing features of the plan and its construction schedule should be distributed to residents, to commuters at their places of employment and to all firms operating routed services and deliveries in the city. Notices warning of traffic control changes and dates of construction should be prominently posted on the control sites several days before construction takes place. Where barriers are to be constructed on internal neighborhood streets, similar warning notices should also be posted at the neighborhood entry points and left standing for at least a week after construction is complete.

Favorable First Impressions

When the first sign of a scheme is obstrusive and ugly without apparent purpose, people naturally react against it. Efforts to present an attractive appearance, even with the low budget temporary devices, are rewarded. The extra cost of **mature** landscaping may be money well spent. Devices initially perceived as ugly may be removed before landscaping has a chance to mature.

Early Surveillance and Adjustment

Planners and engineers should anticipate the inevitable adverse reactions that accompany the installation of traffic control devices. Almost every city contacted experienced some unfortunate experience, ranging from illegal driving maneuvers to out-right vandalism. Professional staff should be on the scene to observe deviant behavior in first-encounter reactions, to note if any design features are its cause and if design modifications can provide a countermeasure to unsafe or purpose-defeating behavior.

Additional police surveillance during the period immediately following installation helps discourage erratic or illegal driving behavior and vandalism. The period of intense first-encounter reaction usually lasts no more than a week or so. After that time, drivers have adjusted their routes sufficiently to avoid the inconvenience caused by the new system.

Committment to Specific Evaluation Period

While minor adjustments as a result of early surveillance findings are possible, a commitment to a specific evaluation period before major changes in the scheme are made should be established. This allows time for traffic and residents to adjust patterns, and for tempers to cool and permits evaluation to be based on longer-term performance rather than initial reactions.

Community Involvement in Implementation

Community involvement at this stage is passive, e.g., citizens receiving information on how plans will be implemented. The technical staff assumes the duties of informing the citizens of plans and schedules to minimize surprises. The continuing **public meetings** or **public information program** can serve as techniques to notify the public - particularly those susceptible to change or negative impacts - of the implementation schedule and work-in-progress plans if construction is needed. Negative reaction to any neighborhood traffic management project may result from residents being taken by surprise by actual implementation activities.

An information process is also useful for identifying problems created by work in progress.

5. EVALUATING THE CONTROL PLAN'S PERFORMANCE

State-of-the-Art Observations

Thorough evaluations of how neighborhood traffic control measures actually perform in use are the exception rather than the rule in current practice. In most cases, if the devices implemented have the effect of silencing the original complaintants and no significant opposition surfaces or serious operational problems result, the program is normally judged to be a success. If the complaintants are not satisfied or substantial opposition does arise, no significantly greater efforts are normally made to collect hard data; the scheme is simply judged a failure.

If decisions can be made so simply, why evaluate? For one reason, evaluation of technical performance and community perceptions is needed to provide an unbiased basis for decisions as to whether a plan is kept or abandoned. Actual performance and impacts are often quite different from what opponents may believe or claim. Public reaction is often shaped by first impressions and observation of erractic initial performance characteristics. An evaluation can clarify issues, bring the more stabilized long-term performance characteristics into focus, and spotlight "hidden" gains and losses which may be significant.

Secondly, evaluation makes modifications possible. Decisions made without evaluation are typically all-or-nothing; retain the scheme or abandon it. Evaluation can point to opportunities for modifying a scheme to make it perform its intended function better or to lessen adverse impacts. It can also be used to determine if the plan should be expanded both in terms of devices and geographical area. Finally, only when evaluations are conducted will there be true growth in the State-of-the-Art in neighborhood traffic control. So little is known today, not because measures haven't been tried, but because the measures which have been applied have not been evaluated sufficiently.

Evaluation Techniques

Most of the measures described in connection with Needs Assessment shown in Table 4 are relevant to evaluation. Basically, measures taken during that planning stage constitute "before" conditions which can be compared to parallel measures of conditions "after" implementation to determine changes resultant from the control scheme. The conduct of the "after" measures and the comparisons comprise the evaluation. In addition, evaluation includes consideration of other data measures not studied in the assessment stage. Some of these measures may be relevant solely on an "after" basis (such as incidents in which traffic controls interfered with emergency vehicle operations); others involve "before" and "after" comparisons of information which was not relevant as an assessment tool but is affected by the plan (e.g., changes in residential property values). In preparing for before and after studies, analysts should take care that all important measures of perishable "before" conditions do get taken, even if some of these are not needed or useful in the initial program planning.

Community Involvement in Evaluation

Public inputs to the evaluation are obtained by continuing an active community involvement process. The public can be helpful in providing feedback on their perception of how well the plan is working, details of problems, possibilities for improvement and any aspects overlooked in the initial planning process.

To evaluate in detail the acceptability - both positive and negative - of the project usually requires a more structured approach in the form of a survey or special neighborhood meetings where questions and reactions can easily be focused and addressed to all concerned groups and individuals.

Timing

In conducting the evaluation, three to six months after implementation should be allowed before "after" data measures are taken. This gives residents and motorists time to become familiar with the controls and make adjustments. With this interval, the "after" measures will be of stabilized reactions rather than first-encounter responses. For this same reason, three to six months would appear to be the reasonable period for application of experimental devices. In explicit experiments, a fixed period for application of the devices should be firmly committed in advance.

This focus of the formal evaluation on stabilized long-term effects is not to suggest that first-encounter responses and early reactions should be ignored. These should be carefully observed from the start so that countermeasures to any serious safety problem or obvious defect can be quickly implemented.

6. MODIFICATION AND RECYCLING THE PROCESS

Minor modification to a neighborhood street's protection plan is a common occurrence. Most modifications are physical changes to individual devices or application of a standard change to all devices of a particular type. Usually such changes are minor measures intended to improve the devices' operation, eliminate some hazardous condition or counter some deviant driver behavior. Most are undertaken by professionals on the basis of their own observations without any extensive formalized review process.

More important are situations where a plan is successful enough that abandonment is not a consideration, but its performance falls short of its intended objectives or it has some undesired side effects. Here significant modifications may be considered to fine-tune the plan.

The evaluation stage doubles as a needs assessment for such modification. In modifications of this nature, which usually relate to a multi-device plan for a sizeable area, on some sites one type device may be substituted for another, some devices may be eliminated entirely or devices may be added, reoriented or shifted from one location to another. Normally, this type of modification involves a mini-version of the analytic and participatory processes used in needs assessment, alternatives development and selection. Because of all that has gone before, the actual activity can be extremely compressed in time and scope, though modification planning should be as thorough and deliberate as the original plan development.

When a plan in deemed to fail irretrievably, "recycling" can occur. In essence, the scheme tried is abandoned and the problem is either returned to the alternatives development stage for a fresh approach or one of the previously dismissed planning alternatives is resurrected for implementation. In actual practice, when neighborhood traffic control schemes have failed, the process involved so much controversy and acrimony that there has been no energy or enthusiasm for a "recycling" process. Calls for modification and recycling can continue years after initial installation.

CHAPTER 3
RESEARCH ON ROAD HUMPS

Overview findings in the state-of-the-art search led to interest in the potential for applying the TRRL road hump, an elongated form of speed bump, on U.S. streets. A major portion of the Phase Two research was devoted to such an effort. Phase Two research on the humps included the following activities.

Further direct communication was established with TRRL researchers and details of their installations, site selection procedures, monitoring procedures and other points not covered in published reports were conveyed. Most recent reports on TRRL's public street tests of the device in Great Britain were obtained and reviewed.

Tests of the device on a closed-site were conducted in St. Louis, Missouri. Further closed-site tests, conducted independently by the City of Sacramento, California, were monitored by the research team.

Local jurisdictions were solicited to participate in public street case study applications of the device. Two public streets in Boston, Massachusetts and one in Brea, California, were selected as case study sites. An additional case study site in Washington, D.C. was selected but implementation did not take place early enough for monitoring in this research program. A public street case study application conducted independently by the City of Sacramento was monitored by the research team. Details of all the foregoing are presented in the sections which follow.

WHAT IS A ROAD HUMP?

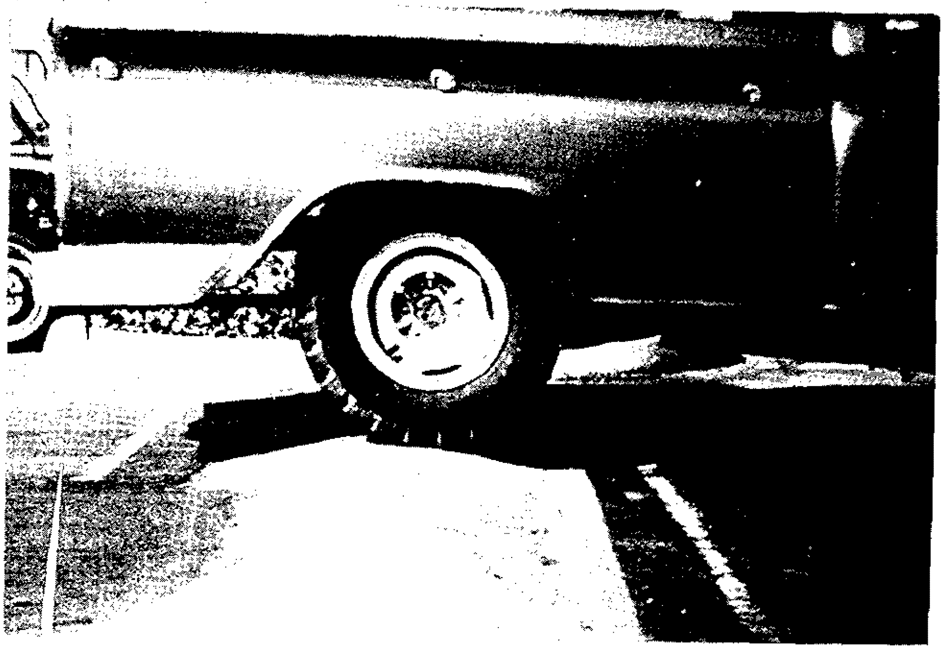
Although "road humps" and "speed - bumps" are discussed in Chapter 2, it is useful to reiterate their characteristics here. A road hump, also known as an "undulation" or a "sleeping policeman" in the literature, is a device intended to control traffic speed. Undulations were developed in research conducted over the last decade by the Transportation and Road Research Laboratory in Great Britain. In order to characterize the road hump, it is useful to define "conventional speed bumps" as well.

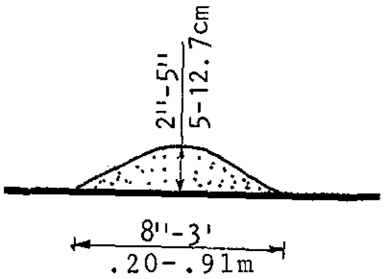
Undulations and speed bumps are raised humps in the pavement surface extending transversely across the traveled way. Length in direction of vehicular travel and specific height distinguishes undulations from conventional bumps. Conventional bumps are abrupt humps, normally less than 3 feet (.91m) in length, varying in heights of up to 5 or 6 or more inches (12.7 -15.3cm) and varying cross section slopes. Undulations are more gradual humps with a length of 12 feet (3.65m), a height of 3 or 4 inches (7.5 - 10cm) and a circular arc cross section. Figure 18 contrasts road humps and conventional bumps. Conventional speed bumps produce greatest driver discomfort (hence, speed control effect) at very low speeds, with discomfort decreasing or disappearing at moderate and high speeds. They appear to have potential for producing vehicle damage or loss of control. They also tend to dislodge gear and pose dangers to personnel riding the exterior of fire apparatus. For these reasons the use of conventional speed bumps has been discouraged.

Road humps appear to be free from (or minimize) the above performance defects of the conventional speed bump. In fact, they were designed with this specific intent as a result of the acknowledged deficiencies of conventional humps. Performance characteristics of road humps are detailed in the sections which follow.

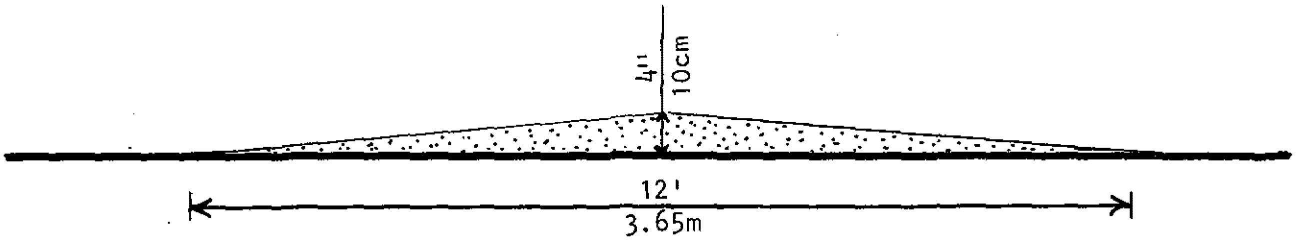
SUMMARY OF ROAD HUMP RESEARCH BY TRRL

In the early 1970's, recognition of the





Conventional speed bump.



Road hump.

Figure 18. SPEED BUMPS AND ROAD HUMPS

deficiencies of conventional speed bumps and of the need for a device to discourage motorists from traveling too fast along certain streets led Transportation and Road Research Laboratory to initiate an attempt to develop a more effective speed control hump.

TRRL researchers theorized that the principal problem with conventional humps was their abrupt shape. The short, abrupt shape leads conventional humps to administer a sharp jolt as each axle passes over the hump. The sharpness of this jolt is what causes much of the potential for vehicle damage, loss of control and dislodgement of personnel. At very low speeds, much of this jolt is transmitted to the driver. But at higher speeds, the sharpness of the jolt is absorbed in deformation of tires and suspension rather than in deflection of the vehicle's sprung mass, thereby limiting the discomfort to drivers (a primary speed control factor). Hence, the abrupt shape punished the very slow drivers while detering the faster ones only by the potential for vehicle damage. It was further theorized that longer humps which administered vertical force over a longer hump crossing time would result in vehicle body deflection (hence driver discomfort) rather than tire and suspension deformation and that maximum discomfort would be experienced at higher speeds rather than extremely low speeds. It was also believed that the longer ramp effect would eliminate the conventional humps' problem of low slung vehicles bottoming-out.

Operating on this theory, TRRL conducted test track experiments on a variety of hump shapes, subjecting each to test runs over a range of speeds by vehicle types ranging from a moped, several sizes of autos, trucks and buses through an articulated truck-trailer rig. As a result of this test track research, TRRL identified the hump shape shown on Figure 18 as most suitable for application on residential streets with 30 mph speed limits.(15)

The next step was public street case study applications on five residential streets in Great Britain. These were conducted between 1975 and 1978, after measures on each being conducted about 10 months after hump installation. Principal findings in these public street case studies (16) are as follows:

- The humps had significant speed control effects. There was a consistent reduction in vehicle speeds at all sites. Eighty-fifth percentile speeds at the fastest points on the five streets ranged between 30.1 and 39.8 mph (48.4 - 64 kmph) before installation. After hump installation, 85th percentile speeds at the fastest points ranged between 21.9 and 27.2 mph (35 - 27 kmph). Mean speeds over the entire test segments (which ranged from almost a quarter-mile to over a half-mile in length and usually included several intersections) dropped from a range of from 22.7 to 30.1 mph (36.5 - 48.4 kmph) before installation to a range from 14.0 to 16.8 mph (22.5 - 27 kmph) after installation. Eighty-fifth percentile speed on actual hump crossings was 14.3 mph (23 kmph) for light vehicles and 12.5 mph (20.1 kmph) for heavy vehicles. Before the humps were installed, a large proportion (at some sites over 50 percent) of the drivers were exceeding the 30 mph (48

15. Watts, G., Road Humps For the Control of Vehicle Speeds, Department of the Environment, TRRL Report LR597. Crowthorne, 1973.
16. Sumner, R., and Baguley, C.. Speed Control Humps On Residential Roads, Department of the Environment RRl Report 878, Crowthorne, 1979.

kmph) speed limit. After installation, less than 5 percent of the drivers did so. Before installation, many vehicles exceeded 40 mph (64 kmph); afterwards, none exceeded 35 mph (56 kmph).

- The humps induced substantial traffic volume reductions. Volumes on test streets decreased from 25 to 64 percent with an average reduction of 35 percent.

- The humps resulted in traffic noise reductions of 2 to 6 dB(A) measured at the housefronts (18 hour L_{10} readings). Noise reductions are attributable to traffic volume reductions as well as to speed reductions.*

- Substantial decreases in accidents were experienced on the test streets. Two midblock accidents and 9 intersection accidents were experienced; 10.1 and 17.8 respectively were expected.** This difference (11 versus 27.9 total) is reported to be statistically significant at the 0.1 percent level. Increases in accidents over those expected on surrounding streets were reported not statistically significant.

- No significant vehicle damage resulting from the humps was reported although 4 individuals made unverifiable claims that repeated driving over them had worn out their shock absorbers. During the test period an estimated 20 million hump-crossings occurred. Some scarring of some hump surfaces was noted. Since the TRRL track tests using an assortment of vehicles had failed to produce "bottoming-out" under any conditions of speed or loading, the scars were attributed to overloaded vehicles with defective suspensions crossing the humps at high speed.

- No incidents involving serious disruptions to emergency services were reported. Fire and ambulance service officials disliked the humps but could site no specific instances of hazard to safety of emergency vehicle occupants or serious impediment to their operations. All police authorities agreed the humps significantly reduced speed and reported no unacceptable operational delays for police vehicles.

THE ST. LOUIS AND SACRAMENTO CLOSED-SITE TESTS

The results of the TRRL work convinced this research team and FHWA that the major case study work of the second phase of this project should be devoted to applications of the undulation device. But before applying the device on

* These results contrast with prior findings on U.S. tests (17,18) of speed bumps which measured only the sound of vehicles at the hump site and did not consider the effect of changes in speed and volume which the humps induce.

** Expected accidents are computed by multiplying the average on the test segments for the prior 4 years by a factor calculated from the numbers of accidents over the same periods on all similar roads in the general area of each test site.

17. Walsh, L.B., Op. Cit., See Reference 1

18. Seattle Engineering Department, Speed Control Test of Raised Crosswalks, Rumble Strips, and Checkerboard Pavement, 1978.

public streets in the U.S., the researchers wished to satisfy themselves first-hand of the device's fundamental safety characteristics as reported in the TRRL results. Particularly with reference to safety-related factors, they wished to confirm that vehicles in common use in the U.S. performed on the humps in substantially the same fashion as vehicles in common use in Great Britain (simulation work performed at the University of Michigan had already provided theoretical confirmation of this). (19) To do this, the team conducted a closed-site test track procedure similar to the orignal TRRL test track work and to the well publicized San Jose, California tests of speed bumps. (20) The City of St. Louis, Missouri, which was interested in the undulations, provided the site, vehicles and personnel to assist in the testing and constructed the hump. A range of vehicles (types and characteristics are listed in Table 5) were tested on a hump constructed to correct TRRL dimensions at speeds ranging in 5 mph (8 kmph) increments from crawl speed to 35 mph (56 kmph) for all vehicles and to whatever higher speed above that each vehicle could attain on the test site (speeds up to 70 mph (113 kmph) for some vehicles were attained).* On each run, vertical displacement, lateral displacement, whether the vehicle actually became airborne, noise level as the vehicle neared and crossed the hump, actual speed at the hump crossing, driver perceptions of control and safety, and driver and passenger perceptions of discomfort were monitored.

Key findings of the St. Louis tests were as follows:

- The undulation did not appear to pose any significant safety problem to passage of automobiles at speeds up to 70 mph (113 kmph). A full range of auto types from subcompact through luxury sedans were tested. No test drivers reported any meaningfull control problems. No incidents of automobiles becoming airborne, bottoming-out or deviations in alignment (swerving) were observed.

- The rear wheels of motorcycles tended to become airborne for a brief instant at speeds above 25-30 mph (40 - 48 kmph) but operators reported absolutely no problems with control on any of the test runs which included speeds up to 49 mph (79 kmph). No problems were observed with a 10-speed bicycle and its operator reported absolutely no control problems at speeds up to 20 mph (32 kmph).

- Long wheelbase vehicle operations were generally safe although the impact of humpcrossing on them was considerably more severe than on automobiles at moderate to high speeds. The rear wheels of the dump truck became airborne and the driver reported moderate control difficulty at speeds above 28 to 33 mph (45 - 53

* Run-up distance available on the test site generally limited the speeds heavy vehicles (fire trucks, bus, dump trucks) were able to attain on approach to the hump to under 45 mph (72 kmph). It was reasoned that this was likely to be the maximum speeds such vehicles might attain on streets where the humps were apt to be used.

19. Post, T.M., and Bernard, J.E., Response of Vehicle to Pavement Undulations, University of Michigan, 1976.

20. Walsh, L.B., Op. Cit., See Reference 1

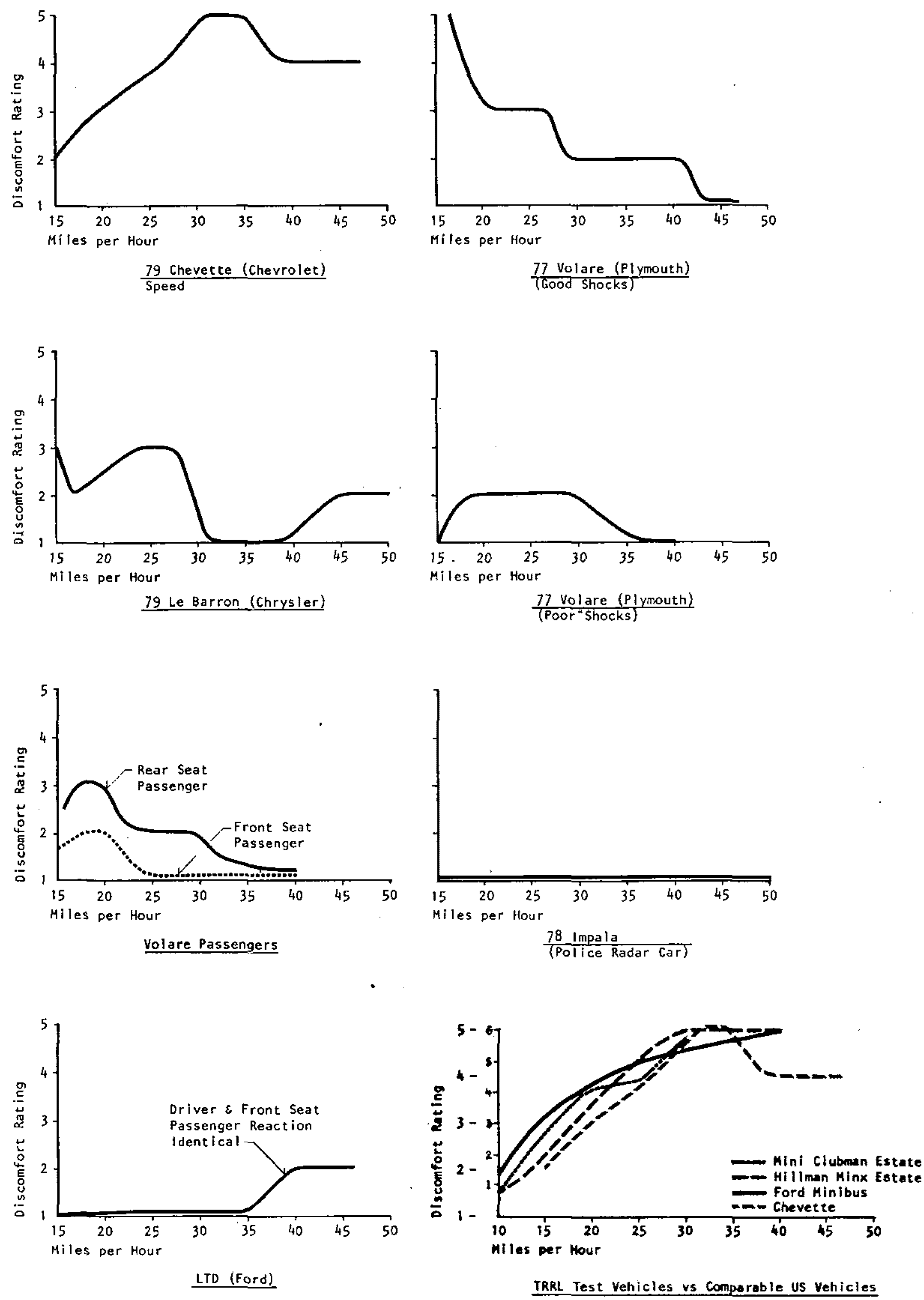
TABLE 5
TEST VEHICLE ROSTER

Vehicle	Wheelbase Inches	(m)	Undercarriage Clearence Inches	(m)
1979 Chevrolet Chevette	95.	(2.41)	6.5	(.16)
1977 Plymouth Volare	110.	(2.79)	8.5	(.21)
1979 Chrysler Le Barron	115.5	(2.93)	9.0	(.23)
1978 Ford LTD	125.0	(3.17)	7.0	(.18)
1978 Chevrolet Impala	116.5	(2.96)	3.75	(.10)
1974 International Tandem Dumper	124.0	(3.15)	19.0	(.48)
1977 Segrave Articulated Snorkle	234.0	(5.94)	10.0	(.25)
1977 Rowe Pumper	183.0	(4.65)	15.0	(.38)
1977 Flexible Bus	293.0	(7.44)	8.0	(.20)
1973 Harley Davidson 3-Wheeler	67.0	(1.76)	5.5	(.14)
1971 Harley Davidson Motorcycle	62.0	(1.57)	4.0	(.10)
1976 Honda 750 Motorcycle	59.0	(1.50)	5.5	(.14)
Windsor 10-speed Bike	38.25	(0.97)	-	

kmph). The ambulance van never became airborne and its driver reported no control difficulty at speeds up to 46 miles per hour (74 kmph). The snorkel ladder truck (fire truck) wheels became airborne at speeds above 25 mph (40 kmph) but its operator reported absolutely no control difficulty at speeds up to 34 mph (55 kmph). One inadequately secured piece of gear-a wheel-chock was dislodged from its storage place at the rear of this vehicle at speeds above 25 mph (40 kmph). The rear wheels of the fire pumper became airborne above 20 mph (32 kmph) and its operator reported moderate control difficulty at 34 mph (54 kmph). Rear wheels of the transit bus became airborne at speeds above 25 mph (40 kmph) but its operator reported absolutely no control difficulty at speeds up to 37 mph (60 kmph). (Maximum speeds tested for these heavy vehicles were not limited to safety considerations; they were simply the fastest speeds these vehicles were capable of achieving on the test site. It was reasoned that these speeds were about the maximum that these vehicles might achieve on the types of residential streets along which the humps might logically be employed.

- No vehicles were observed to "bottom-out" on any of the test runs.

- Discomfort perceptions reported by automobile drivers were somewhat disturbing to the research team because they did not conform entirely to the team's expectations based on the TRRL reports. As expected, virtually no discomfort was perceived by auto drivers below about 20 mph (32 kmph) while between 20 to 30 or 35 mph (32-48-56 kmph), drivers and passengers perceived discomfort levels which they reported would likely induce them to slow down. However, at speeds above 35 mph (56 kmph), discomfort perception decreased to levels similar to those experienced below 20 mph (32 kmph). This decrease in discomfort at high speed was not emphasized in the TRRL reports and led to research team concern that the phenomena might lead some drivers to go faster rather than slower. Figure 19 presents



1mph = 1.6093kmph

Figure 19. DISCOMFORT PERCEPTIONS - AUTOMOBILES

patterns of discomfort experienced in passenger autos. Also shown on Figure 19 are discomfort ratings in the TRRL Test versus the most closely comparable U.S. vehicle.

- In long wheelbased vehicles, discomfort was experienced in a similar pattern to that of automobiles but over a broader range of speeds and maximum discomfort perceptions were somewhat higher. Discomfort levels reported for long wheelbase vehicles are shown on Figure 20. Most pressing concerns were expressed for patient and attendant in the rear of the ambulance and for passengers at the rear of the bus.

- Motorcyclist discomfort, shown on Figure 21, tended to plateau at high speeds. The apparent decrease in discomfort at high speeds observed in autos was not evident with motorcycles.

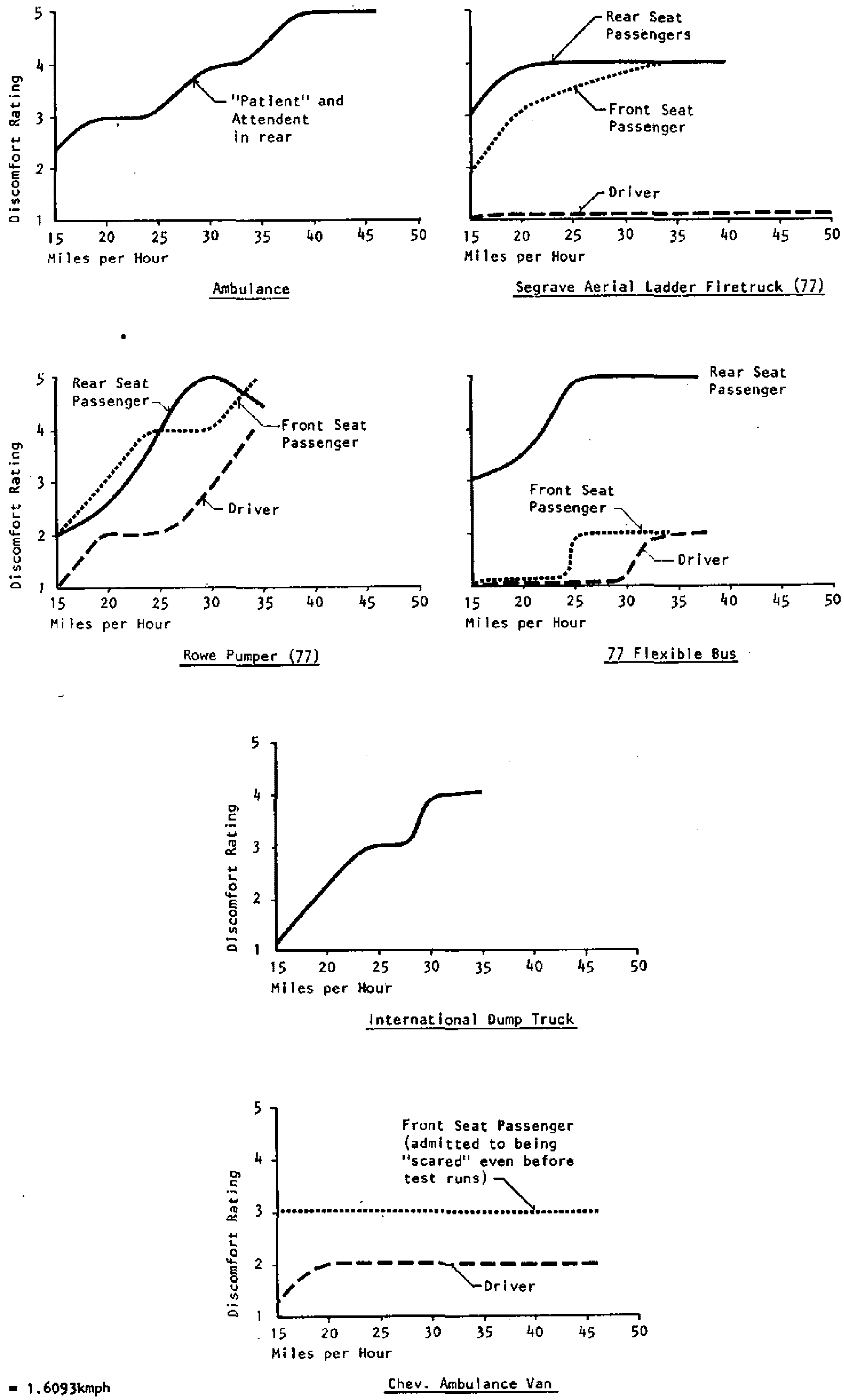
Although the principal purpose of the test was to assure all concerned that the device was sufficiently safe to employ in a public street test, not to test its speed control potential, the driver and passenger discomfort measures do have substantial relationship to likely speed reduction potential of the device.

The City of Sacramento, California, had become interested in the TRRL undulation device by directly obtaining materials from TRRL and through a general awareness of activities on this contract but initiated their experimental activities independently. An undulation was constructed to TRRL specification and after a limited set of preliminary test runs, the Sacramento engineers concluded a single hump did not pack enough force to effectively slow auto speeds. This intuition was based on the perception of a drop off in discomfort effects above the 35 mph (56 kmph) range similar to that noted in the St. Louis test. As a result of this observation, the Sacramento engineers concluded that the humps needed to be relatively closely spaced to have speed reduction effectiveness and resolved to conduct their formal experiments on closely spaced patterns of humps.

Sacramento eventually determined to test two hump sequences, each involving 3 humps. One had 3 standard TRRL undulations with 20 foot (6.1m) separations (nearside to nearside); the second had a standard TRRL undulation followed by two smaller undulations, each 8 feet long, 3 inches high (2.45m by 7.5cm) separated by 12 feet (3.65m) spaces (nearside to nearside).

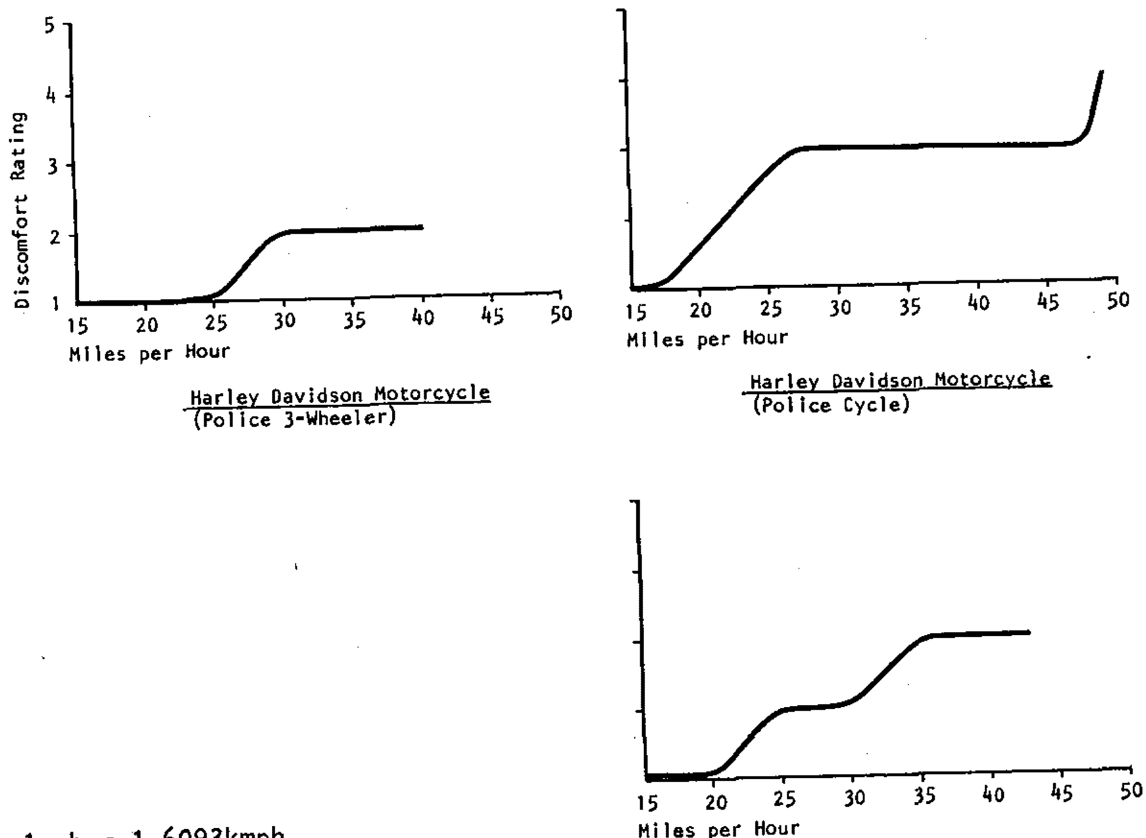
Sacramento tested roughly the same array of vehicles as were observed in St. Louis. The main deductions which can be drawn from the Sacramento tests are:

- For automobiles, discomfort effects occur for a longer period of time with the series than with the single undulation and may be somewhat more intense. But the basic pattern of perceived discomfort - minimal below 20 mph (32 kmph), pronounced between 25 and 35 mph (40 and 56 kmph), and minor above 35 mph (56 kmph) - was quite consistent with the pattern observed for the single undulation. The visual appearance of the series of undulations was judged to be significantly more intimidating to drivers than that of the single undulation. The series did cause one empty milk bottle in a carton of empties in the back seat of a Volkswagon to clink hard enough against another to break. These bottles had reportedly traveled in that position for several months previous without mishap.



1mph = 1.6093kmph

Figure 20. DISCOMFORT RATINGS - LONG WHEELBASE VEHICLES



1mph = 1.6093kmph

Figure 21. DISCOMFORT RATING - MOTORCYCLES

- Bicyclists and motorcyclists appeared able to handle the series well and the series appeared not to have effects significantly different from those of the single undulation.

- Effects on long wheelbase vehicles were similar to those observed in the St. Louis test of the single hump, with the multiple hump appearing to accentuate the effects somewhat.

- One vehicle utilized in the Sacramento tests which was not tried in St. Louis was a garbage truck. The research team's observer rode the rear footboards of the vehicle and was satisfied that this position was "safe" at speeds typical of collection operations during which personnel ride in this exterior position. But at speeds above 25 mph (40 kmph), the observer judged it unsafe to remain in the exterior position.

Interpretation of Results

The fundamental purpose of these closed - site tests was to assure that the humps were safe enough to use in a public street case study. The St. Louis and Sacramento work satisfied the research team that the humps were sufficiently safe to undertake public street case studies of them. It was concluded that any difficulties they posed were no worse that those caused by potholes, excavation patches and other irregularities in pavement occasionally encountered on normal roadways. It was further concluded that careful site selection, hump markings and instruction of emergency vehicle drivers would also help preclude any substantial difficulties involving long wheelbase vehicles.

But the tests, in particular, the decreased perception of discomfort in autos at high speeds, raised considerable doubt as to whether the humps would be effective in controlling speeds.

The reseachers first satisfied themselves that the test humps were accurate reproductions of the TRRL shape. Regarding whether the differences in discomfort observations were the result of differences in suspension characteristics and wheelbase of U.S. and British automobiles, it was concluded that wheelbase and suspension differences were a factor but not a fundamental explanatory one. The U.S. tests had included vehicles similar to the TRRL work. Suspension stiffness and wheelbase differences among autos appeared to affect details rather than the fundamental shape of the discomfort curve. With stiffer suspensions and shorter wheelbases, the dropoff in discomfort perception appears to occur at slightly higher speeds than for vehicles with "mushy" suspensions and longer wheelbases.

Finally, the original TRRL experimental data and reports were re-examined. It was found that many more runs above 30 mph (48 kmph) were made in the U.S. tests than in the TRRL work. It was concluded that as a result of the concentration on high speed runs, the St. Louis and Sacramento tests had identified a phenomena not noted in the British test work.

Still the question remained, would the humps be effective in slowing traffic on U.S. residential streets? It was concluded that this could only truly be answered by performance in U.S. public street case studies. Rationalization leading to this conclusions was as follows:

- The results of the TRRL public street applications are a far more valid indicator of how the public will react to the humps than are the impressions of drivers in a controlled-site test. The after-the-fact impressions of a test driver who drove over the humps at a pre-specified high rate of speed in a fleet vehicle do not necessarily correlate with how fast members of the general public will choose to go over the humps in their own cars.*

- Substantial speed reductions were unquestionably achieved in the TRRL public road tests. The vehicle mix in these applications doubtless included a substantial percentage of vehicles with wheelbase and suspension systems characteristic of those in use in the U.S.

- The humps look ominous to drivers and the discomfort experienced at moderate speeds is not likely to tempt members of the general public to attempt a faster pass on their own. Strategic placement of the first hump close enough to the "entry" to the speed control section that vehicles will not have had the opportunity to accelerate to speeds above the maximum discomfort range can limit the opportunity of the public to learn they can minimize discomfort by going very fast.

THE BREA CASE STUDY

The City of Brea, California became the site of the project's first U.S. public street case study application. Brea is an upper middle class suburban community in north-central Orange County. The city's Manager had previously observed the TRRL undulations in Great Britain and, learning of this FHWA research program, had volunteered the City as a test site.

The Site

Four streets where resident complaints about speed had been substantiated by radar studies were offered as potential case study streets. Of these, La Canada, which happended to have the most extensive record of resident complaints about speed, was sélected. The primary factor in selection of La Canada was that it was relatively flat while the other complaints all had fairly substantial grades. In this first public street case study, it was felt prudent to confine the application to a reasonable level segment. A secondary factor was that prior studies by the City showed that it did indeed have a speeding problem -- 85th percentile speed 38 mph (61 kmph) and many vehicles in the high - 40's range (64 kmph) on a 25 mph (40 kmph) speed limit street.

The test segment on La Canada is a quarter-mile local residential street set in a semi-grid network (generally rectilinear layout but some links of grid missing and some curvilinear elements included). La Canada is approximately 39 feet (12m) wide curb to curb with one travel lane in each direction and parking permitted and moderately utilized on both sides. There are sidewalks on both sides of the streets. Few pedestrians are ever observed but bicyclists are not unusual. Horizontal alignment on the en-

* This is a point which has not been properly considered in other tests of speed bumps. Anyone who has ever observed members of the general public crossing a conventional speed bump must seriously question the conclusion of the previously cited San Jose (21) research that bumps are "ineffective" because discomfort decreases with speed. Rare is the driver who chooses to go fast enough to take advantage of this.

21\. Walsh, L.B., <u>Op. Cit.</u>, See Reference 1 tire proposed test section is straight though the approaches to it are right angle curves. The quarter mile test segment has a continuous slope from north to south of less than 1 percent. The approach curve at the north end has a considerably steeper slope toward the test segment, probably contributing to the observed speeding problem by accelerating vehicles into the test section.

The only cross street intersection in the test segment is a T with a short low-volume residential street (La Serna). This intersection is located immediately south of the north limit of the test section. A general vicinity map of the test site is presented on Figure 22. General positioning of the humps is also indicated.

La Canada does not have any particular significance as a fire or emergency vehicle route except for local access. It does not affect any fixed route public transit services. No outstanding constraint conditions prejudicial to designation of La Canada as a test site were noted in the field review.

Abutting land use along La Canada and the neighboring streets is uniformly single family residential. Residences along La Canada are well appointed upper middle class homes, detached and generously set back from the street. Most were constructed about 15 years ago and many of the residents are original or long term occupants.

When homes on the test segment were constructed, La Canada was a cul-de-sac terminating at the north end of the current test segment. Subsequently, as development proceeded in the area to the north La Canada was extended. It is residents of the several streets in this later constructed "north area" rather than "through" travelers who comprise the "speeders" on La Canada.

Case Study Procedure

"Before" data measures were conducted in late October and early November, 1979. Simultaneously, through a survey and public meeting the City assured that resident concern about speeding was broadbased (rather than limited to a few gadflies) and that there was no strong opposition to the conduct of the test programs. Humps were installed in mid-November 1979 and first encounter reactions were monitored on the day-of and two days immediately following installation. Subsequent observations of traffic reactions were conducted three months and seven months after installation. Seven months after installation, the City surveyed test segment residents and residents of the area to the north who experienced the humps as drivers.

Installation

Three humps, constructed of hot rolled asphalt, were installed on La Canada on a single morning, (November 15, 1980) by City of Brea Public Works crews at a total cost (labor and materials) of about $1,800. It was initially intended to simply overlay the existing pavement except for the last 1.5 feet (46cm) on each edge where excavation to the base was planned. This was to assure minimum overlay thickness at the edges, thereby preventing ravelling of the asphalt. However, Brea's street maintenance superintendent elected to excavate to the base course over the entire hump installation. While this requires a bit more material and effort, it probably results in a more satisfactory installation where humps are to remain as a permanent feature. Figure 23 presents photos illustrating the installation of the humps. The asphalt was hand laid and hot-rolled to shape. A 2 x 12 timber inscribed with the undulation shape was used as a template and was also useful as a pushing blade in spreading the asphalt. The

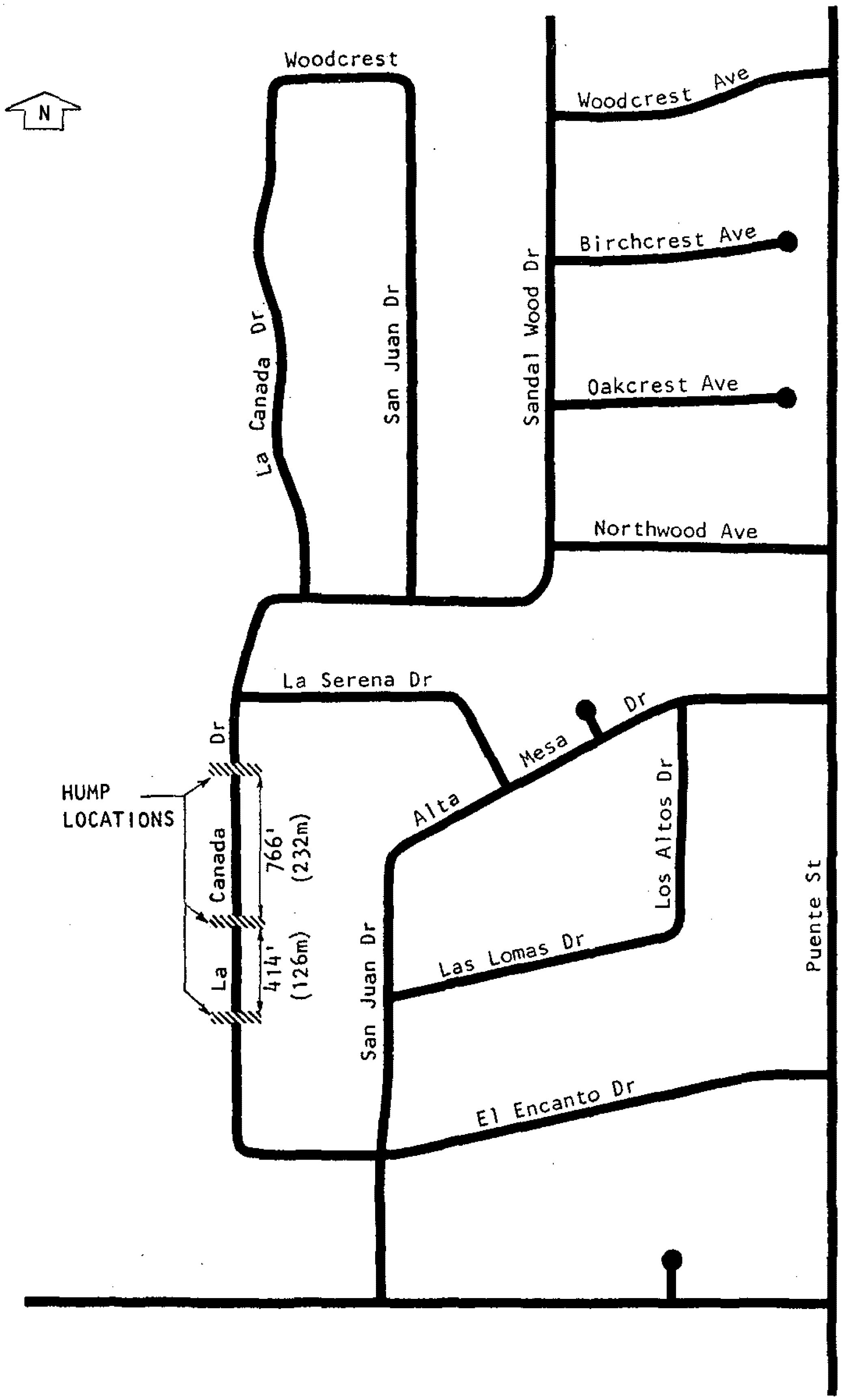
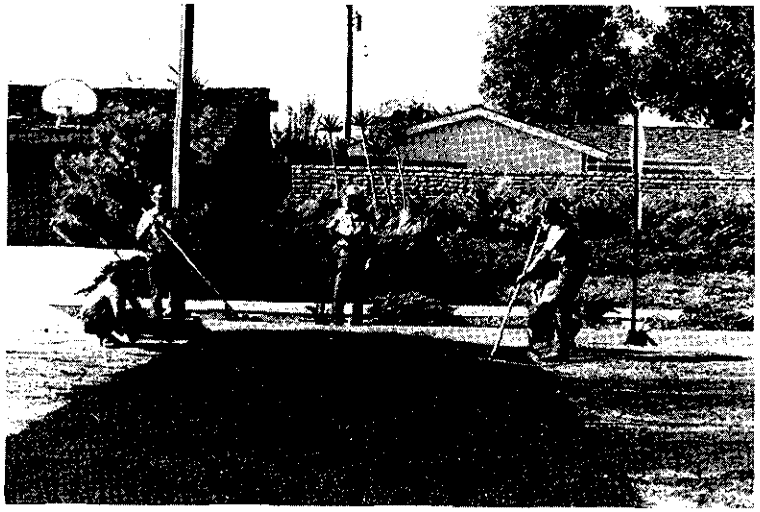
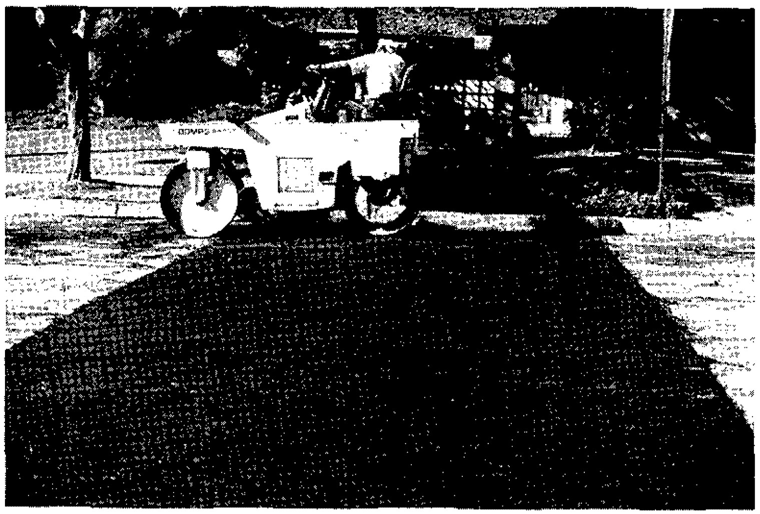


Figure 22. LA CANADA VICINITY MAP



Laying the AC material. A 2x12 board inscribed with the hump shape service as a template.

Using the template as a spreading device.



Rolling out the humps.

The finished hump measured against the template.

Figure 23. INSTALLATION PROCEDURES - BREA

humps were tapered by eye to the gutter pan to preserve gutter flow. (TRRL's installations had carried the humps unbroken curb-to-curb and had incorporated rather costly drainage structures in the humps to preserve drainage flow. Our decision to leave the gutter lines open as a cost-saving measure had operational consequences which are discussed subsequently).

The Brea installation experience convinced the research team that the humps can be constructed to reasonably true shape and without excessive effort by typical public works crews under normal supervision.

Sign detail on the test segment are shown on Figure 24. Advance warning signs were placed in advance of both curves leading to the test segment. An advance warning sign was also placed on a cross street (La Serena) near its intersection with La Canada. This sign had a supplementary arrow indicating the direction of the test segment. Warning signs with supplementary 15 mph (24 kmph) advisory speed plates were also placed adjacent to each hump. The standard MUTCD BUMP signs were utilized rather than the rather unique symbolic signs used in European installations because it was feared these later would become particular targets for souvenir collectors.

PERFORMANCE OBSERVATIONS

As noted previously, formal observations were conducted immediately after installation, after 3 months and after 7 months. Results are compared to previous conditions in the sections which follow.

First Encounter Reactions

Objective performance data recorded during the first encounter period is presented with related data from later monitoring periods. This section deals with qualitative observations of drivers initial reactions to the humps. The research team was particularly concerned with any inherent hazards which might result from drivers being surprised and with any deviant behavior which might result from drivers being enraged by the humps.

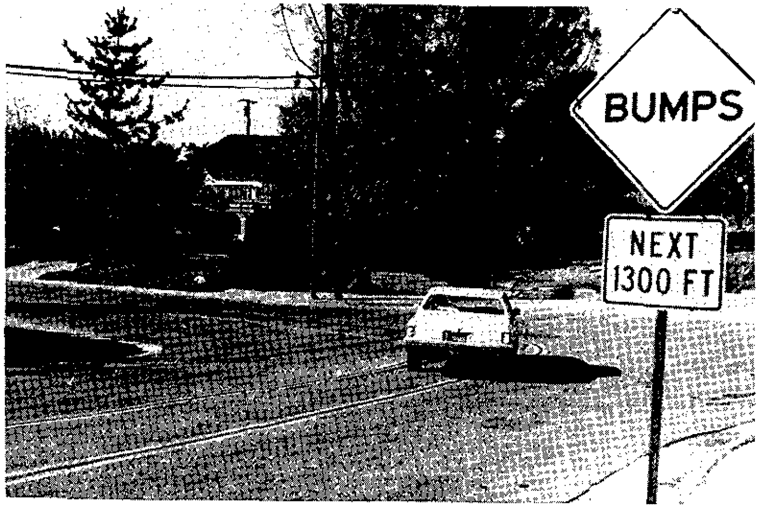
The test segment was observed for seven hours immediately following installation and for lengthy daytime and night periods on the two subsequent days. The very few noteworthy observations and incidents encountered are summarized below.

- No auto drivers appeared to have serious difficulty with the humps. One Porsche driver, traveling at high speed in nighttime conditions was surprised and jolted enough to stop and see what he had hit. One "lowrider" (this is a car culture in which suspensions are modified to hydraulically raise and lower the body; normally they travel with vehicles lowered to minimum possible ground clearance) was observed crossing the humps with extreme caution but without "bottoming out" or taking the trouble to raise the suspension.

- Drivers appeared to go through a learning experience as they traversed the series of undulations, crossing the second and third humps in the series more cautiously than they did the first.

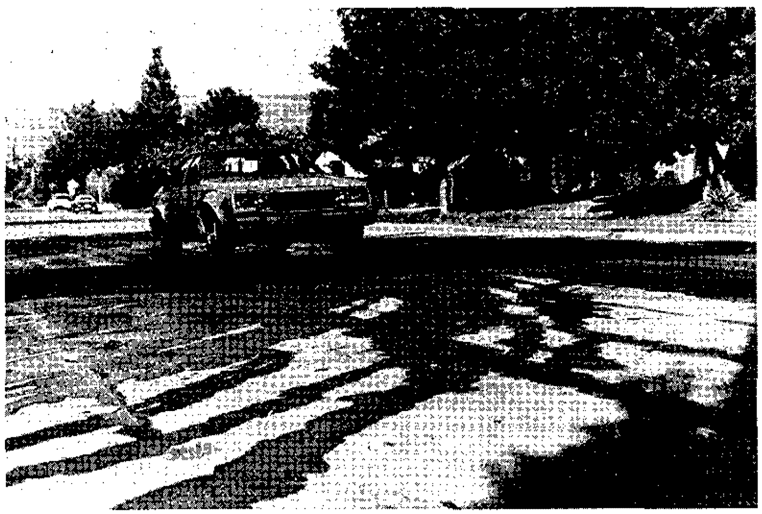
- Though drivers increased speed between humps, the speed increase was usually moderate. The over 750 feet (228m) between the northerly and middle humps did not appear to be too excessive for effectiveness.

- This practice of "gutter-running", discussed in more detail subsequently, was exhibited immediately by a few vehicles but was far less prevalent

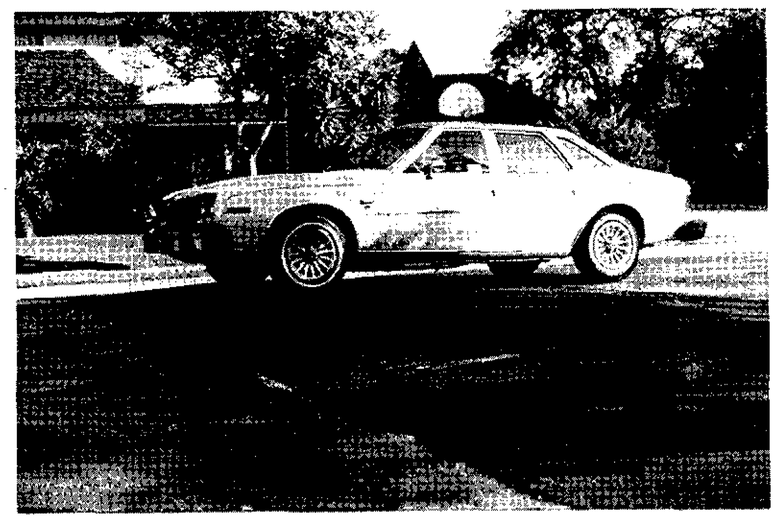


Warning sign on approach to test site.

Warning sign on cross-street approach to test site.



The humps present a deceptively gentle appearance.



Crossing the hump.

Figure 24. SIGN DETAILS AND FINISHED APPEARANCE

than it became subsequently. Even in the first encounter period the number of gutter-runners, who appeared to do so out of caution, was nearly equal to those who ran the gutter to ease their attempt to drive faster.

- Teenage bicyclists were observed to use the humps in performing wheelstands. However, they were observed performing wheelstands as frequently on level sections of the test roadway. One particularly skillful one demonstrated the ability to ride the entire quarter-mile length of the test segment in a continuous wheelstand.

- The driver of a large single unit truck carrying bottle spring water apparently missed the warning signs or didn't believe them and hit the first hump at about 25 mph (40 kmph). This dislodged one of the water flasks from the rear and it burst on the pavement. To observers the driver appeared to be chagrined and accepted the incident as his own fault.

In the judgment of the research team, none of the incidents or deviant behavior observed in the first encounter period indicated unacceptably hazardous conditions. But the observations point up the need for installing adequate signing and markings immediately-before the humped section is opened to traffic following construction.

Traffic Volume

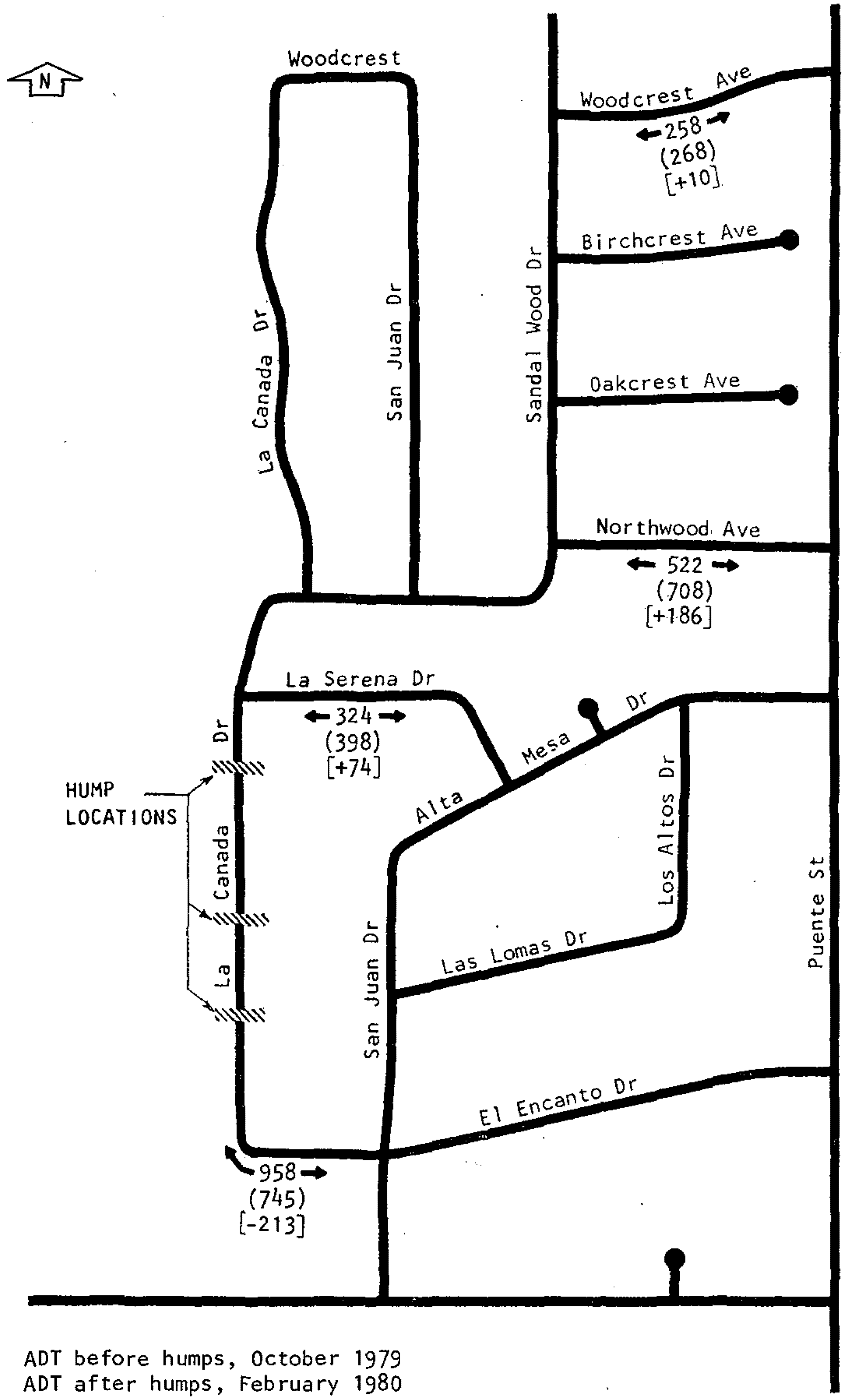
Twenty four hour traffic volume counts on test area streets were machine recorded six weeks before and three months after the humps were installed on LaCanada. The counts on LaCanada and the three alternative access routes to the neighborhood LaCanada serves were taken simultaneously for three midweek days in each counting period. No intervening events (such as construction blockages, traffic control changes or other conditions) to which volume changes might be attributed actually occurred. The entire change in traffic volume pattern is attributed to the presence of the humps on LaCanada.

Figure 25 presents count locations, before and after volumes recorded and net volume changes. The pattern of traffic reduction on LaCanada (a decrease of about 22 percent of the "before" traffic) and corresponding increases on the two most convenient alternative access routes is consistent with the pattern of change which reasonably might have been expected to result from the humps installation. It is also consistent with responses of residents of the "uphill" areas regarding avoidance of the test section and with the perceptions of test segment residents regarding changes in traffic volume on their street.

Traffic Speed

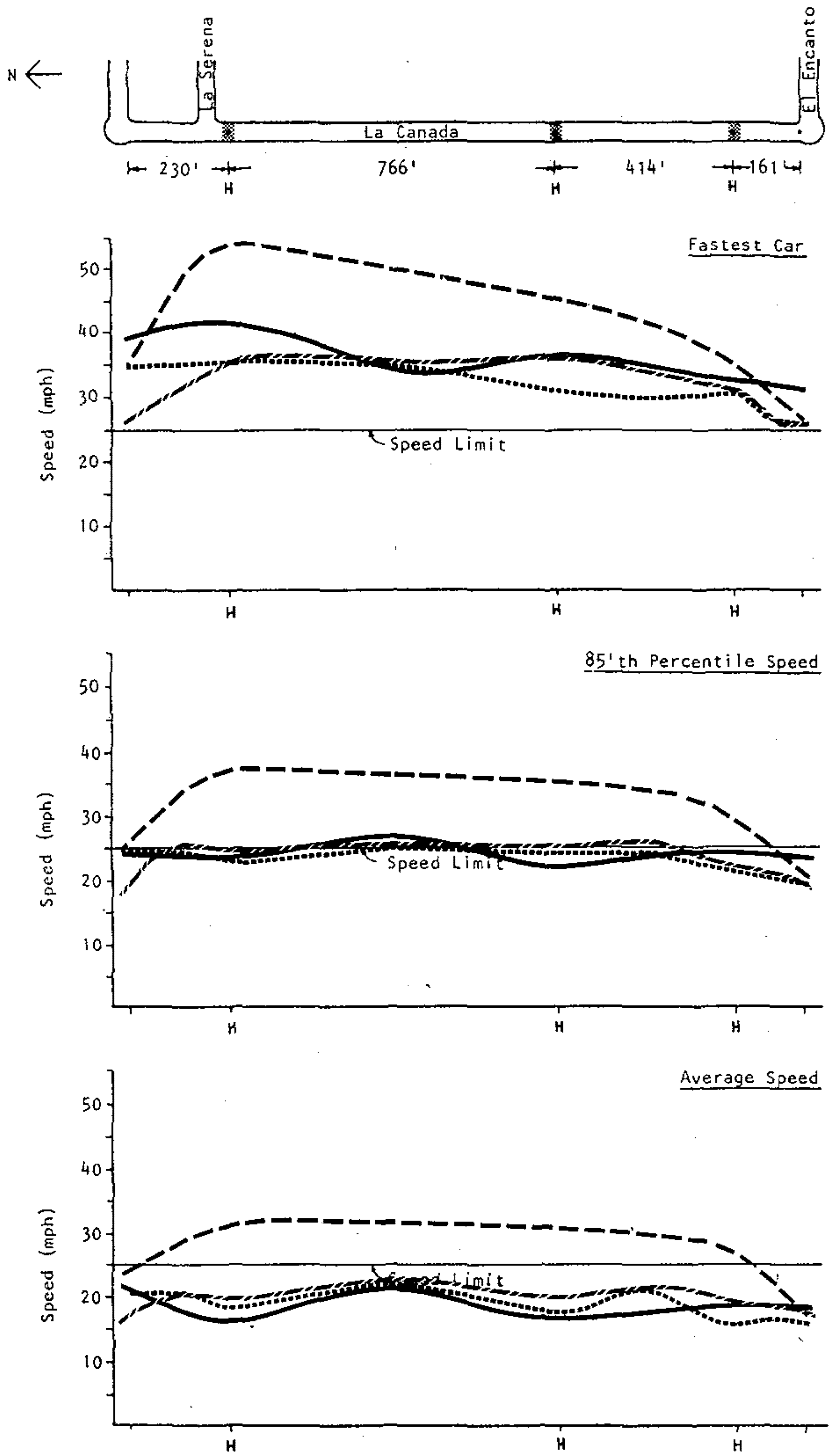
Traffic speed profiles on the test section and its approaches were observed by radar six weeks before installation, immediately after installation (on the day installation was completed and on the following day), three months after and seven months after. Each vehicle was radar tracked through the entire test section and speeds were recorded at each hump, the midpoints between humps, the ends of the test straightaway and the midpoints between ends and the nearest humps. Separate comparisons of the northbound and southbound speed data are presented on Figures 26 and 27. Principal conclusions which can be drawn from these data include:

- All "after" periods show substantial reductions in speeds from those observed in the "before" period at all levels of comparison - mean speed, 85th percentile speed and speed of fastest vehicle observed. Mean speed was re-



000 ADT before humps, October 1979
(000) ADT after humps, February 1980
[000] Net change

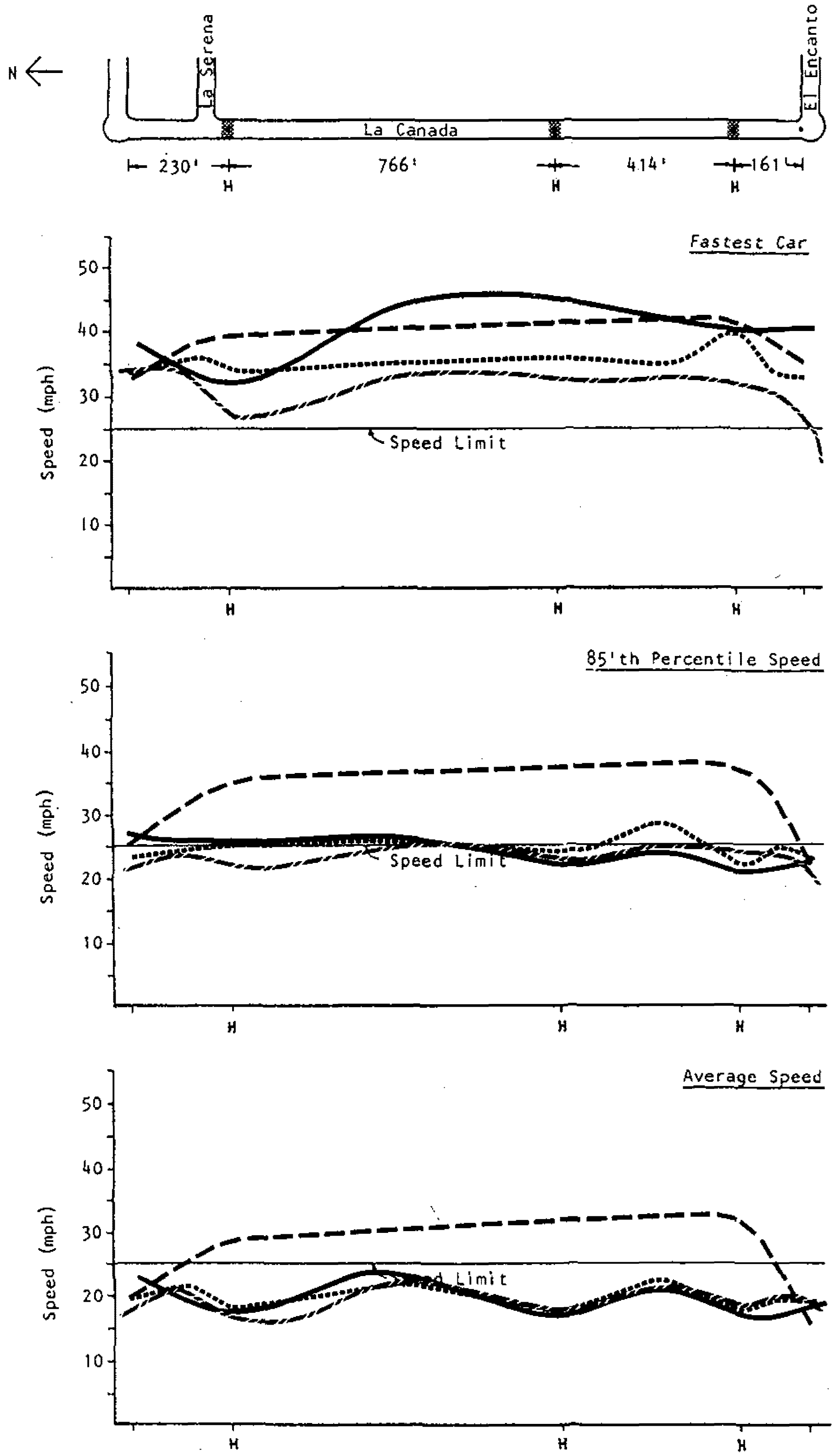
Figure 25. LA CANADA TRAFFIC VOLUME EFFECTS



1mph = 1.6093kmph

Before
After - Immediate
After - 3 Months
After - 7 Months

Figure 26. LA CANADA SPEED STUDY - NORTHBOUND TRAFFIC



1mph = 1.6093kmph

Before
After - Immediate
After - 3 Months
After - 7 Months

Figure 27. LA CANADA SPEED STUDY - SOUTHBOUND TRAFFIC

duced between about 10 and 13 miles per hour (16-21 kmph) over most of the test segment for northbound vehicles and between 8 to 14 miles per hour (13-23 kmph) over most of the test segment for southbound vehicles. Reductions on the same order were observed at the 85th percentile speed level. Reduction in maximum speed observed ranged as high as 19 mph (31 kmph) (at one point; reductions of 5 to 10 mph (8-16 kmph) in the speeds of the fastest cars observed were consistently recorded over most of the test segment.

- There is remarkable consistency in the speeds recorded in the three "after" observation periods. There is <u>no indication of deterioration of speed control effectiveness</u> as drivers become more familiar with the humps. Rather, the data indicates that drivers' reaction to the humps remain fairly constant over time.

  The only noteworthy deviation among the three "after" measurement periods is the fastest southbound vehicle observed in the "immediately after" period. This was a teenage joyrider who made several passes through the site and appeared to be showing-off while an audience of construction workers and supervisors remained on the scene. This "stage performance" is judged non-representative of the speeds at which drivers inclined to drive fast normally choose in traversing the test section. But it is indicative of the kind of unusual behavior which can be anticipated in the "first encounter" period.

- The effect of the LaCanada humps appears particularly favorable. Even though drivers inclined to go fast can go over the humps at any speed they might desire without dire effect, the humps are enough of a deterrent that even the fast drivers <u>choose</u> to go considerably slower than they were inclined to before the humps were in place.

- Speeds at the 85th percentile are very close to 25 mph (40 kmph) over the entire test section in all three "after" observation periods. This is an important result since the 85th percentile speed is the speed commonly cited by traffic engineers as an indication of reasonable conformance to a speed limit and a measure of the reasonability of the speed limit and because 25 mph is the most common speed limit for local residential streets in the U.S.

- The tendency to speed-up between humps appears to be a characteristic primarily of the <u>slowest-traveling</u> vehicles. This is evidenced in the relatively even speed profiles on the "fastest" and 85th percentile graphs and the more wavering profiles on the mean speed graphs of Figures 26 and 27. The pattern is one of relatively mild rather than radical acceleration-deceleration and, because it is largely confined to the slower vehicles, it is not regarded as a substantial problem condition.

- Up to 46 percent of the vehicles using the test segment were observed attempting to partially avoid the impact of the humps by traveling with right-side wheels in the open (un-humped) gutter pan on at least one hump. Table 6 compares mean and 85th percentile speed profiles of vehicles observed running the gutter on all three humps with those of all vehicles observed in the same "after" period and with speed profiles before the humps were installed. As can be seen on the figure, the difference in the after speed profiles between those who run the gutters and those who don't is negligable relative to the difference be-

TABLE 6
SPEED COMPARISON
GUTTER RUNNERS VS. ALL VEHICLES
LA CANADA

	Mean Speed			85th Percentile Speed			Fastest Vehicle		
	Before	All	Avoiders	Before	All	Avoiders	Before	All	Avoiders
North end	22.5	18.8	21.2	26.5	21.9	23.1	36	34	34
Midpoint	27.0	20.7	23.5	32.0	23.4	24.1	48	34	34
Hump	30.0	17.1	20.1	36.0	21.6	22.2	54.5	26	26
Midpoint	31.0	22.3	24.4	36.5	25.0	25.7	50.5	34	34
Hump	31.5	16.5	20.2	36.5	21.9	25.1	45.5	31	31
Midpoint	31.5	21.9	23.8	36.0	24.8	27.1	41.5	32	32
Hump	28.5	17.4	21.3	33.0	23.0	25.1	35.0	20	27
Midpoint	25.0	18.4	21.3	29.5	22.3	24.1	32.0	28	26
South end	17.0	15.5	16.8	22.0	17.0	18.1	26.5	20	20

TABLE 7
SPEED COMPARISONS ON STREETS ADJACENT TO TEST SEGMENT

PUENTE STREET	Average Speeds		85th Percentile	
	Before	After	Before	After
Northbound	33.9	33.4	43.0	37.1
Southbound	34.7	36.1	40.0	43.1
SAN JUAN DRIVE				
2-way	26.9	25.68		

tween each of these and the "before" speed profile.

It appears that those who run the gutters do so primarily to avoid some of the discomfort effects of the hump rather than in an attempt to go faster and that the maneuvering involved in gutter running causes drivers to proceed as slowly and cautiously as going straight over the hump. Despite this finding, the phenomena of gutter-running cannot be entirely dismissed. For even though gutter-running does not lead to meaningful increases in speed, it affects resident perceptions of the humps performance (see subsequent section on Resident Perceptions).

Table 7 presents comparisons of speeds observed on streets most immediately parallel to LaCanada before and after the humps were installed. Based on this data it does not appear that there were any meaningful overall speed change trends in the area which might have influenced the LaCanada results. Futhermore, it does not appear that traffic diverted by the humps from LaCanada to these streets had any meaningful effect on speed patterns on them.

- One of the primary complaints of residents living near the ends of the test segment of LaCanada was that vehicles traveled so fast on the two curves which define the test segment limits that noise from squealing tires was disturbing. Initial attempts were made to measure directly whether presence of the humps on the straightaway influenced speed and tire squeal on the curves. Because of difficulties* in making reliable direct measures of speed on the curves and relating actual speed to noise, assessment of the humps effects on speeds on the curves adjacent to the test segment was limited to resident perceptions.

Obedience

Stop sign obedience studies were conducted at the El Encanto approach to San Juan Drive. This stop sign is immediately downstream of the test segment for vehicles traveling southbound on La

* Because the radar unit was ineffective on the curve, attempts were made to measure speeds by timing vehicles. However, the total travel distance and time on the curve was so short that it was somewhat difficult to make sufficiently accurate measures by hand-held stopwatch. For instance, a two mile per hour (3.2 kmph) difference between vehicles following the same path on the curve involves only a half-second difference in travel time. Moreover, vehicles took different paths through the curve with faster vehicles crossing the centerline to flatten-out the curve and shorten the travel distrance. At the speeds typically traveled, this short cutting could cause a two to three mph discrepancy between actual speeds and speeds estimated by timing. Error introduced by timing inaccurancy and variability of vehicle path appeared to be similar in magnitude to the changes in curve speeds which may have actually resulted from installation of the humps on the straightaways. As a result it was impossible to distinguish real changes in curve speed from the error inherent in the measurements. It was also observed that actual speed traveled on the curve did not relate very closely to the noise problem which was of ultimate concern. Slower vehicles which conformed to the centerline markings (hence making a sharp turn) tended to emit tire squeals as frequently as the faster vehicles which "flattened-out" the curve. For this reason, no further attempts were made to conduct accurate measures of curve speeds and the analysis of the "curve problem" was limited to changes in residents perceptions.

Canada. The obedience studies were conducted to determine whether irritation with the humps might lead to deterioration in obedience levels at the stop. Table 8 presents obedience statistics from one "before" and two "after" monitoring periods. Only vehicles unchallenged by cross traffic were recorded so obedience behavior is entirely voluntary. A significant comparison of the data might lead one to conclude that the humps had indeed induced a deterioration in stop sign obedience. However, the situation is not so clear-cut. Most of the differences in observations is between the "full stop" and "0-5 mph" (0-8 kmph) categories. The percent of drivers in these two categories in the three monitoring periods are all well within the range of obedience which would be considered normal compliance for an intersection of two low volume residential streets. And there is no meaningful change in the percentage of drivers in the "over 10 mph" (16 kmph) category, the real indicator of flagrant disobedience. There does appear to have been some change in behavior at the stop - perhaps the most careful drivers were predominant among those diverted from La Canada by the humps and therefore are not in the sample of vehicles observed at the stop in the "after" periods. But the data and impressions of the field observers give no evidence or sense of flagrant violations and deliberate defiance of downstream traffic controls resulting from driver frustration with the humps.

Accident Experience

On any give low-volume, short-length residential street like La Canada, accident incidence is usually extremely low and reflects random events rather than recurring patterns. Hence, there was little expectation that in the short test period the humps would lead to a statistically significant change in accident experience. The primary intent of the accident review was to identify and analyze any accidents occurring in the test period directly or inferentially attributable to presence of the humps. But with respect to accidents, La Canada is not entirely typical of most residential streets. While the test segment itself had an undistinguished history - no recorded accident in the three years prior to hump implementation - there was an interesting pattern of accidents on the curves which define the limits of the test segment. In the 3 year period before implementation, at least 3 accidents occurred in which speed developed in the test segment was a contributory factor. One other curve accident stemmed from speeding by a vehicle about to enter the test segment. Residents reported many more hazardous incidents on the curves related to speed in the test segment - near misses between vehicles and vehicles spinning out of control but avoiding collision with anything substantial.

Police accident records for the 9 months immediately following hump installation contain no reports of any accidents on the test segments of La Canada or its approaches. This finding provides no reliable statistical basis to assert that the humps reduced the accident rate on La Canada or solved the accident problem on the approach curves. But it is reassuring that the humps did not produce any recorded accidents during a period in which the general driving public made over 600,000 individual hump crossings.

Emergency Service Reactions

Brea police report no negative encounters resulting from the undulations on La Canada. The Brea Fire Department did not identify any serious problem incidents relating to the humps. Fire officials note that the humps cause "brief delays" due to the need to slow down at

TABLE 8
STOP SIGN OBEDIENCE
EL ENCANTO AT SAN JUAN

	Full Stop	0-5 mph	5-10 mph	Over 10 mph
Before	47.6%	39.7%	11.1%	1%
After 3 months	25%	54%	21%	0%
After 7 months	25%	61%	12%	2%
"Reasonable Obedience" Expectation	(- 75-90% -)		8 - 23%	0 - 2%

TABLE 9
RESIDENT RATINGS OF HUMPS EFFECTS ON PERCEIVED PROBLEMS

	Effect			
Problem	Worse than Before	Same as Before	Slightly Improved	Substantially Improved
Traffic too fast overall	0	31	23	46
Extreme speed by some drivers	15	23	15	46
Late night speeding	0	46	31	23
Dangerous for kids	25	8	33	33
Dangerous for bicyclists	33	22	22	22
Noise on curves at ends	20	30	40	10
General traffic noise	17	8	50	25
Motorcycles speed, joyride	8	50	25	17
Dangerous for pedestrians	10	50	10	30
Traffic laws not enforced	10	50	10	30
Too much traffic at night	10	20	40	30
Too much cut-thru traffic	20	20	40	20
Too much traffic overall	11	44	11	33

each hump. As a precautionary measure, fire vehicles have slowed to 10 mph (16 kmph) while crossing each hump out of concern for potential equipment damage. They further suggest the hump markings should be improved for "better night visibility" - they are not easy to identify the first time across and that only "extreme traffic problems" would be justification for hump installation.

REACTIONS OF RESIDENTS AND DRIVERS TO THE HUMPS

Seven months after the humps were installed, the City of Brea solicited the opinions of residents as to how effective the humps were in solving the perceived problems, what new problems they may have created and how they reacted to the humps as drivers. Four separate survey instruments were applied, all using the doorstep-handout, mail-back technique, to the following groups:

- Residents of the test segment of La Canada
- Residents of El Encanto, the continuing street segment linking to the south end of La Canada. El Encanto residents are rarely impacted by the humps as drivers but stand to partially benefit from the impact of the humps on traffic volume and speed on their street.
- Residents of La Serena, a street which forms a T intersection with the test segment of La Canada. Residents of La Serena are rarely impacted as drivers. They may suffer some adverse impact from the hump installation due to small amounts of former La Canada traffic diverted to their street (less than 200 ADT). However, they are close enough to the test segment to have been concious of and even, in some cases, irritated by the prior problems which existed on La Canada. They are also close enough to have neighboring relationships with and sympathy for residents on the test segment of La Canada.
- Residents of several streets to the north of the test segment for whom the test segment serves as one of several potential access routes to their homes. These residents are not likely to benefit from the humps directly and experience them primarily as drivers.

Response from all surveys was extremely high, ranging from 79 percent for the La Serena residents to 49 percent of residents in the area north of the test segment. This response rate and the extensive suggestions and comments of a constructive nature, even on returns by residents opposed to the humps, is indicative of the high level of public interest in the subject. Details of the response are presented below.

La Canada Test Segment Residents

Responses were received from 15 of the 21 households on the test segment of La Canada for a 71 percent response rate. The responses to questions evaluating performance on specific criteria leave the impression that the humps do not fully satisfy residents. But the responses on evaluation questions - "do the humps serve a useful purpose? . . . should they be left on La Canada after the test period? . . .should they be used on other streets?" - leave little doubt that a large majority of the test segment residents favor the humps.

Table 9 presents residents' impressions of how the humps have affected specific problem conditions which were identified at a neighborhood meeting and in a survey before the humps installation. Several indications were quite positive. Sixty-nine percent indicated there had been slight or substantial improvement (lowering) in overall speeds; 61 percent indicated slight or substantial improvement (lowering) in speeds of fastest drivers; 75 percent indicated improvement (lowering) of traffic noise and 70 percent felt that night traffic volume had been reduced. But on other identified problem conditions, substantial percentages of respondents found conditions unchanged and few believed them worse.

Relative to speed conditions, one-third of the residents indicated overall speeds remained "far too high", one-third indicated it was now "only slightly faster than it should be" and one-third felt speed was "about right" for the street. None felt traffic was held to speeds "slower than reasonable" or "much slower than reasonable". Forty percent felt that fast drivers "still travel any speed they wish" while 60 percent indicated the faster drivers had "slowed somewhat, though still traveling too fast". None believed the faster drivers had been confined to speeds "not much faster than average drivers".

The previously described tendency of some drivers to "run the gutters" appeared to have significant impact on residents' perceptions of the humps effectiveness. Twenty-one percent indicated gutter running was "so frequent it defeats the purpose of the humps"; 57 percent indicated gutter running was "fairly frequent, but even gutter-runners slow down some"; 14 percent said gutter running was "not very frequent, but those who do it drive dangerously fast". Only one respondent indicated gutter running was "too infrequent to worry about". Several residents who felt the humps should be kept on the street wrote extended comments complaining about gutter-running and suggesting countermeasures. Two residents who felt the humps should be removed cited gutter-running as the reason for this opinion.

Even with the humps in place, 53 percent of the respondents felt their street was "still quite dangerous" considering safety from traffic of pedestrians, bicyclists and kids in general. One-third felt it was now "about average for a residential street while 13 percent indicated it was now "safer than average".

Twenty percent of the respondents felt that noise of traffic braking and acclerating near the humps was "a severe problem"; 13 percent indicated it was "an occasional nuisance"; 47 percent felt it was "an occasional nuisance but worth it to keep speeds down" while 20 percent indicated this was "not a problem at all".

None of the test segment respondents felt the humps were "too severe for safety of vehicle occupants or could damage vehicles and cargo". Forty-three percent felt the humps were "about right to slow traffic safely"; 33 percent indicated the humps were "somewhat more gentle than they should be" and 20 percent felt the humps were "far too gentle to be effective". Asked if they had encountered any problems crossing the humps as the driver of specific vehicle types, none of the respondents resident on the test segment indicated they had encountered "serious difficulty" in any vehicle type. Fourteen percent of the respondents indicated "moderate difficulty" in autos while 86 percent reported "no difficulty". For vans and pickups, 13 percent of the residents indicated "moderate difficulty" while 87 percent indicated "no difficulty". For bikes, 20 percent of the respondents reported "moderate difficulty" while 80 percent reported "no difficulty". The single test segment residents reporting traversing the humps in each of the "motorcycle," "towing trailer" and "heavy truck" categories indicated "no difficulty". These responses by test segment residents on the "severity" and "hump crossing difficulty" questions are in sharp contrast to responses of residents of the area to the north who drive through the test segment. Those responses are presented in a subsequent section.

Relative to signing and marking of the humps, 29 percent of respondents from the test segment felt that existing provisions were "insufficient to warn drivers"; 43 percent felt they were "about right to help drivers cross safely" and 29 percent felt they were "more extensive than necessary". Many of those reporting insufficiency suggested painting the humps and moving the signs now alongside the humps to an approach position (note that other advance warning signs are actually in place). These comments are echoed in the responses of drivers from the area to the north. With respect to the appearance of the humps and associated signs and markings, 27 percent of respondents felt they "detract from the visual quality of the neighborhood"; 60 percent indicated they were "not particularly attractive but acceptable, considering what humps do"; 13 percent reported them "not a particularly noticeable negative feature".

There was mixed opinion whether outsiders came to La Canada to joyride on the humps. Thirty-six percent reported it *"a serious continuing problem"*; 28 percent said it was "a minor problem"; 36 percent reported it "never was a noticeable problem".

Most residents agreed with the spacing and number of humps on the street. Sixty-four percent reported spacing and number "about right"; 29 percent thought they were too far and too few; only one respondent thought them too close and too many.

Despite the mixed reviews on many of the above points, <u>on fundamental questions as to whether the humps were good or bad, residents of the test segment were strongly in support of the humps.</u> Seventy-nine percent believed the humps' "serve a useful purpose" while only 21 percent felt they do not. Seventy-three percent indicated the humps should remain permanently, while 27 percent advocated their removal. Seventy-seven percent indicated they favored using the humps on other streets experiencing problems similar to La Canada's, while only 23 percent opposed such use. Asked if they believed other measures, excluding cul-de-sacing, could be as effective as the humps in controlling speed, 60 percent of the residents responded "no". Of those who thought other measures work, half cited cul-de-sacing. Most others suggested stop signs and one proposed "doubling" the humps.

El Encanto Residents

Responses were received from 5 of the 7 households on El Encanto (71 percent return).

Asked if the humps affected noise on the curve at the end of the test segment (previously reported as disturbing to El Encanto residents, three reported the noise "decreased" while two reported it "unchanged". All reported "no change" in the amount of traffic on El Encanto (in fact, it decreased 22 percent). Two reported "the humps led some frustrated drivers to speed on El Encanto", two believed El Encanto speeds "unchanged" while one felt "most drivers drive more carefully on El Encanto". Three felt humps on El Encanto "would be helpful," one "opposed" them and one was "not aware of a need" for them.

Relative to other residential streets with speed problems, two "generally favored use of the humps, though not considering them perfect", one unqualifiedly endorsed their use and two expressed no opinion.

La Serena Residents

Responses were received from 11 of the 14 households on La Serena, a 79 percent return rate. General reaction of La Serena residents to the humps appears to be quite favorable. This is particularly impressive since La Serena did suffer some adverse impact (more traffic) as a result of the hump installation on La Canada.

La Serena residents generally felt that the humps were effective in controlling speed on La Canada. Twenty seven percent rated them "extremely effective", 55 percent rated them "partially effective" and 18 percent rated them "slightly effective". None rated them "not effective" or thought they "made conditions worse".

Some La Serena residents were previously impacted by traffic noise on the curve at the north end of the La Canada test segment. One respondent felt the humps "solved" the noise problem; 45 percent indicated the humps "decreased the noise"; 36 percent felt noise on the curve was "unchanged" and one respondent rated it "worse".

Most La Serena residents correctly perceived the increase in traffic on their street resulting from diversion from La Canada (up 75 adt, 23 percent increase over prior La Serena traffic). Thirty-six percent felt there was "considerably more" traffic on La Serena; 36 percent thought there was "slightly more"; 27 percent thought it unchanged. None thought traffic had decreased. Some residents also felt the La Canada humps caused the diverted traffic to speed on La Serena. Forty-five percent thought "the humps caused some frustrated drivers to speed on La Serena"; 55 percent thought there had been "no change" but none thought drivers on La Serena were being "more careful".

Despite perceiving these adverse impacts, La Serena residents had favorable overall impressions about the humps. Forty-five percent favored placing humps on La Serena, 18 percent were categorically opposed while 36 percent were not aware of need for them there. In principle, 20 percent agree to humps on residential streets may be "necessary in special cases"; 60 percent "generally favored the humps, though not considering them perfect"; 20 percent "endorsed" them without qualification. None absolutely opposed the humps.

La Serena residents had generally favorable opinions as to the severity of the humps and the difficulty in driving across them. Sixty-four percent felt the humps were "about right to slow cars safely"; 18 percent rated them "somewhat more gentle than they should be" and 18 percent rated them "far too gentle to be effective". None rated them "too severe for safety of occupants". One driver of a van reported "serious difficulty" crossing the humps; one auto driver reported "moderate difficulty". All other respondents reported "no difficulty" in all vehicle categories.

Ninety percent of La Serena respondent indicated signs and markings gave "adequate warning of the humps location and nature".

Sixty-four percent of La Serena respondents felt the La Canada humps should be "made permanent", 18 percent felt they should be "removed" and 18 percent felt they should be left in place for more testing. One of those for removal suggested a more severe measure, cul-de-sacing, as an alternative. As to general application on other residential streets, 45 percent favored, 45 percent opted for more testing first, one expressed no opinion and none opposed.

Residents of Area to North

Opinions of residents of the area to the north of the test segment were much more favorable to the humps than might have been expected. These respondents gain no direct benefit from the humps and are primarily impacted by the humps as drivers - they are the people at whom the humps were aimed. However, nearly as many of these respondents took positions favorable toward the humps as took opposition views.

Speaking of the humps' speed restraint characteristics in general, 19 percent of the respondents felt the humps "restrict speeds far too much"; 21 percent felt speeds were restricted slightly below what is desirable; 45 percent felt speeds were restricted "to a reasonable level for this street" and 16 percent felt they "hardly restrict speed at all". Several respondents commented that what they resented most about the humps was that they punished the reasonable drivers along with the speeders and that the speeders could still "get away with it" by gutter-running or just speeding over the humps.

Respondents' ratings of their personal driving reactions to the humps were diverse. Thirty-nine percent reported they drove "much slower" on La Canada now; 44 percent rated themselves "a little slower"; 15 percent rated their speed "about the same" as before the humps were installed while one respondent reported driving faster now on La Canada because of the humps presence. Thirty-eight percent of the drivers reported using La Canada as frequently as ever; 11 percent said they "sometimes avoid" the humped segment; 28 percent "avoid the humped segment whenever convenient" and 23 percent usually "go out of their way" to avoid the humped part.

Seventy-two percent of the respondents rated signing and marking of the humps "adequate". Of the 28 percent who rated it inadequate, principal suggestions were for painting the humps and for moving the adjacent warning signs to an advance position.

As to severity of the humps and difficulty crossing them in various vehicles, 52 percent felt the humps were "too severe for safety of occupants and could damage vehicles and cargo"' 44 percent reported them "about right to slow vehicles safely"; and 4 percent believed them "somewhat more gentle than they should be". In their comments, several residents attributed the need to replace shock absorbers on their vehicles and difficulties with wheel alignment to effects of repeated traversal of the humps. No respondents were able to cite incidents or evidence of direct damage to vehicles by the humps. However, two drivers of 4-wheel drive recreation vehicles noted that rear seat passengers heads had "hit the roof" when they drove over the humps. Ratings of degree of difficulty experienced in crossing the humps are summarized in Table 10.

Despite these ratings of severity and crossing difficulty, surprisingly large numbers of residents in the area to the north of the test segment took positions favorable to the humps. Only 21 percent were "absolutely opposed" to the humps in principle; 33 percent "agreed they may be necessary in special cases"; 23 percent "generally favored the humps, though not considering them perfect"; and 23 percent "endorsed" them without qualification.

Sixty-six percent of the "north area" respondents felt the humps on La Canada "served a useful purpose" while 29 percent felt they did not and 5 percent were undecided. Thirty-eight percent felt the La Canada humps should be made permanent and 21 percent thought they should be left in place for more testing. Forty-seven percent felt the humps should be used on other streets with speed problems, 28 percent opposed and 26 percent felt more testing should be undertaken before this decision is made. Many of those favoring the humps suggested other specific streets as candidates for their application.

With the surveys on La Canada, La Serena and El Encanto, response rate was so extremely high that there is no concern that there might be meaningful differences between the attitudes of those who responded and those who didn't. Response rate for the area to the north was, at 49 percent, also extremely high for a survey of this type. But with about as many persons not responding as those who responded, there is a theoretical po-

TABLE 10
DRIVER RATINGS OF HUMP CROSSING DIFFICULTY

Vehicle Type	Serious Difficulty	Moderate Difficulty	No Difficulty
Autos	10%	34%	55%
Vans & Pickups	60%	20%	20%
Bicycles*	14%	0%	86%
Motorcycles**	40%	40%	20%
Towing trailers	58%	33%	9%
Heavy trucks***	100%	0%	0%

* seven respondents in this category
** five respondents in this category
*** three respondents in this category

TABLE 11
FUNDAMENTAL OPINIONS & PREFERENCES RE HUMPS BY GROUP

	Absolutely oppose	OK in special case	Generally approve	Unqualified endorsement
Opinions about humps in principle				
La Serena	-	20%	60%	20%
El Encanto	-	-	67%	33%
North Area	21%	33%	23%	23%
All respondents	18%	30%	30%	23%
Serve useful purpose on La Canada?	yes	no	uncertain	
La Canada	79%	21%	-	
North Area	66%	29%	5%	
All respondents	68%	27%	4%	
Made permanent on La Canada?	yes	no	test more	
La Canada	73%	27%	-	
La Serena	64%	18%	18%	
El Encanto	67%	-	33%	
North Area	41%	38%	21%	
All respondents	51%	32%	17%	
Use on other streets?	yes	no	test more	
La Canada	77%	23%	-	
La Serena	45%	-	45%	
North Area	47%	28%	26%	
All respondents	52%	23%	25%	

tential for a meaningful difference between the attitudes of those who responded and those who didn't. In this case, that potential can be dismissed. In this solidly upper middle class area, there are no language or understanding barriers which might have selectively limited the opportunity to respond to a particular segment of the resident population. There is strong response by both those who favor and those who oppose the humps, so it appears unlikely that those not bothering to respond were particularly polarized in favoring or opposing the humps. Probably, those who didn't respond were persons who predominantly relied upon access routes other than La Canada. Hence, they weren't affected by the humps enough to motivate a response or weren't familiar enough with them to respond intelligently. Others who do travel across the La Canada humps regularly but accept them without forming particularly strong pro or con attitudes may also be among the non-respondents.

Summary of Opinions

Responses of all four groups to the fundamental questions of how they feel about humps in principle, whether they serve a useful purpose on La Canada, whether they should be made permanent on La Canada and whether they should be used on other streets are summarized on Table 11 (note that all four groups were not asked all four questions).

Despite the fact that response to the question of the humps "in principle" is dominated by persons who experience them solely as drivers and are not benefited by them, almost 83 percent of all respondents indicated some level of approval of the humps. Despite the fact that four times as many "drivers" as "benefiting residents" responded to the question of whether the humps served a useful purpose on La Canada, those who felt the humps were useful outnumbered those who did not by a 2.5 to 1 margin. Those who experienced the humps purely as drivers comprised 65 percent of all respondents to the questions of whether the La Canada humps should be made permanent and whether they should be used on other streets. Yet only 32 percent of all respondents thought the La Canada humps should be removed; 68 percent felt they should be made permanent or at least left for more testing. Relative to use on other streets, only 23 percent were opposed; 77 percent approved such use or at least favored more testing.

In conclusion, while there are differences of opinion between residents and drivers - residents feeling the humps are not severe enough a restraint, drivers feeling they are too severe - a strong majority of both groups react to some degree favorable on the fundamental issue of their use. The "residents" and drivers" opinions are about what one who just examined the performance results presented previously might expect. Residents generally favor the device because it keeps most traffic under the 25 mph (40 kmph) speed limit and lowers speeds of even the fastest traffic but are not entirely satisfied because of gutter-running and because the fastest drivers still go well above the speed limit. Drivers do not particularly like the device because it constrains and discomforts them but accept it to some degree because it does not constrain them to unreasonable speeds and because they can see the possibility of it being used to prevent other people from speeding on their own street.

BOSTON CASE STUDIES

The City of Boston was the site of two additional undulatioin case study applications. The fact that Boston had previously applied conventional speed bumps on one public street and had undertaken other extensive residential traffic control measures made it a logical candidate for the undulation studies. Boston also supplied exposure to winter snow conditions, a factor absent in the Brea case studies. Having at least one case study with snow exposure was judged important both to determine the effect on plowing operations and impacts on control during icy conditions.

Case Study Streets

Two case study streets were selected from a list of 10 candidates which had histories of speed complaints by residents. Lochstead Avenue, located in the Jamaica Plain district, is a single block street (Tee intersections at each end) extending approximately one quarter mile (.4 km) between two arterials, Jamaica Way and Centre Street. It is about twenty-eight feet (8.5m) wide with parking permitted but lightly used on both sides and has level, tangent alignment. It is an established upper middle class neighborhood of large older homes which presents an extremely well maintained appearance. In a brief speed study performed while on the site, it appeared that most traffic remained under 30 miles per hour (48 kmph), but occasionally fast cars were observed above 40 miles per hour (64 kmph) and even one passing above 50 miles an hour (80 kmph) was observed. Much of the traffic on Lochstead used it as a transition through route between Jamaica Way and Centre Street.

The other proposed test street, Willow Street in the West Roxbury district, is a one-way street approximately 21 feet (6.2m) wide with parking permitted on one side only. The test segment, approximately one-third mile (.54 km) long, serves as a collector for a fairly large residential area and also a transitional route between the two arterials which define the limits of the test section, Weld Street and Centre Street. The neighborhood appears to be solidly working class and very stable. Most homes appear to be at least sixty years old but well kept. Horizontal alignment of the street is tangent but there are significant changes in the vertical alignment. The upper third of the street near Weld is level as is the lower third near Centre with a fairly steep (up to 5 percent grade) downhill segment in the direction of travel from Weld to Centre in the middle. This hill appears to have much to do with the speed problem. Vehicles seem to travel below thirty miles per hour (48 kmph) on the upper segment then speed up on the hill and travel at five to ten miles per hour (8 to 16 kmph) faster than they were going at the top. Hence, most of the fast travel on Willow appears inadvertant - drivers just naturally building up speed on the hill - and it was believed interesting to test whether the undulations were an appropriate countermeasure for this natural condition, as well as for the more deliberate speeding which seems to occur on Lochstead and La Canada. Resident activity along the street is quite high with many adults observed walking along the street to the street car line on Centre, to local shops, conversing with neighbors and the like as well as children walking along or playing in the street. In an hour's observation during a morning commute period, more than two dozen pedestrians were observed. In a midafternoon period, significant pedestrian activity was also observed along with incidents of street play by children. This level of pedestrian activity along with the close proximity and sense of contact with traffic because of the narrowness of the street may account for the resident sensitivity to traffic speed (note that the observed "before" speeds on Willow indicated on the Figure are not particularly high).

Case Study Procedure

"Before" data measures were conducted

in late October and early November, 1979. Simultaneously, through public meetings and notices, the City insured that resident concern about speeding was broad-based and that there was no strong opposition to the conduct of the test programs. The humps were installed on December 6, 1979 by City public works crews. Interim monitoring took place in January, 1980 and formal "after" measures were taken in late June, 1980, *approximately 7 months after installation.*

Installation Details

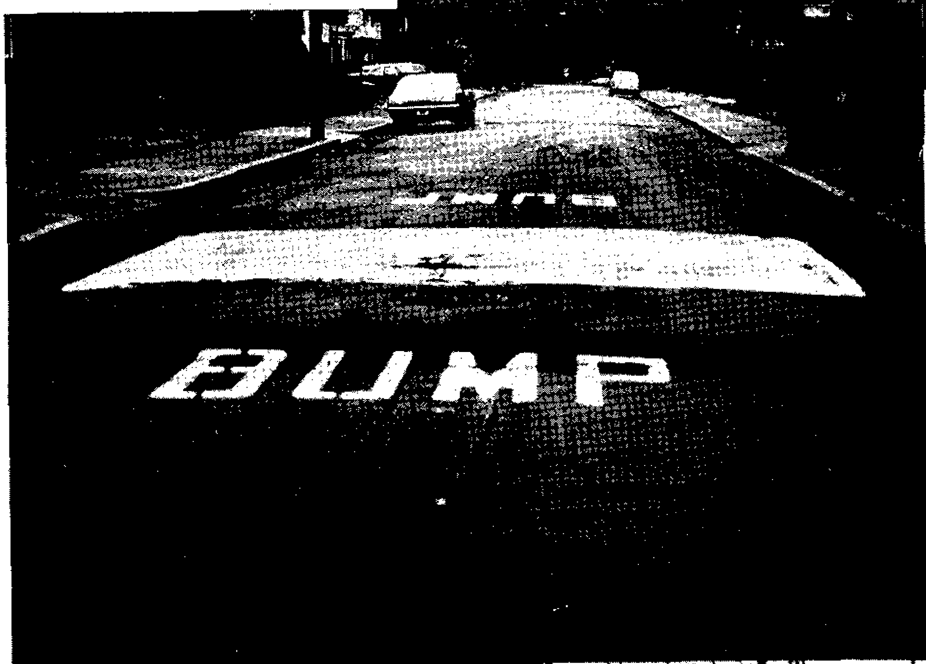
Three humps were constructed on each street. Location and spacing of the humps is shown in the performance graphs presented subsequently.

Unlike the Brea installations, in which the existing pavement surface was excavated to the base before constructing the humps, the Boston undulations were constructed by simply overlaying the existing pavement. Some ravelling of the edges of the overlays was evident as early as a month after installation but even after 6 months, the deterioration had not become unreasonable. It appears that simple overlays are acceptable for test situations. Excavation to base for the last 1.5 feet (46 cm) on each edge of the humps appears desirable on permanent installations but complete excavation as done in the Brea case does not appear necessary.

Figure 28 shows a typical Boston hump installation and signing and marking details. The only signing is "Bumps Ahead" advance warning signs on the approaches to each test segment. In Brea, where each hump was individually signed, residents complained about the number and appearance of the signs. In Boston, residents requested individual warning signs by each hump, though their intent was not to alert traffic. Rather, they hoped the signposts would discourage motorists who allegedly (though this was never witnessed by research team personnel) jumped the curbs to avoid the humps. The Boston humps were completely painted white and the legend BUMP was painted on the pavement in 4 foot (1.2m) letters in advance of each hump. After 6 months the paint had faded considerably and was obscured by black tire marks to a substantial degree. However, these markings still appear to improve hump conspicuity over the Brea conditions. It is also noted that even light snow completely obscures pavement markings and makes it very difficult, even for persons familiar with the humps, to know just where they are. It is recommended in snow country that humps be individually signed as an aid to drivers and plow operators specifically locating the humps. Paint and signing should not be considered as alternatives; both treatments should be applied to each hump.

The humps on Lochstead were terminated abruptly about 4 feet (1.2m) from the curb face. Those on Willow terminate about 2 feet (.6m) from curbface. Both treatments, that on Lochstead particularly, appear considerably more inviting to gutter-runners than the Brea treatment in which the humps were gradually tapered to the curb face. Gutter-running tendencies are discussed subsequently. *One further installation detail* is significant. Because the TRRL work gave no indication as to how steep a slope the undulations could be employed on safely, it was felt prudent that all humps be placed at relatively level points on all the case study streets in these initial U.S. applications. Initial intent in the Willow Street case was to place the last (most southerly) hump at a level point at the tow of the previously described slope. However, in response to specific citizen requests, the City actually installed this hump in a more northerly position at a point where the slope approaches 3 percent. (Since the street

Advance Warning Sign



Hump and
pavement markings

Gutter Runner
in Boston

Figure 28. BOSTON HUMP DETAILS

is one-way, all traffic passes over this hump going downhill).

PERFORMANCE

Figures 29 and 30 present before and after speed profiles for Lochstead Avenue. Figure 31 presents similar speed profiles for Willow Street. On both streets the humps cause substantial speed reductions at all comparison levels - the fastest car, the 85th percentile speed and the average speed. On Lochstead, fastest speed observed dropped 15 mph (from 52 to 37 mph) (24, from 84 to 60 kmph) in the westbound direction and 8 mph (from 42 to 34 mph) (13, from 68 to 55 kmph) eastbound. At the point of fastest speed on the street before installation, the drop in fastest speed was 19 mph (from 52 to 33 mph) (31, from, 84 to 53 kmph).

Eighty-fifth percentile speed dropped substantially over most of the street length. In the eastbound direction, it dropped from a maximum of 34.9 mph (56.2 kmph) before to 25.1 mph (40.4 kmph). Westbound, 85th percentile speed dropped from a "before" maximum of 35 mph to 24.5 mph (56.3 to 39.4 kmph). Net change at the former points of maximum 85th percentile speed was 17.1 and 13.6 mph (27.5 and 21.9 kmph) eastbound and westbound, respectively.

The drop in average speeds between before and after maximums was 11 mph (31 to 20) (17.7, 49.9 to 32.2 kmph) eastbound and 10.1 mph (30 to 19.9) (16.3, 48.3 to 32.0 kmph) westbound. Drops of at least 7 mph (11 kmph) in average speed were achieved over most of the block.

There is little evidence of accleration between the humps among the faster cars. Slower cars do acclerate somewhat between humps. At the average speed level, difference between mid-hump and hump-crossing speeds is about 4.5 mph 7.2 kmph).

"After" speeds on both the average and 85th percentile profiles conform to the 25 mph (40 kmph) speed limit. Before hump installation, 85th percentile and average speeds exceeded the limit over most of the block.

Analysis of the Willow Street speed patterns is more complex. Before installation, Willow did not appear to have a particularly serious speed problem. The fastest speed observed was 37 mph (59.5 kmph). Eighty fifth percentile speed exceeded the 25 mph (40 kmph) limit by only about 4 mph (6.4 kmph) over most of the street and 8 mph at the maximum speed point. Average speed generally conformed to the 25 mph (40 kmph) limit. The one-way southbound traffic showed a pattern of gentle acceleration on the downgrade between cross-streets Schirmer and Alhambra with fastest speeds near the toe of slope at Alhambra.

The humps produced meaningful speed reductions along the entire test segment. Reduction in fastest speed observed was 6 mph (9.7 kmph). Reduction at the point of former fastest speed is 12 mph (19.3 kmph). Fastest 85th percentile speed observed dropped 7.8 mph (from 33 to 25.2 mph) (12.6, from 53.1 to 40.5 kmph). Over the entire segment observed, the minimum drop in 85th percentile speed at any point was 4 mph (6.4 kmph). The minimum drop in average speed at any point was also 4 mph (6.4 kmph). Drop in average speed at the former fastest point was 11 mph (17.7 kmph). The Willow speed profiles do show a pattern of acceleration between the humps on all three (fastest, 85th percentile and average) curves. This is attributable to the downgrade between the humps as much as to deliberate acceleration by drivers. And the former pattern of downhill acceleration is clearly foreshortened by the presence of the southerly hump.

As noted previously, gutter-running was prevalent at the humps on both Boston

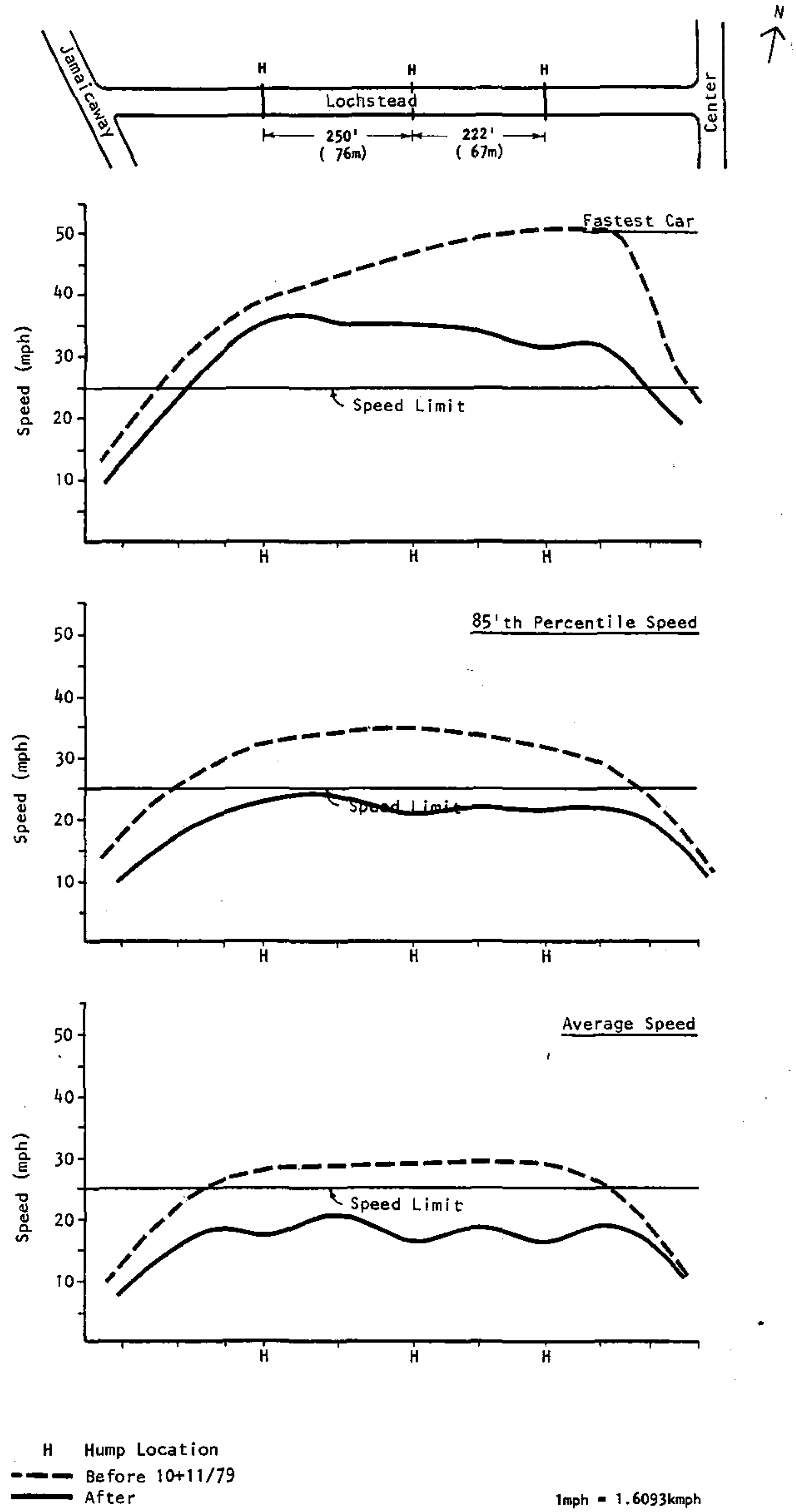


Figure 29. LOCHSTEAD SPEED STUDY - WESTBOUND

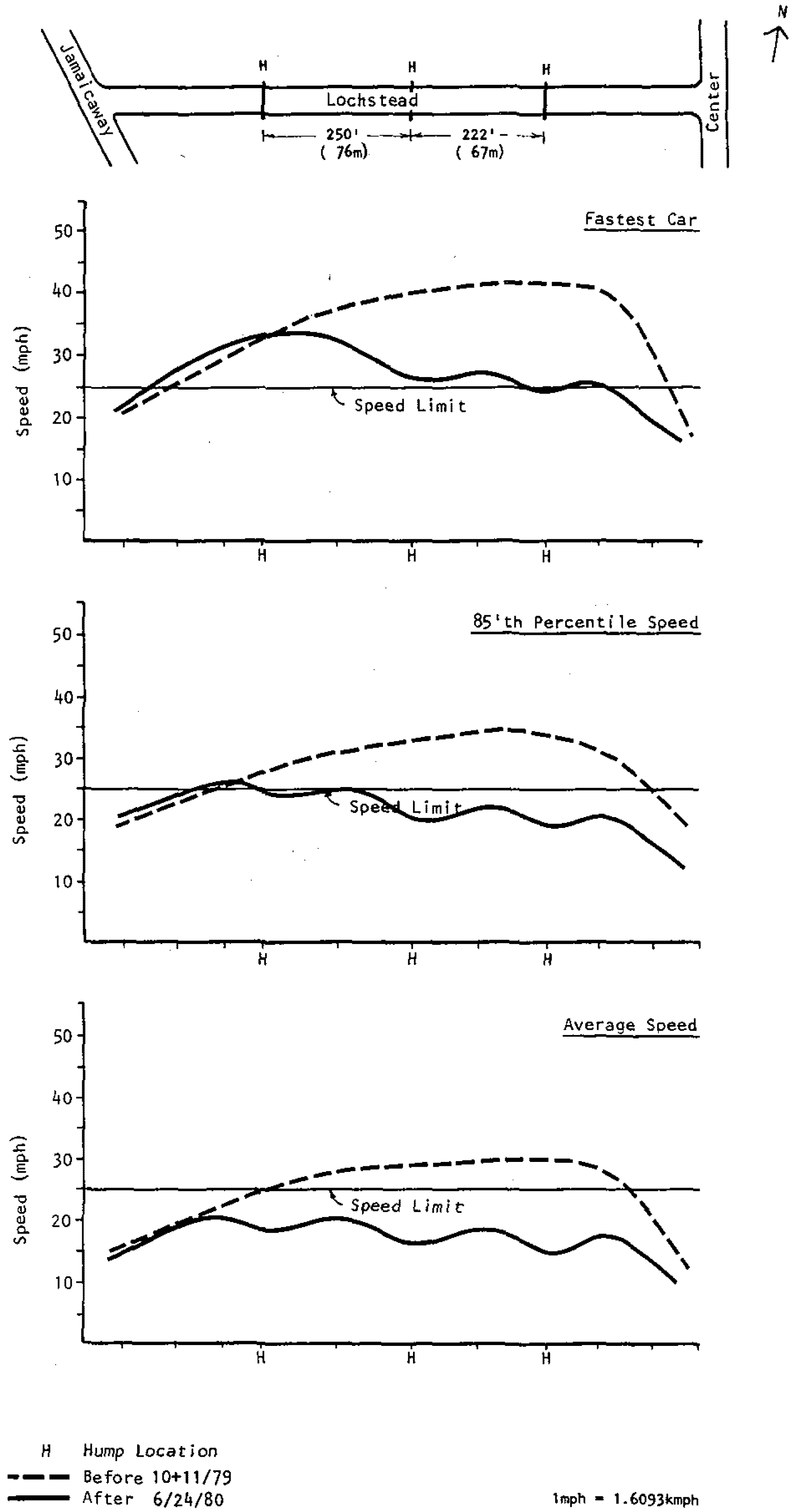


Figure 30. LOCHSTEAD SPEED STUDY - EASTBOUND

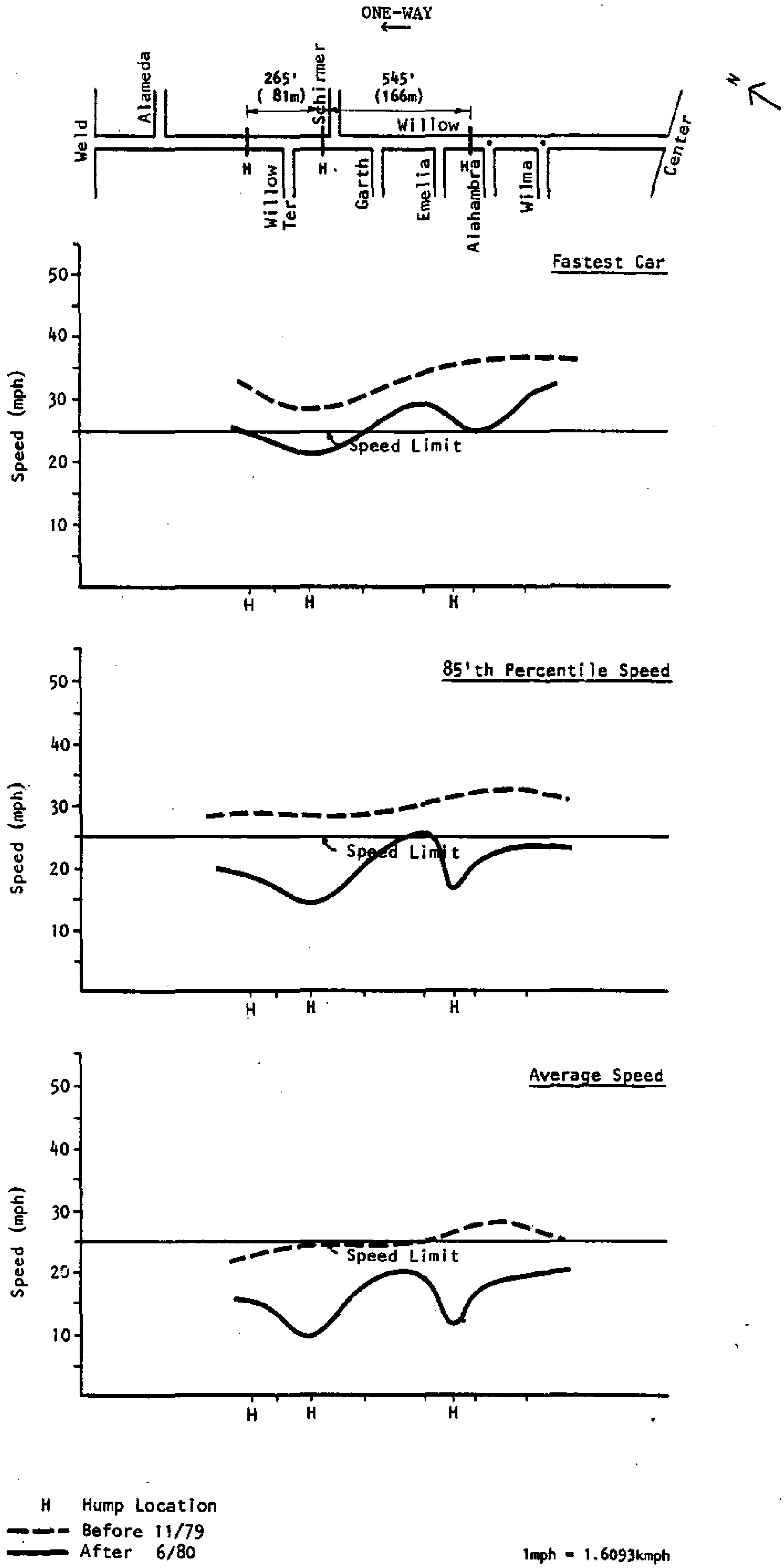


Figure 31. WILLOW SPEED STUDY

Streets. Table 12 presents data on prevalence of gutter-running. La Canada data from Brea is also included for comparison purposes. Gutter-runners comprise a substantial minority of all traffic; at one hump on Lochstead a majority of the cars ran the gutter. Inspection of the table reveals that gutter-running is not substantially more prevalent on Lochstead where the physical detailing of the humps is most inviting for this practice than on one direction of La Canada where the humps gutter taper of the hump might be expected to partially discourage the practice. Most disturbing is practice of a small but noteworthy percentage of drivers on Lochstead who drove on the wrong side of the street to run their left wheels in the gutter - the better to avoid hump impact on the driver's side of the vehicle. This practice was also observed in rare instances on La Canada but never during periods when specific observations of gutter running were being recorded. On Willow, heavy parking on the east side of the street precludes left side gutter running. Table 13 presents a comparison of speeds of gutter-runners versus those of vehicles driving straight over the humps. While the differences in speeds between right side gutter-runners and those driving straight over are somewhat more pronounced than in the Brea case (see Table 6) the conclusion that drivers do this primarily to ease their passage rather than to help themselves go faster still seems to apply. Interestingly, those practicing the more radical avoidance behavior - left side gutter running - go slower than those who drive straight over. This further supports the concept that drivers run the gutters for comfort rather than for speed.

The obvious hazards inherent in gutter-running, particularly in the left side maneuver, suggest that actions be taken in future installations to discourage this behavior. Considering that comfort appears to be the primary motivation, it should be simple to discourage the practice with a few strategically placed jiggle bars.

Traffic Safety

An attempt was made to evaluate traffic safety conditions on the Boston case study streets before and after hump installations similar to the analysis done in the Brea case. However, it proved extremely difficult to extract current year (that is, post-installation) accident reports from the City's accident records system. For this reason the formal comparison of accident records was not completed. However, as of this reporting City traffic officials are not aware of any post-implementation accidents on either case study street directly or indirectly attributable to the humps presence. Safety conditions should be further monitored at these sites when 1980 accident records become accessible.

REACTIONS OF BOSTON RESIDENTS TO THE HUMPS

Ten months after the humps were installed, the City of Boston solicited the opinions of residents as to how effective the humps were in solving perceived problems, what new problems they may have created and how the residents reacted to the humps from the perspective of a driver. Identical survey instruments were administered on Lochstead and Willow using a home interview technique. The instruments were nearly identical to those administered to residents of the La Canada test segment in Brea. Response rates were reasonably good; 51 of the 80 test segment households (64 percent) on Willow responded, 15 of 17 households (88 percent) on Lochstead responded. Details of the response are presented below.

Table 12
Gutter Running Incidence

	Straight Over	Right Gutter	Left Gutter
Lochstead Eastbound			
Hump 1	59%	36%	5%
Hump 2	64%	33%	3%
Hump 3	58%	37%	5%
Lochstead Westbound			
Hump 1	40%	58%	2%
Hump 2	56%	32%	12%
Hump 3	54%	30%	16%
Willow Southbound			
Hump 1	77%	23%	-
Hump 2	67%	33%	-
Hump 3	73%	27%	-
La Canada Northbound			
Hump 1	56%	44%	-
Hump 2	65%	35%	-
Hump 3	67%	33%	-
La Canada Southbound			
Hump 1	89%	11%	-
Hump 2	86%	14%	-
Hump 3	77%	23%	-

TABLE 13
SPEED ANALYSIS OF GUTTER-RUNNING

	Fastest	85th Percentile	Mean
Lochstead Eastbound			
Straight	26	20.5	15.3
Right Gutter	21	18.1	16.3
Left Gutter	18	-	-
Lochstead Westbound			
Straight	28	19.5	14.6
Right Gutter	35	22.6	17.7
Left Gutter	22	16.9	13.9
Willow Southbound			
Straight	16	10.7	8.5
Right Gutter	21	15.5	12.0

TABLE 14
RESIDENT PERCEPTIONS OF HUMP EFFECTS ON
PROBLEM CONDITIONS - WILLOW STREET

	HUMP EFFECTS				
Problem	Percent Perceiving Problem	Made Worse	No Change	Slight Improvement	Substantial Improvement
Traffic too fast overall	88	7	19	19	55
Extreme speed by some	85	6	16	25	53
Late night speeding	88	3	22	28	47
Dangerous for kids	85	3	23	27	47
Dangerous for bicyclists	76	6	28	21	45
Noise from squealing tires	64	11	24	24	41
General traffic noise	74	7	30	19	44
Motorcycles speed, joyride	58	0	36	23	41
Dangerous for pedestrians	65	0	41	15	44
Traffic laws not enforced	57	4	50	14	32
Too much traffic at night	57	0	40	20	40
Too much cut-thru traffic	61	0	43	17	39
Too much traffic overall	74	0	43	22	35

Willow Street Residents

Table 14 presents Willow Street resident ratings of problem conditions which may have existed before the humps were installed and how installation of the humps may have affected the condition. The Table clearly indicates a diversity of opinions as to which conditions were problems before and how much improvements the humps have brought about. However, on all conditions which more than 80 percent of the question respondents rated as a problem, more than 70 percent indicated the humps had produced a slight or a significant improvement. And these particular conditions - overall traffic speed, extreme speed by some drivers, late night speeding and danger for children - are the ones most related to the obvious purpose of placing the humps. Furthermore, on all but three conditions, the numbers reporting that humps produced some improvement comprised over 70 percent of those who rated the condition as a concern before the humps were installed. On the remaining three conditions, more than 60 percent of those reporting them a as concern rated the humps as producing some degree of improvement. While the numbers reporting "no change" in some conditions are substantial, no significant numbers report worsening on any conditions except for "noise from squealing tires" where three respondents (11 percent) disagree with the majority. So overall the humps can be rated as having a very fair degree of success in responding to conditions of concern to residents.

Relative to post-installation speed conditions, 21 percent of respondents indicated overall speeds remained "far too high", 23 percent indicated it was now "slightly faster than it should be", 32 percent felt speed was "about right" for the street and 19 percent believed traffic was held to speeds "somewhat slower than reasonable." Only 5 percent felt traffic was confined to speeds "much slower than reasonable". Twenty-five percent felt that the fastest drivers were still able to travel "any speed they wish", while 60 percent felt the fastest drivers had "slowed somewhat, though still traveling too fast." Fifteen percent believe fastest drivers are now confined to speeds "not much faster than average drivers. These results are quite similar to the perceptions of residents at the Brea installation.

Resident perceptions of "gutter-running" on Willow was also similar to resident perceptions at the Brea test site. Twenty-six percent indicated gutter-running was "so frequent it defeats the purpose of the humps;" 43 percent indicated that gutter-running "was fairly frequent, but even gutter-runners slow down some;" 26 percent said gutter-running was "not very frequent but those who do it drive dangerously fast." Only 6 percent thought gutter-running was "too infrequent to worry about." In the "comment" section, several residents suggested extending the humps to the curb face as a countermeasure to gutter-running.

After hump installation, only 18 percent of Willow Street residents felt their street was "still quite dangerous considering safety from traffic of pedestrians, bicyclists and kids in general". This is markedly better than at the Brea site where 534 percent of the residents felt their street was still quite dangerous. Fifty-five percent of Willow Street respondents felt its safety characteristics were "about average for a residential street;" 24 percent felt it was "safer than average" while only one respondent rated it "very safe". Ten percent of the Willow Street respondents felt that noise of traffic braking and accelerating near the humps was "a severe problem"; 31 percent indicated it was an "occassional nuisance," 27 percent felt it was "an occasional nuisance but worth it to keep speeds down" while 31 percent indicated it was "no problem at all." It is unclear whether those who indicate serious noise disturbance are those living closest to the humps (thus, most exposed to the noise) or whether they are persons who oppose the humps in principle and are just using the potential noise issue as another justification for their position. What is clear is that 50 percent of those who indicated they did not believe the humps served a useful purpose and wanted them removed also indicated noise as a severe problem. Some 24 percent of respondents rated the humps "too severe"; 64 percent rated them "about right to slow traffic safely," 9 percent rated them "somewhat more gentle than they should be" and one respondent rated them "far too gentle to be effective". This is in marked contrast to the Brea results where none of the respondents rated the humps "too severe" and 33 and 20 percent rated the humps in the "somewhat more gentle than they should be" and "far too gentle" categories respectively. This difference seems to highlight the importance of close adherence to the prescribed TRRL hump shape - the Brea humps tended to be about .5 inch (1.25 cm) lower than the intended 4 inch (10 cm) height projection; the Willow (and Lochstead) humps tended to be about .5 inch (1.25 cm) high. Residents were asked to rate the degree of difficulty they had personally experienced while driving various vehicle types across the humps. Expectedly, most experience was confied to automobile operation. Eighty four percent reported "no difficulty"; 8 percent indicated experiences in the "moderate" and "serious difficulty" categories. Five respondents reported experiences as operators of vans or pick-ups; all reported "no difficulty". Ten respondents reported on experiences as bicyclists; 9 reported "no difficulty" while one reported "serious difficulty".

Joy-riders on the humps do not appear to be a serious concern. Only two respondents rated it a serious continuing problem. Sixteen percent said it was "a problem at first"; 35 percent said it "was never a problem". Signing and marking the humps clearly requires improvement. Sixty percent of the respondents rated current provisions "insufficient to warn drivers". Only 38 percent felt the signs and markings were "about right". Less than 10 percent felt that the signs and markings were so obtrusive as to detract from the appearance of the neighborhood.

As to spacing between humps, 68 percent felt the humps were spaced "about right"; 23 percent thought them "too far apart" while only 9 percent rated them "too close". On the related question of the adequancy of the number of humps on the test segment, 53 percent of Willow Street respondents indicated the number (3) was "about right" for the test segment; 39 percent thought there were "too few" humps while 8 percent thought there were too many. In the comment section 8 respondents made specific recommendation for more humps most suggesting a location between the last existing hump and Centre Street.

On the fundamental question of whether the humps were good or bad overall, support for the humps was extremely strong. The two questions, "do the humps serve a useful purpose" and, "should the humps remain on this street after the test period" received an identical 88 percent affirmative response. Eighty-one percent of the respondents thought the humps should be used on other streets experiencing similar traffic problems and 83 percent felt no measures more effective than the humps in controling traffic speeds existed. Responses in the comment section constructively supported the humps by a 22 to 1 margin.

Lochstead Avenue Residents

Lochstead Avenue residents' perceptions that problems existed before installation of the humps and their perceptions that the humps brought about changes closely paralleled those of Willow Street residents presented on Table 15. Some 93 percent of the repondents felt that "too fast overall traffic speeds," "extreme speeds by some drivers" and "danger to kids" were problems before the humps were installed. Of those who expressed concern on these particular problems, between 62 and 75 percent felt the humps had caused a significant or at least a slight improvement.

Relative to post-installation speed conditions two respondents felt speeds remained "far too high", 33 percent indicated speed on the street was "slightly faster than it should be", 40 percent reported speed "about right for this street" and one respondent each believed traffic was confined to speeds "somewhat slower than reasonable" and "much slower than reasonable". Twenty percent felt the fastest drivers still traveled "any speed they wish"; 53 percent felt they "slowed somewhat though still traveling too fast" while 27 percent rated the fastest as "not much faster than average drivers."

Twenty percent felt gutter-running was "so frequent it defeats the purpose of the humps;" 73 percent felt gutter-running was "fairly frequent but even the gutter-runners slow down some;" one respondent indicated that "gutter-running was not very frequent, but those who do drive dangerously fast. In the comment section 40 percent of the respondents suggested extending the humps to the curb face as a countermeasure to gutter-running. An additional measure - bollards behind the curb line was suggested as a counter to gutter-runners who might jump to curb. With the humps installed only 13 percent of Lochstead respondents felt their street was "still quite dangerous"; 47 percent felt it was "about average for a residential street", 33 pecent felt it was "safer than average" and one respondent felt it was "very safe".

One respondent felt that noise of traffic braking and accelerating near the humps was "a serious problem"; 33 percent rated it an "occasional nuisance"; 40 percent said it was "an occasional nuisance but worth it to keep speed down" while 20 percent indicated it was "no problem at all."

Two-thirds of the respondents rated the humps severity "about right to slow traffic safetly"; 20 percent felt they were "more gentle than they should be and the "too severe" and "far too gentle" categories drew one response. In rating hump crossing difficulty experienced as a driver of various vehicle types, only the passenger auto category drew meaningful response. Eighty-seven percent indicated "no problem": crossing the humps while 13 percent indicated "moderate-difficulty".

Lochstead residents do not appear disturbed by joy-riders on the humps. Sixty-nine percent indicated this was "never a noticable problem"; 23 percent rated it a "minor problem" and only one respondent called it "a serious continuing problem".

Lochstead respondents perceptions regarding the adequancy and aesthetics of hump signs and markings appears less pronounced than on the other test streets. Fourty-three percent thought the existing provisions were "insufficient" to warn drivers of the humps presence; 50 percent thought the signs and markings were "about right" while one thought they were "more extensive than necessary". As to appearance, 31 per-

TABLE 15
RESIDENT PERCEPTIONS OF HUMP EFFECTS ON PROBLEM CONDITIONS - LOCHSTEAD AVENUE

	HUMP EFFECTS				
Problem	Percent Perceiving Problem	Made Worse	No Change	Slight Improvement	Substantial Improvement
Traffic too fast overall	93	8	23	8	61
Extreme speed by some	93	8	17	17	58
Late night speeding	79	8	31	15	46
Dangerous for kids	93	17	17	8	58
Dangerous for bicyclists	71	0	30	10	60
Noise from squealing tires	79	31	15	15	39
General traffic noise	75	18	36	0	45
Motorcycles speed, joyride	75	18	36	9	36
Dangerous for pedestrians	62	11	22	0	67
Traffic laws not enforced	71	15	54	8	23
Too much traffic at night	50	10	30	20	40
Too much cut-thru traffic	100	20	40	10	30
Too much traffic overall	67	11	44	11	34

Table 16
SPEED EFFECTS - SACRAMENTO UNDULATIONS

	Speed in MPH			
85th %ile Speed	At humps	400' upstream	400' downstream	Between pairs
Before	37	37	37	37
After	26	21	27	32

cent rated the signs and markings "acceptable" while 69 percent rated them "not noticably negative." None thought them so obtrusive as to detract from the appearance of the neighborhood. As to spacing between the humps, 67 percent felt the installation was "about right", 20 percent thought the humps "too far apart" and 13 percent thought them "too close together". Seventy nine percent thought the number of humps on Lochstead was "about right", 21 percent thought there were "too few" and none thought there were "too many".

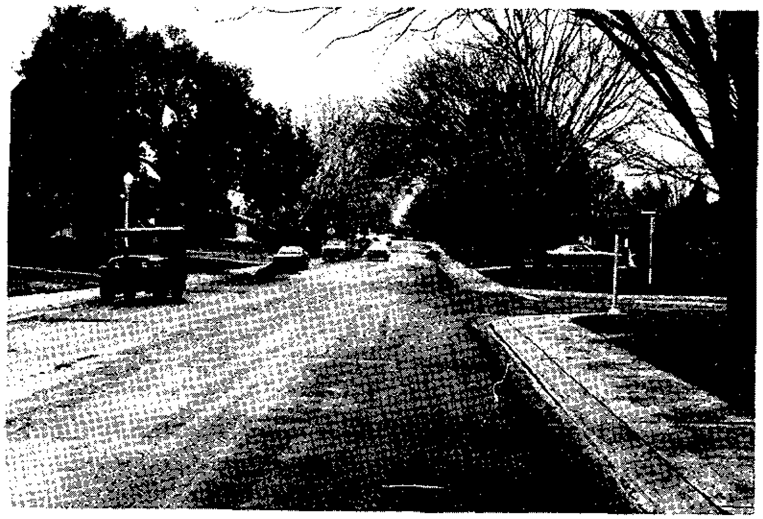
On the fundamental question of whether the humps were good or bad, Lochstead respondents gave strong support. Seventy-nine percent thought they "served a useful purpose", 80 percent indicated the humps "should remain on the street after the test period", 75 percent felt the humps were superior to other ways of controlling speed on the street and 92 percent felt they should be used on other streets with similar speed problems.

SACRAMENTO CASE STUDY

Based upon its controlled site test program described previously, the city of Sacramento undertook a case study application on Sandburg Drive. Sandburg Drive is a 25 MPH (40 kmph) speed limit local residential street which is continuous for over a mile and is used in preference to a nominally parallel collector street by residents of the greater neighborhood and by visitors to a popular riverfront park. Stop signs had previously been installed at several locatons on the parallel collector to discourage speeding there. Sandburg is a comfortable, middle class neighborhood with well maintained older single family homes generously set back from the roadway. Humps were installed on Sandburg in mid-October 1979 and remain in place as of this writing. Three features of this application, undertaken independently of this FHWA research program, stand out. First, the humps were slightly different from the TRRL standard, being only 3 (7.5 cm) rather than 4 inches (10 cm) in height. Second, each of the four installations involved a pair of humps spaced 20 feet (32m) apart. Finally, the hump sets were spaced considerably farther apart than in any of the U.S. case studies or in TRRL's applications. Distances between hump pairs in Sacramento ranged from 1,200 to 1,500 feet (365 to 455m). The maximum separation used in any of the other case studies was 766 feet (232m) (in Brea).

Figure 32 shows Sacramento installation details. Sacramento employs two forms of warning signs with the humps. 'Hump ahead' signs with supplementary advisory speeds are placed in advance warning position; symbolic warning signs depicting the humps are placed adjacent. White lines in a zebra crosswalk style are painted on the humps for additional conspicuity.

Performance-wise, the humps themselves do not seem significantly different from the other U.S. case studies. The slightly gentler ride on the 3 inch (7.5cm) humps seems to be offset by the pairing of humps at each hump site. The lengthy separation between hump sets clearly results in the humps having **localized** rather than **full segment** speed control effects. Table 16 presents Sacramento speed results. Most of the speed reduction occurs within 400 feet (122m) of the humps although some reduction is experienced at the mid-point between hump pairs. We are convinced that had Sacramento split their hump pairs and halved the distance between installations, a more continuous control would have resulted. As in the other U.S. case studies, the Sacramento humps were terminated



Remote advance warning sign sign (right foreground).

Adjacent advance warning sign.

Pavement marking on undulation.

Figure 32. SACRAMENTO INSTALLATION DETAILS

short of the gutter to preserve gutter flows. The broad 'V' gutters which are standard on residential streets in Sacramento invite gutter-running and even led some Sandburg drivers to drive partially on the adjacent sidewalk in avoiding the humps. Sacramento cured this problem by installing metal posts at the back of the gutter line.

Traffic on Sandburg dropped from 1,540 ADT to 1,226 ADT as a result of hump installation, an approximately 20 percent decrease.

Despite a performance which this research team judges inferior to that of the standard TRRL humps as applied in the other U.S case studies, Sacramento was sufficiently impressed with the results on Sandburg to contract for similar installations on 10 additional residential streets in the summer of 1980.

SPEED VS. HUMP SEPARATION

Figure 33 presents plots of between-hump speeds versus hump separation distance and compares the U.S. and TRRL observations. The TRRL results indicate increasing between-hump speeds with increasing hump separation. The U.S. case studies, which included a range of hump separations even broader than those reported in the TRRL work (up to 766 feet (232m) versus a maximum of about 510 feet (155m) for TRRL), show little evidence of increasing between-hump speeds at increasing hump separations. Not plotted on the graph are results from the Sacramento application in which humps were spaced between 1,200 and 1,500 feet (365 to 455m) apart and which had predominant to speed effect only in the immediate area of the humps. There seems to be a threshold point between the 766 foot (155m) spacing used in Brea and the 1200 to 1500 foot (365 to 455m) space utilized in Sacramento at which between-hump speeds begin to increase substantially with hump separation distance. However, this threshold has not been defined in the current research.

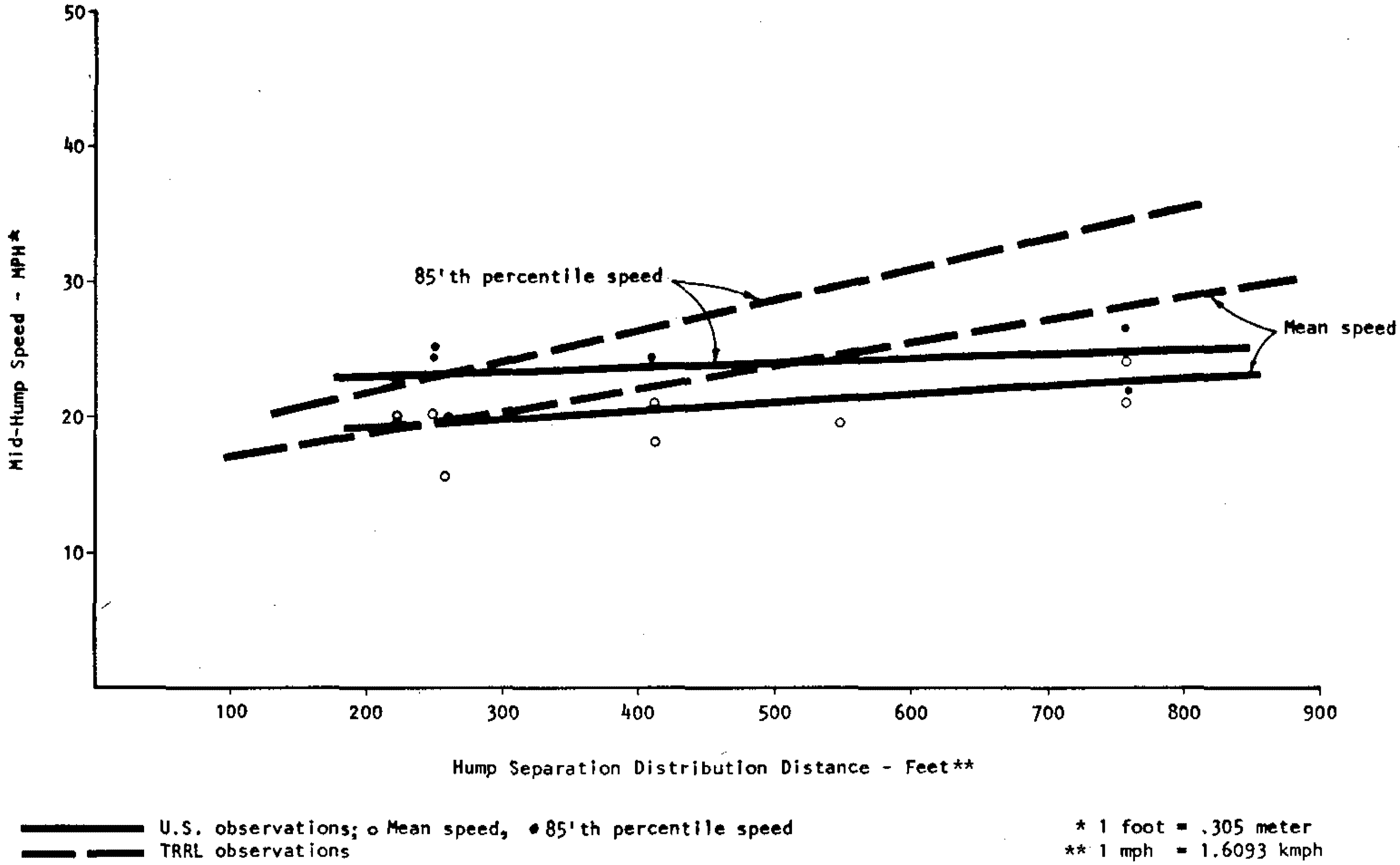


Figure 33. MIDHUMP SPEED VS SEPARATION DISTANCE
COMPARISON: U.S. VS TRRL RESULTS

CHAPTER 4
IMPLEMENTATION PLAN FOR ROAD HUMPS

Applications of the hump on public streets have been observed in New Zealand (one) and in Toronto, Canada (two locations) and reportedly are widespread in India, although little performance evaluation information has been received from any of these sources. The device is also commonly used as a design feature in woonerfs (special residential streets on which cars are required to travel slowly) in the Netherlands and Germany. This evidence of proliferating use plus the original TRRL research and the case study work reported in Chapter 3 of this report make an implementation plan for applications of the road hump appropriate.

At this stage of its development, the road hump cannot be said to have achieved the status of a standard traffic control device like a STOP or YIELD sign. On the other hand, it has performed well enough and long enough in public street applications that it cannot be labeled as raw or untested. It is a device which is promising and with which further experimentation is both needed and encouraged. Hence, the purpose of this implementation plan is not to endorse blanket applications of road humps. Rather, recognizing the need for further testing of road humps under public street conditions, this implementation plan is intended to encourage, facilitate and guide further careful test applications.

SUMMARY OF ROAD HUMPS PERFORMANCE

Substantial reductions in the speeds of the fastest cars can be expected along with an 85th percentile speed of about 25 mph (40 kmph). Average speeds of slightly under 20 mph (32 kmph) can be expected. While automobiles can cross the humps safely at high speeds, virtually all choose to cross them at speeds which are reasonable for local residential streets.

Normally a series of humps rather than a single one are used to control a street segment. When spaced between from about 200 to 750 (61 - 228m) feet apart, the humps tend to exert speed control over the entire test segment rather than just in the immediate vicinity of the humps. While slowest speeds tend to occur right at the humps and vehicles do accelerate somewhat between humps, the humps tend to have a relatively continuous, segment-long control effect.

Automobiles should not "bottom-out" nor their drivers experience control difficulties on the humps.

The humps have more severe effects on long wheelbase vehicles than on automobiles. Potential effects on long wheelbase vehicles, particularly emergency vehicles, are an important consideration when determining whether the humps are an appropriate control for a particular street. This is discussed in detail subsequently.

The humps can be crossed by bicyclists and motorcyclists with no difficulty although both may occasionally use them as an aid in performing "wheelies".

Traffic reductions on the order of 20 percent were experienced on the hump-controlled segments in the case studies. The extent to which diversion will occur in any application will depend on the hump-controlled segment's placement in its area street network and the availability of other convenient routes for drivers.

GENERAL CRITERIA FOR APPLICATION

The humps are an extremely restrictive form of speed control which causes some discomfort for drivers who are traveling too fast. For this reason, they should be used only where there is a confirmed speed problem and where other reasonable speed control measures have failed or do not appear likely to perform satisfactorily. Resident concern about speeding should be broad-based; not limited to a few vocal gadflies.

The *humps should be applied only on* local streets where the speed to which the humps confine traffic is reasonably in keeping with the intended functional role of the street - that is, a street where a 25 mph (40 kmph) speed limit is reasonable. Most likely the street should be one intended primarily to provide local access to residents and be predominantly fronted by residential properties (although use on a local access street in an industrial park might also be appropriate). A street used somewhat by through traffic is acceptable but it should be clear that the through service function is subordinate to the street's basic residential *access character or that through* traffic is undesired on the street. The humps should not be used on streets where the vast majority of the drivers travel at relatively fast speeds (say, 45 or 50 mph (72 - 80 kmph)) and where the objective is to limit them to a more moderate speed (say 35 mph (56 kmph)).

The humps should not be used on streets which are expected to serve heavy volumes of truck traffic or which are on bus routes.

The humps should be used on streets where traversal by emergency vehicles will be only in response to an emergency call in the immediate vicinity - not on routes commonly used by emergency vehicles as access corridors to large areas of the community. The humps should not be used on immediate egress routes from fire and ambulance stations or on immediate access routes to hospitals and emergency clinics.

No absolute traffic volume limits for streets on which the humps might be employed are suggested, though streets carrying under 3000 ADT should generally be accepted. If a candidate streeet serves a volume which implies a strong collector or arterial function, the previously posed question of whether this restrictive form of speed control is consistent with the intended functional role of the particular street must be carefully considered. Where traffic volumes on the candidate street are substantial, the potential impacts of diverted traffic should be considered. Based on case study experience, a diver*sion of about 20 percent of the existing* volume might be a reasonable expectation. Humps should not be placed on streets where diverted traffic would create intolerable congestion elsewhere or adversely impact adjacent local residential streets.

Vertical alignment of the segment to be controlled should be reasonably uniform. The humps have been tested in only one on-grade situation. Placement on long, steep grades or "roller-coaster" profiles is unacceptable A segment which has one or two short, steep grades in an otherwise fairly level section might be acceptable so long as humps are not *placed on the grades.*

Horizontal alignment need not necessarily be tangent but should allow for adequate sight distance to the humps and should not impose the need to traverse a hump while engaged in a sharp turning maneuver.

No absolute limits to the length of a hump controlled street segment are specified. In the British tests, street segments up to .52 (.84 km) miles long have been hump-controlled. The upper limit to the length of continuous street to which the humps might reasonably be applied tends to be a function of the street's role in the area street network *rather than a length-specific one. That* is to say, streets which are continuous over long distances tend to have collector street function and importance as emergency vehicle routes and the facts of its service in these roles rather than its absolute length are the dominant criteria. Very short streets rarely have speed problems. The practical lower limit to the length of segment on which humps could be applied is determined by the ability to provide adequate advance warning and sight distance on all approaches to the humps.

A candidate street for application of the humps should have good pavement surface quality, reasonably good drainage and street lighting and be free of unusual features which might in combination with the humps, cause some sort of unusual performance effect.

INSTALLATION DETAILS

If a street meets the above general criteria, the formal design and implementation program can proceed. Two major activities are involved at this stage:

- Design and constructions
- Dealing with the various people who use the street.

Design and Construction

Fundamental engineering design requirements for a hump control plan are relatively straightforward. But because so many of the details which affect the success of the installation can only be recognized in the field, it is important that basic decisions relative to hump location signing and marking be made by a perceptive engineer working on-site. The following are key considerations in locating the humps.

- The first hump in a controlled segment should be placed such that drivers are unlikely to approach it at high speed. The British followed the practice of placing the first hump in a series about 50 feet (15m) from a STOP or signal-controlled intersection or right-angle turn. The greater offsets of the first humps used in the U.S. case studies (160 to 390 feet (49 - 199m)) provided more room for advance warning and sight distance but also allowed greater opportunity for drivers to accelerate before encountering the hump. First hump location 150 to 200 feet (45 - 60m) from the approach intersection or turn appears to be sufficiently close to confront drivers before they can accelerate to high speed yet sufficiently set back to allow for adequate sight distance and warnings. Most desirable location of the first hump will vary depending on other relevant site details as discussed below.

- The number of humps required and desirable spacing between humps will vary from site to site. The British achieved satisfactory speed control results with hump spacings ranging from about 160 to feet 510 (49 - 155m). In the U.S. case studies, satisfactory control was achieved at spacings up to 766 feet (231m). The following general guides should be considered in determining the number and placement of humps in a control segment.

    1. Single short blocks (under, say, 400 feet (120m)) with speed control problems are unusual. Where such blocks must be treated, a single undulation positioned near mid-block would likely satisfy the "first hump encountered" placement consideration described above and provide satisfactory speed control over the entire block.

    2. Where control is required on single block segments of moderate length, a two hump configuration should be satisfactory.

    3. On very long blocks, 3 or more humps may be necessary.

4. On lengthy continuous segments or on control segments comprised of a number of blocks, it appears desirable to space interior humps 400 to 600 feet (120 - 180m) apart, although spacings up to 750 feet (230m) apart may be satisfactory. At least one hump should be placed in each block of a control segment.

Figure 34 illustrates these spacing concepts.

- Site details should be the dominant consideration in determining the precise location of each hump rather than attempting to provide some uniform separation distance (like exactly 400 or exactly 500 feet (130 or 153m)) or some exact offset distance in "first hump" placement. The "first hump" and separation guidelines above are flexible should only be used for general locational guidance. A partial checklist of site details which should be taken into account in hump location are as follows.

1. Do not locate the humps over manholes, gate valves utility vault accesses and similar features.

2. If a drainage inlet is near where a hump would be placed according to the general spacing criteria, at*tempt to locate humps just down*stream of the drainage inlet.

3. Adjust hump placement to take advantage of the locations of existing street lighting features.

4. Do not place humps at driveway access points.

5. Do not place humps at fireplugs.

6. Consider visibility and placement of warning signs when locating the humps.

7. Attempt to locate the humps on property lines rather than right in front of a residence.

8. Adjust placement to assure adequate sight distance to the humps from both approach directions.

9. Take into account other unique site details which may affect hump placement. For example, do not locate a hump between ends of a loop driveway. Otherwise, a few defiant motorists are sure to use the driveway to bypass the hump, producing an irate property owner.

Figure 35 presents the basic cross-section of a hump (looking at right angles to the direction of traffic). The humps are 12 feet (3.65m) long (in the direction of traffic), have a circular arc cross section (radius equals 54.22 feet (16.6m)) and project to a midpoint height of 4 inches (10cm) above the existing pavement surface. Construction of the hump to reasonably precise shape is important. Humps with maximum heights much less than 4 inches (10cm) are too gentle to be effective. Humps with maximum heights much greater than 4 inches (10cm) can cause vehicles to "bottom-out". A tolerance of plus or minus .5 inch (1.25cm) is suggested. In the case study sites, public works crews were readily able to construct the humps to these tolerances using the methods described below. It is preferable to end up with a hump that is slightly low rather than one which is too high.

Humps are constructed of hot rolled *asphalt overlayed on the existing pave*ment surface. Application of a tack coat is advisable. To assure against separation of the tapering edge of the overlay from the existing pavement surface, the existing pavement should be excavated to a depth of 2 inches (5cm) (or to the base course) along the last 1.5 feet (46 cm) of each hump edge as illustrated on

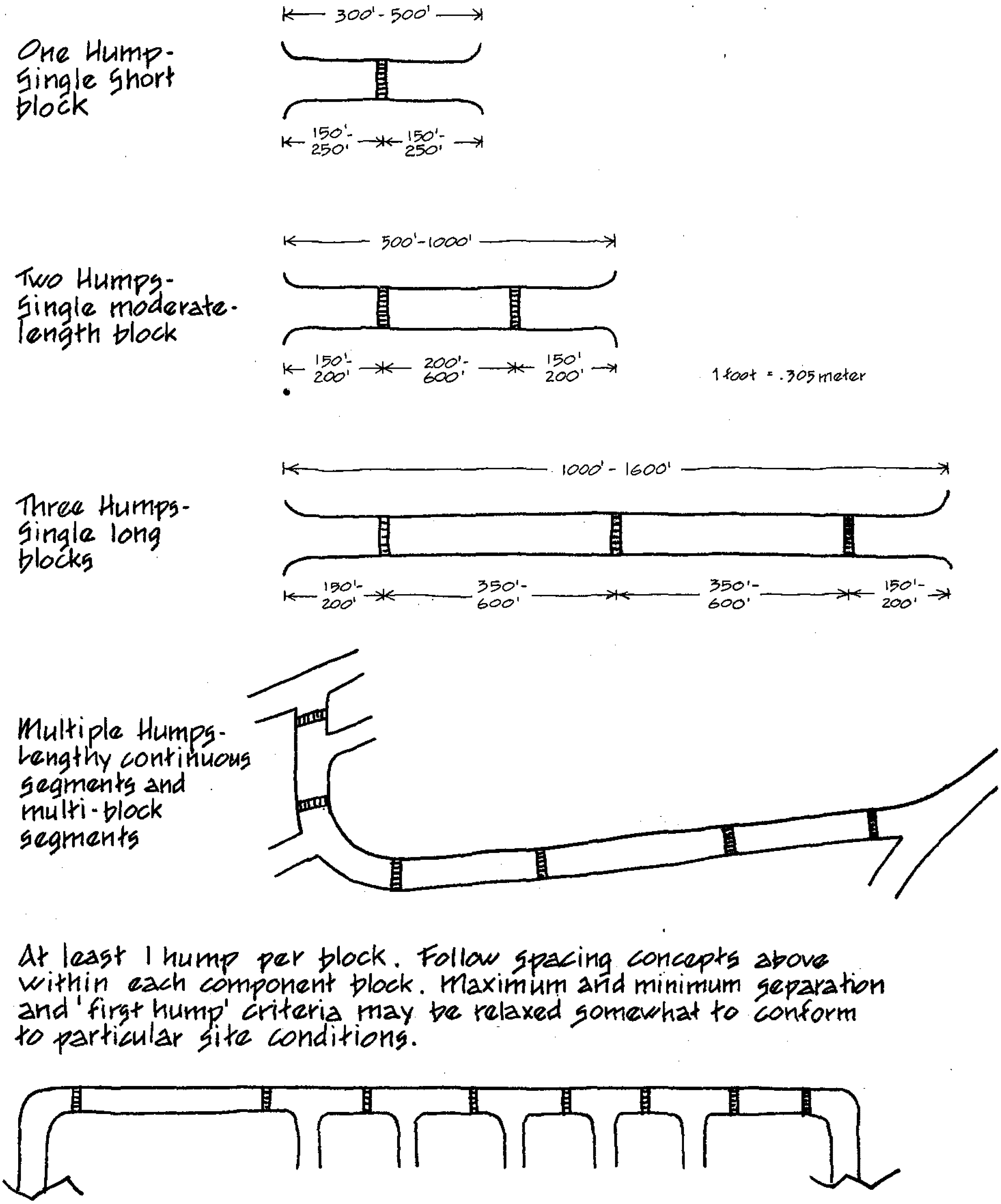
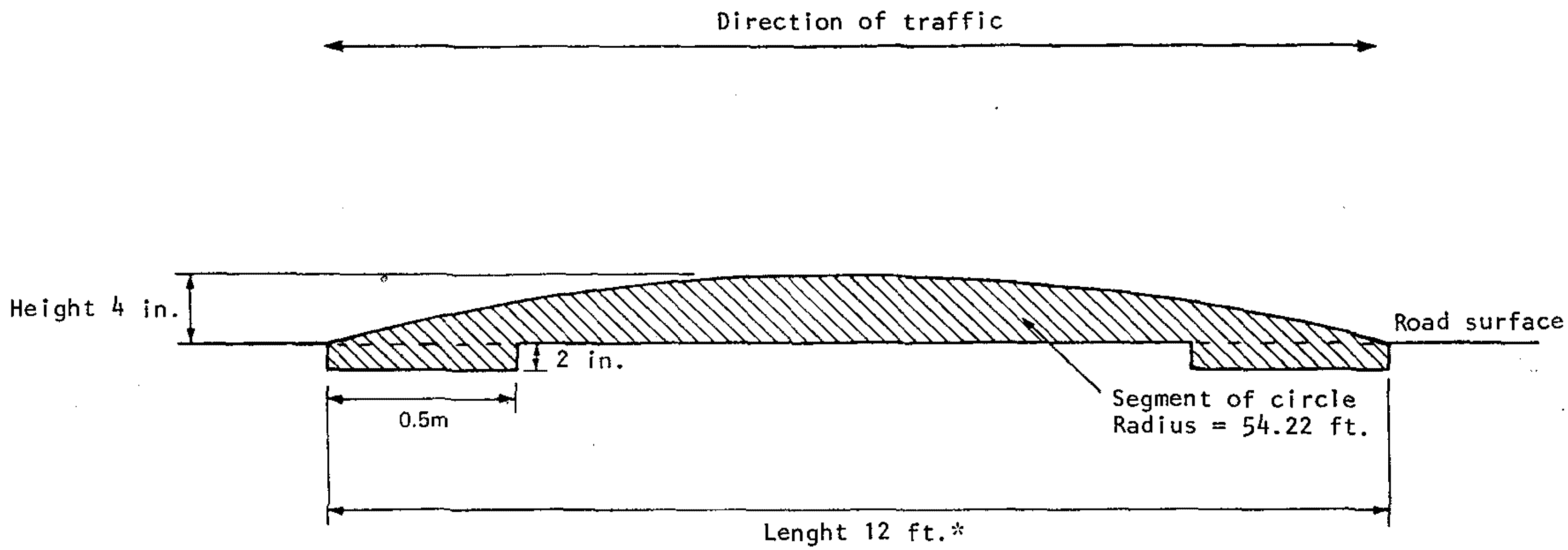


Figure 34. HUMP SPACING CONCEPTS



* 1 foot = .305 meter

Figure 35. CROSS SECTION AND HUMP DIMENSIONS

Figure 35. This provides the necessary overlay thickness to prevent edge ravelling. On temporary trial installations, the designer may choose to omit this detail as a cost saving measure.

The overlay material should be hand laid and hot rolled to shape. A 2' x 12 inch timber inscribed with the undulation shape can be used as a template and is also useful as a pushing blade in spreading the material. Gutter tapers can be laid by eye. A well motivated public works crew of 6 should be able to install 3 to 5 humps in a half-day's work, judging from case study experience.

The sides of the humps should be tapered to preserve existing gutter flows (unless the hump is located immediately downhill of a drainage inlet). Gutter tapers used in the U.S. case studies are shown on Figure 36. Both designs appeared to invite drivers to partially avoid the humps by traveling with one set of wheels in or near the gutter. A suggested taper, also shown on the figure, is believed likely to be less attractive to gutter-runners. In the case studies, most drivers who ran the gutters appeared to do so for comfort or out of caution rather than in an attempt to go faster over the humps; speeds of gutter runners were only marginally higher than speeds of those who drive straight over the humps. But many residents were irritated by gutter runners - they perceived them to be faster and to compromise the effectiveness of the humps.

The British avoided the gutter running problem by carrying the full hump cross-section curbface to curbface and building elaborate drainage structures into the hump itself. But this added substantially to installation costs and the drains tended to become clogged with debris. Hence, the British approach does not appear to be an effective solution to the problem.

On streets where curbside parking is moderate to heavy gutter-running can probably be ignored; parked cars will preclude or substantially deter this maneuver. Where curbside parking is infrequent or non-existent, gutter-running can be discouraged by placing raised traffic bars or buttons on the approaches to the gutter-opening as illustrated on Figure 37. However, the designer should consider the potential effect of such devices on bicyclists. It may be desirable to defer installation of raised bars or buttons until it is determined whether gutter-running is actually a problem at each site. On one of the case study streets, the traveled way was flanked by broad valley gutters rather than vertical curbs. There a few of the gutter-runners were observed mounting the gutter and sidewalk backing it to avoid the undulations. Metal posts installed at the edge-of-walk proved an effective countermeasure. These are also shown on Figure 37.

Signing and marking is important to provide drivers advance warning of the humps and to indicate their exact location. Several varieties of signing and marking treatments were employed in the case studies. Based on that experience, the following sign and marking details are suggested.

Each hump should be painted white, either in entirety or in a pattern similar to a zebra crosswalk. The pavement legend BUMP in 8 foot (2.4m) white letters may be painted on the approach to each hump. A standard BUMP sign (MUTCD W8-1) should be placed adjacent to each hump facing each direction of approach. This is recommended over the symbolic sign used in European installations on considerations of both established recognition and the fact that the rather unique European sign seems a likely target for souvenir hunters. Placement adjacent to the hump rather than in an advance position is suggested so that the signs will indicate the exact location of the humps to motorists and snowplow operators at times when pavement markings and the shape of the humps them-

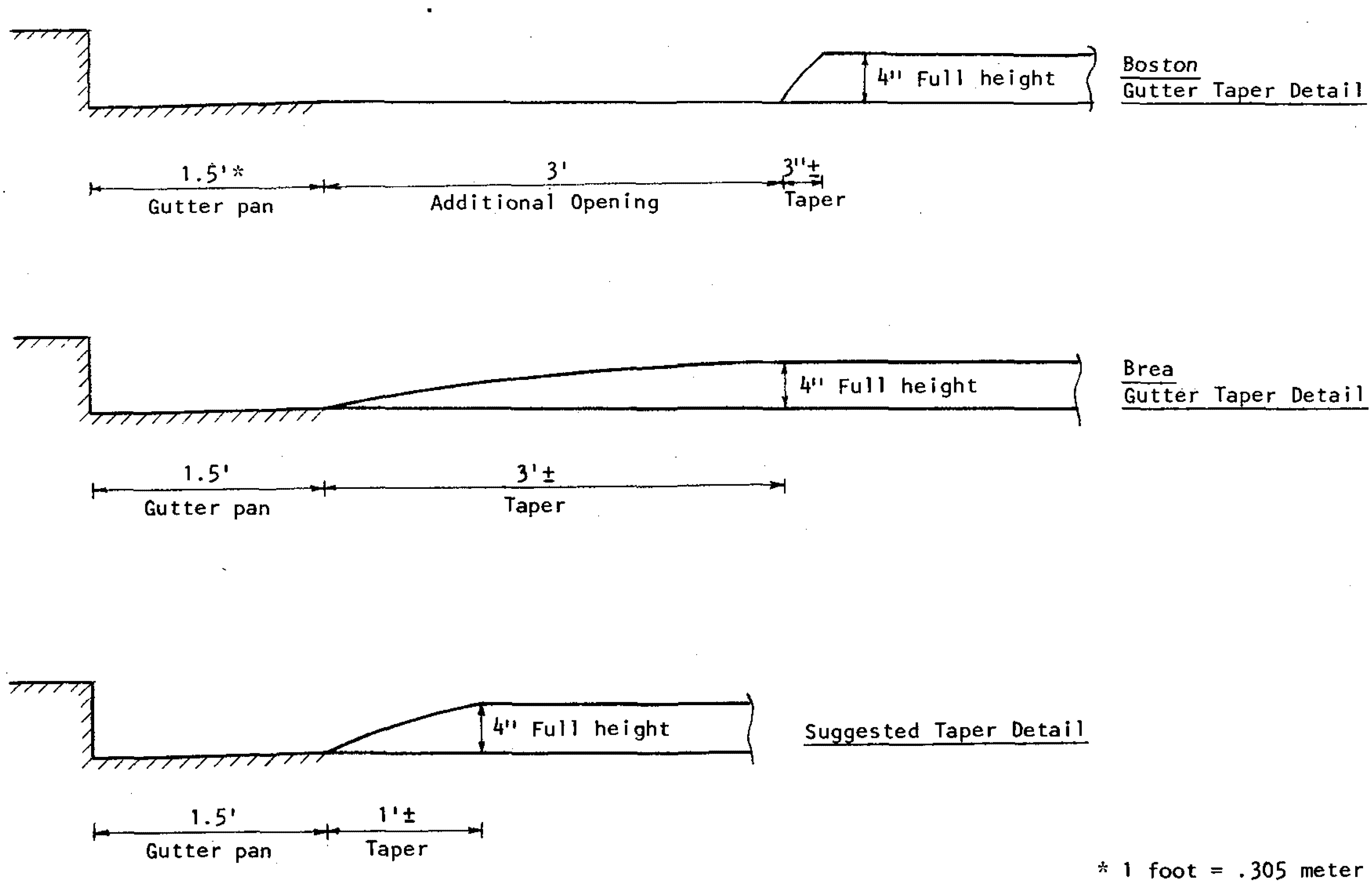


Figure 36. CURBLINE TAPER DETAIL

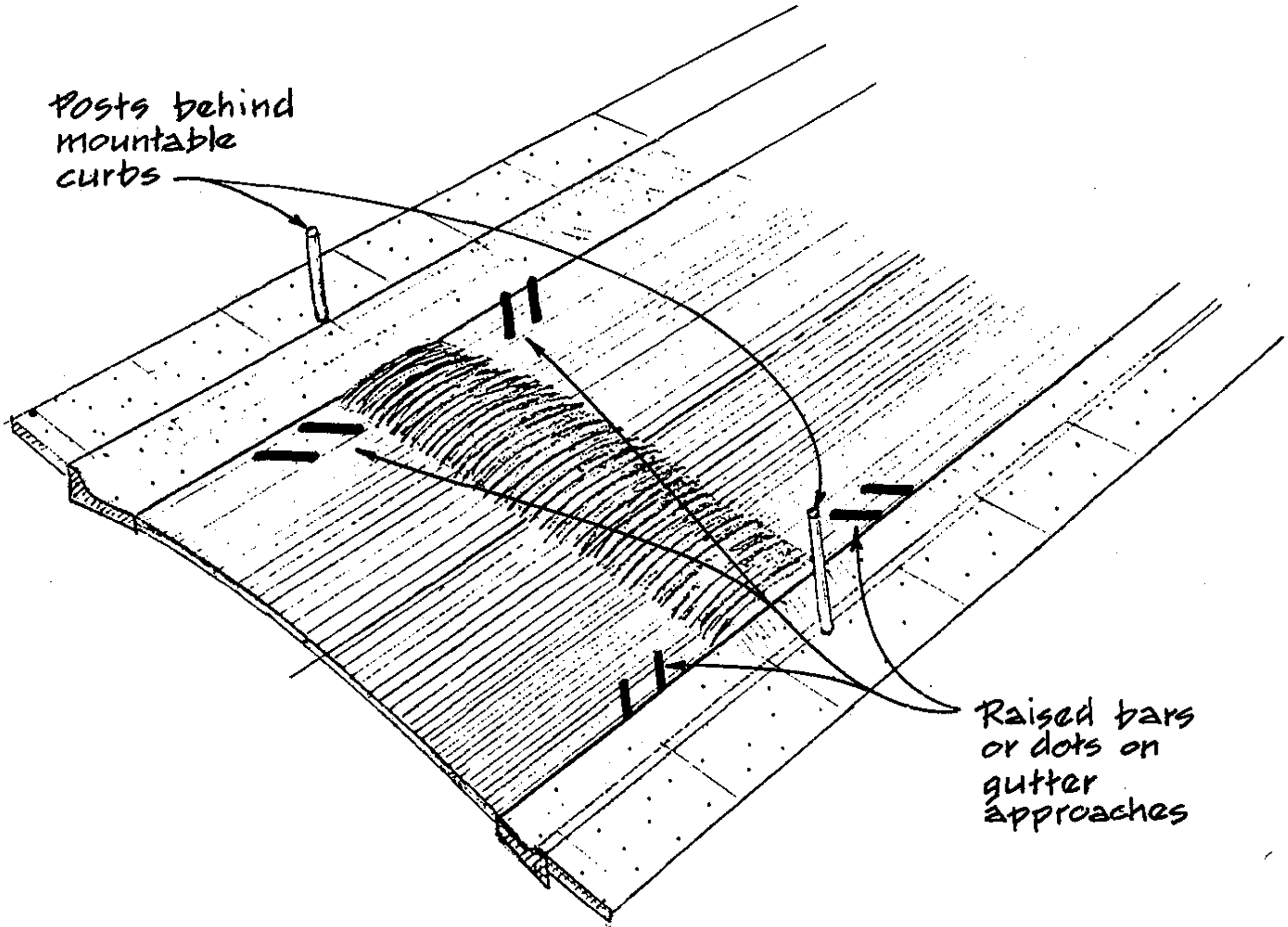


Figure 37. GUTTER-RUNNING COUNTERMEASURES

selves are obscured by snow. Each adjacent sign should be accompanied by a supplementary advisory speed plate 25 MPH, TRUCKS 15 (40 and 24 kmph).

Additional W8-1 signs with the legend in plural - BUMPS - should be placed in advance warning position on both approaches to the street segment controlled by humps. These should be accompanied by the supplementary plate "NEXT X X X X FEET" indicating the humps should be expected.

BUMPS signs (W8-1 plural) should also be placed on the approaches on cross streets from which significant volumes of traffic turn onto the hump-controlled street if not on all cross streets intersecting the hump-controlled segment. These should be accompanied by supplementary warning arrow plates (W1-6 R or L or W1-7) indicating the direction or directions in which the humps are to be expected.

Signs and markings should be in place as soon as the street is opened to traffic following hump construction.

Figure 23 in Chapter 3 shows some installation and signing details from the case study sites

PREPARING THE STREET'S USERS

Three types of user groups need be prepared for installation of the humps: residents of the street; police, fire, ambulance and refuse collection services; and other drivers on the street.

Relative to residents of the street, it is assumed that there has been an ongoing community involvement process* and that it has been insured that a majority of residents are disturbed enough about traffic speed to desire a countermeasure as stringent as the undulations. At this point, the key task is to notify residents of the fact and nature of the installation to take place, the planned date of installation, the duration of the trial period (at least 3 months and preferably 6 months to a year) if the installation is not considered permanent, what monitoring measures will be taken and how residents can communicate their perceptions of the humps performance, what can be expected of the humps and tips for driving various vehicles across them.

For emergency and service operations special instructions are recommended. For police the following points should be covered with top officials and passed down to the individual patrol officers.

- Indicate location of the humps and installation date and the objectives of the installation.

- Advise patrol officers that they can travel safely over the humps as fast as they wish in pursuit and emergency response situations. Request that patrol officers not travel over the humps at high speeds in routine patrol situations so that other drivers will not emulate their behavior.

- Request that police undertake no unusual levels of traffic enforcement or patrol activities near the hump site so as to avoid biasing the evaluation of humps performance. Where officers on normal patrol operations observe hazardous or miscreant driver behavior near the humps, they should take appropriate enforcement action.

- Establish special procedures for bringing accident reports, observations of unusual driver behavior or problems involving the humps to the attention of

* For guidance in community involvement techniques in residential area traffic managmenet see IMPROVING THE RESIDENTIAL STREET ENVIRONEMENT STATE OF THE ART, Federal Highway Administration, December, 1980.

the immediate attention of the traffic engineer.

For fire services, the following points should be covered with top officials and appropriately conveyed down to fire fighters.

- Indicate the location and installation date of the humps, nature of the humps and the objectives of the installation.

- Advise all drivers that all fire vehicles (except autos) should traverse the humps at no faster than 15 MPH.

- Give all drivers in all fire companies within whose primary response area the hump site is located the opportunity to drive over the humps during a training period soon after the humps are installed.

- Establish special procedures for immediate reporting to the traffic engineer any problem incidents involving the humps.

For ambulance services convey the following points through top officials to the individual drivers.

- Indicate the location and installation date, nature of the humps and the objectives of the installation.

- Advise all drivers that they may safely traverse the humps at moderately high speeds when not transporting patients.

- Advise all drivers that when carrying patients, they should not traverse the humps faster than 15 MPH (24 kmph) for the comfort and safety of patients and attendants.

- Attempt to give all drivers serving the area an opportunity to pass over the humps in a training exercise.

- Establish special procedures for bringing any incidents involving the humps to the immediate attention of the traffic engineer.

For refuse collection services, convey the following points through top officials to the individual drivers.

- Indicate the location, nature and installation date of the humps.

- Advise drivers to traverse the humps no faster than 15 MPH, particularly during collection operations when personnel may be riding exterior footboards.

- Establish procedures for reporting any hump - related incidents to the traffic engineer.

If a school bus route traverses the hump-controlled street, follow the same procedures as for refuse vehicles above. Note that humps should not be employed on streets which carry regular transit routes.

Relative to the general driving public, the recommended signs and markings previously described give adequate warning of the humps presence and indication of appropriate driving behavior. However, the implementing jurisdiction may find it advisable to take special measures before and a few days after installation to help familiarize regular users of the street with the devices. One possible action is to hand out leaflets to drivers a few days before installation. The leaflets could also be delivered door-to-door in areas where substantial numbers of street users originate or are destined. The leaflets should indicate the location, nature of the humps, date of installation and suggest appropriate driving behavior for various types of vehicles.

A week or two in advance, large construction warning signs (black on orange) could be placed at the approaches of the segment to be controlled by humps indicating the date and nature of the construction. For the first week or so following installation, temporary flashing warning lights could be attached to the standard warning signs recommended above. However, this seems excessively cautious, unnecessary and inconsistent with the character of the streets on which undulations would reasonable be applied.

MONITORING AND EVALUATING THE HUMPS' PERFORMANCE

Given the relatively limited experience with public street applications of the hump devices, it is crucial that local jurisdictions employing it carefully monitor its performance. The following paragraphs provide guidance in conducting 'before and after' evaluations of the undulations. 'Before' measures should be taken as close to the time of application as is practical. After measures should be taken in at least two and preferably three periods - a 'first encounter' period as soon as the street is reopened following installation, after 2 or 3 months when reaction to the device has stabilized and after 6 to 12 months to detect possible long-term effects. In communities which experiece radical sensonal variations in traffic (summer or winter resorts or college towns, for instance) monitoring periods should be adjusted so that seasonal variations do not confound the interpretation of results. The 'first encounter' observations are intended to:

- assure general adequacy of the installation,
- detect the possible need for any additional temporary or permanent warning devices not included in the initial installation,
- document any deviant driver behavior exhibited as a first reaction to the devices,
- develop countermeasures to any deviant behavior which seems to be undesirable, prevalent and likely to be recurrent (such as the possibility of installing raised bars or dots to thwart gutter-running as described previously),
- obtain an early evaluation of the humps performance and a basis for comparing measures from the later monitoring period to distinguish between short-term and long term effects.

As indicated above, the later monitoring periods evaluate 'stabilized' and 'long-term' effects. Measures which should be taken include the following:

Speed Profiles similar to the examples shown on Figure 26. It is important to evaluate speeds of the fastest vehicles as well as the 85th percentile and mean speeds normally considered in conventional speed studies. Individual vehicles should be tracked by radar speed meter through the controlled segment and speeds at selected points at and between the humps recorded. It would be desirable to obtain separate speed profiles for autos, trucks and motorcycles. But since traffic volumes on the streets where humps will be employed tend to be low, it is probably impractical to obtain observations of sufficient numbers of motorcycles and heavy trucks during monitoring periods of reasonable duration.

Spot speed studies should be carried out on parallel streets to detect whether traffic diverted from the controlled street changes conditions on these other streets.

Twenty-four hour machine recorded counts should be taken on the controlled segment and on logical diversion routes.

Numers of vehicles which run gutters versus those which go straight over the humps should be counted and their speed characteristics compared.

Visual observations should be made of various forms of deviant driver behavior should be recorded.

Noise conditions should be recorded by sound meter. Procedures should be followed to compute an L_{10} or similar durational measure rather than just recording the sound intensity of vehicles passing with and without the humps.

Before and after accident experience in the area should be compared even though on the low volume streets where the humps are likely to be installed accidents tend to be few and are usually random events.

Opinions of residents and drivers should be solicited using survey research techniques. It may not be necessary to intercept drivers on the street to survey them. A doorstep-delivered questionnaire in an area tributary to the controlled street can be effective in eliciting drivers opinions. An examples of a resident and driver questionnaires used at one of the case study sites is reproduced in Appendix B.

Comments volunteered by the general public as well as those elicited from the emergency services should be compiled and analyzed in the evaluation.

Measures of change in street use (do children play along the street more often, do pedestrian's habits change, do bicyclists use the street more frequently) are interesting but difficult to measure objectively.

Not all of these measures are relevant to all monitoring periods and to both the controlled street and parallel streets. Table 17 summarizes the times and locations where each measure is appropriate.

FHWA FOLLOW-UP

The Federal Highway Administration is interested in the results of all applications of the road hump device Jurisdictions employing road humps are requested to communicate their experiences to Mr. John Fegan, Department of Transportation, Federal Highway Administration, Office of Research, HRS-41, Washington, D.C. 20590 (Phone 202-426-0257).

Table 17
MONITORING MEASURES

Measure	Before	First Encounter	2-3 Mos	6-12 Mos
Speed Studies	C/P	C	C	C/P
Volume Counts	C/P		C-Optional	C/P
Gutter-Running		C	C	C
Behavioral Observation		C	C	C
Noise Conditions	C	C	C-Optional	C
Accident Experience	Area		C-Optional	Area
Resident & Driver Opinion				Area
Official Comment				C

C = Measure on Controlled Street

P = Measure on Parallel diversion route

Area = Measure over relevant area.

CHAPTER 5
STUDIES OF SPEED AND VOLUME ON RESIDENTIAL STREETS

THE PROBLEM

At the conclusion of the State-of-the-Art phase of the project, the following question was posed:

> "A number of devices to control speed and volume on local residential streets have been identified. Planning procedures for their implementation have been outlined. But from a resident's perspective, just how fast is too fast for a residential street? How does this compare with curent speed limits typical for residential streets? How much traffic is too much?

Appleyard's landmark studies in San Francisco of resident satisfaction with their residential living conditions in relation to street traffic involved extremely detailed measures of problem conditions and preferences.(22) But responses on these measures were compared across categorizations of traffic volume conditions far too broad to really determine crucial volume thresholds and without reference to any detailed speed condition data. Still, Appleyard was able to provide one important insight to the speed problem - "a single fast car on relatively lightly traveled streets seemed to be far more disturbing to residents than steady volumes of relatively fast traffic on the more heavily traveled streets. Traffic engineers in local jurisdictions frequently comment on the residential street speed phenomenon in a way that supports Appleyard's insight, though they themselves do not share the insight:

> "That street (one about which residents are complaining) doesn't really have a speed problem. There are only a handful of really fast cars."

While the identification of the influence of the "single speeding car" on resident perception of speeding as a problem is an important finding, it still does not answer the questions "how much traffic is too much" and "how fast is too fast".

In the State-of-the-Art report, it was noted that under 800 ADT residents were generally satisfied with traffic volumes on their streets; between 800 ADT and 3000 ADT complaints were frequent and intense as residents became conscious of traffic as an irritant but expected their street to be a quiet, lighly traveled one; at traffic levels above 3000 ADT, residents tend to concede their street to be a busy one and complain less about volume. The report noted that this pattern can be broken in specific circumstances. If a high percentage of what traffic there is on an under-800 ADT street is through traffic, residents will complain. Or if residents of an above-3000 ADT street feel that traffic is unfairly directed onto their street or if there is a reasonable way this traffic can be made to go elsewhere, they, too, will complain. Unfortunately, the above assessment of volume sensitivity is a judgemental one based upon cases reviewed in the state-of-the-art search and prior professional experience; not the product of a rigorous statistical evaluation. Available data would not support such a statistical evaluation.

22. Appleyard, D.A., Liveable Urban Streets, U.S. Department of Transportation, Washington, D.C., 1976.

Another approach considered was relating speed-volume conditions to established criteria for acceptable noise levels in residential areas using accepted techniques for projecting noise levels.(23) The results of such an approach are somewhat satisfying. It can be shown that at typical residential street traffic compositions, the combination of traffic volumes in the 800 to 3000 ADT range identified as critical in the discussion above and speeds in the 25 to 30 mph range are at the threshold area at which noise levels begin to exceed the criteria for residential areas. However, the referenced noise projection techniques are intended for application to considerably higher traffic volume conditions and their application under these conditions may be questionable.

Given all of the foregoing, the research team was requested to devote a modest portion of study resources to direct measures responding to the questions 'how fast is too fast' and 'how much is too much'. The sections which follow detail that research. It must be emphasized that this is a modest effort to "scratch the surface" on this subject matter. The feasibility of the procedure is as much at interest as the findings. The results presented are therefore suggestive of further research rather than conclusive.

RESEARCH PROCEDURE

The approach taken was to subject panels of residents observing their own street to vehicles traveling at different speeds and to platoons of vehicles simulating given volume levels. After each vehicle pass in the speed studies and after each monitoring period in the volume studies, each panelist would independently record whether the observed speed or volume was acceptable or unacceptable. This panel approach was chosen because it gave the opportunity to measure residents' reactions to specific volumes and speeds. An attempt to corollate residents' responses on a questionnaire to traffic conditions naturally occurring on their street would have lacked this specificity. Procedurally, the research went as follows:

Two middle income residential neighborhoods were selected in Berkeley, California (a San Francisco Bay Area city of 100,000 population which is among the frontrunners in traffic management planning). Streets within those neighborhoods were then chosen. Criteria for street selection were that it be a two-way block, usually experiencing light traffic, and that it not be a commercial or arterial route. There also had to be enough physical room for stationing 15-20 observers and 10 cars without disrupting the passage of other pedestrians and traffic, and there had to be no stops at either end of the block, so as to allow cars a safe and orderly run-up to, and slow-down from, test runs on the street. Randomly selected residents of each street were asked to participate in a traffic experiment in which they would spend a Saturday morning observing a number of cars, noting their impressions of both speed and volume. Finally, the procedure was performed on the two streets using the same protocols on each.

The physical characteristics of the two streets selected are presented Table 18.

Except for width, the two streets and their respective neighborhoods were similar.

23. Transportation Research Board, NCHRP Report 174, Highway Noise, A Design Guide for Prediction and Control, 1976.

TABLE 18
CASE STUDY STREET CHARACTERISTICS
SPEED-VOLUME ACCEPTANCE STUDIES

Street Characteristics	Streets: Fulton	Streets: Prince
Width	36 ft.	24 ft.
Length	614 ft.	602 ft.
Number of Houses	14	12
Number of Trees	10	11

TABLE 19
SEQUENCE OF AUTO SPEEDS OBSERVED

Experiment 1: Fulton Street

#	Speed	#	Speed	#	Speed	#	Speed
1	23	11	33	21	33	31	20
2	30	12	15	22	15	32	23
3	25	13	27	23	27	33	30
4	15	14	25	24	20	34	35
5	27	15	20	25	23	35	33
6	35	16	35	26	30	36	15
7	20	17	23	27	35	37	25
8	33	18	30	28	33	38	15
9*	23	19	25	29	25	39	27
10	30	20	35	30	27	40	20

Experiment 2: Prince Street

#	Speed	#	Speed	#	Speed	#	Speed
1	27	11	20	21	30	31	33
2	23	12	33	22	20	32	10
3	25	13	10	23	33	33	35
4	15	14	35	24	10	34	23
5	30	15	23	25	25	35	25
6	20	16	25	26	23	36	27
7	33	17	27	27	25	37	20
8	10	18	15	28	15	38	30
9	35	19	30	29	27	39	15
10	27	20	15	30	20	40	25

For the main part of the procedure, observers were seated on the sidewalk at mid-block. Each held a pencil and bound booklet containing socioeconomic questions about the observer as well as questions for the runs they were to observe.

For the speed perception evaluation, individual drivers were instructed to drive past the panel at pre-specified speeds. Accuracy of speed on each pass was assured by radar monitoring. Forty runs were made, giving 5 repetitions of each of 8 different speeds between 15 and 35 mph (24 to 56 kmph) (see Table 19). The sequence was random and the order in which the different speeds were observed is also given in Table 19. For volume perception questions, the whole fleet was run past observers with timed intervals between cars; "stray cars" were added in later when calculating the vpm (vehicle per minute) experienced by observers. One run was made for each of four differing vpm's as shown on Table 20. The observers in the experiment consisted of 18 residents on Fulton Street and 14 on Prince Street. Thus our data base for speed questions was 1280 responses and our data base for volume questions was 128.

A week after completing the experiment, speed and volume measurements were made at the test streets to compare actual traffic volumes to resident observers' characterization of simulated traffic conditions during the test.

HOW FAST IS TOO FAST, HOW MUCH IS TOO MUCH?

While limited in scope, the experiment showed surprisingly clear indications of what residents thought were acceptable speeds and volumes with the majority of residents in agreement of which speeds were too fast and what level of volume was too high.

Speed Acceptablility

Three questions were asked:

1. Do you think this is an "OK" speed for cars on this block?

2. Would this car's speed be OK when children are playing on the street?

3. In your opinion, how does this car's speed compare to the cars usually using this block?

Panelists were not told what was the actual speed of the vehicles they were observing.

Speed Results

Figure 38 presents the panel's responses to question 1 above for each street. On both streets speeds below 20 mph (32 kmph) were rated acceptable by an overwhelming majority of observers and speeds over 30 (48 kmph) were rated unacceptable by similar large majorities. The plot of the transition from broad-based acceptance to broad-based non-acceptance as speeds increase from 20 mph to 30 mph (32 to 48 kmph) is quite linerar and closely parallel for the two streets, although Fulton Street residents tend to accept speeds higher than Prince Street residents. This is perhaps explained by the facts that Fulton is considerably wider (12 feet) (3.65 m) than Prince (hence giving residents less feeling of proximity and exposure to traffic) and because Prince has always been a relatively lightly traveled residential street while Fulton, though now relatively lightly traveled, until 5 years ago had been a heavily traveled one-way arterial with fairly high speed traffic. Hence, Fulton residents may have some residual acclimation to higher speed traffic.

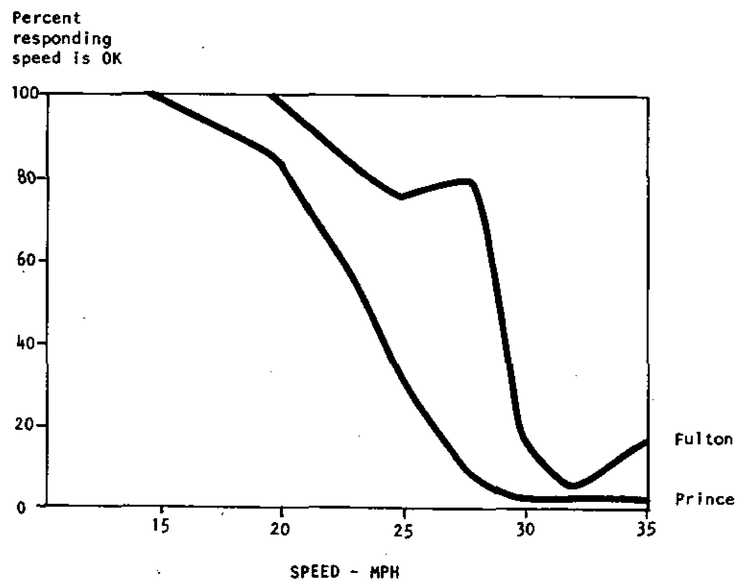


Figure 38. RESIDENT SPEED ACCEPTANCE

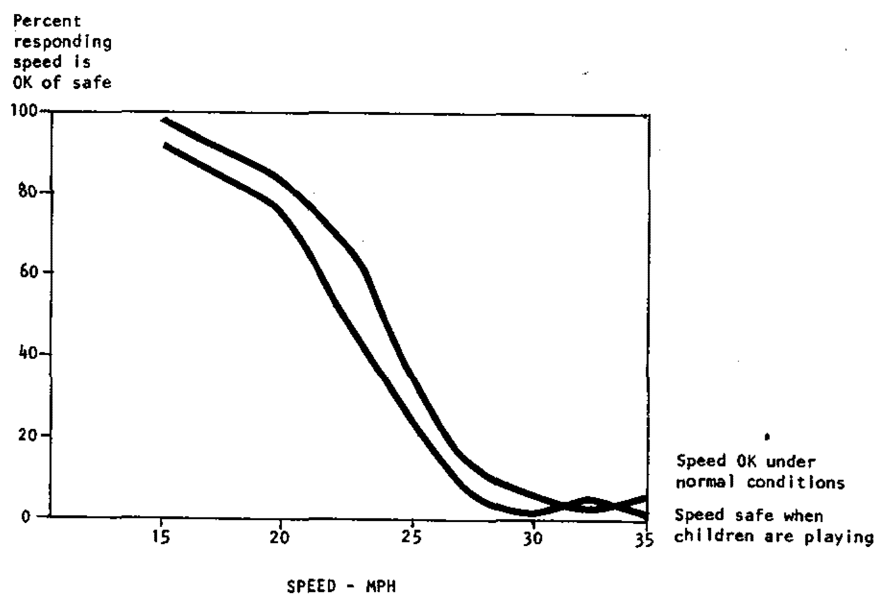


Figure 39. SPEED ACCEPTANCE CONSIDERING CHILDREN
PRINCE STREET RESIDENTS

1mph = 1.6093kmph

When asked question 2 above, resident acceptance profiles paralleled the responses to question 1 but were offset (lower) by about 2 to 4 miles per hour (3-6 kmph), as shown on Figures 39 and 40.

Comparisons of the resident panels' ratings of speed as being "usual" for their street with distributions of actual traffic speeds measured on the streets about a week after the panel sessions is presented on Figures 41 and 42. On both streets large numbers of residents rated test speeds which were at the upper end or above the distribution of speeds actually occurring on their street as being 'usual' for their street.

Discussion

Significant inferences which might be drawn from the results include the following:

- Resident opinion as to whether speed is acceptable or unacceptable changes from almost total acceptance to almost total non-acceptance over a relatively narrow range of speeds -- from 20 to 30 miles per hour (32 - 48 kmph). That is to say, resident opinion about speed appears extremely sensitive to differences which are quite small when considered from a driver's perspective.

- The 25 mile per hour (40 kmph) speed limit currently most prevalent on residential streets in the U.S. is central to the range of speed over which resident opinion changes from almost total acceptance to almost uniform non-acceptance and is close to the speed which about half the residents consider acceptable, half unacceptable.

- Even if the vast majority of drivers conformed to the 25 mph (40 kmph) limit, nearly half the residents of the street might not be satisfied. If the street is one along which a substantial level of childrens' play activity occurs, a majority of residents may not be satisfied.

- Speeds which a predominant share of residents would consider acceptable are several miles per hour slower than most drivers choose* to drive on residential streets. Ineffectiveness of extremely low speed limits as a control on residential streets was documented in the State-of-the-Art report. It appears that the only effective ways to ensure that speed conditions will achieve uniform acceptability to residents is through establishment of Woonerf-like conditions or installation of control devices like undulations.

- This research <u>is not</u> firm grounds for advocating lowering of speed limits now common on residential streets. First, it provides no indication of how dissatisfied residents are with speeds they indicate "unacceptable" but which are within or close to the opinion transition range described above. Secondly, it does not consider reasonability of speed from a driver perspective.

- Several interpretations may be placed on the fact that large percentages of residents rated test speeds as "usual" for their street which were in fact rare or not recorded at all in the observations of traffic actually using the street. It is possible that a panelist's assessment of whether a particular speed is "usual" for the street is

* This reference to drivers' speed choice is a generalization postulated upon review of speed data more extensive than that collected in this portion of the research.

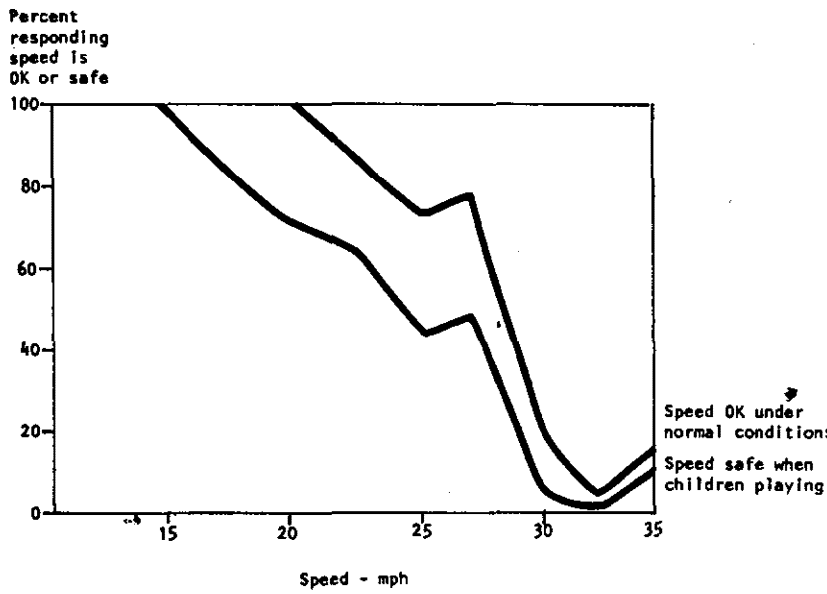


Figure 40. SPEED ACCEPTANCE CONSIDERING CHILDREN
FULTON STREET

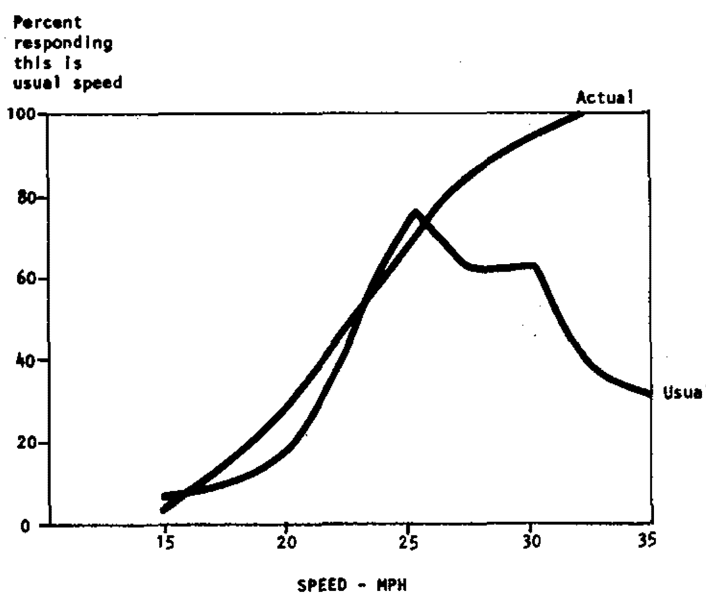


Figure 41. ACTUAL SPEEDS VS RESIDENT PERCEPTIONS
FULTON STREET

1mph = 1.6093kmph

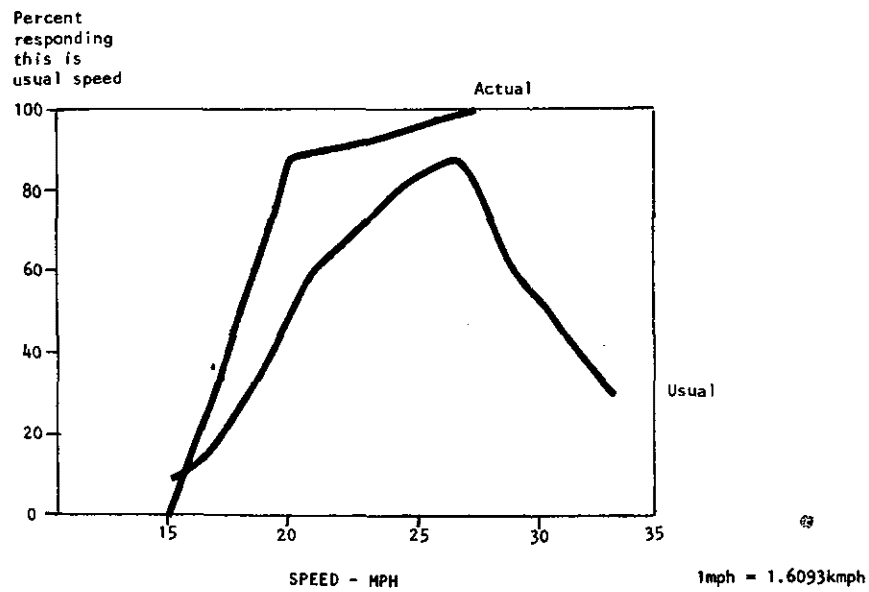


Figure 42. ACTUAL SPEEDS VS RESIDENT PERCEPTIONS PRINCE STREET

TABLE 20
SEQUENCE OF VOLUMES OBSERVED

Seconds Between Cars	Vehicles per Minute	Equivalent to Number of Cars: Per Hour*	Per 24 Hours **
30	2	102	1020
15	4	204	2040
10	6	306	3060
5	12	612	6120

* Assumes constant rate over peak 15 minutes and 0.85 peak hour factor
** Assumes peak hour volume is 10 percent of ADT

both less realistic and independent from that same panelist's judgment of whether the speed is "acceptable" to himself. It is also possible that panelists' reporting of speeds higher than those actually occurring as being usual for their street is somehow indicative of a downward bias in speed preference created by the panel situation - because of their concern for speed, panelists may be inclined to report faster speeds occur on their street than actually do in real life and to rate speeds as being unacceptable which they would actually be undisturbed by in a real-life situation.

More likely this overstatement of the commonness of the higher speeds is simply a confirmation of the previously cited Appleyard theory - that resident perceptions are most dominantly impacted by the few fasted cars. Therefore, it is natural for them to believe the fastest vehicles are more typical of the speeds experienced on their street than is in fact the case.

Volume

Three volume questions were asked.

1. Do you think this is an OK level of traffic for this block?

2. How does the level of traffic you've just seen compare to the traffic usually using this block?

3. If you wanted to cross the road when there was this level of traffic going by, would you cross here or walk to the corner?

Results

The survey of residents' perceptions of acceptable volumes was somewhat limited by the initial range of volumes selected for the experiment (see Table 20). The range selected, 2 vpm-12 vpm, proved to be too broad and oriented toward the high end of resident tolerance. This had the result that there were not sufficient midpoints to fine tune the volume results in the same fashion as the speed findings. As presented in Figure 43, respondents from both streets indicated similar responses to the questions. Large majorities of panelists on both Fulton and Prince Streets indicated above 4 vehicles per minute (vpm) would be unacceptable. Most residents from both streets, perhaps oblivious to National Safety Council warnings, would cross midblock with volumes ranging between 6 and 12 vpm (Figure 44).

This seems to indicate that for other reasons residents become concerned about traffic volumes at lower levels than those at which they become concerned about volume considering jeopardy to pedestrians. As with speeds, persons' perceptions of usual traffic volume were different from the actual peak hour vpm measured. As shown in Figure 45, Prince Street residents indicated that 2-4 was the "usual" vpm whereas Fulton Street residents indicated even a lower vpm was the norm - below 2 vpm. In fact, the actual peak hour vpm for Prince was .5 and 1.8 for Fulton.

Discussion

As a result of the limited set of volumes chosen in a range which appears to have overshot the primary range of transition of acceptance to non-acceptance, there are few noteworthy results from this portion of the experiment. However, the procedure does appear to have merit for developing further insight to residents' traffic volume tolerance levels.

Conclusion

The limited scope of this element of the research must be emphasized. The work was performed on only two streets in one

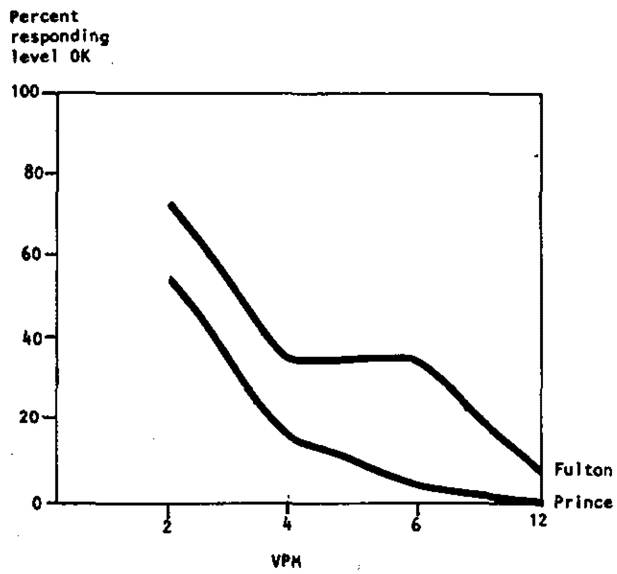


Figure 43. VOLUME ACCEPTANCE

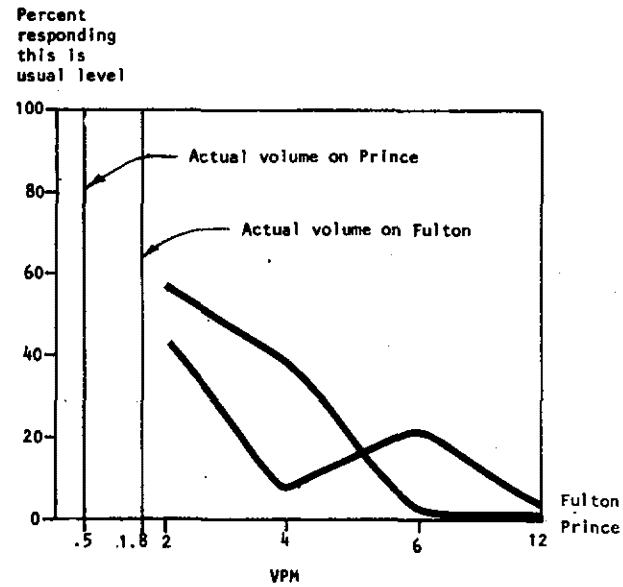


Figure 45. ACTUAL VOLUME VS RESIDENT PERCEPTIONS

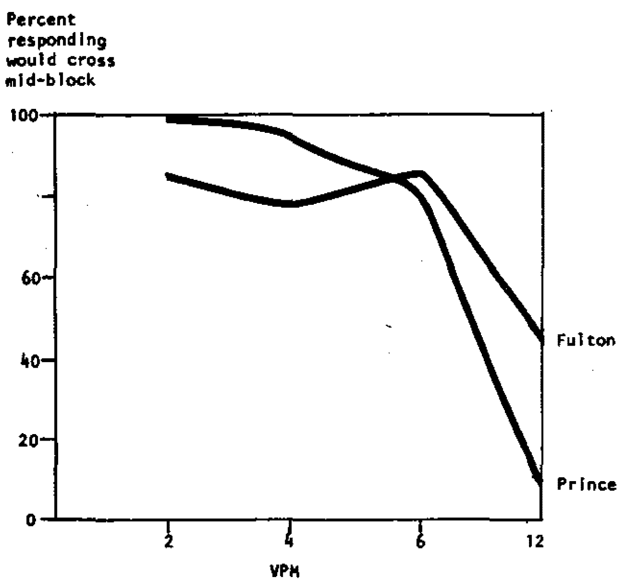


Figure 44. WILLINGNESS TO CROSS AT MIDBLOCK VS VOLUME

particular city. A total of only 32 resident panelists were involved. In keeping with the exploratory nature and limited budget of this activity, no sophisticated measures were taken to assure that panel compositions accurately reflected the overall composition of the entire adult resident population of their blocks relative to relevant characteristics (such as age, sex, whether or not they had children at home, owners versus renters, people who spend a lot of time home versus those who spend little there, those who drive a lot versus those who drive little or not at all). Given that the panelists were respondents to a request for volunteer participants in a traffic study, it is likely that the panels may have been comprised of persons more sensitive to traffic issues than the overall resident population.

- While the limitations of the current work must not be overlooked, the results pose considerable food for thought. If resident satisfaction with traffic speed is to be truly achieved, it may be necessary to create Woonerf-like conditions, not just substantial conformity to current speed limits. And despite the cited limitations, the results appear sufficiently satisfying that it seems reasonable to consider undertaking further research of this nature. Future research attempts should include the following elements:

  - Many more streets should be included in the data base. Streets should be drawn from large city residential neighborhoods and from suburban and small city neighborhoods. Streets experiencing a range of volume and speed conditions should be selected in each category.

  - More rigorous sample control should be exercised over the composition of the panels.

  - The range of volumes tested in future attempts should be focused at the low end of that used in the current effort.

EFFECTS OF STREET ENVIRONMENT ELEMENTS ON TRAFFIC SPEED

The foregoing research examined resident preferences with respect to speed. Another key question is "what is it about the street environment that induces drivers to travel fast on one particular street and not on another?". The reason for interest in examining effects of street environmental variables on speed is this: Since direct controls (stop signs, road humps, rumble strips, diverters) sometimes arouse drivers' ire and often create undesired secondary impacts, a form of control which relied upon the subtle influences of the surrounding environment on drivers' behavior might be preferable to direct controls. However, to do this we must understand what elements in the residential street environment exert these subtle influences on driver behavior. Such an analysis must screen-out or neutralize the influence of pure individual driver motivational factors (the joyrider, the person late for work or an engagement). It must also screen out speed elements introduced by positioning in the network (the street used as a cut-through route between two arterials) and land use patterns.

The following street environmental variables are postulated to have potential impact on driver speed behavior.

<u>Alignment:</u>

- horizontal: Relevant conditions include tangents, long radius curves, sharp curves and serpentine.

- vertical: Relevant conditions include level sections, relatively continuous grades and undulating sections.

Block Length:

- A range of conditions from short blocks (say 200') (61m) to lengthy segments (quarter to half mile) are relevant because length affects how long drivers have to build up speed.

Continuity:

- Relevant characteristics include end conditions of the block (cul-de-sac, T, L or 4-way intersection) and continuity of motion (does the vehicle enter the block from a standing stop or with established momentum).

Parking:

- The relevant characteristic is presence/absence of parked vehicles rather than permitted/prohibited. Parking is relevant as a constraint on the effective width of the traveled way. Parallel versus angled conditions are also relevant.

Setbacks:

- A range of building setbacks must be considered. The concept is that buildings set close to the street create a sense of confined space or narrowness of the street while broad setbacks create a driver impression that the street itself is wide and unconstrained.

Structure Type:

- Row houses create a continuous wall which intensifies the impact of close setback while the gaps between detached houses moderate setback effects.

Trees:

- Large street trees are hypothesized to have similar impacts to close building setbacks - creating a sense of a narrower street. Small trees or absence of trees create the sense of a wide street.

Width:

- Only streets of a single lane in each direction are considered. Narrow streets are hypothesized to both require greater driver care and create a sense that the street is not a place for fast traffic. Wider streets give the sense that auto service is the dominant objective of the street and encourage arterial speed behavior. A range of widths need be considered.

A thorough research analysis on all of these environmental conditions is beyond the resources of this study. Presume 5 values were considered for each of the above factors for which ranges of conditions are relevant (widths, length, setback). Presuming this, we have then identified 8 major variables, one with six subconditions, three with five, two with four subconditions, one with three, and two with two subconditions. Just to examine each variable independently, holding the others constant, would require speed observations on an extremely large number of streets to achieve statistical reliability. The necessary number of observations require resources well beyond those which could be devoted to this facet of the study. However, a pilot exploration was attempted to examine the feasibility of a more detailed exploration of these factors through simple observation of speeds of existing street traffic.

Eleven residential streets in San Francisco were selected in the pilot study. All streets carried traffic light enough that the speeds of observed vehicles were not constrained by the speed of other vehicles using the street. The potential effects of network and land use factors described above were controlled by selecting purely residential streets imbedded in a neighborhood - well away from arterials and divergent land uses. All streets selected were level tangents with parallel parking permitted and present on both sides. With these factors held constant, it was possible to perform some limited exploration of the effects of the others.

RESULTS

Effects of Street Width and Setback on Speed

The first hypothesis was that actual pavement and apparent width would both have an effect on traffic speed, reducing it as the street and its visual "walls" narrowed.

Table 21 shows correlations between pavement width and traffic speed. Correlations, especially with average speed (r = .62), are very high. They are even higher when the setbacks on both sides are added to the pavement width (r = .84) with average speed), although setbacks by themselves account for little (r = .37 with average speed). The correlations with the 85th percentile speeds, a measure that accounts more for the faster traffic were slightly less. There is a close relation, therefore, between both actual and visual width and traffic speed.

Figure 46 is a set of plots of speed versus width and speed versus width plus setback. On them the effects of width and apparent width seem clearer. Streets of 30 to 35 feet (9.1 - 10.7m) width were found to have mid-block median speeds under 20 MPH (32 kmph), while those of exactly 40 feet (12.2m) were found to have speeds of 26 and 27 MPH (42 - 43 kmph). Wider streets generally experienced higher speeds. A 45-foot (13.7m) wide street (600 feet long) (182m) had average speeds of 26 MPH (42 kmph), as did a short 60-foot (18.2m) wide street (221 feet (63.7m) long).

When setbacks were added to pavement width (Figure 46), the pattern of speeds appeared to vary even more consistently with width between house frontages. Median speeds of 20 MPH (32 kmph) were measured on streets of between 60 and 70 feet (18.2 -21.2 m) facade to facade, while two 90-feet (27.2m) street - width - plus - set - backs streets experienced speeds of 26 and 27 MPH (42-43 kmph).

Eight-fifth percentile speeds were higher, and since these are the problem speeds, they demand particular attention. The 85th percentile speeds on the 30- and 35-feet (9.1 - 10.7m) wide streets were still 23 and 25 MPH (34-40 kmph), within the legal limits. However, on all other streets, 85th percentile speeds were over 25 MPH (40 kmph). Those of 38-39 feet (11.6 - 11.9m) were 26 to 28 MPH (42 - 46 kmph), those of 40 feet (12.1m) were 28 and 30 MPH (46 - 48 kmph). On the widest streets, 85th percentile speeds ranged from 26.5 MPH (42.6 kmph) (52 feet (16.5m) wide but only 250 feet (76m) long) to 33 MPH (53 kmph) (46 feet (14m) wide and 622 feet (190m) long).

Effects of Block Length

The examination of the speed versus width plots gave some indication of the importance of block length. Two of the wider streets which have short block lengths experienced speeds which appear lower than what might be expected considering the rest of the pattern of speed versus width relationship. (A 52-foot (16.5m) wide street experienced average speeds of only 21.5 MPH (35 kmph), but its block length was only 250 feet (76m). A 60-foot (18.2m) wide street with a block length of only 220 feet (63.7m) was found to have average speeds of only 26 MPH (42 kmph)). Direct relationship of block length to speed showed less correlation than width but it is nevertheless important. The higher correlations of block length are with the 85th percentile speeds (r = .53)

TABLE 21
CORRELATION BETWEEN SPEEDS, WIDTH, SET-BACK, AND BLOCK LENGTH

	Average Speed	Median	85th Percentile
Width	.62	.55	.51
Width and Set-Back	.85	.78	.70
Set-Back	.37	.41	.36
Length	.35	.32	.53

rather than with mean or median midblock speeds (r = .35 and .32, respectively). Figure 47 presents the scatter plot of midblock 85th percentile speed versus block length. When block lengths are plotted against median speeds, a less clear pattern emerges. Blocks of vastly different lengths experienced similar median midblock speeds while blocks of similar lengths experienced vastly differing median midblock speeds. This apparent lack of relationship between median speed and block length seems to be explained by street width - the short blocks with high speeds were the wider streets while the long blocks exhibiting low speeds were the narrower streets.

Two conclusions can be inferred from this:

- Block length appears to have more influence on the faster drivers' speeds than it does on median and mean speeds.
- Width appears to have a more powerful influence on speeds than block length.

Combined Effects of Block Width and Length

Figure 48 attempts to explore the combined effects of street block length and width on speed. If curves are drawn through the plot of blocks which have common median speeds, there is the suggestion of a pattern that might conform, with a larger sample, to a hypothetical graph (also shown on Figure 48). The pattern is one where speeds are lower when length and width are less, and are higher when both are larger. However, the data no more than hints at this possibility.

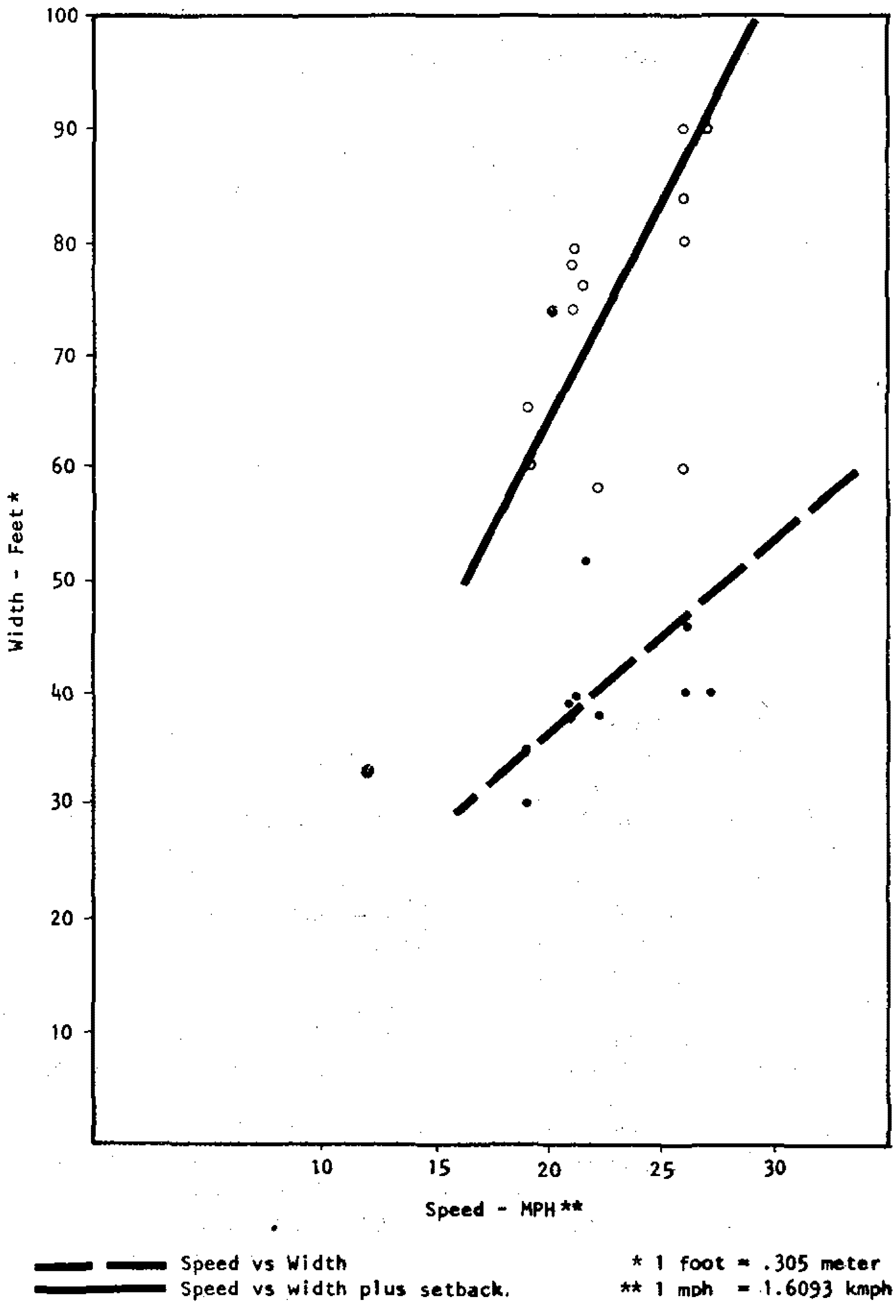
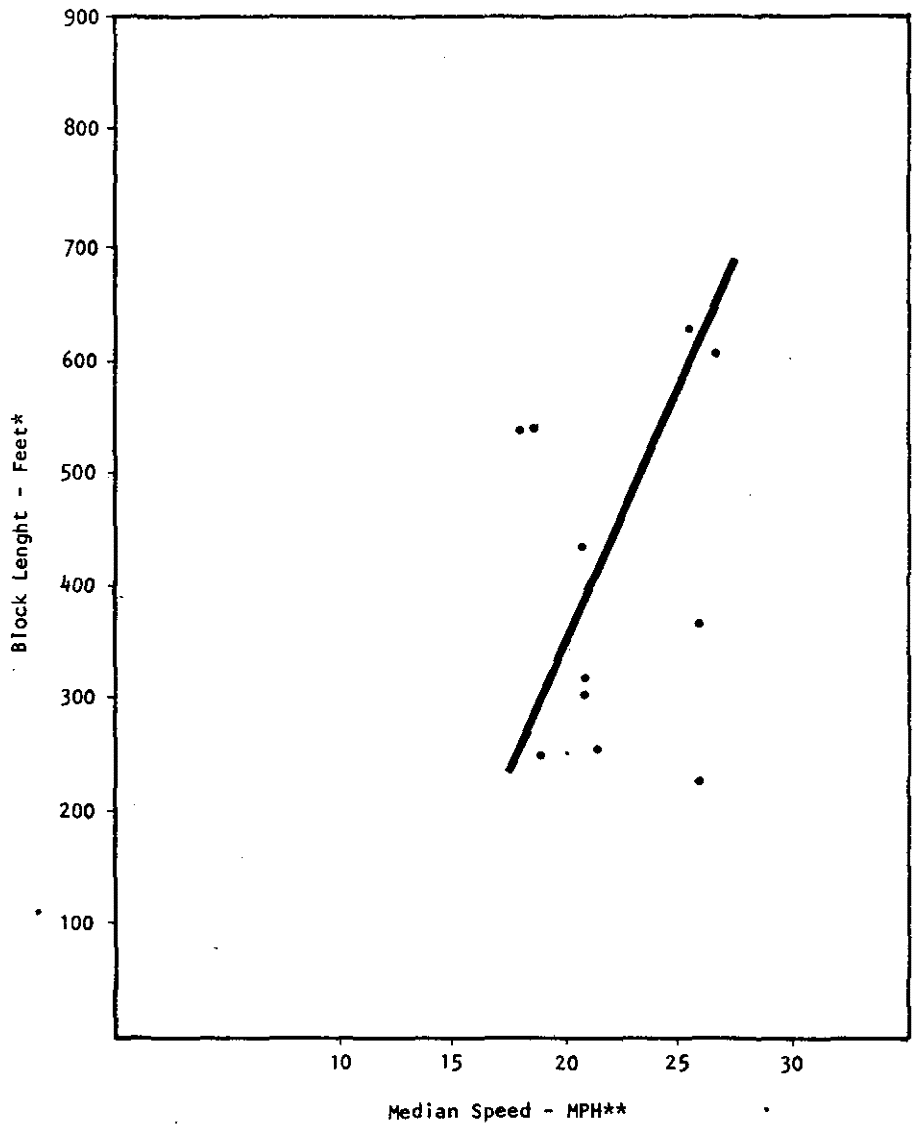
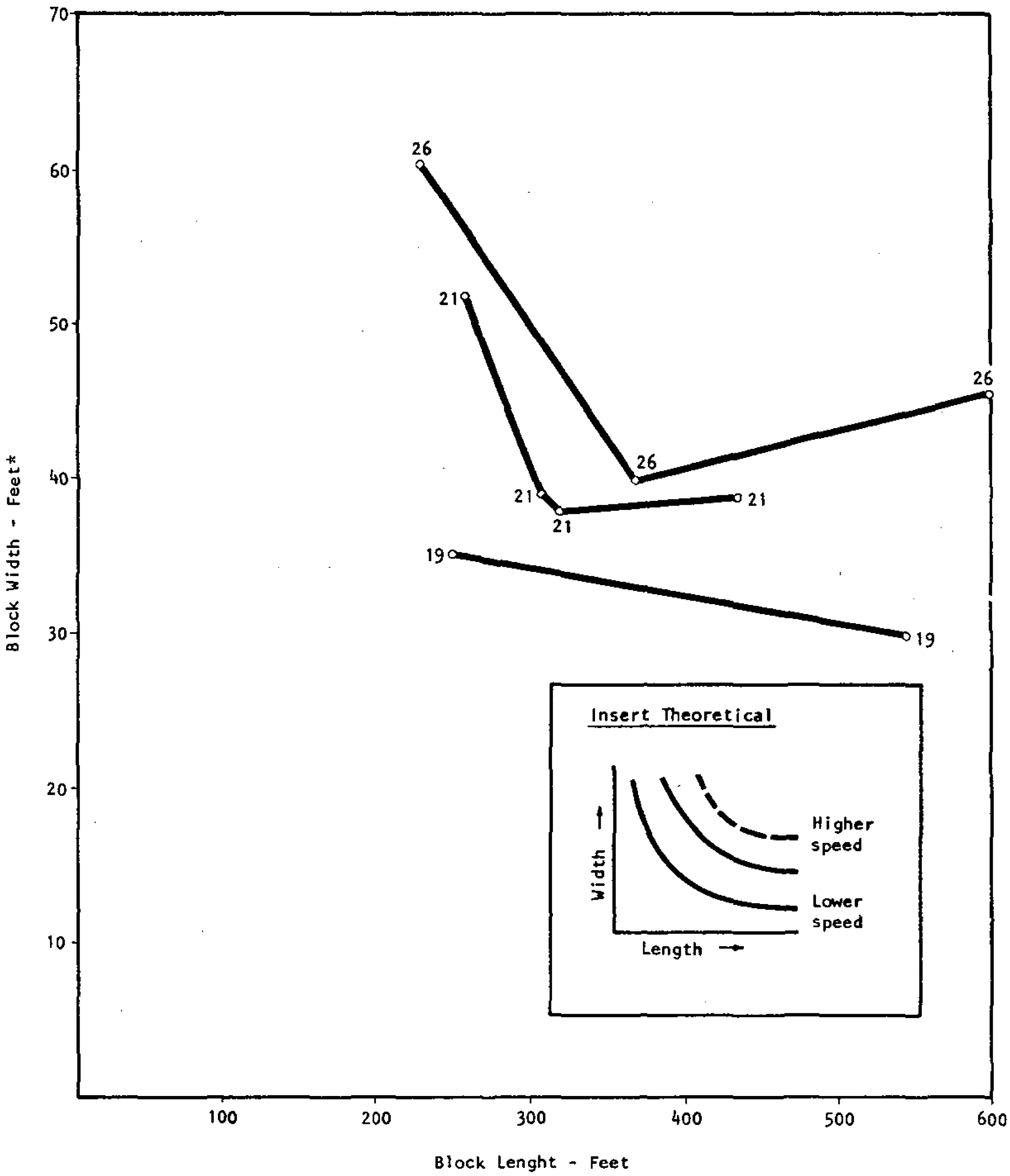


Figure 46. SPEED VERSUS WIDTH AND WIDTH PLUS SETBACK



* 1 foot = .305 meter
** 1 mph = 1.6093 kmph

Figure 47. SPEED VS BLOCK LENGTH



* 1 foot = .305 meter

Figure 48. SPEED VS BLOCK LENGTH AND WIDTH

Effect of Entry Intersection Character - Continuity

As discussed earlier, traffic speed on a block can be affected by the way in which a vehicle enters the block. If the intersection is one where the traffic has to turn to enter the block, it may enter at a very slow speed, unless it is coming off a high speed road. If it enters from a 4-way intersection, entry speed may be affected by the presence of a STOP sign, a traffic signal or cross traffic, each of which will allow it only a relatively low initial entry speed or entry from a standing stop. If there is no cross traffic, no STOP signs on the cross streets and a high degree of visual continuity, traffic may enter the block at substantial initial speed.

The sample of streets was far too small to indicate any correlation between "stopped" or "rolling" entry conditions and midblock speed. Attempts were made to adjust "effective length" of the block by subtracting various "stopped" entry conditions but, with this small sample, the pattern of relationship of "effective length" to speed did not appear meaningfully improved over that of actual block length to speed.

Effects of Structure Type

Structure types on the streets observed varied from single family, two-story houses to three- and four-story row houses. When plotted against speeds, there was no clear pattern of response. Effective width of the street, however, may be affected by the height and continuity of adjacent buildings. If a larger sample of streets were considered, it still might be possible to show that at a given setback, tall continuous buildings cause drivers to travel faster or slower.

Conclusion

There appears evidence, even on this small sample, that environmental factors such as street width, set-back, and block length affect speed of traffic on lightly traveled residential streets. Is this just a confirmation of intuitive sense or can we make practical use of it somehow in controlling speed on existing residential streets? Surely, it is not suggested that setbacks of existing buildings be changed or that costly projects to narrow streets by moving curb, gutters and drainage inlets can be attempted on a broad basis. The importance is this: if speed can be affected not just by width but by apparent width and apparent width - the visual "walls" of the street - can be influenced by other things than just building setback - say, tall, densely foliated trees set at curbside - in essence, an effective "psychological control", in keeping with the concept discussed in Chapter 2, has been identified.

Determination of the strength of this psychological control as well as identification of other potential ones which play upon the subtle influences of street environmental factors on driver behavior would require far more effort than was possible in this pilot study. The examination of just a few of the variables on the basis of observations on just eleven street blocks produced result patterns which appear promising. However, absolutely no statistical reliability can be claimed for these findings. Development of statistically reliable results on the range of variables identified would require classification of and speed observation on literally thousands of blocks. Speed studies are manpower-intensive, particularly on low volume residential streets where observing enough vehicles to obtain a reliable distribution of speeds takes a long time. Despite the inherent high cost, this study project points to what may be a fruitful topic for future residential street research.

CHAPTER 6
LEGAL ISSUES IN NEIGHBORHOOD TRAFFIC MANAGEMENT

The controversial nature of neighborhood traffic control and restraint has led to a number of challenges to neighborhood traffic management actions. An extensive review of the nature and disposition of these court challenges has been prepared by Frederick Van Antwerp. (24) This chapter presents a summary and further interpretation of the principal findings and conclusions of Van Antwerp's research. In particular, findings related to Berkeley, California's traffic management plan are updated to reflect latest decisions in the case.

AUTHORITY OF LOCAL JURISDICTIONS TO UNDERTAKE RESIDENTIAL AREA TRAFFIC MANAGEMENT

The vast majority of challenges to neighborhood traffic management actions have involved the ground that the local jurisdiction lacked the power to regulate traffic in such a prohibitory manner.

The right to regulate and control the operation of motor vehicles on the public highways and streets ordinarily rests with the state under its police power. States routinely delegate this authority over local streets to the local jurisdictions. Within the limitations of the delegated authority, local jurisdictions regulate the use of public streets by passing ordinances.

Enabling legislation which delegates this authority to local jurisdictions varies from state to state. In some it is clear and strong. In others it may not be specific enough to cover actions like applying retrofit cul-de-sacs or diagonal diverters or other forms of diversionary channelizations which might be held to be actions "closing" the streets. In such cases, the local jurisdictions' powers are dependent on omnibus clauses which typically empower them to, in addition to powers specifically delegated, make, enforce and maintain such reasonable ordinances, rules and regulations with respect to traffic as specific local conditions may require so long as these actions do not conflict with powers reserved to the state.

Local communities initiating traffic management plans should be conscious of just what legal authority they have. This is not just a question of whether the enabling legislation is weak or strong. There is the question of whether the actions will be taken under powers to control traffic or under the power to close streets. Both options may be open. Powers to "close streets" are normally used when a jurisdiction abandons or vacates all or apart of a street. In its application to neighborhood traffic management, the logic is not that the space occupied by a diverter or cul-de-sac is abondoned or relinquished as a public right-of-way in the strict sense of the word. (That space is held to be an area of the public right-of-way which is declared to be outside the designated traveled way for automobiles.) The logic is

24. Van Antwerp, Frederick, THE RESTRAINT OF THE AUTOMOBILE IN ESTABLISHED RESIDENTIAL AREAS: AN IMPLEMENTATION POLICY ANALYSIS, Pennsylvania State University Transportation Institute, University Park, Pa., August, 1979.

that if jurisdictions have the power to go so far as to completely abandon, vacate or relinquish a street, then the partial closure which a cul-de-sac, diverter or other device brings about is simply a less forceful or partial exercise of that same power. *This interpretation of legality of* diverters and cul-de-sacs as instruments of "partial closure" under the power to close streets is a fundamental point in the ajudication of the Berkeley case discussed subsequently.

If both powers to control traffic and power to close streets are available, the local jurisdiction should choose the strongest and most convenient. The jurisdiction must weigh the strength of the enabling legislation under each versus the fairly rigid procedural requirements and criteria which may accompany the conveyance of the "power to close streets" and the potential involvement in the issue of whether diverters, semi-diverters, retrofit cul-de-sacs and the like are legitimate traffic control devices or "approved" geometric features of the road if "powers to control traffic" are relied upon. Understanding the legal basis for traffic management actions from the outset may affect the specific form of actions taken and will better prepare the community for legal challenges which may ensue.

While reasonability of actions by the local jurisdiction is important in all cases, it is a particular priority where the delegation of authority to the local jurisdiction is weak and unspecific. Weak or unspecific legislation generally requires the court to broadly interpret the local jurisdiction's authority. Willingness of the court to do this may be heavily dependent on demonstration of reasonable need for action and reasonableness of the actions taken. The following section expands on the subject of reasonableness.

REASONABLENESS IN EXERCISE OF THE POLICE POWER

Whether the authority of the jurisdiction to act is or is not in doubt, the traffic management actions taken can be, and in many cases have been, challenged on the grounds that they are arbitrary, capricious and unreasonable and therefore not a legitimate exercise of the police power. The reasonableness test appears to have been a dominant concern in recent court cases. Van Antwerp's study of traffic management court cases identifies the following factors as being important to the courts in determining whether the exercise of police power was *reasonable:*

- Evidence of Need for Action - Harm to Residents

  This was not restricted to hard evidence such as traffic accidents or traffic counts, but included noise, air pollution, litter, fear of traffic, child safety concerns, and general complaints of traffic nuisance.

- Traffic Survey

  Levels of traffic at all times of the day, as well as traffic composition (percent of trucks, motorcycles versus autos; percent of "through" versus "neighborhood" traffic) were influential. In at least one case the fact that the Master Plan for the area included a description of the intended use of the residential street in question was a factor. Such Master Plan statements provide a basis for judging whether the traffic conditions observed are or are not consistent with the intended function of the street and, hence, whether cause for action exists.

- Alternative Traffic Control Measures, Attempted or Considered

The use of stop signs, increased surveillance, and other less severe traffic control measures were considered evidence that the local jurisdiction was acting reasonably.

- Inconvenience to Residents

  It was influential that the municipality took into consideration the circuity of alternate routes travelled by residents of the area.

- Integration of the Diversion Strategy

  The court in many cases felt it was very important that the diversion scheme be a part of the overall transportation plan for the area. This included the idea that through-traffic be provided with a safe and convenient route around the "protected" area. The most important idea here is that evidence should be shown that the local jurisdiction is not simply planning in response to site- or neighborhood-specific problems with little regard for consequences outside the residential area.

- Emergency Vehicles

  The fact that reasonable access to emergency vehicles was taken into consideration when designing the strategy was considered very important.

- Public Hearings

  It was influential that the local jurisdiction had widely publicized and held public hearings or other forms of community involvement in determining whether and how the strategy was to be worked out.

These "reasonability conditions" place heavy emphasis on the importance of a thorough planning program - not just as a vehicle for developing the traffic management scheme itself but as a program which lays solid groundwork for defense against legal challenges which may ensue.

RIGHTS OF ACCESS

The question of "standing before the court" (the right of the plaintiff to bring the court challenge) was raised in many cases. Decisions on this issue revolved around whether the parties in opposition to the diversion devices had suffered damage. In most cases the damage cited was inconvenience caused by the circuity of the new route. The court has been firm and consistent on this issue. Unless access to the property in question has been denied completely, the inconvenience suffered has not been considered sufficient to challenge the diversion, and the court has considered the inconvenience "an incidental result of a lawful act". (25)

The U.S. Supreme Court has also removed any standing on the grounds that the injured party has been denied equal protection as provided in the 14th Amendment of the Constitution, by stating "A community may also decide that restrictions on the flow of outside traffic into particular residential areas would enhance the quality of life, thereby reducing noise, traffic hazard, and litter. By definition, discrimination

25. Mackie v. City of Seattle, 1978. 576 Pacific Reporter, 2d., 414. For a further expansion of the concept of injury in traffic management cases as interpreted in Mackie, see Board of Supervisors vs. Alexandria City Council, 1978. In Chancery No. 9708.

against non-residents would inhere in such restrictions". (26)

Strictly speaking, the court's decision was made solely with respect to the equal rights issue and should not be interpreted as providing blanket power for a community to divert traffic seemingly at will. The court seems to be saying that a community may divert traffic and successfully withstand a legal challenge based upon charges of discrimination. Tests of sufficient police power and the reasonable exercise of such power must still be met.

CONFORMANCE TO TRAFFIC CONTROL AND DESIGN STANDARDS

In Berkeley, California a challenge to an extensive traffic management plan on the grounds that the traffic control devices the plan employed did not conform to any specifications for traffic control devices found in the State's TRAFFIC CONTROL MANUAL was initially successful. In subsequent appeal, the appellate court reversed in favor of the City, ruling that:

- The diverters, cul-de-sacs, et cetera were indeed "traffic control devices".
- These control devices were not covered in California's TRAFFIC CONTROL MANUAL.
- That manual is the the State Department of Transportation's administrative regulation, not a law.
- Since the devices are not covered in the manual, they are therefore subject to a catch-all state law which provides that traffic control devices not specifically covered by regulations shall conform to any statutes in effect at the time of installation.
- The only statutory provision (in California) operable in this subject area allows local government to "close" any highway to vehicular traffic.
- The closure of streets to <u>through</u> traffic is a proper partial "closure" so long as the partial closure applies to all drivers (distinguishing cases where residents might otherwise be allowed to somehow pass through the barriers while outsiders are denied).

Hence, while the Berkeley case was ultimately decided in favor of the traffic management plan on the basis of legal technicalities specific to California, the case raises issues of importance throughout the U.S.

In most states traffic control device compliance with the Manual on Uniform Traffic Control Devices (MUTCD) published by the U.S Department of Transportation or with parallel state manuals is to some degree required by law. There is considerable variation in wording and intention of legislation across the country; in some states compliance being mandatory, in others discretionary. Many of the devices commonly used in neighborhood traffic management schemes-diagonal diverters, semi-diverters, retrofit cul-de-sacs, speed control circles, undulations-are not addressed in the MUTCD. Particularly in states where statutory language regarding compliance is mandatory, there is the concern that, upon court challenge, removal of the devices may be ordered because they are not found in the MUTCD or parallel state manuals. There is further concern that in states where compliance

26. <u>County Board of Arlington v. Richards</u>, 1977. 434 United States Reporter 5.

is mandatory, motorists involved in accidents may successfully claim negligence on the part of the responsible jurisdiction was contributory to their accident. If the state statute permits the acting jurisdiction to exercise discretion, then the MUTCD or parallel state manual is admissible only as some evidence of the standard of care. Study of such cases showed the MUTCD was considered "as neither an absolute standard nor as scientific truth (but as) illustration and explanatory material along with other evidence in the case bearing on ordinary care." (27) The most straightforward response to this concern is for the MUTCD and parallel traffic control manuals published by the states to be updated to include specific standards and guidelines for neighborhood traffic control devices like diverters, semi-diverters, retrofit cul-de-sacs, undulations and the like. While such action is a recommendation of this study, its implementation will take time.

An alternative direction is to define some of the devices not treated in the MUTCD as "geometric features of the road" rather than as "traffic control devices". There is little fundamental difference between retrofit cul-de-sacs and cul-de-sacs routinely designed into new residential subdivisions. Likewise, there is little difference between street patterns created by diagonal diverters and discontinuous curvilinear street patterns commonly employed in new residential subdivisions. There is little difference between speed control circles used in neighborhoods and traffic circles or rotaries sometimes used to organize flows at major intersections. There is little distinction between channelization designed to force or prohibit turns in neighborhood situations for traffic management purposes and channelization intended to similarly force or prohibit turns in arterial situations for traffic flow improvement purposes.

None of these geometric features in their conventional applications are treated as control devices in the MUTCD. They are treated in basic reference texts on geometric design of streets and highways. However, to date, only one text regarded as authoritive and broadly used as a traffic engineering design reference has covered their application to neighborhood traffic restraint situations (28) even though their application is extremely pervasive.

The notion that a device like a diverter is a change is the geometrics of the street rather than a traffic control device per the MUTCD definition seems most clear when permanent features like curbs, gutters, sidewalks and landscaping are incorporated in its design. Where the device is comprised of temporary materials like bollards or barricades, whether the device is a traffic control or a geometric feature seems much more an open question.

Implications of all of the foregoing are:

- While all devices covered in the MUTCD are traffic control devices which warn, guide or regulate traffic it is not true that all devices used by traffic engineers as common good

27. Thomas, Larry W. Liability of state and local governments for negligence arising out of the installation and maintenance of warning signs, traffic lights, and pavement markings. NCHRP Research Results Digest No. 110, April, 1979.
28. Homburger, W.S. and Kell, J.H., Fundamentals of Traffic Engineering, 9th Edition, Institute of Transportation Studies, Berkeley, California, 1977.

practice to warn, guide or regulate traffic are covered in the MUTCD. Many such devices that control traffic are geometric features not treated in the MUTCD but rather in other authoritative references on traffic engineering and geometric design.

- Many of the so called "residential street traffic controls" are geometric features employed for traffic control purposes and are virtually identical to geometric features common to approved design for new residential streets or for arterial situations.

- Authorative reference manuals on geometric design, with one exception, have as yet not treated the application of conventional geometric control features to residential traffic control situations. This situation should be corrected.

- If a device is considered a geometric feature, its installation may imply some sort of change in the use of or a "closing" of some portion of the street. If this is the case, local jurisdictions should follow procedures specified in legislation delegating the power to close streets in their particular state.

- Use of permanent materials (like curbs and gutters) rather than temporary materials (like moveable bollards or barricades) may be important in confirming the device as a geometric feature rather than a traffic control.

APPENDIX

TABLE 22
LA CANADA SPEED DATA
NORTHBOUND

	North End	Mid Point	North Hump	Mid Point	Center Hump	Mid Point	South Hump	Mid Point	South End
FASTEST VEHICLE									
Before	35	48	54	50	46	42	35	30	27
Immediately After	39	41	42	34	37	35	33	32	31
After 3 Mo.	35	35	36	35	31	30	30	26	26
After 7 Mo.	26.5	31.5	35	35	35	33	29	25	26
85TH %TILE									
Before	26	34	37	36	35	34	29	24	21
Immediately After	24	24	24	27	22	24	24	24	24
After 3 Mo.	25	24	23	25	24	24	21	20	20
After 7 Mo.	20	25.9	24.9	26.7	24.3	25.5	22.1	20.7	18.7
MEDIAN									
Before	24	29	32	32	31	30	26	22	18
Immediately After	21	18	16	21	17	18	19	19	19
After 3 Mo.	21	21	19	22	18	21	16	17	16
After 7 Mo.	17.5	21	19.3	22.7	19.1	22.1	17.6	18.5	16.8

TABLE 23
LA CANADA SPEED DATA
SOUTHBOUND

	N. End	Mid Pt.	No. Hump	Mid. Pt.	Cent. Hump	Mid. Pt.	So. Hump	Mid. Pt.	So. End
Fastest Vehicle									
Before	33	37	40	41	42	42	42	38	35
Immediately After	38	34	32	44	45	42	40	40	41
After 3 Mo.	34	35	34	35	36	35	40	33	33
After 7 Mo.	34	34	26	34	31	32	30	28	20
85'th Percentile									
Before	26	31	35	37	38	38	37	30	22
Immediately After	27	26	26	26	22	24	21	21	22
After 3 Mo.	23	24	25	26	24	28	22	25	23
After 7 Mo.	22	23	22	25	22	25	23	22	17
Median									
Before	20	25	29	31	32	32	32	25	16
Immediately After	23	19	18	23	17	21	17	17	19
After 3 Mo.	20	22	18	22	18	23	18	19	20
After 7 Mo.	19	21	17	22	17	22	17	18	16

TABLE 24
WILLOW STREET SPEED DATA
SOUTHBOUND

	N. End	Cent. Hump	Garth	Emelia	So. Hump	Alhambra	Willow
Fastest Vehicle							
Before	30.0	29.0	31.0	34.0	36.0	36.0	37.0
After	24.0	21.0	25.0	29.0	26.0	25.0	31.0
85'th Percentile							
Before	28.8	28.8	29.0	30.9	32.0	32.5	32.7
After	16.7	13.5	22.3	25.2	15.4	19.7	24.5
Mean							
Before	23.7	24.5	24.4	25.0	26.3	27.5	27.5
After	14.4	9.6	18.8	20.9	11.2	15.9	20.1

TABLE 25
LOCHSTEAD SPEED DATA
EASTBOUND

	Fastest Vehicle		85'th Percentile		Mean	
	Before	After	Before	After	Before	After
West End	21.	22.	19.0	20.0	16.3	15.0
80' East	26.	28.	22.5	23.4	19.5	18.3
158' East	30.	31.	26.0	26.4	22.6	21.0
W. Hump	34.	34.	28.5	24.5	25.0	17.9
Mid. Pt.	37.	33.	31.7	25.1	28.2	21.2
Cent. Hump	41.	26.	33.5	19.6	29.5	15.7
Mid. Pt.	42.	27.	35.0	22.6	30.0	20.0
E. Hump	42.	24.	34.0	17.8	30.5	14.4
92' E	41.	26.	31.0	20.7	28.0	17.7
186' E	29.	19.	23.6	15.9	19.2	14.1
E. End	15.	14.	15.0	11.0	12.0	9.0

TABLE 26
LOCHSTEAD SPEED DATA
WESTBOUND

	Fastest Vehicle		85'th Percentile		Mean	
	Before	After	Before	After	Before	After
West End	19.0	13.	18.0	11.	14.	10.
80' East	29.0	22.	26.0	17.4	22.5	15.0
158' East	35.4	31.	30.0	21.8	27.0	19.3
W. Hump	39.5	37.	32.0	22.4	28.0	17.5
Mid. Pt.	44.0	36.	34.5	24.5	29.0	21.1
Cent. Hump	48.0	35.	35.0	21.2	29.5	15.6
Mid. Pt.	50.5	34.	34.0	22.9	29.5	19.4
E. Hump	52.0	31.	32.0	20.5	29.0	15.2
92' E	51.0	33.	29.0	23.7	26.3	19.9
186' E	40.0	24.	23.0	19.7	18.8	16.0
E. End	22.0	17.	14.0	12.0	9.0	9.0

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Boston

Dear Willow Street Resident:

A few months ago, the City installed experimental speed control bumps on Willow Street. Your answers to this questionnaire will help evaluate the humps effectiveness. Please return your filled-out questionnaire in the attached post-paid envelope.

Robert F. Drummond

Traffic Engineering Director
Boston Traffic and Parking Department

1. If you were not resident here before November 1979, check this box ☐ and skip to question 4. Others, please answer all questions.

2. Before the humps were installed, residents identified traffic problems in letters and petitions and at a neighborhood meeting. Primary concerns are listed below. For each item, please indicate whether or not you think it was a problem before and how you think conditions have changed since the humps were installed.

	PERCEPTION OF PROBLEM BEFORE		CHANGE SINCE HUMPS			
PROBLEM CONDITION	Condition was a problem before humps installed	Conditions was not a problem before humps installed	Condition worse than before hump	Condition same as before humps	Condition slightly improved since humps	Condition substantially improved since humps
	CHECK ONE		CHECK ONE			
Traffic is too fast overall	☐	☐	☐	☐	☐	☐
Extreme speed by some drivers	☐	☐	☐	☐	☐	☐
Late night speeding	☐	☐	☐	☐	☐	☐
Street is dangerous for kids	☐	☐	☐	☐	☐	☐
Street is dangerous for bicyclists	☐	☐	☐	☐	☐	☐
Noise from squealing tires	☐	☐	☐	☐	☐	☐
General traffic noise	☐	☐	☐	☐	☐	☐
Motorcycles speed, joyride & create noise	☐	☐	☐	☐	☐	☐
Street dangerous for pedestrians	☐	☐	☐	☐	☐	☐
Traffic laws not enforced enough	☐	☐	☐	☐	☐	☐
Too much traffic at night	☐	☐	☐	☐	☐	☐
Too much cut-thru traffic	☐	☐	☐	☐	☐	☐
Too much traffic overall	☐	☐	☐	☐	☐	☐

3. Did you attend the neighborhood traffic meeting last fall? ☐ Yes ☐ No

PLEASE COMPLETE THE FOLLOWING STATEMENTS, CHECKING THE BOX BESIDE THE ONE YOU AGREE WITH MOST.

4. Since the humps have been installed, overall traffic speed is . . .

   - ☐ still far too high
   - ☐ slightly faster than it should be
   - ☐ about right for this street
   - ☐ somewhat slower than is reasonable
   - ☐ much slower than reasonable

5. Since the humps have been installed, the fastest drivers on the street . . .

   - ☐ still travel any speed they wish
   - ☐ have slowed somewhat, though still traveling too fast
   - ☐ are not much faster than average drivers here

6. Driving with wheels in the gutter to avoid the humps is . . .

   - ☐ so frequent it defeats the purpose of the humps
   - ☐ fairly frequent, but even the gutter-runners slow down some
   - ☐ not very frequent, but those who do it drive dangerously fast
   - ☐ too infrequent to worry about

7. Considering safety from traffic of pedestrians, bicyclists and kids in general, with the humps in place, our street is . . .

- ☐ still quite dangerous
- ☐ about average for a residential street
- ☐ safer than average
- ☐ a very safe street

8. The noise of traffic braking and accelerating near the humps is . . .

- ☐ a severe problem
- ☐ an occasional nuisance
- ☐ an occasional nuisance but worth it to keep traffic speed down
- ☐ not a problem

9. I believe the humps are . . .

- ☐ too severe for safety of drivers and passengers and could damage vehicles and cargo
- ☐ about right to slow traffic safely
- ☐ somewhat more gentle than they should be
- ☐ far too gentle to be effective

10. The signing and marking of the humps is . . .

- ☐ insufficient to warn drivers of their presence
- ☐ about right to help drivers cross them safely
- ☐ more extensive than necessary for driver safety

11. The warning signs and appearance of the humps . . .

- ☐ detract from the visual quality of the neighborhood
- ☐ are not particularly attractive but are acceptable, considering what the humps do
- ☐ are not an especially noticable negative feature

12. As a driver, have you had any serious difficulty crossing the humps? (Answer only for the types of vehicles you and your immediate household have driven over them).

	Serious difficulty	Moderate difficulty	No difficulty
Automobile	☐	☐	☐
Vans and Pickups	☐	☐	☐
With Trailer	☐	☐	☐
Bicycles	☐	☐	☐
Motorcycles	☐	☐	☐
Heavy Trucks	☐	☐	☐

13. Residents of other neighborhoods coming to this street to joyride on the humps . . .

- ☐ is a serious continuing problem
- ☐ was a serious problem only at first
- ☐ is still a minor problem
- ☐ never was a noticable problem

14. The humps are spaced . . .

☐ too far apart ☐ about right ☐ too close together

15. The number of humps on this street is . . .

☐ too few ☐ about right ☐ too many

16. Overall, do you think the humps serve a useful purpose on this street? ☐ Yes ☐ No

17. Should the humps remain on this street after the trial period? ☐ Yes ☐ No

18. Other than closing off the street, do you think there are other measures to control speed on this street which could be more effective than the humps?

☐ Yes ☐ No If yes, what?____________________

19. Should the humps be used on other residential streets experiencing traffic problems similar to this street's? ☐ Yes ☐ No

Use this space to make other comments about the humps or to report unusual incidents you observed.

____

____

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