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16. Abstract

Steady increases in travel demand coupled with minimal increases in arterial street capacity have led to an increase in traffic-related safety problems in residential neighborhoods. These problems stem from the significant number of motorists that divert from the arterial to the residential street system in an effort to avoid arterial-related delays. Diverted motorists add to neighborhood traffic volumes and increase crash exposure for pedestrians, bicyclists, and other vehicles. In addition, diverted motorists often drive at excessive speed which increases both the potential for a crash and its severity.

The objective of this research was to develop guidelines for the use of both neighborhood traffic management and corridor traffic management techniques for improving safety in residential neighborhoods. The focus of this research is on neighborhood and corridor traffic management techniques that have the potential to reduce speed or cut-through volume on the local street system. The approach taken to conduct this research was to develop as much of the guideline material through a synthesis of the literature and to supplement this synthesis with some investigative research in areas where information was lacking.

A model was developed for this research that can predict the percent of arterial drivers that cut-through the adjacent neighborhood streets. The data used to develop this model were obtained from extensive simulations of a typical city street system that includes arterial, collector, and local streets. The model variables include average arterial travel speed, signal density (in signals per mile), and the degree of saturation of the signalized intersections on the arterial. Percent cut-through traffic was found to range from 0.0 to 30 percent of the arterial volume, with the higher percentage associated with oversaturated signalized intersections.

Several recommendations for future research in the area of traffic management techniques were developed. Fundamentally, it is recommended that additional research be conducted on the effectiveness of alternative traffic management techniques. For neighborhood traffic management techniques, before-and-after data are needed to assess technique effectiveness in terms of volume reduction, speed reduction, and crash reduction. For corridor traffic management, further research efforts are necessary to verify the accuracy of the cut-through traffic prediction model developed for this research.

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COMPREHENSIVE ENGINEERING APPROACH TO ACHIEVING SAFE NEIGHBORHOODS

FINAL REPORT

for

Research Project No. 167707

SOUTHWEST REGION UNIVERSITY TRANSPORTATION CENTER

**TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM**

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September 2000

ABSTRACT

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EXECUTIVE SUMMARY

Steady increases in travel demand coupled with minimal increases in arterial street capacity have led to an increase in traffic-related safety problems in residential neighborhoods. These problems stem from the significant number of motorists that divert from the arterial to the residential street system in an effort to avoid arterial-related delays. Diverted motorists add to neighborhood traffic volumes and increase crash exposure for pedestrians, bicyclists, and other vehicles. In addition, diverted motorists often drive at excessive speed which increases both the potential for a crash and its severity.

The objective of this research was to develop guidelines for the use of both neighborhood traffic management and corridor traffic management techniques for improving safety in residential neighborhoods. The guidelines would provide a framework for evaluating the effectiveness of a traffic management plan developed for a specified neighborhood and associated street system. This framework would allow for an evaluation of alternative techniques on a consistent basis.

The focus of this research is on neighborhood and corridor traffic management techniques that have the potential to reduce speed or cut-through volume on the local street system. The techniques considered for neighborhood traffic management are limited to those commonly deployed on residential streets by city agencies. Such techniques include: street closures, speed humps, traffic circles, and roadway narrowings. Techniques considered for corridor traffic management are limited to those that increase arterial travel speed. Such techniques include: signalization improvements, geometric improvements, and access management.

The approach taken to conduct this research was to develop as much of the guideline material through a synthesis of the literature and to supplement this synthesis with some investigative research in areas where information was lacking. Some information was found in the literature for the more common neighborhood traffic management devices. However, no information was found that described the effect of arterial operations on the number of drivers that might divert from the arterial through the adjacent neighborhood. Based on this finding, research was conducted to develop a relationship between arterial travel speed and the percent of drivers that cut-through adjacent neighborhoods.

The synthesis of neighborhood traffic management techniques focused on three measures of effectiveness: volume reduction, speed reduction, and crash reduction. Average reductions (expressed as a percentage) were obtained from two sources that reflect conditions on several hundred city streets. Three management techniques that had been used most, as reported in these studies, include speed humps, traffic circles, and speed tables. These devices were found to reduce street volumes from 5 to 25 percent. The reduced speeds from 15 to 20 percent and crash rates from 4 to 15 percent, depending on the device.

A model was developed for this research that can predict the percent of arterial drivers that cut-through the adjacent neighborhood streets. The data used to develop this model were obtained from extensive simulations of a typical city street system that includes

arterial, collector, and local streets. The model variables include average arterial travel speed, signal density (in signals per mile), and the degree of saturation of the signalized intersections on the arterial. Percent cut-through traffic was found to range from 0.0 to 30 percent of the arterial volume, with the higher percentage associated with oversaturated signalized intersections.

A sensitivity analysis using this model indicated that the percent cut-through traffic decreased rapidly with increasing arterial travel speed. The percentage of cut-through traffic also decreased with an increase in signal density. This latter trend may appear counterintuitive; however, further analysis indicated that it actually reflected an increase in delay on a "per signal" basis. Hence, it was concluded that percentage of cut-through traffic increases with an increase in delay per signal.

The sensitivity analysis also revealed that there is the possibility of a threshold arterial travel speed associated with no cut-through traffic. If arterial travel speed could be maintained at this threshold (or higher), cut-through traffic would essentially disappear. This threshold was found to equate to an average arterial travel speed that is about 50 percent of the free-flow speed. Thus, when average speeds are one-half of the free-flow speed or less, drivers will likely cut-through the neighborhood adjacent to the arterial.

Several recommendations for future research in the area of traffic management techniques were developed. Fundamentally, it is recommended that additional research be conducted on the effectiveness of alternative traffic management techniques. The existing body of knowledge is based on informal studies conducted by agency staff for the purpose of assessing the effect at a given street location. Such studies rarely record all of the relevant data or control for area-wide influences. The result is considerable variability in the reported effectiveness of any given technique.

For neighborhood traffic management techniques, before-and-after data are needed to assess technique effectiveness in terms of volume reduction, speed reduction, and crash reduction. Studies that quantify the level of volume reduction should also report the "connectivity" (i.e., number of street segments per intersection or cul-de-sac) or a similar measure that provides some indication of the availability of alternate routes. Studies that quantify speed reductions should also report: (1) the location of the measurement relative to the location of the technique, (2) the distance to other techniques, and (3) the geometry of the device, if a device is used. Studies that quantify crash reduction should include traffic volume so that crash *rate* reduction can be computed. Crash rate is defined as the number of crashes per million vehicles. It was shown in this research that crash rate reduction is a much more accurate method of evaluating a technique's ability to improve safety.

For corridor traffic management, further research efforts are necessary to verify the accuracy of the cut-through traffic prediction model developed for this research and the findings associated with a sensitivity analysis of this model. Specifically, additional research is needed to:

1. Verify the existence of a threshold travel speed above which there would be no cut-through traffic,
2. Expand the model to include sensitivities to a wider range of factors (e.g., size of the neighborhood, density and connectivity of the local street system, and application of specific route modification and calming devices), and
3. Validate the model using real-world data.

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Chapter 1
INTRODUCTION

OVERVIEW

Background

Steady increases in travel demand coupled with minimal increases in arterial street capacity have led to an increase in traffic-related safety problems in residential neighborhoods. These problems stem from the significant number of motorists that divert from the arterial to the residential street system in an effort to avoid arterial-related delays. Diverted motorists add to neighborhood traffic volumes and increase crash exposure for pedestrians, bicyclists, and other vehicles. In addition, diverted motorists often drive at excessive speed which increases both the potential for a crash and its severity.

Some indication of the extent of the safety problem in residential neighborhoods is provided in Table 1. The data shown in this table indicate that most fatal crashes occur on minor arterials. However, an analysis of crash *rate* (i.e., crash frequency "normalized" by the amount of travel) indicates that local streets have the poorest safety record. These data indicate that the probability of a fatal crash on a local street is almost three times greater than that for an interstate highway. This trend is likely due to the high probability that one of the participants in a local-street crash is a pedestrian or bicyclist.

TABLE 1 Comparison of crash rates by roadway classification in urban areas (*1*)

Roadway Classification	Fatal Crashes	Vehicle-Miles Traveled (millions)	Crash Rate (crashes per 100 million vehicle-miles)
Interstate	1,791	285,325	0.6
Other Freeway	1,619	128,242	1.3
Minor Arterial	5,081	338,987	1.5
Major Collector	3,171	240,402	1.3
Collector	1,149	107,272	1.1
Local Roads/Streets	**2,928**	**188,365**	**1.6**
Unknown	27	--	--
Total	15,766	1,288,593	1.2

Excessive speed is a major contributing factor in crashes of all types. In fact, excessive speed was a contributing factor in 30 percent of all fatal crashes in 1997 (*2*). Excessive speed has serious consequences for pedestrians. The likelihood of a pedestrian being hit by a vehicle increases with speed. Motorists traveling at high speeds are less likely to see a pedestrian and, if they see the pedestrian, are less likely to be able to stop in time to avoid hitting the pedestrian.

Finally, the severity of a crash increases sharply with speed to the extent that pedestrians struck at speeds of 35 mi/h or more rarely survive (*3*).

Many of the pedestrians in neighborhoods are children. In 1997, 30 percent of the 5 to 9-year-old children who died in car crashes were pedestrians (*4*). Additionally, nearly one-third of the bicyclists killed in motor vehicle crashes in 1997 were between 5 and 15 years old (*5*).

Studies of child-involved crashes in New South Wales, Australia (as reported in Reference *2*), show that about 25-30 percent of all crashes occur on local neighborhood streets. Eighty percent of pedestrian-involved crashes with children under the age of 10 occurred within one-half mile of their home.

Studies in England, the Netherlands, Germany, and Sweden (as reported in Reference *2*) have compared child-involved crash rates in newly-constructed residential areas with those in older areas. These studies indicate that newly-constructed areas have crash rates two to five times lower than the older areas. The lower crash rates were explained by the following factors:

- Through traffic is often heavy in old areas, and the street network is more complex. New areas have a more differentiated street network according to traffic function in order to discourage or eliminate cut-through traffic. Also, some new streets include cul-de-sacs.

- Older areas often include mixed activities, resulting in some on-street parking. The older areas often lack playgrounds, so children use the streets for playing, biking, and other recreational activities.

- New areas have access to numerous playgrounds and green areas that are free from motor vehicle traffic. There are often separated walkways and bicycle paths that lead to school and to other activities of interest for children.

Finally, Jacobsen *et al.* (*5*) note that "society cannot adapt children to traffic; society has to adapt traffic to children." The study emphasizes that the nature of children prevents them from handling the demands of traffic and that speed is a strong risk factor for child pedestrian injury.

Methods of Managing Traffic to Improve Safety

Numerous engineering techniques have been used to manage traffic on neighborhood streets. These techniques are intended to provide a safe environment for both pedestrians and motorists by minimizing the number of diverted (or "cut-through") vehicles and by maintaining safe vehicle speeds. These techniques can be grouped into two categories, depending on their intended area of impact. The first category includes techniques used for neighborhood traffic management (NTM); these techniques are intended for direct application to the affected residential streets. The second category includes techniques used for corridor traffic management (CTM); these techniques indirectly address the problems associated with cut-through traffic by reducing the incentive to divert. Techniques that may be used for NTM and CTM are illustrated in Figure 1.
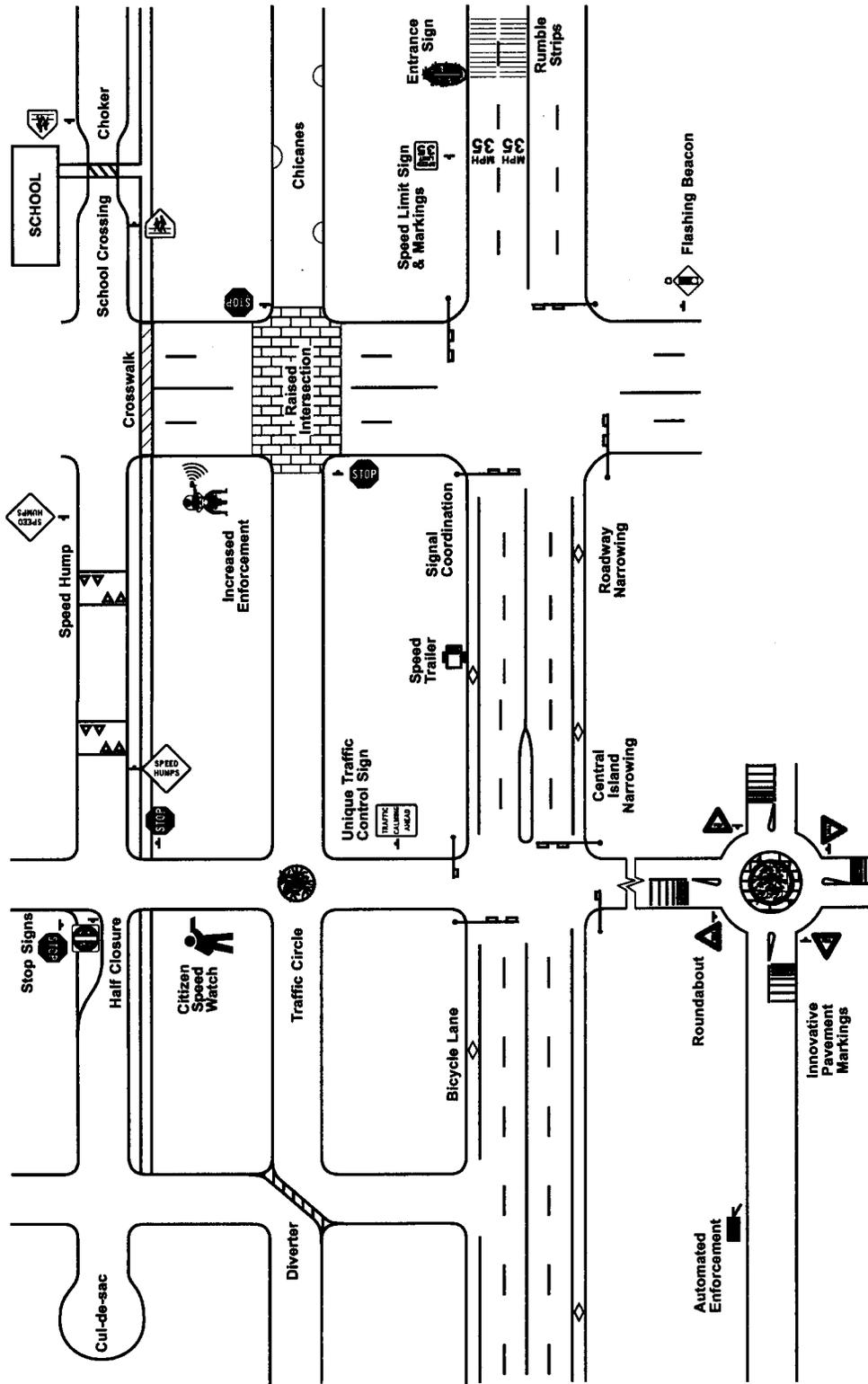
Figure 1. Illustration of speed management techniques.

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Neighborhood Traffic Management Techniques

Neighborhood traffic management techniques are designed to improve safety, provide a greater sense of security, and increase neighborhood livability. These techniques generally focused on *reducing* speed and volume at a specific neighborhood location. They include "traffic calming" techniques, traffic control devices, and enforcement activities. NTM techniques are often used in area-wide applications as part of a comprehensive "traffic management program." Although many traffic management programs address only neighborhood concerns, they may be expanded to include higher-speed and higher-volume streets (such as collectors or arterials).

There are numerous NTM techniques available for consideration; they range in their level of "presence" (or impact) on the street system. Less restrictive NTM techniques include speed zoning and innovative pavement markings. More restrictive techniques include one-way streets, stop signs, speed humps, and enforcement. The effectiveness of these techniques (in terms of a lasting speed and/or volume reduction) is not known with certainty; however, there is evidence that each technique can have a small positive effect.

Corridor Traffic Management Techniques

CTM techniques offer a system-wide approach to mitigating the diversion problem by reducing the incentive to divert. These techniques focus on *improving* the operation of the arterials adjacent to the neighborhood. Maintenance of an "acceptable" travel time on the arterial street system surrounding the neighborhood should reduce volume (and possibly speed) by reducing the attractiveness of the cut-through route. CTM techniques include: improved signal coordination, increased arterial through movement capacity, and reduced access-point density along the arterial.

In spite of their potential to improve neighborhood safety, CTM techniques have received less attention from transportation agencies than other techniques. This trend may be due to the means by which the problems come to the public transportation agencies. Citizen groups tend to advocate specific solutions to specific problems as opposed to improvements to the adjacent arterial street systems. This trend may also be due to the urban planning origins of traffic management. Urban planning professionals tend to consider factors that increase speeds in urban areas (even if it is the speed on an arterial street) as inappropriate. Hence, the vast number of traffic management techniques appear to be oriented toward speed reduction.

Question of Effectiveness

The effectiveness of most NTM techniques is not well known, although they tend to be more frequently applied than CTM techniques. It is likely that NTM techniques have received more attention because they are a highly visible, immediate, and a direct treatment of a specific problem. CTM techniques have not received as much attention possibly due to their lower visibility, slower maturity, and more subtle effect on cut-through volume on a given street. However, it is speculated that the CTM category may offer a more cost-effective and lasting solution under some conditions. Based on this assessment, it was determined that research was needed to develop quantitative guidelines describing the use and effectiveness of alternative techniques.

OBJECTIVE AND SCOPE

The objective of this research was to develop guidelines for the use of both neighborhood traffic management and corridor traffic management techniques for improving safety in residential neighborhoods. The guidelines would provide a framework for evaluating the effectiveness of a traffic management plan developed for a specified neighborhood and associated street system. This framework would also allow for evaluation and comparison of alternative techniques on a consistent basis.

The focus of this research is on neighborhood and corridor traffic management techniques that have the potential to reduce speed or cut-through volume on the local street system. The techniques considered for neighborhood traffic management are limited to those commonly deployed on residential streets by city agencies. Techniques considered for corridor traffic management are limited to those that increase arterial travel speed through capacity increases or signal timing changes that improve progression.

The guidelines described in this document are intended for application to urban settings where there is a mature street system that is functionally complete. The street segments that comprise this system should have an arrangement and length that is consistent with the hierarchy of movement, as described in the AASHTO publication *A Policy on Geometric Design of Highways and Streets* (*6*).

CONCEPTS AND DEFINITIONS

The objectives of a traffic management program are to reduce traffic volumes or maintain reasonable speeds on the residential streets within a neighborhood. A wide range of techniques can be used to achieve this objective. Most of these techniques can be categorized in terms of their effect on drivers. These effects can be described as "traffic calming," "route modification," or "regulatory."

The concept of traffic calming has been defined in several different ways. One of the more widely accepted definitions is that coined by Lockwood (*7*). His definition is as follows:

> "Traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior, and improve conditions for non-motorized street users (*7*)."

Based on this definition, traffic calming techniques rely on the laws of physics to slow traffic down. They are self-enforcing and do not explicitly reroute drivers.

Route modification techniques are intended to reduce traffic volume on selected streets by using some type of traffic restriction or by making operational improvements to alternative routes. Traffic restrictions include lane closure, turn movement prohibition, or diverters. Improvements to alternative routes include realignment, increased capacity, or improved traffic progression.

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Alternative routes would typically be those of the arterial classification that are intended to provide for through traffic movements.

Finally, regulatory techniques are intended to reinforce safe and legal driving practices through the implementation and enforcement of traffic control devices. These techniques include speed limit signing, Stop or Yield control devices, and pedestrian crosswalks all of which are combined with a routine system of enforcement.

Chapter 2
NEIGHBORHOOD TRAFFIC MANAGEMENT TECHNIQUES

OVERVIEW

Historically, transportation engineers have focused on providing motorists with high-capacity, high-speed roadways. This focus is reflected even in the design of residential streets in terms of generous cross sections, infrequent horizontal curves, and ample sight distances. Unfortunately, the needs of pedestrians and bicyclists have not received a similar level of attention. This deficiency is most prevalent in neighborhoods where residents are demanding "livable neighborhoods." These residents want neighborhood streets that have low vehicular volumes and speeds such that a serene and safe environment is sustained throughout the day.

Neighborhood traffic management techniques have become an increasing popular method for providing family-friendly streets. This trend is partly due to the proliferation of citizen groups that have organized to restore the integrity of their neighborhoods. These groups tend to be well organized and vocal in advocating speed-reduction or street-closure options on their affected street. The trend is also a result of agency recognition of the limited ability of "spot" treatments (e.g., adding a speed limit sign) to solve neighborhood traffic problems. It is now generally recognized that a neighborhood-wide solution is necessary to preclude "shifting" the problem (i.e., diverting traffic) to an adjacent neighborhood street.

Objective and Goals

Neighborhood traffic management has the overall objective of maintaining neighborhood livability by regulating vehicular volume and speed within the neighborhood street system. Consistent with this objective, neighborhood traffic management programs have the following goals:

1. Minimize the volume of cut-through traffic on neighborhood streets,
2. Maintain safe speeds on neighborhood streets, and
3. Minimize conflicts between vehicles and pedestrians and between vehicles and bicycles.

Achieving the first goal is likely to increase the odds of achieving the other two goals. However, any effort to minimize cut-through traffic must consider the entire neighborhood street system and treatments thereon in order to preclude the shifting of traffic to an adjacent local street.

Common Techniques

Most traffic management techniques have some ability to reduce the volume and speed of vehicular traffic on the local street. All of them tend to be associated with a reduction in the frequency and severity of crashes. In general, a given technique will have a primary effect (e.g., volume reduction) for which it is typically selected and one or more secondary effects. Many of the techniques currently used are listed in Table 2. The techniques listed in this table are described more fully in the appendix.

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TABLE 2 List of neighborhood traffic management techniques

Category	Technique	Primary Measure of Effectiveness
Route Modification Devices	Full closures	Volume reduction
	Half closures	Volume reduction
	Diagonal diverters	Volume reduction
	Semi-diverters	Volume reduction
	Median barriers	Volume reduction
	Forced turn islands	Volume reduction
Traffic Calming Devices	Speed humps	Speed reduction
	Speed tables	Speed reduction
	Raised intersections	Speed reduction
	Speed cushions	Speed reduction
	Traffic circles	Speed reduction
	Central island narrowings	Volume reduction
	Roundabouts	Speed reduction
	Roadway narrowing	Volume reduction
	Chicanes	Speed reduction
	Neckdowns	Volume reduction
	Chokers	Volume reduction
Regulatory Measures	Speed trailers	Speed reduction
	Speed limit signs and markings	Speed reduction
	Increased enforcement	Speed reduction
	Citizen watch programs	Speed reduction
	Automated enforcement	Speed reduction
	Bicycle lanes and paths	Crash reduction
	High visibility crosswalks and wider sidewalk areas	Crash reduction
	Innovative pavement markings	Crash reduction
	Turn or through traffic prohibition signing	Volume reduction

The techniques listed in Table 2 as being in the "traffic calming" and "route modification" categories represent physical objects applied at a point on the roadway for the purpose of affecting driver behavior in the immediate vicinity of that point in a self-enforcing manner. Because of this characteristic, these techniques are also referred to as "devices."

Related Issues

Development and Implementation Policies

The goal in developing a neighborhood traffic management program is to produce an integrated set of policies, objectives, and procedures that will include the program's vision, a set of guidelines, and the policy basis for making future decisions. Achieving this goal will provide consistency in addition to the political and technical framework for making decisions. This

requires that thought be given to the problems that the program is designed to solve and what mechanisms will be used to solve them. Successful programs are structured to allow citizens and elected officials to be comfortable in moving projects forward but are also flexible enough to adjust to challenges of individual projects. The types of policy issues that need to be considered during program development are listed in Table 3.

TABLE 3 Typical procedures and issues considered in developing a neighborhood traffic management program (*4*)

Procedure	Issues to be Considered/Corollary Issues
How to handle project requests.	If program is reactive, who can submit a request? Are there pre-submittal requirements? Is there a time limit for reconsideration? How will incident related or other special requests be handled?
Evaluation and ranking of projects.	Will objective criteria be used? Do these criteria reasonably represent the nature and extent of the problem? Does the evaluation adequately rank the severity of the problem? Is there a minimum score for eligibility for a project? Are there different minimums for different types of project solutions? Will the potential project list(s) rank projects city-wide or within specific boundaries (e.g., political boundaries, neighborhood association boundaries, geographic boundaries)?
Project selection procedure.	How are projects selected (e.g., by a prioritized list, elected officials, neighborhood associations)?
Public notification and involvement.	How will initial resident support for the project be determined? How much support is needed for the project to proceed? What citizen/resident notification method(s) will be used? How far away from the project street will residents be notified about the project? How will citizen/resident communications and involvement be handled throughout the project? Will businesses, the transit provider(s), the emergency response and other service providers be included? How will the project design be determined? Will City Council or other elected officials need to approve the project?
Construction.	Will construction be completed by outside contractors or on-staff crews? Will temporary techniques be used as an interim measure pending final construction?
Ongoing program evaluation.	How will project results be reviewed and on what time frame? How is political support assessed and retained? How are resident and citizen satisfaction assessed and retained? How and who will keep the inventory of techniques used?

Public Involvement

Effective public involvement is critical to the success of a neighborhood traffic management program because residents are generally the first to recognize problem areas. Most residents have some sense of ownership of the street space in front of their house, even though they know that the street is public property. Nearly everyone in a neighborhood feels strongly that they should have a voice in what happens on their street. Therefore, it is critical to involve the public in the decision making process, although this process is time consuming and often frustrating.

The public involvement process should balance the public's desires with the need for a project that is safe, does not negatively affect the overall transportation system, and can be constructed for a reasonable cost. However, the way that local residents perceive traffic safety problems and their solutions may be very different from the way the problems and solutions are perceived by a traffic engineer. The traffic engineer must be able to recognize these differences and be able to use neighborhood input without compromising engineering judgement.

Legal Issues

Concern about increased liability risk from implementation of neighborhood traffic management techniques is partially due to the lack of standards for their construction. Because such standards are lacking, the best way for a jurisdiction to protect itself from legal challenges is to develop a rational, well-thought-out program for the planning and implementation process. Formally adopted program policies limit a jurisdiction's exposure to tort liability suits by showing that the jurisdiction's actions were not arbitrary, capricious, or unreasonable. Project files should also document the activities and decisions made during the project.

Local jurisdictions are often concerned about the additional risk they accept by developing a neighborhood traffic management program. This concern is valid; however, the jurisdiction can protect itself by periodically inspecting the physical elements of the traffic calming measure. According to Ewing *et al.* (*8*), "You have little or no exposure, provided your traffic calming measures are well-designed, well-signed, well-lighted, and well-documented."

The issue of government liability always surfaces in discussions of neighborhood traffic management. However, lawsuits and damage claims are not as prevalent as is commonly assumed. A survey of nearly 50 cities and counties by Ewing (*9*) found that many have had no legal problems at all, and the others have experienced more threats than legal actions.

The legal issues associated with implementing a neighborhood traffic management program include statutory authority, constitutionality, and tort liability. A jurisdiction must have adequate authority to implement neighborhood traffic management techniques. The jurisdiction must also respect the constitutional rights of affected landowners and roadway users. Finally, the jurisdiction has responsibility to minimize the risk to roadway users. Parham *et al.* (*10*) indicate that tort liability is generally the issue that concerns local jurisdictions the most.

Emergency Response Issues

Emergency response agencies have become more concerned and vocal as neighborhood traffic management programs have become more common. Many projects have been postponed or stopped because an agreement could not be reached with emergency response agencies.

Opposition from fire-and-rescue services can be a major obstacle to neighborhood traffic management. Neighborhood traffic management techniques that are effective in slowing or diverting automobiles have the same, or even greater, effect on fire or rescue vehicles. The biggest challenges are to keep the effect on emergency vehicle response times within acceptable limits and to find new ways of slowing and diverting automobiles without substantially impeding emergency response vehicles.

Several agencies have performed controlled tests of selected traffic calming devices to quantify the delay they produce. During these tests, multiple runs were made with multiple vehicles driven by multiple drivers in order to estimate travel time as a result of the device. These travel times were then compared with travel times on streets without traffic calming devices. Results of several tests have been reported by Ewing (*9*). These results were averaged for several common traffic calming techniques and are listed in Table 4.

TABLE 4 Emergency vehicle delays due to selected traffic calming devices

Traffic Calming Device	Delay to Listed Emergency Vehicles (seconds)[1]			
	Fire Engine	Custom Rescue Vehicle	Ladder Truck	Ambulance with patient
12-ft speed hump	5.1	--	5.0	9.7
14-ft speed hump	5.2	2.9	6.6	--
22-ft speed table	3.0	0.3	8.3	--
16 to 25-ft traffic circle	6.2	3.1	6.9	--

Notes:
1- Based on data reported in Table 7.3 of Reference *9*.

Based on an examination of the test data, Ewing (*9*) offered the following observations:

1. The delay is almost always less than 10 seconds, regardless of the traffic calming device or fire-rescue vehicle tested.
2. Traffic circles appear to create longer delays than speed humps.
3. The delay to fire engines will likely be incurred for all emergency calls as fire engines are generally included in all emergencies.

TECHNIQUE EFFECTIVENESS

The objective of neighborhood traffic management is to provide a safe environment by reducing the speed and volume of traffic to acceptable levels. Neighborhood traffic management techniques are often reported to reduce the number of crashes on treated residential streets. For example, a report by Geddes *et al.* (*11*) that summarized the findings of 43 safety studies indicated that collision frequency declined an average of 80 percent with a range of 8 to100 percent.

This section summarizes a review of the literature on the effectiveness of alternative neighborhood traffic management techniques. The measures of effectiveness include volume reduction, speed reduction, and crash frequency reduction. The discussion of techniques is separated into two categories: (1) route modification and traffic calming techniques and (2) regulatory techniques. Techniques in the first category tend to represent specific devices with physical elements that are self-enforcing whereas those in the second category represent the application of traffic controls and require some level of law enforcement.

Route Modification and Traffic Calming Techniques

Case study findings reported by Ewing (*9*) provide the most recent, comprehensive look at the effectiveness of individual neighborhood traffic management techniques. Average reductions in volume, speed, and crashes are shown in Table 5. The data in this table that are attributed to Ewing (*9*) reflect measurements at 378 locations in 11 U.S. cities. Sample sizes underlying each average vary from 3 to 179 locations with an average of 38 locations.

TABLE 5 Effectiveness of selected neighborhood traffic management techniques

Category	Technique	Primary Measure of Effectiveness	Percent Reduction In...			Ref.
			Volume	**Speed**	**Crashes**	
Route Modification Devices	Full closures (1 to 4 blocks away)	Volume reduction	44	--	--	9
	Half closures (1 to 4 blocks away)	Volume reduction	42	19	--	9
	Diagonal diverters	Volume reduction	35	4	--	9
Traffic Calming Devices	Speed humps	Speed reduction	18 to 22	22 to 23	13 to 40	9
	Speed tables	Speed reduction	12	18	45	9
	Raised intersections	Speed reduction	--	1	--	9
	Traffic circles	Speed reduction	5	11	28	9
	Roadway narrowing	Volume reduction	10	4	--	9
	Chokers	Volume reduction	20	14	--	9
Regulatory Measures	Speed trailers	Speed reduction	9	7	10	12
	Speed limit signs and markings	Speed reduction	4	7	3	12
	Increased enforcement	Speed reduction	8	28	28	12

Volume changes resulting from the application of a technique can vary with the degree of speed reduction and with the presence of attractive alternate routes. A case study reported by Ewing (*9*) illustrates this concept. Two identical streets were both treated with a series of 12-ft speed humps located at comparable spacings. One street did not have a convenient alternative route; the other street had a good alternative route. Speed reductions were nearly the same on both streets. However, only the street with an alternate route experienced a volume reduction. The statistics associated with this case study are listed in Table 6.

TABLE 6   Effect of alternate route availability on volume change (*9*) [1]

Parallel Route?	Speed Reduction [2]			Volume Reduction [2]		
	Before	**After**	**% Change**	**Before**	**After**	**% Change**
No	36	25	30.6%	2,456	2,593	-5.6%
Yes	37	27	27.0%	1,472	1,071	27.2%

Notes:
1 - 12-ft speed humps at 500 to 580-ft spacing.
2 - negative changes denote an *increase* rather than a reduction.

The speed reduction associated with a given technique can vary depending on the spacing between such techniques. Data reported by Ewing (*9*) for speed humps, indicate that speeds tend to increase with distance between techniques. An examination of the data indicates that the percentage speed reduction decreases about 2 percent for every 100 ft increase in spacing. For example, speed humps located about 200 ft apart were found to reduce speeds by 33 percent; those located about 400 ft apart were found to reduce speeds by only 29 percent.

Crash frequency reductions reported by Ewing (*9*) (and listed in Table 5) were examined to determine the possible influence of volume. As noted previously, a significant portion of the crash frequency reduction is often due to volume reduction rather than an increase in safety as a result of the traffic management technique. A subset of the data provided by Ewing (*9*) was found to have both volume *and* crash data (i.e., 33 speed humps, 6 speed tables, and 15 traffic circles). Linear regression was used to examine this data to determine the change in crash rate for the "before" and "after" scenarios. The resulting relationships are shown in Column 2 of Table 7.

TABLE 7   Effectiveness of three traffic calming devices

Traffic Calming Device	Crash Rate Equation [a]	R^2	Effective Crash Rate Reduction Percent	Reported Crash Freq. Reduction Percent
Speed Humps	$y = 0.8459 x$	0.49	15 %	13 to 40 %
22-ft Speed Tables	$y = 0.9594 x$	0.21	4 %	45 %
Traffic Circles	$y = 0.9413 x$	0.96	6 %	28 %

Notes:
a - y = crash rate after installation; x = crash rate after installation (crashes per million vehicles).

The regression relationships were used to compute the effective crash rate reduction percentages (i.e., percent reduction = $(x - y) / x * 100$). These percentages are shown in Column 4 of Table 7. The last column of Table 7 lists the crash frequency reduction percentages reported by Ewing (*9*) and listed in Table 5. Comparison of the percentages in the last two columns provides convincing evidence that volume reduction associated with the implementation of a traffic calming device is the primary reason that crash frequency decreases. Hence, actual improvements to the *safety* of a street treated with one or more techniques are likely to be small (as reflected by a reduction in crash rate of only 4 to 15 percent).

Regulatory Techniques

There is limited evidence available on the effectiveness of regulatory techniques. However, these activities cannot be dismissed because there have been successes. Average reductions in volume, speed, and crash frequency for three techniques are listed in Table 5, as reported in Reference *12*.

Targeted enforcement activities have been successful in reducing speed; however, continued enforcement is required to sustain acceptable levels of speed reduction. There is also some doubt about the cost-effectiveness of these activities. Data reported by Ewing (*9*) for one city indicate that targeted enforcement has a net annual cost of more than $150,000 (= salary less revenue from fines). This cost was found to be about five times that associated with speed humps.

Neighborhood speed watch programs have varying results. Such programs serve to involve and educate residents on the true nature and extent of the problem. However, in a review of the effectiveness of three programs, Ewing (*9*) found that actual speed reductions were negligible. Some neighborhood speed watch programs continue to focus on reducing speeding through newsletter publications.

Photo-radar speed enforcement has been found to yield sustained speed reductions over time. However, because of its operating expense, photo-radar is only cost-effective on high-volume streets that have both excessive speed and safety problems and which are also the least amenable to the use of other techniques.

Chapter 3
CORRIDOR TRAFFIC MANAGEMENT TECHNIQUES

OVERVIEW

Corridor operating efficiency and safety are at the heart of urban traffic operations. Arterial streets carry the bulk of the traffic in urban areas which has made them the focus of considerable research through the years. Corridor traffic management provides for the safe and efficient travel of all motorists along and in the immediate vicinity of the arterial street, including the adjacent collector and local street system. This chapter describes corridor management techniques that are intended to minimize the volume of traffic that diverts through neighborhoods. This goal is achieved by maintaining a high travel speed along the arterial street such that diversion through a neighborhood is an unattractive alternative.

Objective and Goals

Corridor traffic management has the overall objective of ensuring that the corridor street system is functionally balanced and that all streets in the system provide an acceptable quality of traffic service. The goals of a corridor traffic management program include:

1. Minimize travel time to through vehicles on arterial streets.
2. Minimize neighborhood intrusion by providing a hierarchy of local, collector, and arterial streets.
3. Minimize conflicts between vehicles and other travel modes.

The ultimate goal of corridor traffic management is to preserve or improve the mobility function of the arterial (or pair of arterials) in a corridor. Mobility is usually associated with high speeds and shorter travel times, lower delay, and fewer stops, which are all objectives of corridor traffic management. Safety is also a concern, and reduction in crash rate is another objective.

As traffic demands continue to grow and arterial streets become more congested, some drivers seek alternative routes in hope of reducing their travel time. However, problems can occur when the alternative routes include neighborhood streets. Smith, *et al.* (*13*) aptly phrased the principal problem with flow in traffic networks:

> "Many motorists simply regard any street in any location as, first and foremost, a place to drive. Further, they have certain expectations as to how a street system should operate, and if the street becomes congested beyond their tolerance, they will seek other paths."

Unfortunately, the criteria used by a driver when selecting the "other path" has no bearing on the roadway's functional classification. The result is that drivers use local streets for high-speed through trips instead of low-speed property access. This problem is illustrated in Figure 2. The street system shown in this figure offered several alternative paths for trips between downtown Atlanta, Georgia, and Harmony Grove Road. Unfortunately, many drivers chose to

avoid the delay at the signalized intersection of Harmony Grove Road and U.S. 29 by using the residential streets (i.e., Braden Dr. and Kenvilla Drive).
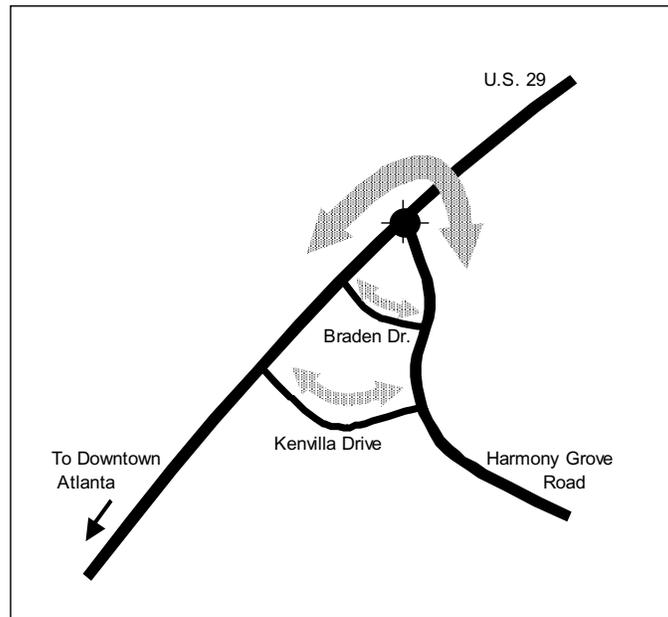
Figure 2. Example of alternative routes that lead to cut-through traffic.

To prevent the misuse of the local street system, the traffic engineer should set a goal of minimizing delay and travel time along the arterial streets that bound the neighborhood. To achieve this goal, the arterial should have its signal timing plan periodically reviewed and updated to insure that the arterial continues to provide an adequate level of service to motorists. Occasional physical improvements to the intersections (e.g., add a turn bay) may also be needed to accommodate changing traffic patterns.

Common Techniques

Corridor traffic management techniques are focused on increasing arterial travel speed such that the arterial remains attractive to through drivers. Travel speed can be improved using one or more of the following techniques: signalization improvements, geometric improvements, or access management. All three techniques are intended for application to the arterial street (or streets) within the corridor. Each of these techniques is briefly described in this section.

Signalization Improvements

The signalized intersections and their associated spacing along the arterial street dictate the level of service provided by the arterial. Because of their significant influence on operations, the control mode and controller settings at each intersection should be adapted to traffic volumes and patterns that occur throughout the day. Signalization improvements include: optimize signal

phase durations, coordinate through phases, improve progression bandwidth, remove signals that are unwarranted, and provide traffic-responsive operation.

Geometric Improvements

Geometric improvements can also increase arterial capacity. These improvements may include: adding turn lanes, adding through lanes, or converting the street to one-way operation. Geometric improvements tend to be more difficult and costly to install than traffic signal improvements. They may also be much more permanent. However, they have the potential to offer greater capacity gains than any other improvement technique.

Access Management

Access management reflects a system-wide application of techniques aimed at mitigating the negative effects of access points located along the arterial. The number, spacing, and design of these access points are highly correlated with corridor operations. More frequent access points result in lower travel speeds. Access management techniques include: changing the median type, introducing turn prohibitions, and reducing the total number of access points along the arterial. The objective of these techniques is to minimize delays to through vehicles due to left or right-turn maneuvers from the arterial.

Related Issues

Corridor Preservation

Corridor preservation seeks to protect the corridor street system from disruption due to new development. It is not a traffic engineering tool; rather, it is a legislative and policy basis for access management and allows for planned geometric improvements to the arterial street system. Corridor preservation represents the planing element of a corridor traffic management plan.

Arterial Traffic Calming

Brindle (*14*) classifies traffic management programs into three different levels, each one broader in scope than the other. Level 1 is effectively neighborhood traffic management as it relates to the residential application of route modification, traffic calming, or regulatory techniques. Level 2 is effectively arterial traffic calming. Level 3 involves area-wide or metropolitan traffic management. It relies on a variety of demand-reduction policies, pricing policies, land-use policies, and other high-level decisions that can influence driver mode and route choice. Level 3 traffic management is largely outside the scope of this report.

Pline (*15*) indicates that the purpose of arterial traffic calming is to improve the environment around the arterial for all users and to "adapt the arterial to the town." One objective of arterial traffic calming is to limit excessive arterial speeds, but not at the expense of increased delay or reduced capacity. A second objective of arterial traffic calming is to avoid the diversion of traffic to the local street system. The second objective may be at odds with the first objective

because reduced arterial speeds are very likely to increase the volume of diverted traffic, especially if alternative routes through the neighborhood exist.

TECHNIQUE EFFECTIVENESS

The goals of corridor traffic management offer some insight into the measures of effectiveness that can be used to assess alternative management techniques. One goal is to minimize arterial travel time. A second goal is to minimize the number of vehicles that divert through the neighborhoods adjacent to the arterial street. Based on this assessment, two measures of effectiveness are identified: volume reduction on neighborhood streets and speed increase on the arterial street.

Measures of Effectiveness

Volume Reduction on Neighborhood Streets

The three corridor management techniques described in a previous section (i.e., signalization improvements, geometric improvements, and access management) are intended to directly improve arterial travel speed. In turn, these improvements may affect the volume of cut-through traffic in a neighborhood.

Savage *et al.* (*16*), present a series of "toolboxes" for dealing with residential traffic problems. They acknowledge that one approach to neighborhood cut-through traffic "may be to improve the arterials and attract drivers back to the through streets." However, nothing more is said about how to achieve this goal. A similar acknowledgment is provided in the *Traffic Engineering Handbook* (*15*).

Fisher (*17, 18*) outlines a "carrot and stick" approach used by the City of Los Angeles in dealing with residential cut-through traffic. The concept behind this approach is to make the arterial more attractive that the local streets. This is accomplished by providing ample left-turn capacity (via phasing and turn bays) at the arterial-to-arterial intersections. In contrast, the turn phase is intentionally very short at the arterial-collector intersections. This approach tends to make travel along the major streets more attractive, while discouraging cut-through traffic at collector street intersections. This concept is shown in Figure 3. Fisher reports that this system works "reasonably well," although quantitative information was not provided.

There are a few publications that define acceptable levels of neighborhood traffic volume. For example, Spitz (*19*) has proposed a range of volume levels for different degrees of acceptability. These levels are shown in Table 8.

Appleyard (*20*) suggests a maximum local street traffic volume of 500 to 800 veh/d. This maximum is consistent with the "good" and "acceptable" ranges in Table 8. Collectively, these values suggest that, for an arterial improvement to be considered "effective," neighborhood street volumes should be reduced to below 1,500 veh/d and preferably below 1,200 veh/d.
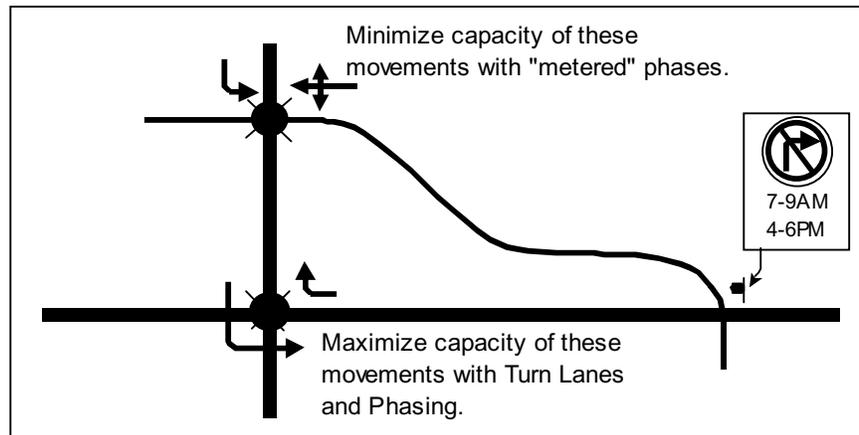
Figure 3. Signalization and geometric improvements that reduces cut-through volume.

TABLE 8 Acceptable levels of local street traffic volume (*19*)

Traffic Volume or Flow Rate Range		Acceptability
Daily Volume (veh/d)	**Flow Rate (veh/m)**	
0 to 300	0 to 0.5	Excellent
300 to 600	0.5 to 1.0	Good
600 to 1,200	1.0 to 2.0	Acceptable
Over 1,200	Over 2.0	Poor

Speed Increase on the Arterial Street

Procedures in the *Highway Capacity Manual* (*21*) (*HCM*) can be used to determine the effectiveness of capacity improvements on arterial streets. These improvements are directed to the capacity of the arterial through movements. They can be the result of changes in signalization or the addition of traffic lanes. The effectiveness of the improvement is assessed in terms of the increase in average travel speed.

The *HCM* defines travel speeds that reflect acceptable levels of service for an urban street. These level-of-service thresholds are listed in Table 9. These thresholds are expressed as a percentage of the free-flow speed. Free-flow speed reflects vehicle speeds when traffic volumes are relatively light such that the speed limit, the street's geometry, and its immediate environment are the only factors that influence a driver's speed choice.

Effectiveness of Individual Techniques

This section describes the effectiveness of selected corridor traffic management techniques. These techniques include signal coordination and capacity improvements.

TABLE 9 Relationship between free flow speed and level of service (*21*)

Travel Speed (as a percent of free flow speed)	Operating Conditions	Level of Service
90 to 100 %	Free Flow	A
70 to 89 %	Unimpeded	B
50 to 69 %	Stable	C
40 to 49 %	Periodically Unstable	D
33 to 39 %	Unstable	E
< 33 %	Congested	F

Signal Coordination

Poor progression on an arterial can be due to sub-optimal timing, but it can also be due to poor or uneven signal spacing. In general, good arterial progression can be maintained as long as signal spacing is uniform and the sum of the travel time in both directions is equal to a multiple of the cycle length. In contrast, an arterial with poor signal spacing can almost never have good two-way progression, regardless of the signal timing.

The benefits of signal coordination have been demonstrated in two recent state-wide traffic signal optimization projects. These two projects are California's Fuel-Efficient Traffic Signal Management Program (FETSIM) (*22*) and Texas' Traffic Light Synchronization Program (TLS) (*23*). The FETSIM program involved about 2,500 signals while the TLS program included 1,600 signals. The results of each program are summarized in Table 10. The results are generally similar overall; however, the TLS program has considerable variation for individual systems and intersections.

TABLE 10 Effectiveness of signal coordination and signal timing adjustment

Project	Signal Improvement	Equipment	Reduction Percentage (%)			Sample Size
			Delay	Stops	Fuel Use	
TLS (*23*)	Timing adjustment only	Existing	55	26	34	10
		New	31	13	11	147
	Coordination only	Existing	60	29	31	60
		New	29	16	14	201
	Both	Any	14	28	11	1,606
FETSIM (*22*)	Both	Any	14	13	9	2,500

Capacity Improvements

Capacity improvements include changes to arterial geometry (e.g., add lanes) or the timing of the through movement at each traffic signal. The effectiveness of these improvements is difficult to generalize, since the same improvement may perform very differently under different conditions. Figures provided in Chapter 10 of the *HCM* provide some indication of the effect of a change in capacity (via a change in the volume-to-capacity *v/c* ratio) on average travel speed. Two of these figures are reproduced in this report as Figures 4a and 4b. The three trend lines in each figure reflect different signal spacings, as expressed in terms of "signals per kilometer." For reference purposes, Figure 4a is illustrative of a "Class II" street, as defined in the *HCM* and Figure 4b is illustrative of a "Class III" street.
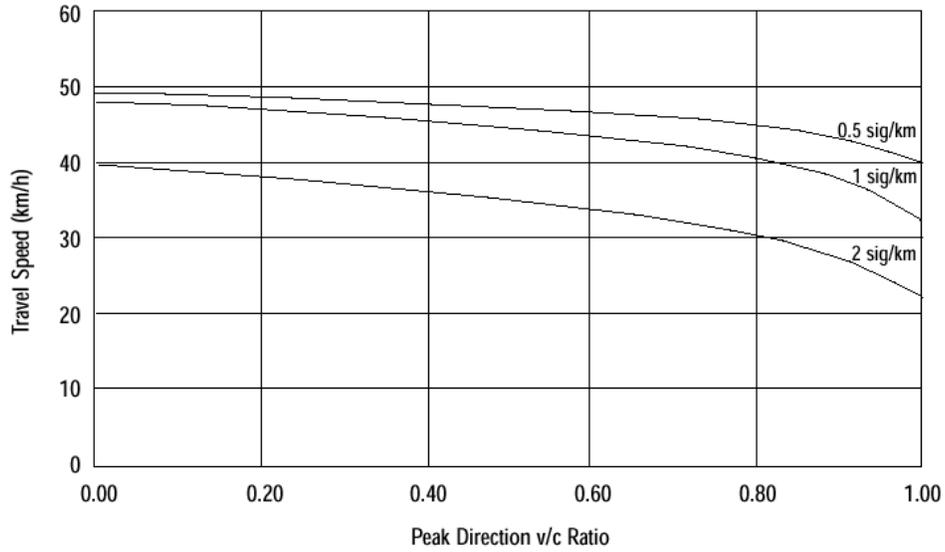
Note:
Assumptions: 65 km/h midblock free-flow speed, 10 km length, 120 s cycle length, 0.45 g/C, arrival type 3, isolated intersections, adjusted saturation flow rate of 1700 veh/h, 2 through lanes, analysis time period of 0.25 h, pretimed signal operation.

a. Average travel speed for suburban arterials with a speed limit of 40 or 45 mi/h (Class II).
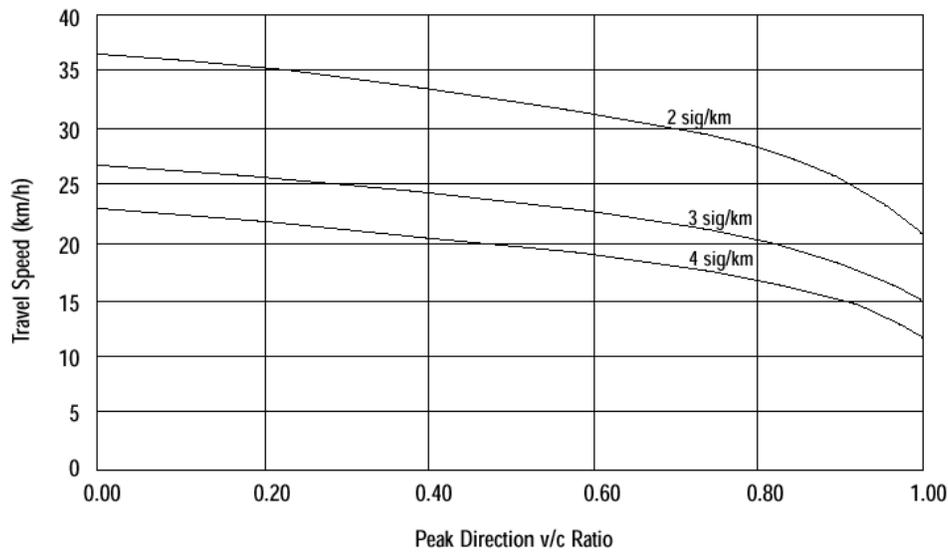
Note:
Assumptions: 55 km/h midblock free-flow speed, 10 km length, 120 s cycle length, 0.45 g/C, arrival type 3, isolated intersections, adjusted saturation flow rate of 1700 veh/h, 2 through lanes, analysis time period of 0.25 h, pretimed signal operation.

b. Average travel speed for suburban arterials with a speed limit of 30 or 35 mi/h (Class III).

Figure 4. Effect of volume, capacity, signal spacing, and speed limit on average travel speed.

Chapter 4
DEVELOPMENT OF A CUT-THROUGH TRAFFIC PREDICTION MODEL

OVERVIEW

Excessive traffic on residential streets is often a result of non-local (or "through") drivers diverting from the adjacent arterial street system in an attempt to reduce their travel time. Neighborhood traffic management techniques (e.g., closures, diverters, turn prohibition) have traditionally been used in a reactive manner to prevent drivers from diverting through the neighborhood. Some success has been achieved from this practice; however, several engineers (*16, 17*) have pointed out that improving arterial operations can offer a proactive approach that is intended to preclude through driver diversion.

This chapter describes a relationship between diverted (or cut-through) traffic volume and arterial street performance. The relationship was developed using simulation modeling of a street network consisting of arterials, collectors, and local streets. The relationship can be used by engineers to predict the benefit of arterial improvements in terms of reducing cut-through volume. It can also be used to compare alternative improvements or to justify the cost of an improvement.

TRAFFIC SIMULATION PROCESS

Simulation Model Selection

Generally, there are two types of transportation models: planning and operational. Planning models follow the "4 Step" process of trip generation, trip distribution, mode split, and network assignment. These models are intended to provide an estimate of future daily traffic demands on the major streets within a metropolitan area. Street capacity and intersection delay are modeled in a very approximate manner that is consistent with the precision needed for planning applications. On the other hand, operational models provide a very detailed view of the operation of one street or a small network of streets. In these models, the interaction between individual drivers and roadway elements (signs, signals, lane assignments, and so on) is of primary importance. Operational models can provide very detailed information about the performance of selected traffic lanes and intersection approaches as they are affected by signal timing, intersection geometry, vehicle mix, and speed limit.

It was determined that elements of both planning and operations models would be needed to develop a relationship between arterial performance and cut-through volume. Specifically, what was needed was a traffic simulation model that could assign trips to a street network (thus allowing route changes to be modeled) *and* analyze operational effects of various types of geometric features and signal settings. The model chosen was Integration. It is a deterministic simulation model developed by Van Aerde (*24*). Integration is capable of modeling the operation of signalized and unsignalized intersections, turn lanes, and queue spillback. It can also model driver response to control devices and other delay sources through its use of an origin-destination-based traffic assignment module.

As with any model, Integration has some limitations. First, Integration uses a speed-density model requiring the definition of free-flow speed, speed at capacity, capacity, and jam density for each street segment. Unfortunately, little information is available regarding the value of these parameters for interrupted flow (i.e., signalized street systems), especially for local streets. Therefore, they must be estimated based on experience and judgement.

Second, Integration cannot optimize coordinated signal systems during the simulation. It has the capability to optimize the signal timing of individual intersections during the simulation; however, this capability is not extended to signal offset optimization. Offsets and timing plans that promote good progression must be developed by the analyst (for different times of day) and provided as input to the simulation model prior to its execution.

Finally, modeling left-turn bay lengths and left-turn driver behavior under congested conditions is also a problem for Integration. Integration does not allow drivers to "look ahead" more than one street segment at a time. Thus, the simulated driver makes decisions about lane choice based only on traffic conditions on the upstream segment. This decision making causes problems when the left-turn bay overflows to the extent that the queue spills back into the upstream segment. Integration "instructs" all drivers on the upstream segment to avoid the queue and enter the "problem" segment in an adjacent through lane. The problem is that drivers intending to turn left from the problem segment are now unable to get into the overflowing left-turn bay. Integration instructs these left-turn drivers to block the adjacent through lane until they can enter the left-turn bay (which may not happen). In the "real-world," these left-turn drivers would have joined the queue on the upstream segment.

In spite of these limitations, Integration provided the best mixture of detailed operational analysis and modeling of driver route-choice.

Scope of Simulation

Several factors were identified as possibly having an influence on, or being related to, the volume of cut-through traffic in the simulated street system. These factors are listed in Table 11. Because of limited project resources, only those factors indicated by check ( ) were investigated in this research.

As noted in Table 11, several items were not investigated during the simulation effort that may have considerable bearing on cut-through traffic. One of the most important of these items was the investigation of the effect of individual neighborhood traffic management techniques. However, any factorial evaluation of all reasonable combinations of technique and spacing-between-techniques would require an analysis effort that greatly exceeded the project resources. Also, for many techniques, there is insufficient data available regarding its effect on traffic speed. The density and connectivity of the local street system was another important variable that could not be covered in this research because of limited resources.

TABLE 11 Factors related to cut-through volume on local streets

Category	Factors Related to Cut-Through Volume	Factors Investigated
Travel Time	Total Trip Length	
	Travel Speed/Delay	
Arterial Street Conditions	Signal Operations	
	Cross section (e.g., number of through and turn lanes)	
	Traffic Demand	
Neighborhood Street Conditions	Network Density (Street Spacing)	
	Operating Speed	
	Traffic Control	
	Neighborhood Traffic Management Techniques	
	Network Connectivity (Street Configuration)	

Note:
 - denotes factors explicitly evaluated in traffic simulation process.

Finally, limited resources precluded an investigation of the effects of a wide range of signal timing plans. The effects of signal timing on arterial operations are well known, but the effect on neighborhood cut-through traffic is not. The "aging" of signal timing plans may have an incremental, progressive effect that gradually increases the volume of cut-through traffic.

The factors identified in Table 11 were examined using simulation in order to quantify their effect on the volume of cut-through traffic. In order to make this measure of effectiveness more interpretable, it was expressed as a percentage of the arterial traffic entering the street network that bounds the neighborhood. Thus, the percent of cut-through traffic represents the measure of effectiveness developed from the simulation analysis. This measure was computed using the following equation:

$$\%CT = \frac{V_E - V_L}{V_T} \times 100 \qquad\qquad (1)$$

where:
$\%CT$ = percent cut through traffic, percent;
V_E = total number of vehicles exiting neighborhood streets (i.e., the collector and local streets) and entering the arterial streets, veh/h;
V_L = total number of local vehicles exiting neighborhood street, veh/h; and
V_T = total number of vehicles entering the arterial street system that bounds the subject neighborhood, veh/h.

Simulated Traffic Network

The network used in this analysis was a 1/4 mile by 1/4 mile grid bounded by arterial streets, as shown in Figure 5. The arterial streets had four through traffic lanes (two lanes each direction) and a free-flow speed of 40 mi/h. In the "base condition," the arterial-arterial and arterial-collection intersections were signalized. The characteristics of this arterial are consistent with the Class II criteria defined in Chapter 11 of the *HCM* (*21*).
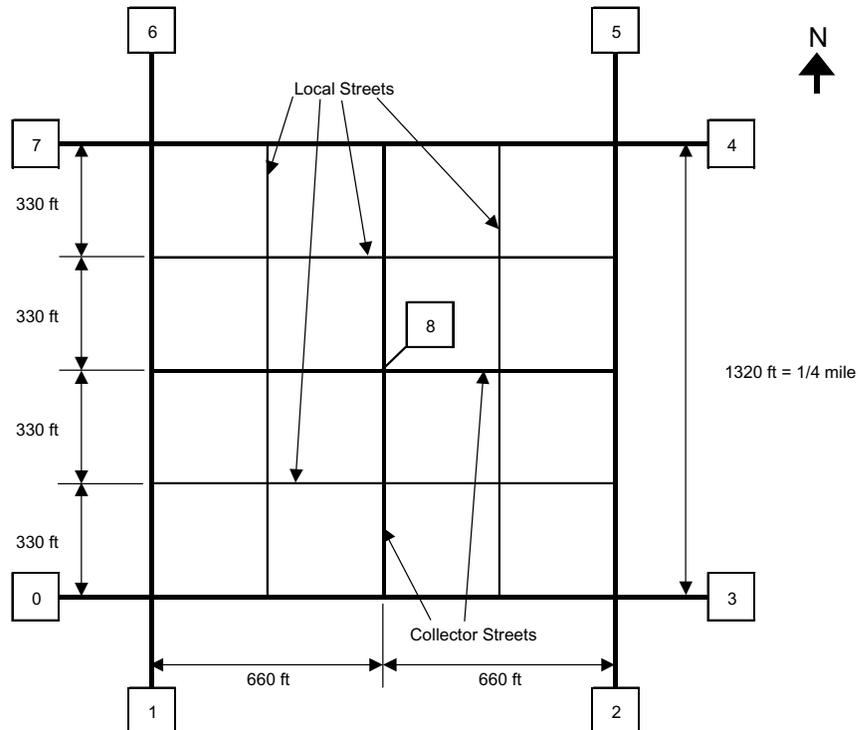
Figure 5. Simulated traffic network.

Street Spacing and Speed

Local and collector streets were located as shown in Figure 5. Collector streets are parallel to and 1/8 mi from the arterial streets. Local streets are parallel to and 1/16 mi from the nearest arterial street. Each collector street had two through traffic lanes and a free-flow speed of 30 mi/h. Local streets were spaced halfway between the collector and arterial. Each local street had two through traffic lanes and a free-flow speed of 20 mi/h.

Traffic Control

The traffic control conditions for each intersection are shown in Table 12. The Arterial-Collector intersection was signalized for the "base condition"; however, two-way stop control was substituted for a series of simulations intended to evaluate the effect of signal spacing on cut-through volume.

TABLE 12 Traffic control at intersections

Intersection Type	Control
Arterial-Arterial	Signal
Arterial-Collector	Two-way stop or Signal
Arterial-Local	Two-way stop (local)
Collector-Collector	All-way stop
Collector-Local	Two-way stop (local)
Local-Local	Alternating yield

All signalized intersections were provided with left-turn lanes. To avoid some of the problems associated with driver "look ahead" behavior (as noted in the section titled Simulation Model Selection), the turn lanes were extended to the next upstream intersection (in this case, 330 ft). Signal operation included protected-permitted left-turn phasing.

Trip Distribution

In order to use Integration, an origin-destination-based trip assignment was needed. The network being analyzed had eight origin-destination zones for arterial traffic plus a ninth origin-destination zone for local traffic. The origin-designation zones are indicated by number in Figure 5.

Because these zones both produced and attracted trips, a method was needed to initially distribute trips among the zones. The distribution method used was a doubly-constrained gravity model. This model has two constraints. First, total productions must equal total attractions. Second, the "cost" (i.e., travel time) of making the trip must also be reflected in the distribution, with fewer trips being distributed to the more "expensive" routes.

As a first step in the trip distribution process, a distribution of background traffic was assumed. This distribution was based on an assumed orientation of the simulated network relative to the central business district (CBD) of a large city. Specifically, it was assumed that the simulated network was south of the CBD. It was also assumed that traffic flows reflected the afternoon peak hour. Based on these assumptions, it was rationalized that 36 percent of all traffic flowing into the network would be traveling south, 24 percent would flow north, and 20 percent would flow both east and west. Each of these percentages was split evenly among the two external nodes on the corresponding side of the network. The result of this distribution is shown in Figure 6.
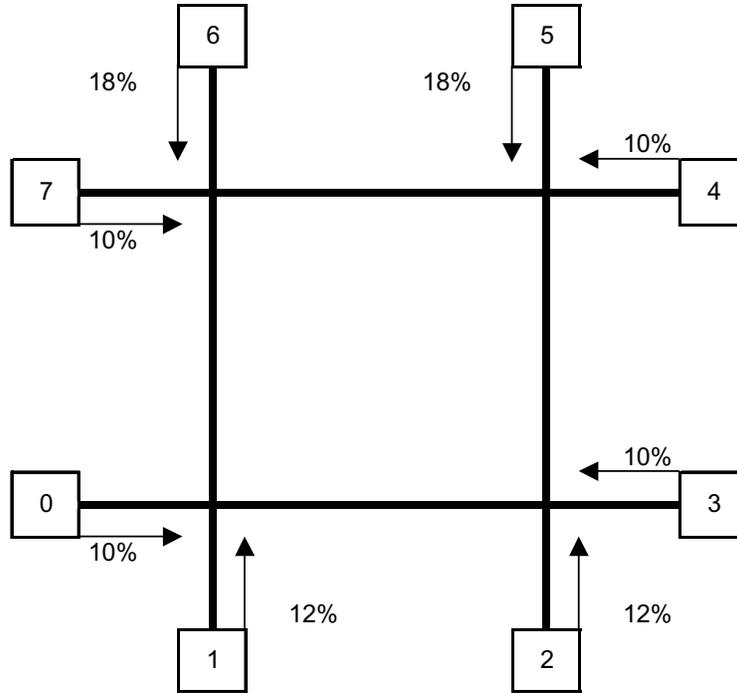
Figure 6.   Distribution of trip origins by zone.

Next, impedance factors were created to account for the relative attractiveness of the various destination zones. These impedances were subjectively determined and intended to reflect the relative delay at each intersection associated with a particular turn movement. The impedances used were 5, 10, and 15 for the through, right-turn, and left-turn movements, respectively.

The impedances were created to assign a "cost" for each possible traffic movement on the arterial streets within the network. For instance, a vehicle traveling from Zone 1 to Zone 3 would have a right turn at the first arterial intersection encountered and then travel through at the second intersection. The total impedance for this trip is 15 (= 10 + 5). The impedances used in trip distribution are shown in Figure 7.

Origin	Destination Zone							
Zone	0	1	2	3	4	5	6	7
0		10	15	10	35	30	25	20
1	20		20	15	30	35	10	25
2	25	40		10	25	10	35	30
3	10	25	20		20	15	30	35
4	35	30	25	40		10	35	30
5	30	35	10	25	20		20	15
6	25	10	35	30	25	40		10
7	20	15	30	35	10	25	20	

Figure 7.   Impedance values for each origin-destination pair.

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Figure 8 illustrates the results of the trip distribution process when the total traffic demand on the arterial streets is 175 veh/h/ln. Other values were obtained for other traffic volumes; however, the relative magnitudes shown in Figure 8 were maintained.

Origin Zone	Destination Zone							
	0	1	2	3	4	5	6	7
0		76	56	45	14	18	27	22
1	37		61	44	25	23	97	26
2	32	32		72	33	90	54	41
3	60	37	49		31	44	46	26
4	22	40	51	17		83	29	22
5	35	47	174	37	53		69	60
6	45	176	99	63	45	31		95
7	30	62	62	29	60	26	38	

Figure 8.   Sample origin-destination matrix for a lane volume of 175 veh/h/ln.

The gravity model used in the distribution process was found to yield a constant percentage of vehicles that effectively travel "diagonally" through the network (e.g., from Zone 6 to Zone 2). Diagonally oriented vehicles were the most likely vehicles to cut-through the neighborhood in order to avoid delays along the arterial. In order to fully evaluate the effect of arterial operations on the volume of cut-through drivers, the origin-destination matrix produced by the gravity model was adjusted slightly to achieve a desired percentage of cut-through vehicles.

Local Traffic Demand

The area bounded by the arterial streets was assumed to be residential, with a housing density of 10 dwelling units per acre. This density is estimated to be about one-half of the maximum density that can be supported by the street network. Procedures described by Ewing (*9*) were used to estimate the peak hour trip production for this size network. Based on this analysis, 640 total trips were estimated with 60% (384 trips) inbound during the peak hour and 40% (256 trips) outbound. This volume was added to the arterial traffic volumes obtained from the gravity model.

Unlike the arterial trips, local trips were distributed evenly to all of the external destinations. The total amount of local volume was relatively small compared to the arterial volume. In fact, the addition of local traffic to the network had very little effect on the volume of cut-through traffic. To simplify the modeling process, all local traffic was assumed to originate at Zone 8.

Geometric and Operational Variations to the Network

Figure 9 lists the various operational and geometric factors that were varied during this analysis. Each combination of free-flow speed and traffic control was individually simulated for each signal density, demand level, and diagonal percentage.   The signal density was varied by

adding signals to the arterial-collector intersections. All-way stop control was used at every collector-collector, collector-local, and local-local intersection.

Demand Level (veh/h/ln)	Total Arterial Volume (veh/h)	Diagonal Percentage
100	1400	14
175	2800	19
250	4200	23
325	5600	27
450	8400	

Signal Density:	8 signals/mile (signals at arterial-arterial and arterial-collector intersections)
	4 signals/mile (signals at arterial-arterial intersections)

The following factors were evaluated for each signal density, demand level, and diagonal percentage combination:

Factor	Base Condition	Change in Factor
Arterial Street Free-Flow Speed	40 mi/h	+ 5 mi/h
		- 5 mi/h
Collector Street Free-Flow Speed	30 mi/h	+ 5 mi/h
		- 5 mi/h
Local Street Free-Flow Speed	20 mi/h	+ 5 mi/h
		- 5 mi/h
Collector streets	Collector streets at 1/8 mi.	Collectors become local streets (20 mi/h free-flow speed) and alternating Yield control.
Local & Collector Street Control	Two-way stop and Yield controls.	All-way stop control.

Figure 9.   Network operational and geometric factors investigated.

DATA ANALYSIS AND RESULTS

Simulation Data

A total of 360 simulation runs were performed to investigate all of the combinations shown in Figure 9. From the output of each run, the total number of vehicles exiting the neighborhood (i.e., entering the arterial from a local or collector street) was collected. This data was used with Equation 1 to compute the percent cut-through traffic. Visual inspection of the simulation in progress showed that exiting vehicles sometimes re-entered the neighborhood, but the number of double-entry vehicles was very small. Also collected from the output of each run was the travel time and average travel speed on the arterial streets.

A comparison of average lane volumes and travel speed for the base condition with "8 sig/mi" density is shown in Figure 10. The trends for the other factor combinations were similar. The travel speeds are closely grouped for lane volumes up to 325 veh/h/ln, then they diverge for higher volumes. The divergence is because the higher diagonal percentages (23% and

27%) had larger left-turn delays at the higher volume levels than the lower diagonal percentages. Lane volumes of 450 veh/h/ln generally resulted in congestion for one or more movements at the arterial-arterial signalized intersections.
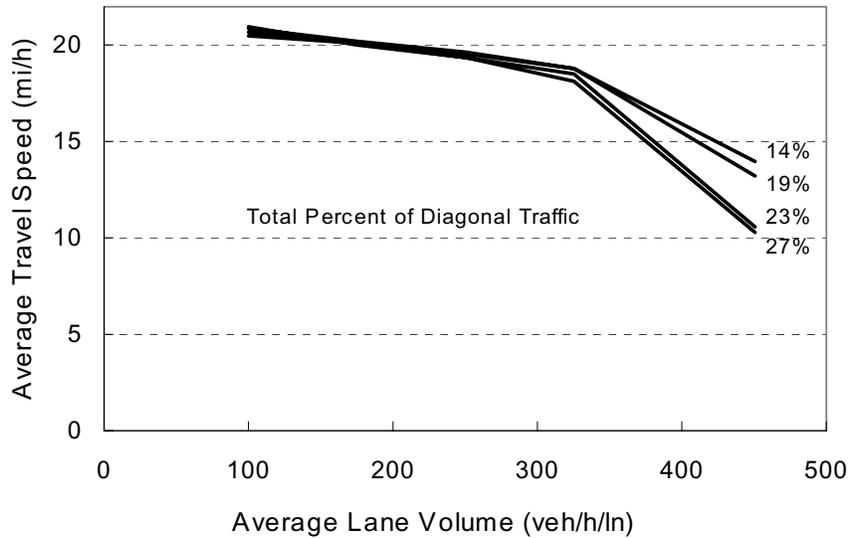
Figure 10.   Average travel speed as a function of lane volume and diagonal percentage.

Further analysis of the data revealed that signal density has a significant effect on travel speed. This effect is illustrated in Figure 11. The *HCM (21)* levels of service for a Class II street are superimposed on the figure for reference.
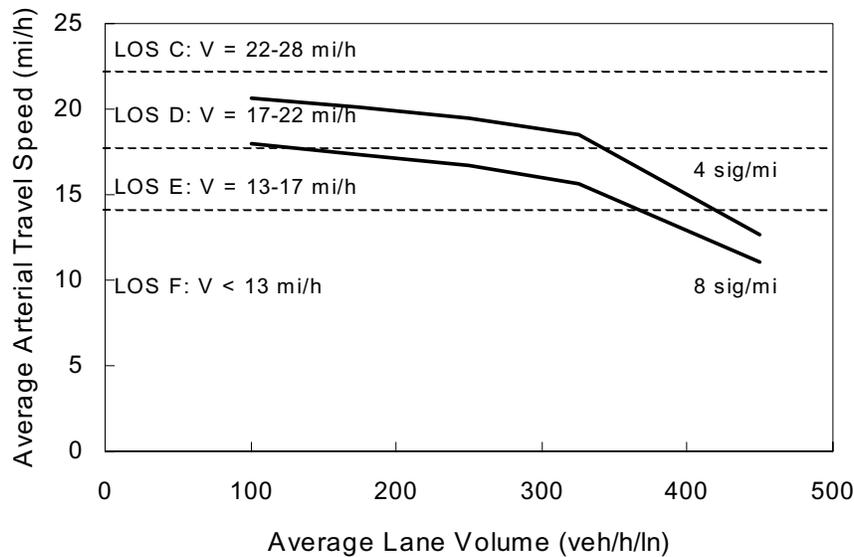
Figure 11. Average travel speed as a function of lane volume and signal density.

The percent of cut-through traffic for the base condition and "8 sig/mi" density are shown in Figure 12. In general, the amount of cut-through traffic increases as the average lane volume increases and as the diagonal percentage increases. An examination of the cut-through percentage for other factor combinations indicated similar trends; however, the specific percentage for a given lane volume and diagonal traffic level was found to vary by ± 5 percent.
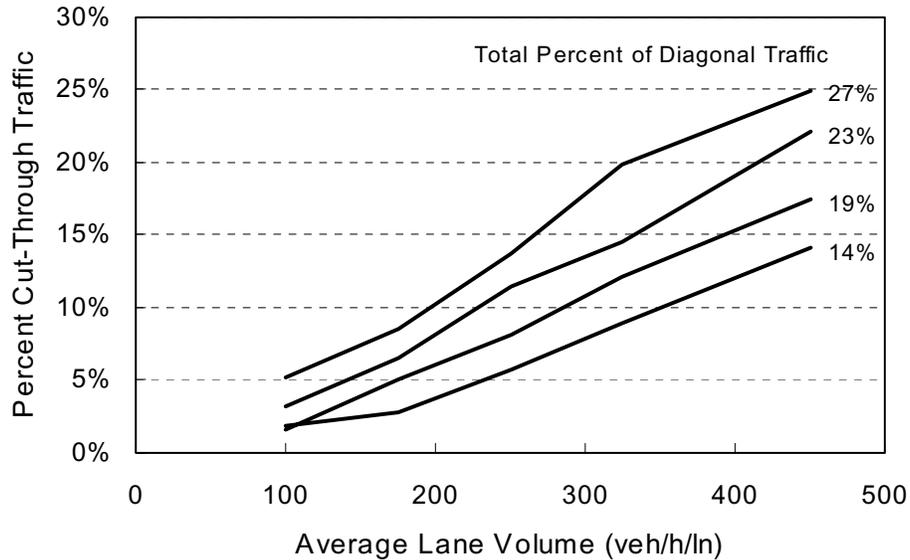
Figure 12. Cut-through percentage compared to average lane volume for base condition.

A plot of all 360 data points is shown in Figure 13. Examination of this figure indicated the existence of three regions. One region includes data for a density of 4 sig/mi and lane volumes at or below 325 veh/h/ln. A second region includes data for a density of 8 sig/mi and lane volumes at or below 325 veh/h/ln. A third region includes data for all densities and lane volumes above 325 veh/h/ln. As noted previously, lane volumes in excess of 325 veh/h/ln were typically oversaturated at the arterial-arterial intersections. It was also noted that the percent of cut-through traffic had a minimum value of 12 percent during oversaturated conditions.

An interesting trend can be observed in the data shown in Figure 13. For a given travel speed, the lower signal density is associated with a larger cut-through traffic percentage than the higher signal density. This trend would seem counterintuitive because more frequent signals would logically be more unattractive and would encourage more diversion. However, the fact that the travel time is the same indicates that the delay at each signal is higher for the "4 sig/mi" density. To illustrate, consider an arterial with a free-flow speed of 40 mi/h (travel time is 90 s/mi). An average travel speed of 18 mi/h equates to a 200 s/mi travel time. The difference in travel time of 110 s/mi must be divided evenly among the signalized intersections. This equates to 27.5 s/veh for a "4 sig/mi" density and 13.7 s/veh for an "8 sig/mi" density. Intuitively, drivers are more likely to divert to avoid the lengthy queues associated with the "4 sig/mi" density.
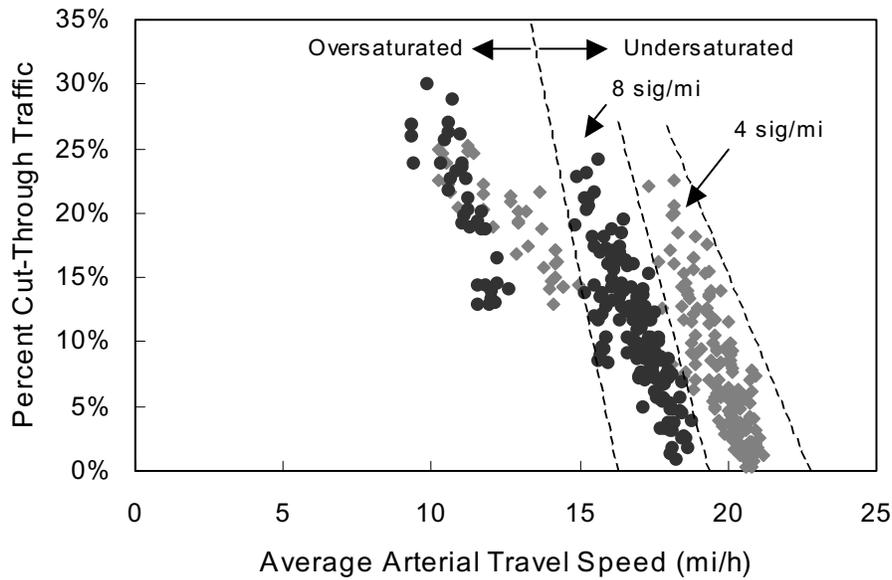
Figure 13. Percent cut-through traffic compared to average arterial travel speed.

Analysis Results

Based on the examination of the simulation data, a model for predicting cut-through traffic percentage was defined. It was then calibrated using regression analysis. This analysis yielded the following equation:

$$\%CT = 51.42 - 0.101V^2 + 0.017S^2 - 13.95D - 0.00069(V \cdot S)^2 \qquad (2)$$

where:
$\%CT$ = percent of cut-through traffic based on total arterial traffic;
V = average arterial travel speed, mi/h;
S = signal density, sig/mi; and
D = indicator variable (0.0 if system is undersaturated; otherwise 1.0).

The quality of the model fit to the data was quite good, as indicated by an R^2 value of 0.81. The predicted relationship between the percent cut-through traffic, speed, and signal density is illustrated in Figure 14.

It should be noted that Equation 2 is valid only for four-lane arterial streets with a free-flow speed of about 30 to 50 mi/h and signal densities of 4 to 6 sig/mi. The precision of the model prediction will decrease for conditions that significantly deviate from the calibration conditions.

33
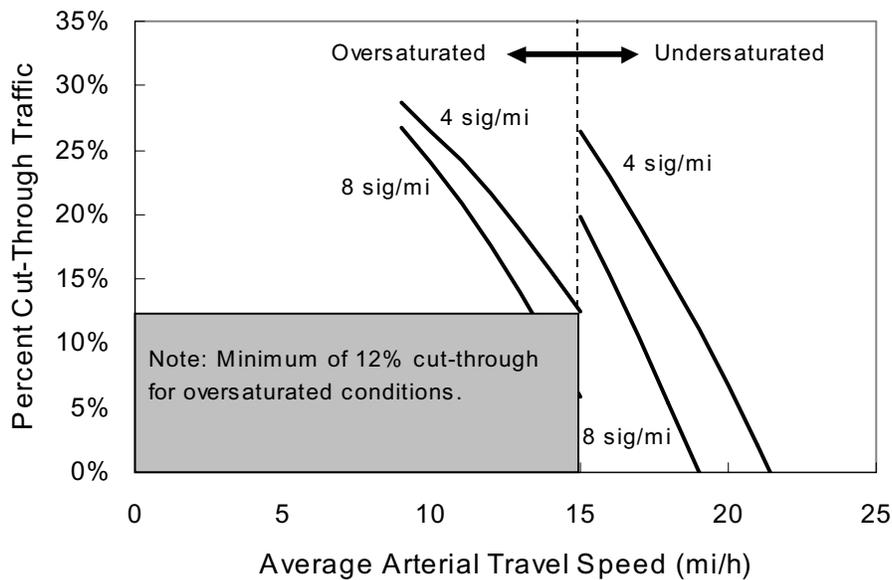
Figure 14. Predicted cut-through traffic percentage as a function of speed and signal density.

The variables in the prediction model (i.e., Equation 2) include average arterial travel speed, signal density, and degree of saturation. A term that accounts for the interaction between these two variables is also included in the model. Average arterial travel speed is the total distance traveled divided by total travel time (including stopped time). This variable is equivalent to the arterial travel speed used in Chapter 11 of the *HCM* (*21*).

The interaction term included in Equation 2 is highly significant, in spite of the very small coefficient. This term reflects the increased influence of speed at higher signal densities. Neither the arterial demand level nor the proportion of diagonal traffic was found to be significant.

Equation 2 accounts for the effect of arterial travel speed and signal density on percent cut-through for the base condition, as described in Figure 9. The results from the other investigation of the other factors listed in Figure 9 are provided in Table 13. The values listed in the last column of this table represent adjustments to the percent cut-through obtained from Equation 2. Specifically, they would be added to the value of *%CT* (negative values would be subtracted). It should be noted that the adjustments associated with each factors reflect relatively modest changes in the percent of cut-through traffic.

The adjustments in Table 13 suggest that changes in local street speed limits have a relatively small effect on the percentage of cut-through traffic. These data indicate that reducing local street speeds by 5 mi/h may reduce traffic volumes only 1 to 1.5 percent. This small amount of reduction would probably not be noticeable to local residents.

TABLE 13 Adjustments to Equation 2 to account for selected factors

Factor	Change in Factor	Change in Percent Cut-Through [1]
Local Street Free Flow Speed	+ 5 mi/h	+ 1.15%
	- 5 mi/h	- 1.2%
Collector Street Free Flow Speed	+ 5 mi/h	+ 1.16%
	- 5 mi/h	- 1.23%
No Collector Streets	- 10 mi/h to collector free flow speed and change collector street traffic control to alternating yield	- 1.92%
Local Street Traffic Control	All-way stop at all intersections	- 0.55%

Note:

1 - percentages listed are added to (negative values are subtracted from) the value obtained from Equation 2.

There is some debate in the literature as to the effectiveness of using all-way stop control to control speeds and discourage through traffic. In this study, all-way stop control reduced traffic volume only about 0.55 percent. This finding demonstrates that, within the limitations of this study, all-way stop control is not effective at altering driver behavior and therefore is not an effective neighborhood traffic management technique.

Sensitivity Analysis

Effect of Oversaturation at Arterial Intersections

The calibrated model was used to develop Figure 15 for undersaturated conditions and Figure 16 for oversaturated conditions. A comparison of these two figures suggests that higher cut-through volumes will occur for undersaturated conditions for the same signal density and speed. However, it should be remembered that travel speeds during oversaturated conditions tend to be considerably lower than those during undersaturated conditions. In fact, the data suggest that oversaturated conditions are associated with about a 6 mi/h speed drop for the same signal spacing.

It has long been known that oversaturation has a detrimental effect on arterial operations, and it is generally recognized that oversaturated arterials tend to aggravate cut-through problems. The results of this study indicate quantitatively that this problem can occur, and that oversaturated arterial intersections can increase cut-through traffic 10 to 15 percent above that due to other factors.

Even though Figure 16 shows curves for 0.0 and 10 percent cut-through traffic, the amount of cut-through traffic in oversaturated conditions was never found to be less than 12 percent. Therefore, a 12 percent cut-through is likely to represent a minimum value for oversaturated conditions. Also, travel speeds are likely to be limited to a maximum of 15 mi/h for oversaturated conditions.
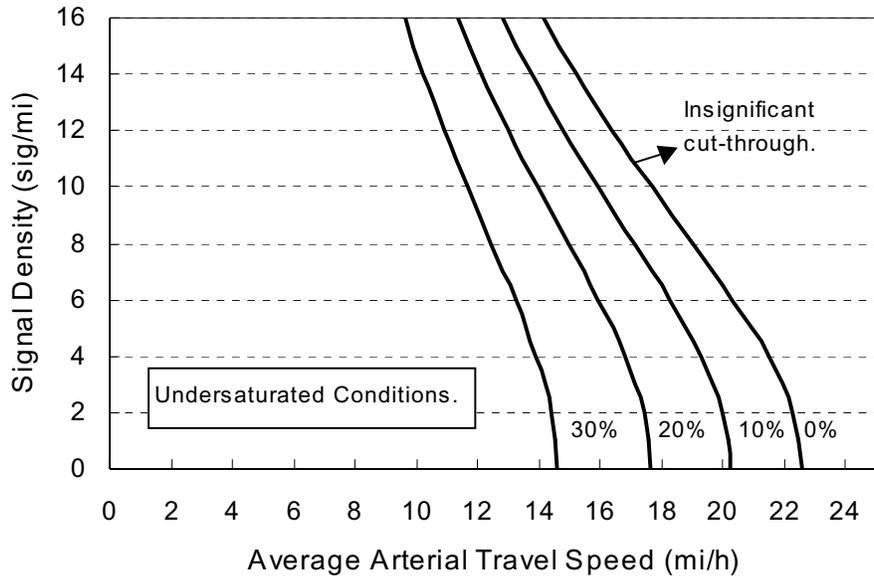
Figure 15. Predicted cut-through traffic percentage for undersaturated operating conditions.
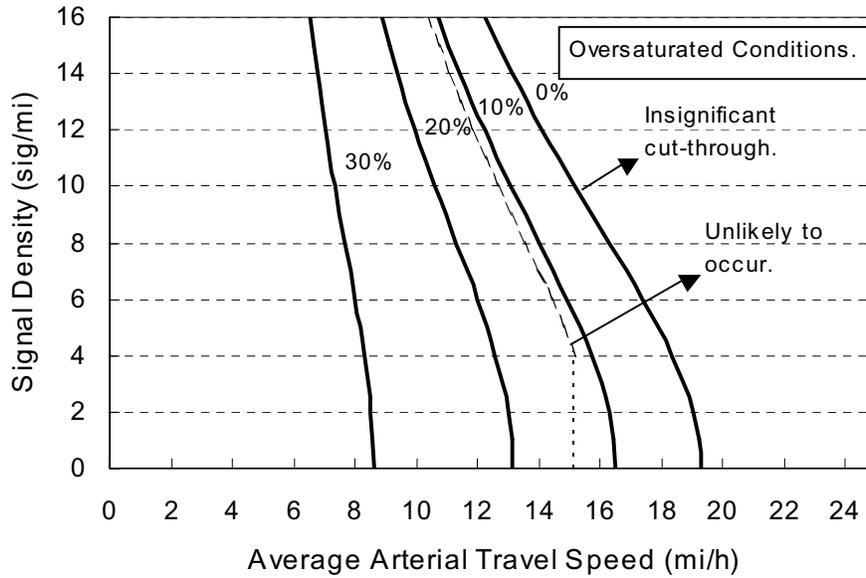
Figure 16. Predicted cut-through traffic percentage for oversaturated operating conditions.

Threshold Speed Associated with No Diversion

The 0.0-percent trend line in Figure 15 suggests that there is the possibility of a threshold arterial travel speed associated with no cut-through traffic. If arterial travel speed could be maintained at this threshold (or higher), cut-through traffic would essentially disappear. Although this speed varies with signal density, it is somewhere around the level of service C to D boundary, as defined in Chapter 11 of the *HCM* (*21*).

Example Applications

This section describes two example applications of the cut-through prediction model (i.e., Equation 2 combined with Table 13). The traffic signal density is determined from inspection of the street network. Average arterial travel speed can be determined using field measurements or estimated using the procedures in Chapter 11 of the *HCM*. Also, if a desired percentage of cut-through traffic is specified, the required average travel speed to yield this percentage can be found by solving for *V*. The following examples illustrate the usefulness of the cut-through prediction model.

Example 1

A neighborhood, shown in Figure 17, is surrounded by four, four-lane, Class III arterials. Each arterial has a free-flow speed of 35 mi/h. The entering arterial traffic volumes during the peak hour are also shown in the figure. The system is operating in an undersaturated condition. There is an average of 6 sig/mi on each arterial street, and the average arterial delay per signal is 15 s/veh. The engineer desires to estimate the cut-through volume that could be expected in the neighborhood.
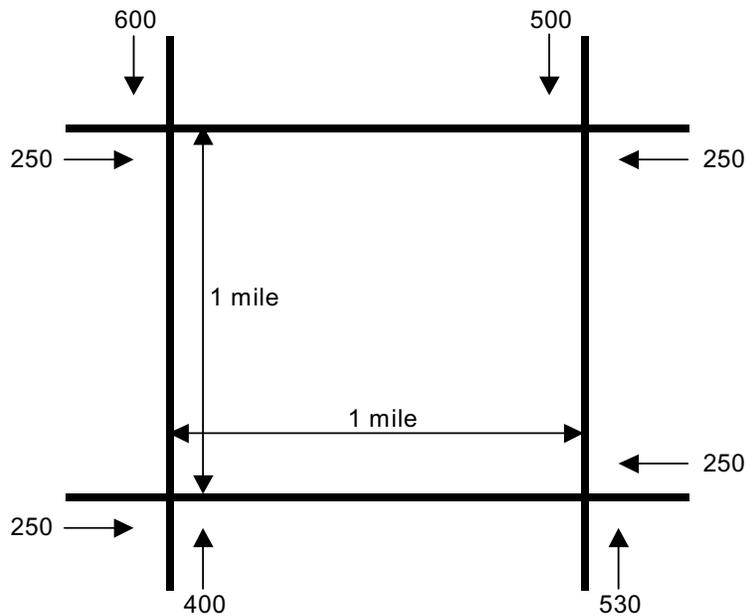
Figure 17. Street network and traffic volumes for Examples 1 and 2.

First, the average arterial travel speed must be determined. The *HCM*'s expression for average travel speed (i.e., Eq. 11-1) is used for this purpose. The form of the equation is:

$$V = \frac{3600 \cdot L}{\left[(RT \cdot L) + \sum d_i \right]} \tag{3}$$

where:
- $V =$ average arterial travel speed, mi/h;
- $L =$ length of study area, mi;
- $RT =$ running time per mile (from Table 11-4 of the *HCM* (*21*)), s/mi ; and
- $d_i =$ approach control delay at intersection i, s/veh.

At a free-flow speed of 35 mi/h and signal spacing of 0.17 mi, Table 11-4 of the *HCM* indicates that the running time for a Class III street would be 133 s/mi. Solving Equation 3 for V yields an average travel speed of 16.15 mi/h. Therefore, using Equation 1, with $V = 16.15$ mi/h, $S = 6$ sig/mi, and $D = 0$ (i.e., undersaturated):

$$\%CT = 51.42 - 0.101\,(16.15)^2 + 0.017\,(6)^2 - 13.95\,(0) - 0.00069\,(16.15 \cdot 6)^2 \tag{4}$$

$$\%CT = 19.2\%$$

From Figure 17, the total entering volume is 2,830 veh/h. Therefore, the total cut-through volume would be 544 veh/h (= 2830 * 0.192).

Example 2

Signal coordination improvements are planned for the network in Example 1. Thus, the traffic engineer desires to estimate the target average arterial delay per signal needed to eliminate cut-through traffic.

To determine the necessary delay per signal for 0.0% cut-through traffic, the average travel speed corresponding to this level of cut-through activity must be found. Because the total cut-through percentage, the signal density, and operating conditions (undersaturated) are known, it is possible to solve for the average arterial travel speed using Equation 2. The solution process is demonstrated in the following computations:

$$0 = 51.42 - 0.101\,V^2 + 0.017\,(6)^2 - 13.95\,(0) - 0.00069\,(V \cdot 6)^2$$

$$52.032 = 0.12584\,V^2 \tag{5}$$

$$V = 20.3 \text{ mi/h}$$

Substituting the travel speed of 20.3 mi/h (= 177 s/mi) in Equation 3 along with a running time of 133 s/mi (based on Table 11-4 of the *HCM*), yields a total approach control delay of 44 s/veh. Dividing this delay evenly among the six signals equates to an average approach delay of 7.4 s/veh.

Therefore, cut-through traffic can be eliminated by reducing the through delay at each intersection by about 7.6 s/veh (= 15 - 7.4), relative to the existing delay of 15 s/veh. Whether the signal timing could be modified to produce such low delays is doubtful as 15 s/veh is indicative of fairly good signal timing. The irony here is that the individual signalized intersection approaches are operating at a level of service "B" (based on the level of service definitions in Chapter 9 of the *HCM* (*21*)). However, the frequent occurrence of signals along the arterial results in a relatively "slow" trip for the through driver. The likely result of this frequent spacing will be considerable diversion through the adjacent neighborhood.

Chapter 5
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The objective of this research was to develop guidelines for the use of both Neighborhood Traffic Management and Corridor Traffic Management techniques for improving safety in residential neighborhoods. These guidelines were developed by synthesizing the available literature and supplementing this information with some focused research into the effect of arterial operation on neighborhood traffic volume. This section summarizes the guidelines developed from this research.

Neighborhood Traffic Management Techniques

Neighborhood traffic management techniques have been used successfully in many communities through the world. However, as indicated in this report, defensible data are available for only a few techniques. Based on an analysis of this data, typical volume, speed, and crash frequency reductions have been developed for three techniques. These reductions are listed in Table 14.

TABLE 14 Expected effectiveness of selected traffic calming devices

Traffic Calming Device	Expected Volume Reduction (%)[1]	Expected Speed Reduction (%)	Expected Crash Rate Reduction	Design Speed of Device
Speed humps	10 to 25	20	15 %	15-20 mi/h
Traffic circles	5 to 20	15	6 %	20-25 mi/h
Speed tables	5 to 15	15	4 %	25-30 mi/h

Note:
1 - The larger value listed is likely to be found when alternative routes exist.

Corridor Traffic Management Techniques

Traffic engineers have a wide range of corridor traffic management techniques to consider when attempting to improve neighborhood traffic conditions. These techniques include: signal timing adjustments, geometric adjustments, and access management techniques. Individually or in combination, these measures do a reasonably good job of improving arterial traffic conditions. Unfortunately, there appears to be no quantitative information reported in the literature about the effect of these improvements on the number of drivers diverting to local streets.

The model developed for this research represents a first attempt to provide a method to explain and predict neighborhood cut-through traffic based on arterial operating conditions. The model is represented by Equation 2 and the adjustment factors in Table 13. It has several promising features. First, it is relatively simple to use. Second, it is compatible with the analysis

procedures in Chapter 11 of the *HCM* (*21*). Third, it can provide some indication about the magnitude of traffic that will cut-through a neighborhood.

A sensitivity analysis of the model revealed that there is the possibility of a threshold arterial travel speed associated with no cut-through traffic. If arterial travel speed could be maintained at this threshold (or higher), cut-through traffic would essentially disappear. Although this speed varies with signal density, it is somewhere around the level of service C to D boundary, as defined in Chapter 11 of the *HCM* (*21*).   This boundary equates to an average arterial travel speed that is about 50 percent of the free-flow speed. Thus, when average speeds are one-half of the free-flow speed or less, drivers will likely cut-through the neighborhood adjacent to the arterial. The percentage of arterial drivers that cut-through will increase as the arterial travel speed decreases.

RECOMMENDATIONS

Several recommendations for future research in the area of traffic management techniques were developed for this research. Fundamentally, it is recommended that additional research be conducted on the effectiveness of alternative traffic management techniques. The existing body of knowledge is based on informal studies conducted by agency staff for the purpose of assessing the effect at a given street location. Such studies rarely record all of the relevant data or control for area-wide influences. The result is considerable variability in the reported effectiveness of any given technique.

Neighborhood Traffic Management Techniques

A wide range of neighborhood traffic management techniques are in use throughout the world. However, more data are needed to accurately quantify the effectiveness for most techniques. In addition, more precision in the study process is required. Specifically, the location of the technique relative to where measurements are taken and the period of time before and after measurement are essential to the evaluation of effectiveness. Recommended methods for quantifying this effectiveness for three measures are described in this section.

Volume Reduction

The amount of traffic volume on a given residential street is highly dependent on the capacity and orientation of the surrounding street network. The availability of alternative routes around a neighborhood can have as much of an impact on residential street volume as the type and spacing of traffic management techniques deployed in the neighborhood. Studies that quantify the level of volume reduction should also report the "connectivity" (i.e., number of street segments per intersection or cul-de-sac) or a similar measure that provides some indication of the availability of alternate routes.

Speed Reduction

The magnitude of speed reduction resulting a from a given technique depends primarily on its geometry (if it is a traffic calming device) and the spacing between it and other techniques. Device geometry (e.g., length and height of a speed hump) is highly correlated with the speeds at which motorists will cross the device. Spacing determines the extent to which motorists might speed up between the various techniques, if they are so inclined. Unfortunately, in many before-and-after studies of speed reduction techniques, it is unclear where speed measurements were taken in relation to the location of the technique. In many instances, drivers slow only in the vicinity of the technique and return to a desired speed at some point downstream of it. Studies that quantify speed reductions should also report: (1) the location of the measurement relative to the location of the technique, (2) the distance to other techniques, and (3) the geometry of the device, if a device is used.

Crash Reduction

Neighborhood traffic management techniques are often reported to reduce the number of crashes on treated residential streets. However, reported crash reductions must be evaluated cautiously because a technique's true impact on crash potential is often skewed by its effect on traffic volume. The observed crash frequency reduction associated with a given technique may be attributable to a corresponding reduction in traffic volume. In extreme cases, the roadway may be *less* safe after the technique is introduced, and yet crash frequency is reduced because of a reduction in volume. Studies that quantify crash reduction should include the measurement of traffic volume and use this data to compute the crash *rate* reduction. Crash rate is defined as the number of crashes per million vehicles.

Corridor Traffic Management Techniques

Literally volumes of material have been written on the subject of corridor traffic management during the last half century. Many of these reports describe various techniques or combinations of techniques and report on their effectiveness (or lack thereof) to improve arterial operations. However, a review of this information also indicates two problems. One problem is that it is very difficult to accurately extrapolate a technique's effectiveness (as observed at one location) to other locations. This problem stems from the wide range of variables that affect arterial operation and the likelihood that conditions will vary widely from one arterial to another.

Another problem is the lack of information on the effects of arterial improvements on the operation of adjacent local streets. Logically, there should be some connection between the operation of the two types of roadways. However, it is usually assumed that there are no operational problems on the local streets and that this operation will be unchanged by a change in arterial operation. In short, the effect of a change in arterial street operation on neighborhood street operation is currently unknown with the exception of the model developed for this research.

Further research efforts are necessary to verify the accuracy of the model developed for this research. Additional research is also needed to verify the findings associated with a sensitivity analysis of this model. This research should:

1. Verify the existence of a threshold travel speed above which there would be no cut-through traffic,
2. Expand the model to include sensitivities to a wider range of factors (e.g., size of the neighborhood, density and connectivity of the local street system, and application of specific route modification and calming devices), and
3. Validate the model using real-world data.

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APPENDIX

Neighborhood Traffic Management Techniques

NEIGHBORHOOD TRAFFIC MANAGEMENT TECHNIQUES

Route Modification Techniques

Full closures completely close the roadway to through traffic at one end or at a midblock location using diagonal diverters, cul-de-sacs, or signing. Key advantages include reducing traffic volume and the number of conflict points while still allowing bicycle and pedestrian access. Key disadvantages include restricting emergency vehicle and transit access, increasing trip length, and possibly being unsightly.
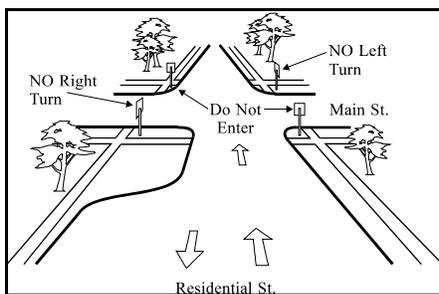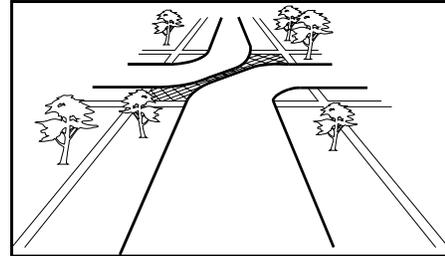
Half closures limit access to or from a roadway through the use of semi-diverters, median barriers, exclusion lanes, or forced-turn barriers. Key advantages are reducing through traffic, providing for bicyclists and pedestrians, and appearing attractive if landscaped. Key disadvantages are increasing emergency response time, less than 100 percent compliance, and additional maintenance requirements if landscaped.

Traffic Calming Techniques

Speed humps are raised areas in the roadway pavement perpendicular to the traffic flow. Key advantages are reducing speed, not affecting intersection operations, and being inexpensive to install. Key disadvantages are increasing emergency vehicle response times and possibly shifting traffic to parallel streets.
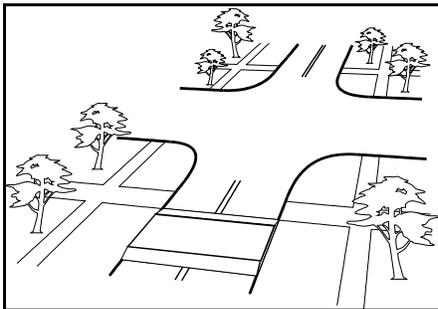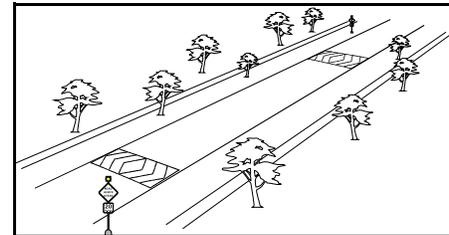
Speed tables are elevated plateaus in the roadway with descending ramps on each side. Raised intersections elevate the entire intersection above the normal roadway surface.

Speed cushions are smaller raised areas within a traffic lane. Key advantages of speed tables, raised intersections, and speed cushions are reducing speed, drawing attention to intersection and pedestrian areas, flexibility for use on higher or lower volume streets, and the potential to be aesthetically pleasing.
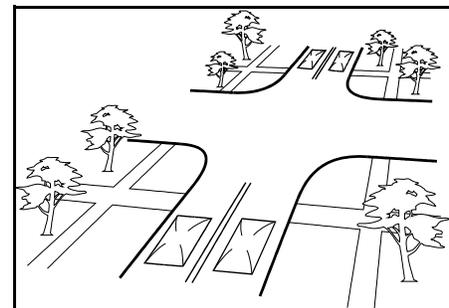
Key disadvantages are the expense to construct and maintain, the affect on emergency vehicle response times, and the additional signage and driver education required.

Traffic circles are small circular islands placed in the center of existing local intersections. Key advantages are reducing vehicle speeds, improving safety conditions, and the potential to be visually attractive when landscaped and maintained. Key disadvantages are adding a potential hazard to the middle of the roadway, increasing emergency vehicle response times, and impeding unfamiliar drivers, especially when making a left turn.
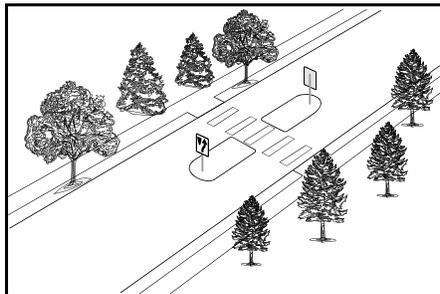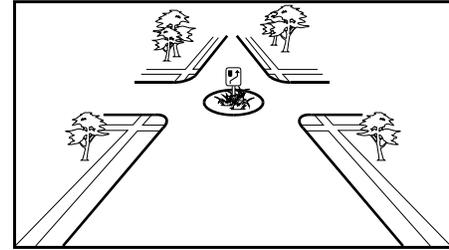
Central island narrowings are used in the center of the roadway to provide refuge to pedestrians during the crossing maneuver. Key advantages are creating a refuge so pedestrians can cross half the street at a time and making pedestrian crossings more visible to drivers. Key disadvantages include the potential to: give pedestrians a false sense of security, create potential crash obstacles for drivers, and create problems for street-sweeping or snow-plowing efforts.

Roundabouts are raised islands that create a circular one-way flow of traffic. Key advantages are reducing speeds, reducing the number of conflict points at the intersection, increasing capacity, providing an orderly and continuous flow of traffic, and being effective at multi-leg intersections. Key disadvantages are being restrictive for some larger emergency and service vehicles unless mountable, requiring pedestrians and bicyclists to adjust to less traditional crossing patterns, and causing some reduced aesthetic value due to safety signage.
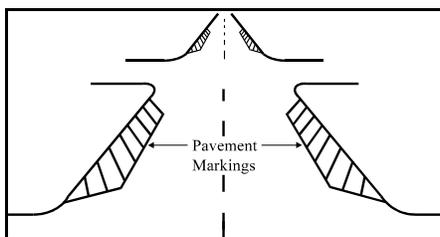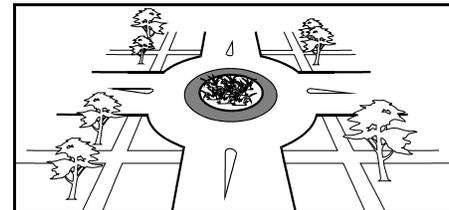
Roadway narrowing techniques narrow the roadway for a continuous length using geometric features, pavement markings, or landscaping. Key advantages are providing continuous, visual channelization, quick installation, and being inexpensive to install. Key disadvantages are requiring regular maintenance, increasing the cost of roadway resurfacing, and the potential to be expensive to install, depending upon the technique.

Chicanes are devices that alter the linear progression of a vehicle so that the driver must change paths to avoid the device. Key advantages are reducing speeds at the chicane
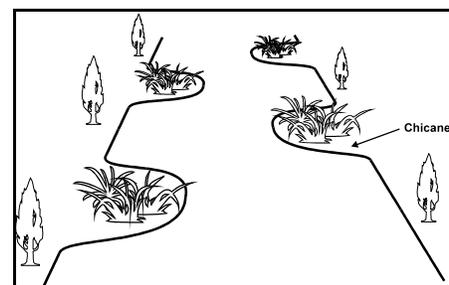
(or on the entire street length if installed in series) and reducing cut-through volumes. Key disadvantages are requiring high initial costs, restricting emergency and service vehicles, and creating potential crash obstacles for drivers.
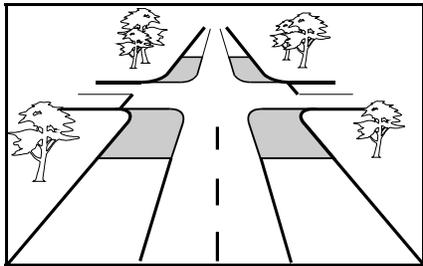
Neckdown
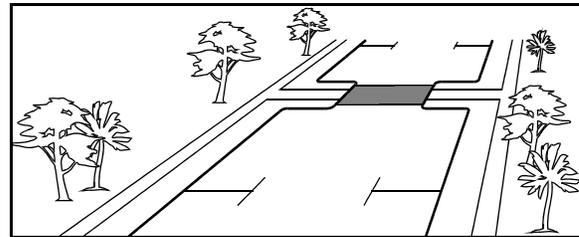
Choker

Neckdowns and chokers are constrictions of the roadway to reduce the width of the traveled path. Neckdowns are located at intersections, and chokers are located midblock. Key advantages are shortening the crossing time for pedestrians, making pedestrian crossings more visible to drivers, and not slowing emergency vehicles. Key disadvantages are that they may: require some parking removal, give pedestrians a false sense of security, and   create potential crash obstacles for drivers.

Regulatory Techniques

Speed trailers are mobile roadside devices that use a radar device to detect the speed of approaching vehicles. The devices display the speed limit and the speed of approaching vehicles. Key advantages are educating the public of posted and excessive speeds, serving as a good educational and public relations tool, and the ability to easily move them from one location to another. Key disadvantages are that they do not appear effective in reducing speeds after the trailer is removed, have limited effectiveness unless combined with enforcement, and have limited effectiveness on multi-lane roadways.

Speed limit signs display the speed limit established by law or by regulation. Speed limit pavement markings may be used to reinforce the message. Key advantages are that signs are well recognized and understood, pavement markings reinforce speed limit signs, and both are inexpensive to install. Key disadvantages are that speed limit signs have significant non-compliance rates, speed limit pavement markings are proven not to be effective, and speed limit pavement markings may cause concern regarding conspicuity and legibility.
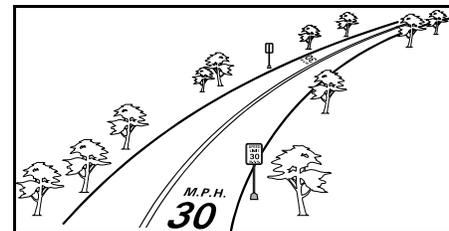
Increased enforcement (conventional) increases the use of conventional enforcement to reduce speeds in target areas. Key advantages are reducing

speeds during enforcement period, increasing driver awareness of speeding, and making response quick and effective. Key disadvantages are requiring regular long-term enforcement to gain long-term benefits and being costly for law enforcement agencies.

Citizen speed watch programs are public awareness programs involving residents, agency staff and motorists. Residents are trained to operate equipment to monitor and record vehicle speeds. Key advantages are serving as an effective public relations and educational tool, making neighbors feel that they are part of the solution for speeding problems, and the long-term effects that are possible due to resident interaction. Key disadvantages are that the programs are very labor intensive and that they are not an enforcement tool.
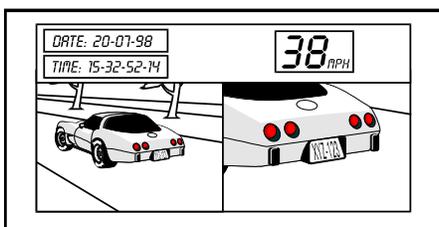
Automated enforcement uses a radar device, processing unit, and camera to record vehicle speeds and to photograph those vehicles exceeding the speed limit. Key advantages are detecting and recording information about a large number of speeders, providing enforcement in areas where roadway geometry makes it difficult for police officers, and targeting speeders objectively. Key disadvantages are allowing impaired or unsafe drivers to remain on the road (because no traffic stop is made), the possibility of being a less effective learning tool than if the violator were stopped and given a citation immediately, and not allowing an officer to give discretion for an emergency situation.
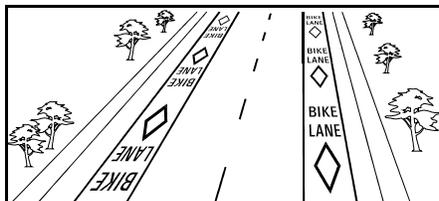
Bicycle lanes and paths are used to accommodate bicyclists. Techniques include shared lanes, bike lanes, bike paths, or bicycle routes. Key advantages are encouragement of non-motorist travel and a better defined area where bicyclists are expected to travel. A key disadvantage of bicycle lanes or paths is the potential to create additional conflicts between vehicles and bicycles.

Higher visibility crosswalks attract additional attention to pedestrian areas. Wider sidewalk areas provide additional pedestrian space and streetscaping space off of the roadway. Key advantages are that higher visibility crosswalks provide more visibility to drivers than standard crosswalks, and wider sidewalks provide additional space for pedestrians

and street furniture and can improve the aesthetics of the area. Key disadvantages are that higher visibility crosswalks may provide a false sense of security to pedestrians; they also require consideration of the effect of the materials on the vehicle tires. Both higher visibility crosswalks and wider sidewalk areas may require increased construction and maintenance costs.
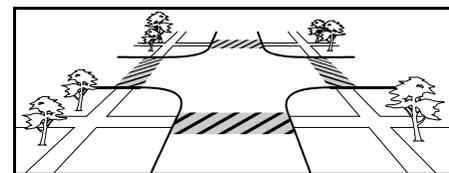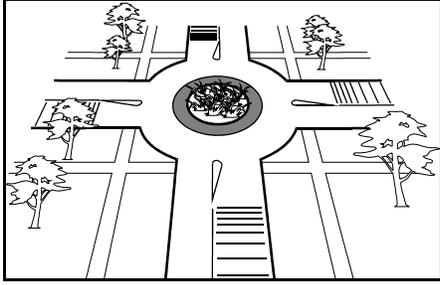
Innovative pavement markings are used to give drivers the illusion that are traveling faster than they really are. Key advantages are serving to reduce traffic speeds and crashes by warning or alerting drivers to an upcoming situation (by causing drivers to perceive that they are traveling too fast) and possibly giving drivers a heightened sense of awareness so they are better prepared to avoid a crash even if vehicle speeds are not reduced. Key disadvantages are the more research is needed to verify the use of these patterns along with the expense to maintain the complex marking patterns.