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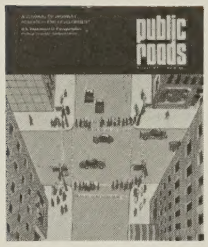

COVER:
Artist's conception of a signalized intersection.

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Traffic delays
" capacity
Traffic control - Intersections

Cohen, S. A.
Reilly, W. R.,
Motion pictures

Delay Measurement at Signalized Intersections

by S. L. Cohen and W. R. Reilly

get p. 82

In 1973, the Office of Research of the Federal Highway Administration (FHWA) was asked to undertake a study of intersection performance measurement. This request was made by FHWA's Office of Traffic Operations to find a substitute for the measure "load factor" which was used in the 1965 Highway Capacity Manual. *(1)*[1] Users of the 1965 Manual found load factor as a measure of performance to be unsatisfactory because it was not well defined for traffic actuated signals, for signals in a coordinated system, and for oversaturated conditions. One important requirement for a new measure of intersection performance was manual estimation of the measure in the field.

The study "Definition and Measurement of Delay at Intersections" has resulted in a precise definition of and manual measurement technique for intersection delay. The research product includes a user's manual expressly designed to assist traffic departments in the use of the measurement technique developed in the study.

[1] Italic numbers in parentheses identify references on page 84.

Introduction

In recent years, resistance to the construction of new traffic facilities has grown. Thus it has become increasingly important to improve the operating characteristics of existing facilities. In particular, it is important for local transportation officials to increase the capacity and improve the level of service of existing signalized intersections.

Chapter 6 of the 1965 Highway Capacity Manual is an important guide to analyzing the performance of signalized intersections. *(1)* It describes how the capacity of a signalized intersection should be calculated and defines the measure load factor for determining the level of service. Load factor on an approach to a signalized intersection can be defined as the ratio of the number of loaded green phases to the total number of green phases in a given period (usually 1 hour). A green phase is considered loaded if, during its entire duration, there is traffic in all lanes ready to enter the intersection and no excessively long vehicle headways occur. This measure of performance has several deficiencies:

- It is not applicable to actuated signals because an actuated signal which is properly timed should have load factors close to 1.0 regardless of the traffic volume beyond a certain minimum demand.
- It is an inadequate measure in cases where oversaturation occurs because load factor has a maximum value of 1.0 which is achieved at saturation.
- It is not a good measure of intersection performance in a coordinated signal system because in such a system, load factor can have a value of 0.0 for quite high values of the volume-to-capacity ratio, depending on the signal progression between adjacent intersections.

In response to these problems, FHWA's Office of Traffic Operations undertook a pilot study in 1973 to determine if vehicle delay could be substituted for load factor as a measure of level of service. This study, results of which have been published *(2)*, attempted to determine a definition of vehicle delay and a manual measurement technique for measuring vehicle delay. The study concluded that a major research study was needed to resolve these questions and problems.

In response to the findings of the pilot study and a request from the Office of Traffic Operations, FHWA's Office of Research awarded a contract to conduct a full-fledged research study on definitions of delay and vehicle delay measurement techniques.

Study Design

The research study consisted of six tasks:

1. Define delay types (for example, stopped delay).

2. Define and analyze possible measurement techniques.

3. Select 10 filming sites in 4 cities.

4. Film 50 minutes of peak and 50 minutes of offpeak traffic at each site.

5. Reduce delay data off the film; analyze data to determine the best delay measurement technique.

6. Perform a field study using the selected techniques at three intersections.

In Task 1, three delay types were identified, and the concept of an approach section was formulated. The following definitions resulted from Task 1:

Approach free-flow speed—The speed a vehicle would travel on an intersection approach if unimpeded by other vehicles or red signal indications.

Approach section—A segment of an intersection approach beginning at the stopline and extending back far enough so that vehicles entering it are moving at the approach free-flow speed.

Approach delay—The total time a vehicle spends in this approach section less the total time the vehicle would have spent in the approach section if it was unimpeded and able to move at the approach free-flow speed.

Time in queue delay—The total time a vehicle spends in the queue on an approach until it is discharged from the intersection at the stopline.

Stopped delay—The total time a vehicle is stopped on an approach (that is, has locked wheels).

In Task 2, it was found that measurement techniques could be categorized in four basic procedures (or combinations thereof):

Point sample—This technique is based on a periodic sample of some factor. An example is the Berry-VanTil procedure in which the number of stopped vehicles on an approach is noted and recorded at regular intervals (for example, every 15 seconds). *(3)*

Input-output—This technique is based on a factor being observed at both its beginning point (input) and its end point (output). An example would be counting vehicles joining a queue while simultaneously counting vehicles leaving a queue. *(4)*

Path-trace—In this method a vehicle is followed from the time it enters the approach section until it discharges from the section. All actions (for example, stop, start, cross stopline) and their time of occurrence are noted. This is similar to the floating car concept except that a stationary observer is used.

Modeling—In this method, a simple traffic model is used to supplement data gathering techniques. *(5)*

After a careful review of previous literature, it was decided to perform the following experiments:

- Use the point sample method to estimate both time in queue delay and stopped delay.
- Use the path-trace method to estimate approach delay, time in queue delay, and stopped delay.

This selection was based on a set of criteria developed from an analysis of each possible experiment. The criteria consisted of the following:

1. Field manpower requirements.

2. Simplicity of field procedure.

3. Data reduction manpower requirements.

4. Simplicity of data analysis.

5. Relationship of method to signal operations.

6. Requirement for establishment of a base speed/approach section.

7. Generalized application of procedure.

8. Effects of traffic control, demand, and geometry.

In Task 4, 10 intersection approaches in 4 metropolitan areas were filmed both in real-time using 16 mm film at 16 frames/second and in time-lapse using super-8 film at 1 frame/second (figs. 1 and 2). The 10 approaches represented a wide variety of geographic areas, intersection geometrics, traffic volumes, and signal control types.

In Task 5, data were reduced off of the films. The experiments described above were performed in real-time on the 16 mm film and the "true" values of the three delay types were reduced from the time-lapse super-8 film.

Figure 1.—Typical camera setup for filming the intersection approach.

Figure 2.—One of the intersection approaches.

The analysis of the reduced data (Task 6) indicated that the experiment showing the best overall result was the point sample method applied to stopped delay. It was found that the correlation coefficient between the manual and time-lapse results was 0.99 but that the manual method has an upward bias of 10 percent. The linear regression line for this result is shown in figure 3. A further finding of interest was that stopped delay and approach delay were highly correlated with a correlation coefficient 0.96. The linear regression line for this result is shown in figure 4. Based on this finding, one could estimate approach delay from measurement of stopped delay.

Figure 3.—Point sample estimate of stopped delay versus time-lapse estimate of stopped delay.

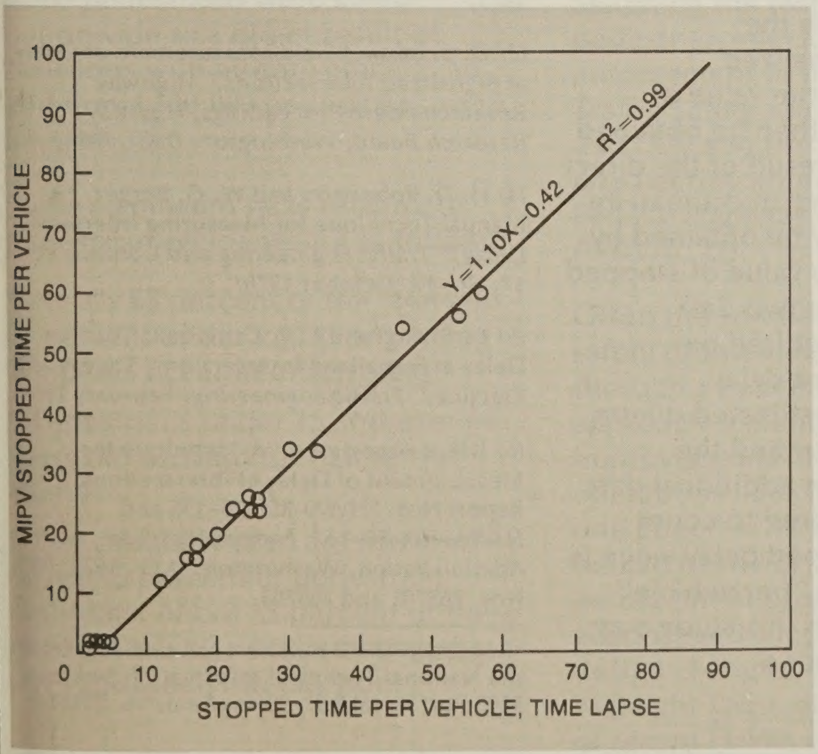

Figure 4.—Time-lapse estimates of approach delay versus time-lapse estimates of stopped delay.

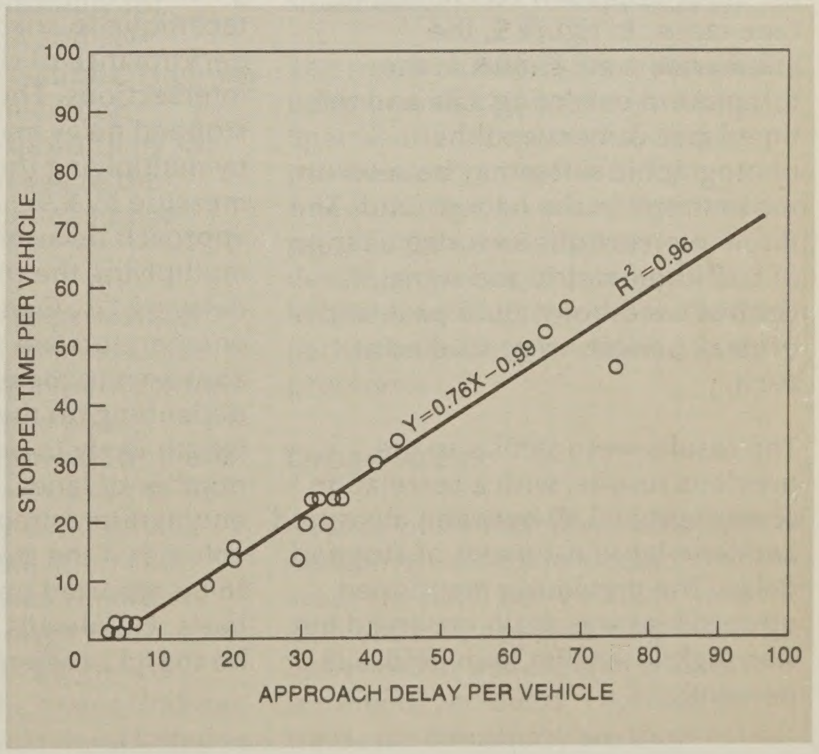

Figure 5.—Data enumerators at an intersection approach.

In Task 7, the point sample method was tested in the field at three intersection approaches in Tucson, Ariz. Observers were placed at the intersection to use the method while the study approach was filmed in time-lapse. In figure 5, the enumerators are shown in the foreground collecting data and the time-lapse camera and the photographic setup may be seen on the platform in the background. The three intersections included a range of traffic geometric and signal control conditions. Both peak and offpeak periods were studied at each.

The results were similar to the previous results, with a correlation coefficient of 0.99 between measured and time-lapse estimates of stopped delay. The previously mentioned upward bias was again observed but was slightly smaller than before (5 percent).

Conclusions

Based on the results of this study, the point sample method applied to stopped delay is recommended as a good manual measurement technique to analyze the performance of signalized intersections. The true value of stopped delay may then be obtained by multiplying the result of the direct measure by 0.92, and an estimate of approach delay may be obtained by multiplying the true value of stopped delay by 1.3. One or two data enumerators are required per approach to measure delay, depending on the estimated queue length likely to occur and the number of lanes. An additional data enumerator is required to count volumes if the stopped delay value is to be reported on a "per vehicle" basis. Full details on this study may be found in reference 6.

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Fegan, John C.
Pedestrians - Accidents
" - Safety programs
U.S. Federal Highway Administration

Major Engineering Approaches Toward Increasing Pedestrian Safety

by John C. Fegan

Introduction

Since 1971, pedestrians have accounted for 18 percent of annual highway fatalities. *(1)* [1] In many metropolitan areas, such as New York City and Washington, D.C., pedestrians have represented half of the total highway fatalities. In 1976, 8,300 pedestrians were killed nationwide as a direct result of collisions with motor vehicles; an additional 100,000 pedestrians were injured. *(1)*

Some significant facts relating to pedestrian accidents are as follows:

- Nearly 65 percent of the fatal and 85 percent of the injury-producing accidents occur in urban areas.
- Pedestrians under 15 and over 64 years old account for half of the fatalities.
- Preschool children are involved in nearly 15 percent of pedestrian accidents. About 55 percent of these children are hit while crossing the street between intersections.

What can be done to effectively address the dangers facing a pedestrian in his or her daily interactions with motor vehicles? Solutions are typically educational, enforcement-oriented, or engineering in approach. Highway Safety Standard Number 14 encourages this distinction by assigning the responsibility for pedestrian education and law enforcement to the National Highway Traffic Safety Administration (NHTSA) and the responsibility for engineering approaches to the Federal Highway Administration (FHWA). *(2)*

Often the solutions to pedestrian safety problems are accomplished through a combination of the three approaches mentioned above. Improvements in highways or traffic operations have been shown to be one effective means of modifying human behavior. Education and enforcement programs should support and supplement these design changes. This article will highlight some of the major findings of recent FHWA research included as part of Project 1E, "Safety of Pedestrians and Abutting Property Occupants," in FHWA's Federally Coordinated Program of Highway Research and Development (FCP). The thrust of the research is to provide engineering approaches to enhance pedestrian safety and to pinpoint specific countermeasures that may be useful in various highway, traffic, and pedestrian situations. p. 90.

The research efforts were directed at urban, rural, and suburban areas. Special attention was directed to problems of pedestrians on freeways. Finally, a model pedestrian program has recently been developed to serve as a guide to localities willing to address their own particular pedestrian safety problems.

Urban Areas

As previously indicated, a majority of pedestrian accidents occur in urban areas. To date, most studies have concentrated on observing the behaviors of pedestrians and drivers leading to accidents. Highway or traffic modifications are then instituted and these behaviors are again monitored. If there are

[1] Italic numbers in parentheses identify the references on page 90.

favorable changes in pedestrian/driver behavior, the modification is tentatively adopted. Subsequent accident studies are then required to conclusively demonstrate that accidents are being reduced as a result of the modifications.

In 1969, Snyder and Knoblauch studied over 2,000 pedestrian accidents in 13 large cities to determine the behavioral antecedent and socio-economic environments of different "types" of pedestrian accidents. *(3)* As a result of this investigation, eight accident "types" or classes were identified which accounted for over 55 percent of the pedestrian accidents studied:

1. Dart-out (first half)—A pedestrian, not in an intersection crosswalk, appears suddenly from the roadside. The quick appearance and short exposure to the driver are the critical factors.

2. Dart-out (second half)—This is the same as number 1, except the pedestrian covers half of a normal crossing before being struck.

3. Intersection dash—This category covers cases similar to 1 and 2, but the incident occurs in or near a marked or unmarked crosswalk at an intersection.

4. Vehicle turn/merge with attention conflict—The driver is turning into or merging with traffic; the situation is such that the driver attends to auto traffic in one direction and hits the pedestrian who is in a different direction from the driver's attention.

5. Pedestrian strikes vehicle—These are crashes not covered by other clear types in which the pedestrian ran or walked into the car.

6. Multiple threat—The pedestrian is struck by car X after other cars blocking the vision of car X stopped to avoid hitting the pedestrian.

7. Bus stop related—These include cases in which the location or design of the stop appears to be a major factor in the causation.

8. Vendor-ice cream truck—The pedestrian is struck going to or from a vendor's vehicle on the street.

Research was then initiated by FHWA in cooperation with NHTSA on nine countermeasures that offered promise of affecting these "types" of accidents. *(4)* The research indicated that six of the nine countermeasures tested affected behaviors associated with various accident "types" (fig. 1).

As previously indicated, longer term, carefully controlled *accident* investigation is required before conclusive statements may be made about the safety effectiveness of these or other countermeasures.

In urban areas, approximately one-fourth of all fatal pedestrian

ACCIDENT TYPES	Preventive Markings	Median Barrier	Crosswalk Set-Back	Midblock Crosswalk	Diagonal Parking	Meter Post Barriers	Stop Line Relocation	Vendor Warning Signal	Bus Stop Relocation
Dart-Out (First Half)		X			X	X			
Dart-Out (Second Half)		X		X					
Intersection Dash									
Vehicle Turn/Merge With Attention Conflict									
Pedestrian Strikes Vehicle		X							
Multiple Threat							X		
Bus Stop Related									X
Vendor-Ice Cream Truck									

(COUNTERMEASURES)

Figure 1.—Urban pedestrian accident types and countermeasures.

Figure 2.—Urban pedestrian traffic.

accidents occur at or near intersections. An investigation of safety and operational pedestrian problems at intersections was conducted. *(5)* By employing accident data, expert opinion, behavioral observations, and conceptual investigation, a list of problems associated with the interaction of pedestrians and vehicles at intersections was developed. The 30 problems identified were grouped into 4 major areas:

- Undesirable pedestrian and vehicle interactions.
- Undesirable pedestrian and/or driver behaviors.
- Undesirable intersection characteristics.
- Undesirable traffic control device characteristics.

Eleven possible countermeasures were developed to deal with these problems. Of this group of countermeasures, two were intensively evaluated:

- Improved signal timing.
- Improved pedestrian signal messages, color, and displays.

Investigations of improved signal timing resulted in guidelines in three areas: The minimum walk interval, the minimum clearance interval, and the allocation of excess pedestrian time. The standard 7-second minimum WALK interval is long enough to accommodate pedestrian queues at the majority of locations and under most conditions. Recommendations for either lengthening or shortening this interval were developed for specific site conditions. The minimum clearance interval depends on the number of pedestrians using the crosswalk (fig. 2). When peak hour pedestrian volumes exceed 15 per cycle on any crosswalk, a clearance interval based on a pedestrian walking speed of 1.1 m/sec instead of 1.2 m/sec should be considered. Similar attention to walking speed must be given to locations used heavily by elementary school children, the elderly, or the handicapped. With respect to excess pedestrian time, common practice has been to divide the pedestrian signal cycle in such a way that the minimum amount of time is allocated to the WALK phase and the remainder to the DONT WALK phase to minimize conflicts between pedestrians and vehicles. Because the pedestrians soon learn that extra time is allowed for the DONT WALK phase, serious consideration should be given to allocating extra time in the cycle to the WALK instead of the DONT WALK phase. This would encourage greater pedestrian compliance with the proper signals.

The second countermeasure investigated for urban intersections was pedestrian signal display and operations. Comparisons were made

Figure 3.—"Before/after" displays for signal study.

Figure 4.—Rural pedestrian traffic.

between words and symbolic messages to convey basic crossing information to pedestrians. The three symbolic pedestrian displays shown in figure 3 were field tested in two color sets (red-green and orange-white) in before/after studies in two cities. Pedestrian behavior, pedestrian compliance, and user understanding were the operational measures of effectiveness. The following conclusions were drawn from analysis of these field evaluations:

- The Hand-Walking Man symbol display is a significant improvement over the standard DONT WALK-WALK display.
- The Standing Man-Walking Man symbol display appears to be as effective as the DONT WALK-WALK display.
- The Circle Slash-Walking Man symbol is not as effective as the DONT WALK-WALK display.
- Even though pedestrians indicated a preference for red and green signal indication colors, compliance with orange and white was significantly higher.
- If symbolic pedestrian signals come into use, an educational program will be necessary for elementary school children.
- There is a clear need for further research to determine both the optimal clearance indication and the best means of alerting both drivers and pedestrians to turning vehicle conflicts. FHWA is planning to undertake such research in the near future.

Rural and Suburban Areas

Approximately 35 percent of the fatal and 15 percent of the injury-producing pedestrian accidents occur in non-urban areas. Following the approach taken in the urban area, pedestrian accidents were investigated by Knoblauch in a joint FHWA/NHTSA research effort to determine "types" or behavioral classes of non-urban accidents for which countermeasures could be developed. *(6)* A stratified random sample of 1,531 pedestrian accidents was investigated, and the 7 accident types that together accounted for 76 percent of the accident sample are listed below and in table 1.

The major types for rural pedestrian accidents were as follows:

1. Walking along roadway—This involves a pedestrian, usually 10 to 24 years old, walking along a two-lane roadway in a residential country location (fig. 4).

2. Dart-out (first half)—This typically involves a child running into a two-lane local residential street, not at an intersection, during the late afternoon.

3. Dart-out (second half)—Same as number 2 except the pedestrian successfully crosses the first half of the roadway before being hit.

4. Midblock dash—This typically involves a child running across a two-lane road midblock in a residential area.

5. Intersection dash—This typically involves a child running across the roadway at an intersection in a residential or commercial area.

6. Disabled vehicle related—This typically involves a young man working on or standing next to a disabled vehicle at night on a secondary or primary highway in an open, country location.

7. Other—This includes other unusual accident situations which were not one of the more specific accident types previously described, for example, pedestrian lying in roadway.

Analysis revealed that no single countermeasure is likely to have an impact on a high percentage of the rural and suburban pedestrian

Table 1.—Rural and suburban pedestrian accident types

Accident types and related behaviors	Percent of accident sample
Walking	12
Dart-out (first half)	11
Dart-out (second half)	10
Midblock dash	10
Intersection dash	10
Disabled vehicle related	6
Other (nonclassifiable)	17
Total	76

Table 2.—Countermeasures for rural and suburban pedestrian accidents

Countermeasures	Percent of projected accident reduction
Improve roadway markings	12
Provide sidewalks/paths	12
Improve roadway lighting	12
Improve pedestrian safety at nonsignalized intersections	9
Provide fenced play areas	8
Provide crosswalks	8

Table 3.—Countermeasures identified by accident type analysis

Countermeasures	Projected annual target number of pedestrian accidents
Median barriers:	
At interchanges	122
Between interchanges	48
Right-of-way fencing:	
At interchanges	42
Between interchanges	20
Motorist aid system	144
Hitchhiking regulation	88
Law enforcement personnel safety	36
Construction personnel safety	28
Total	528

accidents. Rather, specific countermeasures will have to be employed to treat specific accident situations. As a result of the accident typology development, countermeasures were identified and projections of their effectiveness were made. Table 2 presents this information for the countermeasures expected to affect 8 percent or more rural and suburban pedestrian accidents.

Freeways

Approximately 1,000 pedestrians are injured each year on freeways, but these injuries tend to be more serious and result in fatalities 3 times as often as pedestrian accidents

Figure 5.—A six-step cyclic process.

Figure 6.—Sample page—model pedestrian safety program.

SIDEWALKS	ADVANTAGES	DISADVANTAGES	TARGETS		IMPLEMENTATION CONSIDERATIONS
			PEOPLE	LOCATIONS	
PERMANENT SIDE-WALKS AND SIDE-WALKS IN GENERAL.	Reduce number of accidents in residential and business areas. Separate pedestrians from traffic. Provide safer and more easily traveled areas for the elderly and the handicapped. Separate pedestrian area from roadway. Provide paved places for children to play (vs. in the road). Often funded by property owners.	May give pedestrians a false sense of security. May require a complicated political process to get installed. Difficult for handicapped to negotiate curbs. Exposed to weather: Snow removal problems. Cracking caused by severe weather requires maintenance.	All pedestrians.	Locations where the roadway is not clearly delineated from the shoulder. School routes. Areas of retail, office, service, and institutional use. Areas with high pedestrian and vehicle volume. Locations with accidents involving pedestrians walking or standing in the road.	An overall planning strategy is necessary to determine policies on location of sidewalks, funding, and design. Legal restrictions must be considered and regulations enacted. Funding can come from assessment of property owners, city funds, or both. Locations for sidewalks can be determined through accident records, requests or complaints, or demonstration of apparent need. In designing sidewalks the following should be considered: —The needs of the elderly and handicapped. —1.2 to 1.5 m wide, uninterrupted, nonslip, smooth, low glare surface with curb cuts/ramps and careful placement of street furniture. —Pedestrian flow and level of service. —Topography. —Potential drainage, litter, and snow removal/storage problems. —Width should be at least 1.2 to 1.5 m; intensely used shopping areas need 4.6 to 9.1 m wide sidewalks.
SHOULDER IMPROVEMENTS.	Least expensive of the alternatives. Provides a multiple use facility. Conceivable for areas with low pedestrian volumes.	Pedestrians are not separated from traffic.	All pedestrians.	Locations with low pedestrian volumes, especially rural roads.	The road edge might be marked with a painted line to delineate areas for vehicle traffic from those for pedestrian use.
PATHWAYS.	Less expensive than permanent sidewalks.	Temporary. May need annual maintenance.	All pedestrians.	Locations with moderate pedestrian volumes.	May be separated from the road by curb and drainage facilities.

occurring elsewhere. Because such accidents occur on a freeway system of approximately 64 400 km, any countermeasure identification and development effort must carefully consider the implementation costs in relation to expected benefits. About 50 percent of the pedestrian accidents investigated probably can be prevented by using traditional pedestrian- or roadway-oriented engineering countermeasures. Table 3 indicates the projected annual total reduction in pedestrian accidents if the countermeasures were installed at all potential freeway sites and were 100 percent effective in producing the desired effect. *(6)*

In view of the expanse of the freeway system and the relatively low rate of pedestrian accidents per kilometre, the blanket application of any one countermeasure does not appear economically justified. Therefore, the countermeasures listed in table 3 should be considered only as spot treatments for very site-specific locations where there is a behavioral or accident history justification for their installation.

The Model Pedestrian Safety Program

Based on the research findings and operational practice, a six-step cyclic process has been developed which serves as a guide or model for communities to follow in addressing their own particular pedestrian problems (fig. 5).

Details of the process are presented in a user's manual which includes information on procedures to be followed, analyses to be conducted, and documentation to be developed. *(7)* Of particular interest is a series of charts describing the advantages, disadvantages, targets, and implementation considerations for each of 24 pedestrian safety improvement techniques. A sample page is shown in figure 6. A methodology is also presented to allow the local official a means of choosing among several alternatives when attempting to solve a particular pedestrian safety problem. Implementation guidelines and funding sources are also discussed. An informative brochure which discusses the need for and activities involved in developing and maintaining an effective pedestrian safety program has been prepared for decisionmakers. *(8)* Together, the user's manual and the brochure offer positive direction on what can be done to increase the safety of pedestrians in urban, suburban, rural, and freeway locations.

FHWA is currently planning further research on the safety of pedestrians. This work, scheduled to begin in fiscal year 1980, is designed to develop detailed guidelines for localities able to commit their resources to increasing pedestrian safety.

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[2] Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

Improving Urban Traffic Through Truck-Oriented Measures

by Paul Ross

Introduction

Although our knowledge of automobile traffic is imperfect in most respects, traffic engineering can show some significant accomplishments, and a "science" is beginning to develop. However, only the automobile component of traffic is well understood; the special problems of trucks and buses have not been studied as thoroughly as those of automobiles.

There are reasons for this neglect, with the most important being the question of priorities. "First things first" meant that the historical concern of traffic engineers was to understand the problems of traffic as a whole; when it has been possible to study the components of traffic, the major component—the automobile—has naturally received the major emphasis. Also, separate study of commercial traffic has often been considered unnecessary, because traffic changes which benefit automobiles generally benefit trucks and buses, too.

However, the effects and interests of commercial vehicles are not identical with those of automobiles, and the differences must be studied. The purpose of this article is to urge more interest in the effects of trucks on urban traffic and to locate the most promising returns on short range investments. The emphasis will be on short range improvements to urban traffic in general and not on improvements that specifically benefit goods vehicles. However, it appears that the changes designed to benefit traffic in general also decrease the overall cost of goods movement. Therefore, many of the proposals here are similar to proposals from planners and economists whose primary goal is to improve the goods movement system.

This article will consider only urban traffic, not traffic on rural roads and freeways. The effects of commercial vehicles on traffic on such roads are somewhat different from those considered here. "Commercial vehicle" and "truck" refer to any vehicle engaged in picking up, delivering, or transporting goods or services for other than private use. Pickup trucks and vans used for personal transportation are considered part of the automobile component of traffic.

Commodity Flow Versus Truck Operations

Urban goods movement seems to have two active subfields: *Commodity flow* and *truck operations.* Commodity flow studies generally concentrate on the shipment and transshipment of identifiably different types of goods. It is a broad category; for example, the determination of the optimum point at which to stop shipping energy in the form of coal and, instead, convert it into electricity for further transmission could be considered a commodity flow problem.

Commodity flow is fundamental—at least in the sense that it can be considered the "cause" of the other forms of goods transportation. For example, the flow of wastes "causes" garbage truck trips and the demand for fresh baked goods "causes" bakery truck trips.

Because commodity flow appears causal, the really fundamental changes that are desired in the goods movement system can most effectively be implemented through changes in commodity flow. The belief that such changes will considerably increase the efficiency of the goods movement system or, equivalently, lower the cost of goods delivery is implicit in many studies. *(1–8)*[1]

Unfortunately, there are no clear-cut results to support this belief. Commodity flow analysis has not had such conspicuous success as traffic engineering. Because of this lack of clear-cut results, there has been little financial support for the field—which, in turn, explains why very little data on commodity flows have been collected.[2]

Trucks represent the visible element of the various commodity flows in urban areas. It may seem that truck operation studies attack the symptoms without understanding the disease but, nevertheless, several studies have been completed and the symptoms have often been ameliorated. *(12–21)* The cities of Charlotte, N.C., Chicago, Ill., Dallas, Tex., and New York, N.Y., have adopted comprehensive truck regulations. *(16–17, 22–23)* In Chicago, for example, trucks are prohibited from the downtown loop area except for deliveries; large trucks (over 10 m) may not even make deliveries from the public right-of-way during the day.

Data are not yet complete but a general picture of the truck operations situation is emerging, and a program to improve it can be tentatively outlined. It appears that truck operations are highly constrained *(15)*, but concerted action to relax the constraints may be possible because the interests of private automobile owners and truck operators seem to coincide; more efficient truck operations will improve traffic flow. *(24)*

Trucks in the Moving Traffic Stream

When considering the effects of goods vehicles on the flow of traffic, two conditions should be identified: (1) Trucks in the moving traffic stream; and (2) trucks which are loading, unloading, or maneuvering in or out of loading spaces.

It appears that *moving* trucks are not substantial contributors to delay in most urban traffic systems. This is contrary to common opinion which is probably influenced by the high visibility of trucks, the unpleasantness of following them closely, and the severity of truck-caused delays when they do occur. Truck trips constitute about 15 percent of central business district (CBD) traffic, but they rarely make up more than 5 to 8 percent of the peak-hour, peak-direction traffic. *(23)* At peak periods, a large part of the commercial traffic is confined to industrial areas, side streets, or counterflow direction. This reflects the fact that commercial drivers can arrange their itineraries to avoid congestion better than the ordinary commuter. CBD daily cordon counts detect only about 10 to 12 percent trucks. *(16, 23)*[3] Truck traffic peaks after the morning and well before the evening rush hours. *(25)*

The above percentages for trucks, although accurate, are not as meaningful as they might appear to be. Truck counts normally include all the vehicles that can be called "trucks"; single unit trucks, semi-trailers, pickup trucks, and camping vans are all lumped together. Some of these "trucks" are actually being used as private vehicles and should not be classed as commercial traffic. Conversely, some of the "private automobiles" are actually used for commercial purposes—for example, small package and pharmaceutical delivery vehicles (fig. 1). The conclusions in this article are nonquantitative and do not depend on exact numbers; it is enough to note that commercial vehicles constitute only a moderate proportion of typical urban traffic.

An upper bound for the maximum possible time saving from any form of truck control in the moving traffic stream can be obtained. The maximum possible time saving to automobiles from controlling truck traffic is certainly less than the time saved if trucks could be totally eliminated from the traffic stream. If trucks constitute 8 percent of the traffic and volumes are half the street capacity, the disappearance of trucks would produce about 4 to 5 percent travel time savings on freeways and 2 to 3 percent on arterials, according to tables compiled by Levinson and Conrad. *(23)* When traffic is flowing at capacity, much more dramatic time savings are theoretically possible—24 to 28 percent on freeways and 26 to 41 percent on arterial streets—*provided that the trucks are not replaced by automobiles.* This large time savings is due to the fact that when a street is operating near capacity, the removal of any vehicles—even automobiles—has relatively more impact on traffic flow than under other conditions. However, in real, capacity-limited flow, there are always vehicles waiting to use the road which would immediately occupy the spaces relinquished by trucks. In

[1] Italic numbers in parentheses identify references on page 97.

[2] Some authors blame lack of results on the paucity of data. *(9–11)* It probably makes little difference which is the cause and which is the effect.

[3] Truck cordon counts are lower than the corresponding trip distribution, because trucks make more trips that do not cross the cordon lines than do passenger vehicles.

Figure 1.—Private automobile being used for commercial purposes.

capacity flow on level streets, the total elimination of truck traffic would produce only small improvements in traffic flow and travel time, but it would allow two or three automobiles to replace each truck and, thereby, somewhat shorten the rush period.

Appropriate rules for the control of moving trucks follow logically from these facts. On streets that operate at appreciably less than capacity, restrictions on moving trucks are not likely to produce significant improvements unless there are special circumstances, such as short turning radii, that affect trucks quite differently than they affect automobile traffic. On streets that operate near capacity, each truck will be replaced by several automobiles and the question becomes, "Which is more important—one truck or three cars?" Generally trucks that brave the rush hour do so because they are carrying cargo which has low tolerance for delay; restricting these trucks may have a disproportionately large adverse economic impact.

The above rather theoretical analysis is supported by several field studies which have also concluded that delay due to moving trucks in urban areas is not an important problem. *(13, 14, 26)*

There is no general reason for restricting the *movement* of trucks. Only in isolated circumstances, where trucks encounter unusual conditions (such as short, steep upgrades or restricted maneuvering space), are there *traffic-related* reasons to control truck movements. Truck routes have been considered and abandoned in London *(27)*, and no logical rules for them were discovered in a Canadian study. *(28)* Of course, there are many nontraffic-related reasons for controlling moving trucks. Truck routes may be established to preserve the character of certain neighborhoods or to protect streets with substandard pavement. Other legitimate reasons for restricting trucks include bridge weight limits, safety considerations, low underpasses, and steep grades.

Loading, Unloading, and Maneuvering

It is generally agreed that trucks have large impacts in CBD's and other areas where the incidence of curbside loading is great. *(29)* A poll of major city traffic engineers reveals that most of them believe that trucks are a problem only in CBD's. *(15, 30)* Trucks that are double parked (fig. 2), maneuvering into or out of loading spaces, or cruising to look for parking spaces are obvious offenders. Because of this interference, in some cities the slowest traffic speeds and greatest delays of the day occur between the traffic peaks, not during the time of heaviest flow as would be expected. *(13, 14, 31)* In contrast to the situation with moving trucks, appreciable improvements in traffic flow are likely if systematic changes can be made. In the area of loading and unloading operations, substantial traffic improvements can be made and research is likely to be most fruitful.

Long term improvements

Long term improvements—those that will require several years to several decades to implement and become effective—are the most effective changes that can be made in loading and unloading operations. Some of the most often proposed actions are as follows:

1. *Consolidated receiving.* If large commercial buildings will consolidate receiving and shipping operations for all

Figure 2.—Double parked mail truck causes through traffic to move to far left lane.

tenants, instead of having tenants handle their own pickups and deliveries, the truck drivers will avoid searching for individual receivers and shippers, and truck time in the loading zones will be reduced. This will increase the loading zone turnover and decrease double parking. *(19)*

Several methods for achieving consolidated receiving have been proposed; one of the most attractive is to impose a surcharge for individual deliveries. If trucking companies were required to collect surcharges for individual pickups and deliveries, financial pressure would be exerted on building tenants to pool their goods services. However, pressure on building tenants is a devious and inefficient way to force building owners to provide consolidated receiving. Optional surcharges would probably be even less effective because, in the highly competitive trucking industry, carriers would readily waive the fee. Required surcharges may be self-enforcing if competitors complain to the regulatory agency about violations. Municipalities might find surcharges to be an attractive way to raise revenue.

This proposal is justified only by plausibility; data for estimating the benefits do not exist. Such items as the number of separate deliveries and the time involved in each delivery are needed.

2. *Consolidated truck terminals.* In this concept, all goods destined for a given building or city block would be loaded into a single truck at a large suburban terminal. Consolidated terminals would also be used for the outbound flow; pickups would be made by a single truck and returned to the terminal where they would be sorted by destination or carrier. *(4)* Among other benefits, the number of trucks competing for a given curb space would be reduced (fig. 3). The carriers would presumably benefit by decreasing their handling costs while the general public would benefit from reduced traffic impact. However, practical experience with this concept has been discouraging so far: The Newark Freight Terminal of the Port of New York Authority was designed as a consolidated terminal but never actually operated as such due to institutional constraints *(32)*, and a Dallas study concluded that negligible benefits would be gained through this technique because many carriers are so large that they already operate terminals that are, in effect, consolidated. *(16)*

Although United States experience has been discouraging so far, Japan is showing considerable interest in freight consolidation. Intercity trucks are banned from urban areas so carriers are forming cooperative services to consolidate their pickup and delivery operations. The economic benefits realized have not been as great as predicted.

Figure 3.—This situation could possibly be alleviated by consolidated terminals.

3. *Improved vehicle design.* Commercial vehicles that could load and unload more rapidly and maneuver more easily in confined areas would obviously decrease traffic interference. The New York City Transportation Administration has proposed the construction and testing of a prototype vehicle.[4] United Parcel Service has evolved standards for their delivery trucks including such items as skylights in the truck body to provide illumination. Evolution will probably continue falteringly in this area.

4. *Offstreet loading.* One effective solution is the removal of the loading and unloading process from the public right-of-way (fig. 4). This can be implemented by zoning restrictions which require adequate offstreet loading facilities. Unfortunately, zoning regulations can only affect new construction; little can be done about existing buildings. Significant improvement cannot be expected in less than the 50- to 60-year lifespan of downtown buildings.

5. *Separation of function.* An ideal solution is to completely separate the goods delivery function from the traffic function. In Chicago, goods delivery was done at one time through a narrow gage railway tunnel that still exists in the loop area—although it is now unusable. *(32)* There are also limited truck tunnel systems in operation in Dallas, Tex., and New Haven, Conn. *(16)* Such solutions are so capital intensive that it is unlikely that they will ever be significant except where existing facilities can be converted.

[4] "A Proposal for an Urban Truck Research and Demonstration Proje[ct] in New York City," by New York City Transportation Administration[.] Unsolicited proposal submitted to U.S. Department of Transportation, May 1975.

Figure 4.—If offstreet loading were implemented, trucks would not hinder traffic by parking on the curb.

6. *More effective enforcement of parking and loading restrictions.* Traffic problems would certainly be alleviated if the parking and loading restrictions already in force were better observed (fig. 5). Some of this problem stems from violations by private autos—such as parking in loading zones—and, short of a radical change in public attitude, can only be solved by spending money for more policemen.

The remainder of the enforcement problem stems from violations by truckers. In many Eastern United States cities, a common attitude is that traffic obstructions must be endured for expeditious goods movement. Policemen are often reluctant to ticket drivers whom they regard as doing their jobs as well as they can under difficult circumstances, and many carriers pay fines for standing violations without question. This attitude even extends to State legislatures; in Massachusetts, for example, trucks may double or even triple park to make pickups and deliveries or service calls.

Such attitudes are less common and enforcement is more vigorous in western cities where streets are wider and loading facilities are more adequate. One might speculate that improved enforcement and observance follow improved facilities.

Short term improvements

Short term improvements should concentrate on eliminating double parking and reducing interference due to trucks entering and leaving curbside spaces. Although these measures should include a prohibition against double parking, such a prohibition alone is unlikely to be effective unless an adequate supply of curbside space is available, because it is the tacit policy of many carriers to pay fines for standing violations rather than experience the delay inherent in the use of remote loading zones. There is also a security problem inherent in leaving a truck unattended for appreciable periods while walking to the destination. *(23, 33)* For these reasons the effective "search pattern" of most delivery trucks extends only 30 m from their destination—at least, this was the distance observed in Brooklyn, N.Y. *(15)*

Moving loading zones from arterials to side streets is a superficially attractive solution. This would move the conflict from the heavy traffic stream to where the traffic impacts are much less. Unfortunately, truckers are generally very reluctant to use loading zones that are distant from the delivery point, especially because loading zones that are out of sight of the destination

Figure 5.—Example of regulatory signing.

present severe security problems.[5] Experiments with such side street loading should certainly be tried where they appear feasible, but poor compliance should be expected unless the relocation is accompanied by vigorous enforcement measures.

Off-hours or night delivery is another class of superficially attractive solutions that is likely to be ineffective unless very carefully implemented. The basic difficulty is that off-hours delivery provides a public benefit at a private expense; that is, the general public would undoubtedly benefit from improved traffic flow but the expenses would be borne by the carriers and businesses that would be required to provide night receiving and shipping service. An experimental program in London, "Operation Moondrop," failed for exactly this reason. *(35, 36)* Incentives, such as subsidized service, could equalize the incurred expenses. In the United States there are institutional constraints which will inhibit such an experiment—principally the fact that many contracts require double time pay for work before 8 a.m. or after 6 p.m. It may be worthwhile to see if these constraints can be relaxed.

Research Opportunities

In view of the foregoing, there are several areas where research appears to have a high potential for improving traffic conditions by controlling trucks without spending large amounts of capital. The Federal Highway Administration has instituted a major research project on Metropolitan Multimodal Traffic Management which is investigating large, areawide traffic analysis and control measures. *(37)* Within the project, the analysis of truck effects constitutes a major part of one of the tasks, Strategy Development and Testing. Five specific areas have been identified for study:

1. To understand the operations of trucks at curbside and decrease their impact, accurate data and models of the process are needed. Particularly important are well calibrated models that will be able to predict the traffic impact of changes in the system. For example, how much would traffic benefit if curb cuts were made to facilitate the movement of hand carts? Where should these curb cuts be made? Virtually nothing is presently known about the *details* of the loading/unloading process. It is important to examine all of its components so that the good and bad effects of altering one component can be predicted.

2. It is clear that turnover in loading zones would be increased if consolidated receiving were commonly practiced. Increased turnover has a beneficial traffic impact because it decreases the double parking and queueing for loading space. What measures would be most effective for the city in encouraging consolidated receiving operations? Should tariffs be adjusted to favor this kind of operation? This kind of proposal highlights the need for accurate and detailed models of the truck loading and unloading process; such models could be used to predict the decrease in delivery times resulting from consolidated receiving and shipping and the consequent increase in loading zone turnover.

3. One way to reduce the traffic impacts of trucks is to get them to operate at night, or at least during offpeak hours. There has been no research in the United States to see what would be required to get such a program started. Of course there are many obstructions to such a program, but the benefits to be gained are so great that its feasibility deserves careful study; the Federal Highway Administration has such a study underway.

4. Although truck routes are usually chosen for environmental rather than traffic reasons, they should be rationally and consistently chosen. Because very little is known about systematic truck routing, there is considerable need for such research. What reasons are there for truck routes? Where should they be located for the greatest efficiency and the greatest economic benefit? What *is* the current practice throughout the United States with respect to locating truck routes?

5. Because trucks have different acceleration capability from passenger automobiles, the presence of trucks that have to stop and start at signals in traffic streams considerably degrades the local traffic performance. In certain situations, it might be advisable to extend a green display rather than stop a truck. Detectors for this purpose should be easy to produce by modifying bus detectors which have already been developed. More important than the hardware development are other questions: What are the exact effects of trucks in this situation? How much improvement can be expected if trucks are favored by the signals? What is the most effective strategy?

[5]Break-in damage to unattended trucks is so prevalent in New York City that at least one carrier has considered making deliveries from Army surplus Patton Tanks. *(34)*

Summary

This article has discussed the state of the art of what is known about the effects of trucks on urban traffic. It appears that congestion due to trucks loading and unloading at curbside in CBD's is the most severe impact. However, the details of the loading/unloading process are almost unknown, as are most of the other details of the impacts of trucks on traffic. Several areas of research to be investigated under the Metropolitan Multimodal Traffic Management project were outlined.

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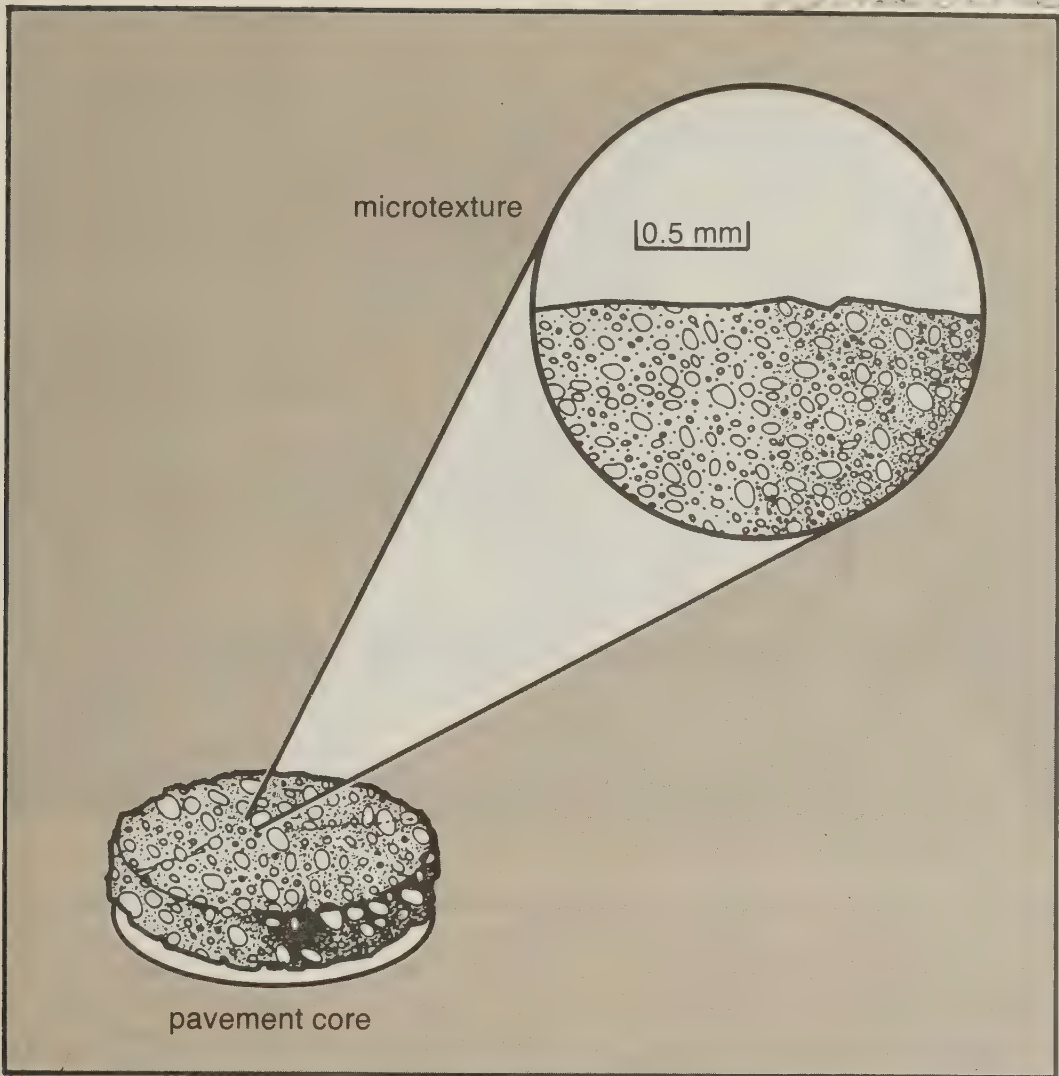
Kenneth C. Clear Receives Award

Mr. Kenneth C. Clear was the recipient of the award in the first annual outstanding paper competition held among the employees of the Federal Highway Administration's (FHWA) Offices of Research and Development. This award covers the documentation of any technical accomplishment which may take the form of a publication, technical paper, report, or package; an innovative engineering concept; instrumentation systems; test procedure; new specification; mathematical model; or unique computer programing. Each eligible candidate is judged on the basis of excellence, creativity, and contribution to the highway community, general public, and the FHWA.

Mr. Clear, a highway research engineer in the Materials Division, Office of Research, received the award for his research report on "Time-To-Corrosion of Reinforcing Steel in Concrete Slabs."



Automated Aggregate Microtexture Measurement: Description and Procedures

by Stephen W. Forster

Introduction

The safety of highway travel is dependent on the nature of the interface between the vehicle and the highway pavement. The characteristics of this tire-pavement interface are constantly being scrutinized in order to provide adequate wet weather skid resistance through changes in tires and pavements. Optimum pavement surface properties can be achieved only by careful selection of the pavement materials. This is true because aggregate type and gradation, binder properties, and wear and polish resistance are diverse. The problem is compounded by the difficulty in measuring and quantifying the profile of the pavement surface with which the tire comes in contact.

Over the years, numerous devices and procedures have been developed to measure a pavement's skid resistance or its texture, on which skid resistance depends. *(1)*[1] A pavement must have both macrotexture and microtexture to maintain adequate skid resistance during high-speed, wet weather conditions. *(2)* The macrotexture (coarse asperities) provides relief

[1] Italic numbers in parentheses identify the references on page 104.

channels for the rapid expulsion of water at the tire-pavement interface. The microtexture, on the other hand, provides the harshness or grittiness needed to penetrate the water film and develop frictional forces with the rubber tire.

In fiscal year 1976, the Federal Highway Administration (FHWA), Office of Research, Materials Division, formulated a staff study to evaluate the microtexture of aggregates in relation to pavement frictional characteristics. In order to better quantify the microtexture and to correlate it with friction measurements, a device was needed to more completely measure and characterize microtexture. The equipment described in this article was especially obtained for this purpose.

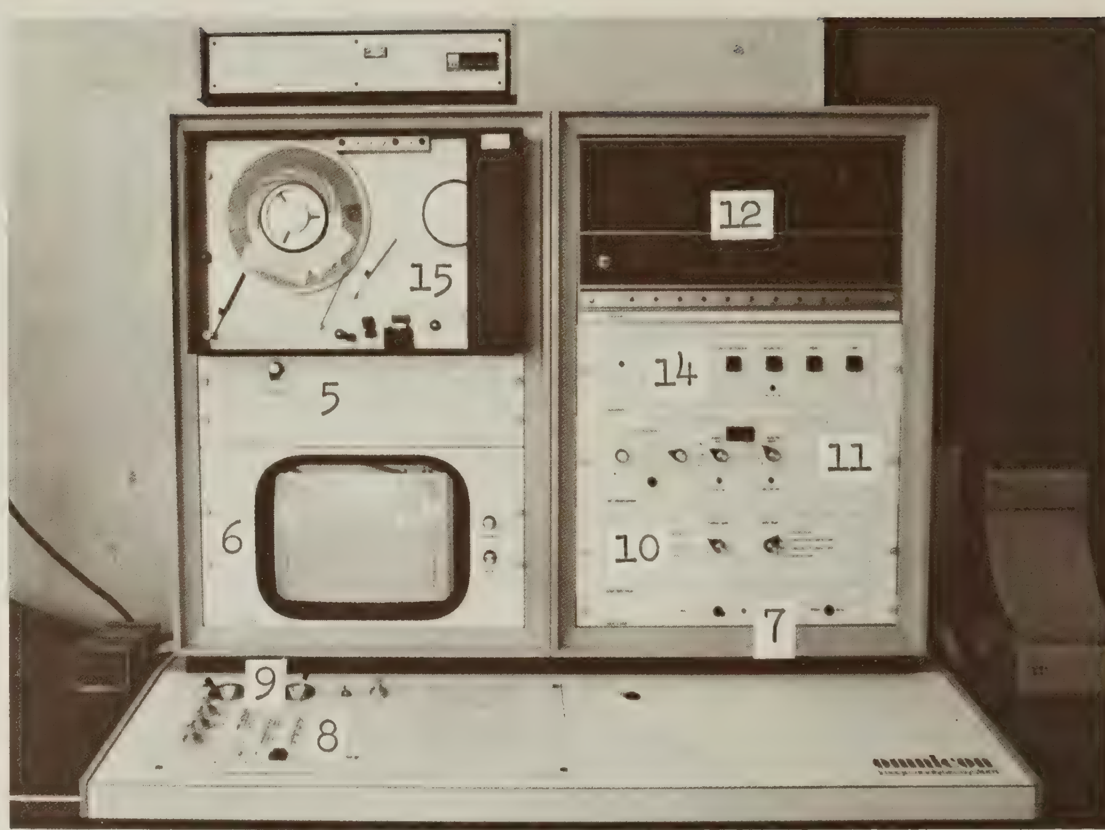
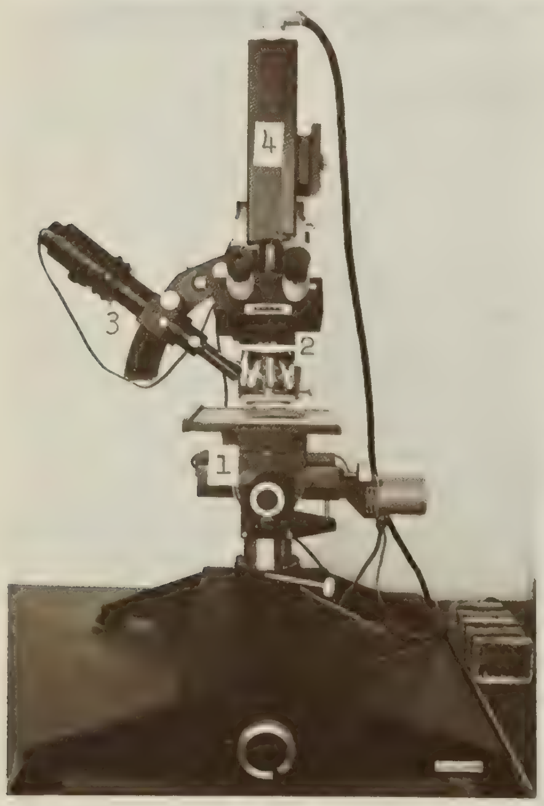


Figure 2.—Main console of the image analysis system.

Equipment Description

In 1977, FHWA sponsored the development of an automated device for aggregate surface texture measurement (figs. 1, 2, and 3). The device consists of the major components listed below; a block diagram showing the interaction of the components is shown in figure 4.

Figure 1.—Microscope portion of the image analysis system.



- A special microscope stage (1)[2] was designed to support the large samples to be examined. The stage can move far enough in the x and y directions to examine an area of up to 7 700 mm^2.
- A Balplan binocular microscope head (2) with objectives of 2.5X, 4X, 10X, and 20X for viewing the specimens is mounted over the stage. Also attached to the microscope stand is the light source (3) for the sample which can project a straight line dark field/light field boundary on the surface of the sample to produce a profile.
- An image scanner (4), similar to a TV camera, is mounted above the microscope. It can be focused through the microscope's lens system or can scan the sample directly for viewing large areas. Its sensitivity is set on the scanner control module (5) according to the level of difficulty in detecting the desired features.
- The display or TV monitor (6) shows the area being scanned. Superimposed on the image are various numerical displays resulting from the analysis.
- The basic module (7) supplies power to the other parts of the system; converts the information from the scanner into the image on the monitor; generates the numeric displays on the monitor; and produces the fixed or variable frame on the monitor, which determines the portion of the image that is measured.
- The console controls (8) are used for feature selection and detection.

[2] Numbers in parentheses refer to the numbers shown on figures 1, 2, and 3.

Figure 3.—Teletype used by the operator to communicate with the system's processor.

The size and location of the variable frame is controlled by means of two joysticks (9). Detection of the features is also controlled from here. Detection is based on the features' gray level (on a scale from white to black) or on their contrast with the background. Detected features may be either outlined or filled in (in bright white) on the screen for easy visibility. Counts and measurements are also initiated here when the equipment is operated in the manual mode.

- The entire field count module (10) counts the selected features in the image. Counts that can be made include feature count, lower negative tangent count, and lower positive tangent count. These measurements can be made on an individual field or multifield basis.
- The size measurement module (11) performs the desired measurements on detected features including total area, average area, total projected length (features projected on the "y" axis), average projected length, percent area, and oversize count.
- The processor (12) is a minicomputer which controls the operation of the system. In the automatic mode, it collects and formats the output, controls the microscope stage, interacts with the operator through the teletype terminal, and interfaces with the magnetic tape deck from which programs are fed to the processor. It has a memory of 16,000 16-bit words.
- The keyboard terminal (13) is used both to communicate with the processor during automatic operation and to print output resulting from automatic measurements.
- The automatic module (14) functions as an interface between the processor and the rest of the system. It drives the microscope stage and controls the sequence in which measurements are made in the automatic mode.
- The magnetic tape deck (15) is used to load programs into the computer and to store data from measurements as required.

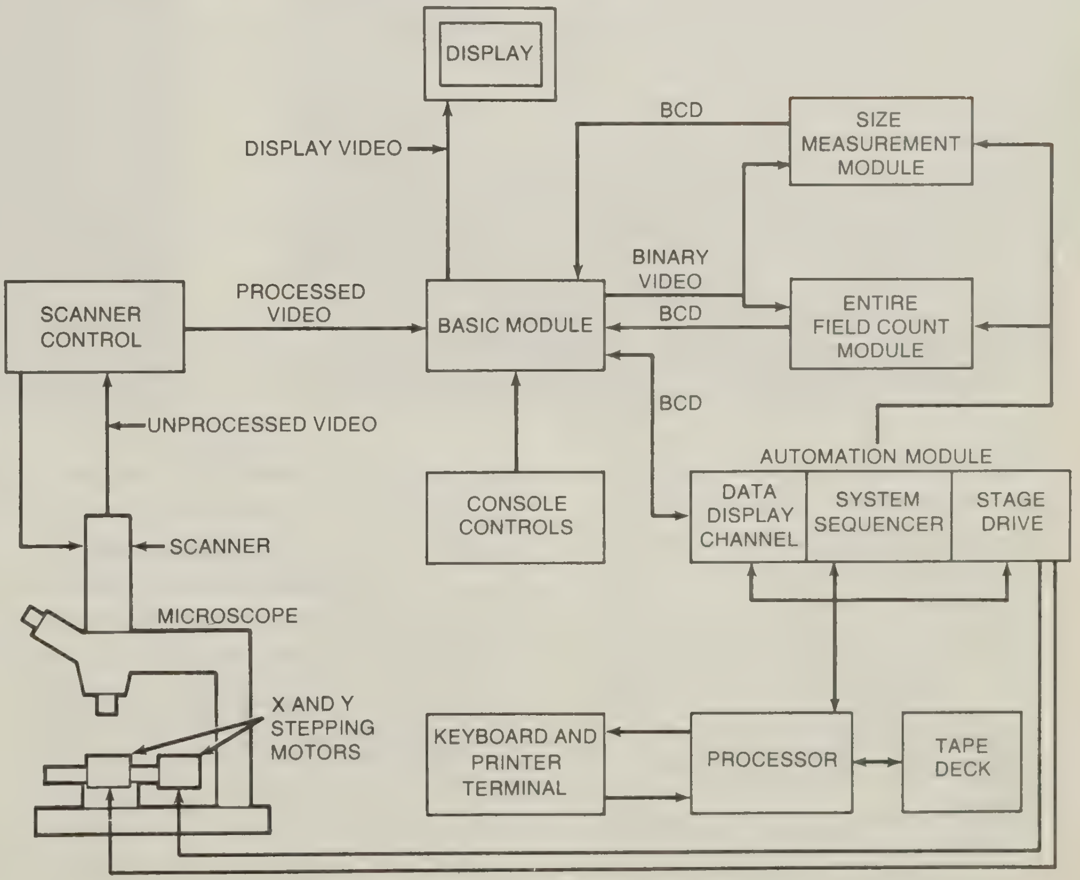
Texture Measuring Procedure

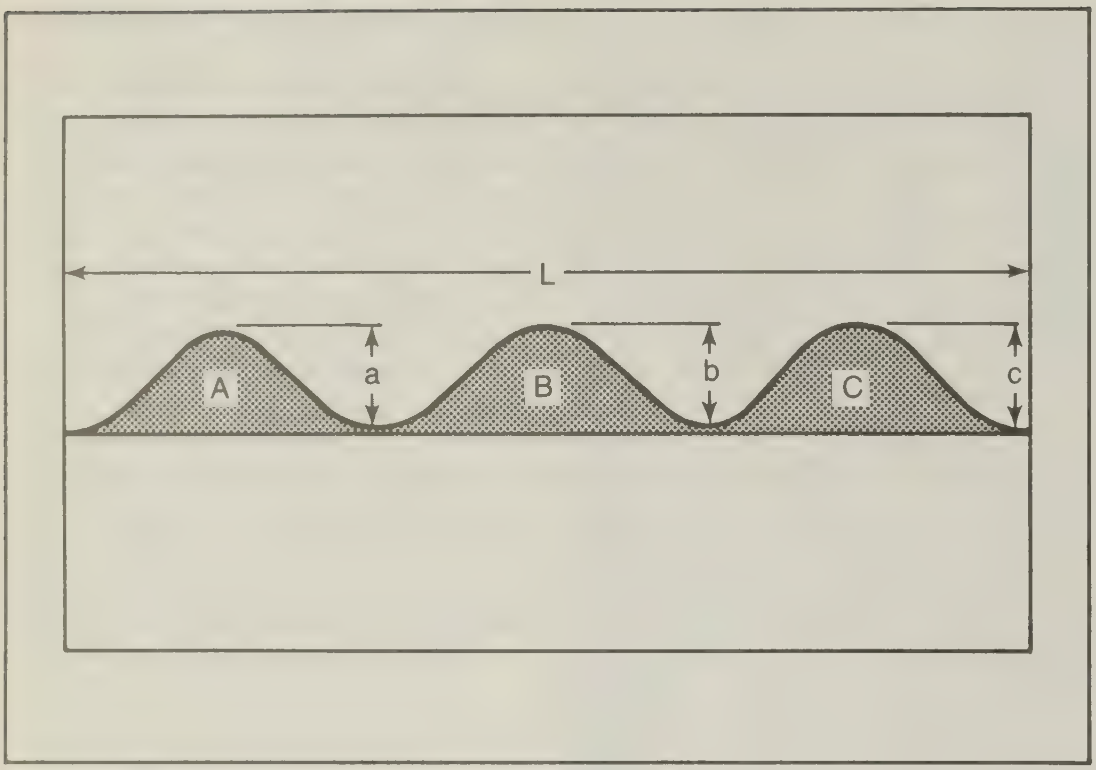
The programs used in this study to measure textural features are constantly being upgraded and revised as simpler and more accurate methods of measurement are found. Currently, three measurements are being made on each aggregate sample: Density of microasperities (peaks) on the surface, average height of the asperities, and a shape factor for the asperities—the ratio of the average height to the average width of the asperities (fig. 5).

Samples being measured at this time are British wheel specimens,[3] which consist of coarse aggregate particles

[3]These specimens were used in determining the polish susceptibility of aggregates; see ASTM D3319–74T, "Accelerated Polishing of Aggregates Using the British Wheel." *(3)*

Figure 4.—Block diagram of the image analysis system.





$$\text{Average asperity density} = \frac{\text{count of peaks}}{\text{length of profile}} = \frac{3}{L}$$

$$\text{Average asperity height} = \frac{\sum \text{heights}}{\text{count}} = \frac{a + b + c}{3}$$

$$\text{Average shape factor} = \frac{\text{average height}}{\text{average width}} = \frac{\frac{a + b + c}{3}}{\frac{L}{3}}$$

Figure 5.—Definitions of texture measurements currently being used.

embedded in an epoxy mortar (fig. 6). The measurements are being made on the row or rows of aggregate pieces along the centerline of the specimen where constant contact with the tire of the British wheel apparatus is assured during the test run (fig. 7).

An actual measurement would proceed as follows:

1. Adjust the light source and scanner sensitivity on optimal settings.

2. Place the standard calibration slide (fig. 8) supplied with the equipment on the stage and focus.

3. Calibrate the equipment by entering the known area of the feature on the slide using a program supplied. The "calibration factor" that is determined is then stored in the processor for future reference as measurements are made.

4. Position the sample on the stage, and focus the image.

5. Enter the program for texture measurement into the computer. This program interacts with the operator by requesting sample information, such as type, source, and date taken. Before the measurements begin, the number of fields of view to be measured and the amount of microscope stage travel between each field are also entered. For this program, a sharp straightedge is positioned halfway across the path of illumination to divide the field of view into a dark half and a light half. The straight line of demarcation between light and dark areas becomes a profile that indicates the true sample profile (fig. 9). The program includes a correction factor for the angle of the illumination from the horizontal to equilibriate the measurements of the profile, as seen from above, with the true dimensions of the sample's vertical profile.

6. Take the measurements after the stage movement information is inserted. Currently, on British wheel coupons, seven 2.5 mm profiles are measured on each chosen aggregate piece (usually five pieces per coupon). The asperity density, average height, and average shape factor measurements are made on the full-length profile.

7. Print the final results via the teletype in terms of averages for the measurements made on a sample. Asperity density is given in peaks/micrometre, asperity height is given in micrometres, and the shape factor is unitless (the relation of height to width).

Test Results

Repeated measurements have shown that the results using the current procedure are reproducible for a given sample. The question now being addressed is how closely changes in these measurements relate to changes in the pavement

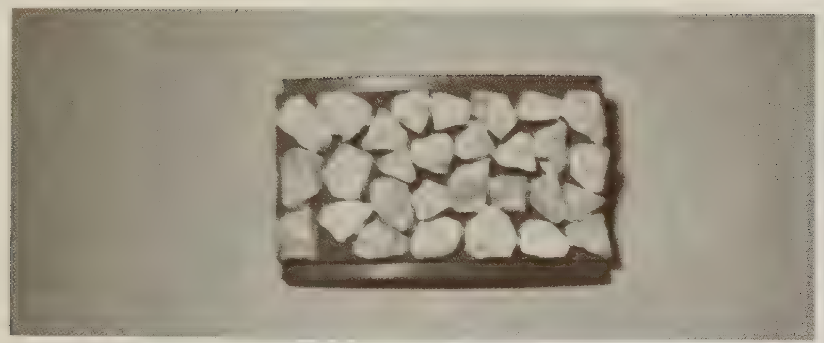
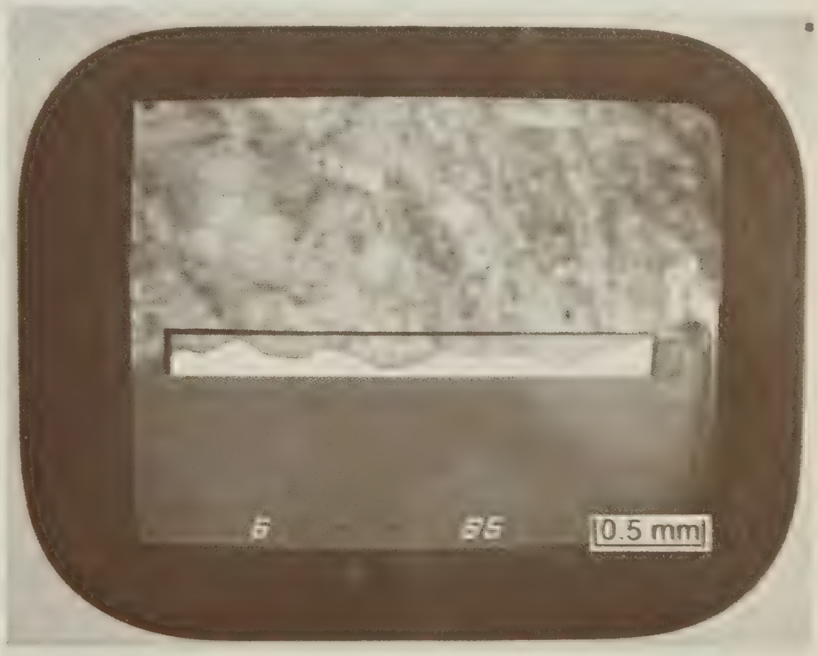


Figure 6.—A sample used on the British wheel apparatus for testing aggregate polishing.

Figure 7.—The British wheel apparatus used for testing aggregate polish susceptibility.

Figure 8.—The calibration slide as viewed on the monitor screen.

Figure 9.—A profile generated from an aggregate particle in a British wheel specimen.



surface's frictional characteristics. To this end, samples are being examined from two studies of specialized aggregate beneficiation being conducted for FHWA by Brookhaven National Laboratory and the U.S. Bureau of Mines. The Brookhaven study deals with improving wear-resistant properties of aggregates by impregnation with various polymers, and the Bureau of Mines is investigating ceramic processes for production of wear-resistant and polish-resistant aggregates. Both of these research efforts include the preparation and testing of British wheel coupons. These samples will be examined for microtexture before and after being run on the British wheel in an attempt to correlate observed changes in microtexture with changes in friction measurements.

Preliminary examination for correlations between the Polish Values (P.V.'s) obtained with the British Portable Tester and the microtexture measurements have been made. On the basis of 40 specimens, the P.V.'s correlate best with the shape factor measurement, which reflects variation in both the asperity height and asperity width. The correlation is positive, that is, the samples with higher P.V.'s tend to have larger shape factors, although the relationship is not perfect. The correlation coefficient for available data is 0.79. Thus far only linear correlations have been attempted, and it may be that the actual relationship is some form of nonlinear function.

Also to be examined during the course of the staff study are coupons made and tested at the Fairbank Highway Research Station (McLean, Va.) and pavement cores taken from highways after measurement of skid resistance. The effect of microtexture variation on tire-pavement friction will be determined by correlation of microtexture measurements and the skid numbers obtained on the road.

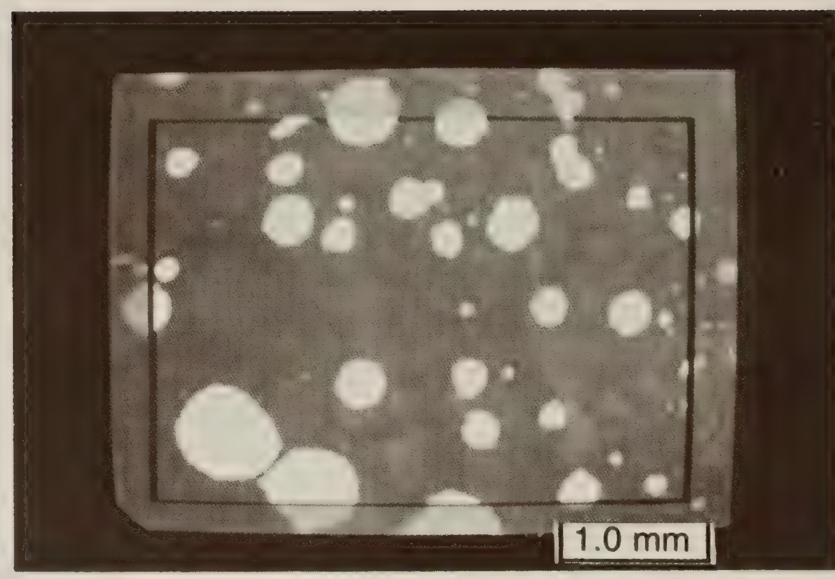


Figure 10.—A polished portland cement concrete sample showing the air voids contained therein.

Additional Uses

Because this equipment can be programed, it should be adaptable to many types of repetitive measurements in which features of interest can be differentiated from the surrounding material. One such use, which was incorporated into the system, is the ability to determine the air content of hardened concrete. Currently, this measurement is made by passing a polished sample of concrete under a binocular microscope by means of a movable stage and measuring the total length of this movement and the total chord length of all air voids which pass beneath the cross hairs of the microscope.[4] From these length measurements, the percentage of air in the sample is calculated.

Depending on the size of the sample, this can take 4 to 8 hours to run. A program was supplied with the equipment which allows air contents to be measured automatically on the same type of sample (fig. 10). The program directly measures the percentage of the total area occupied by air voids for each field of view (the number of fields are specified according to requirements) and prints out the results in 5 to 10 minutes. The savings in operator time and eye fatigue are obvious.

Summary

The purpose of the equipment described here is to measure the microtexture of aggregate samples and relate these measurements to frictional measurements made on the same samples. By noting which microtextural characteristics or combinations of characteristics correlate with various levels of frictional forces, it should be possible not only to predict skid resistance of various aggregate materials based on texture, but also to delineate an optimum microtexture for aggregate. Determination of such an optimum would be useful in studies involving the beneficiation of natural aggregate, as well as the manufacture of artificial materials.

This equipment also has potential applicability to other types of repetitive measurements. One of these, the determination of air content in hardened concrete, is currently being made with a running time approximately 1/50 of that needed for the standard equipment and manual procedure.

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[4]This procedure is specified in ASTM C–457–71, Standard "Recommended Practice for Microscopical Determination of Air-Void Contents and Parameters of the Air-Void System in Hardened Concrete." *(3)*

[5]Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

Since the publication in 1973 of "Water in Roads," a report prepared by an Organization for Economic Cooperation and Development (OECD) initiated research group, highway engineers around the world have taken a new look at the effect of water on the performance of pavements and at design features intended to either minimize the water or resist its effects. ***(1)*** **[2]**

In the United States, recent State-Federal workshops have helped to define the problem and have emphasized the importance of roof leakage in pavements and solving the problem with hydraulic and filtration principles. This article briefly reviews the problems and presents general design criteria essential to the construction of economical, effective, and long lasting drainage systems for pavement structures.

Drainage Design Criteria for Pavement Structures

by George W. Ring [1]

Introduction

The performance of pavement structures is a function of the complicated interaction of structural geometrics, materials properties, applied wheel loads, maintenance timing and effectiveness, subgrade properties, and environmental influences. Although independent discussion of any one of these factors is not a good system approach, this article deals primarily with environmental influences. Discussed are subdrainage problems, design requirements to minimize these problems, and recent efforts in the United States to improve the design and construction of subdrainage systems. These items must be interpreted in relation to other factors of performance and compromised with any economic and engineering trade offs which may be necessary.

Subsurface Drainage Problems

The importance of drainage design criteria is emphasized by noting that poor subsurface drainage, combined with frost action, can result in the temporary loss of as much as two-thirds of the strength of flexible pavements and one-third of the strength of rigid pavement systems. *(2)* The subgrade, structural layers within the pavement, and the entire pavement structure as a unit can have widely different performance or behavioral characteristics, depending on the amount of water present.

Sources of water within pavement structures include the following:

- *Ground water*—Migration from the shoulders or drainage ditches, migration from the water table, seepage from higher ground, and migration from water-bearing strata.
- *Surface infiltration*—Through permeable surfaces and through cracks, joints, and other discontinuities.

Surface infiltration, or roof leakage, is the more important source of water for many pavements. *(3)* When outflow occurs, it is usually either vertically downward through the pavement system into the subgrade, laterally through more permeable layers of the pavement system either

[1] Paper prepared for presentation at the Symposium on Road Drainage, sponsored by the Road Research Program of the Organization for Economic Cooperation and Development, held in Berne, Switzerland, May 22–25, 1978.

[2] Italic numbers in parentheses identify references on page 110.

to underdrains or through the shoulder, or a combination of the two. One indicator of poorly drained pavements is seepage of water upward from joints and cracks downgrade from the inflow source (fig. 1). In an ideally drained pavement, the outflow through drainage elements, plus storage, will be equal to the inflow.

While the water is passing through or being stored, a number of conditions contributing to premature pavement distress may become evident, depending on other interactive factors in the performance of a specific pavement. Some of these conditions are as follows:

- Reduced strength of the subgrade.
- Reduced strength of subbase and base course materials.
- Pumping of bases, with a resulting loss of subgrade support.
- Increased frost action and/or heaving of pavements over swelling soils.
- Reduced structural strength as a result of water separated layers.

Over the years, a primary engineering concern with subdrainage has been to protect the subgrade because strength of the subgrade is highly dependent on its moisture content. In 1965, the uncertainty of and difficulty in arriving at a design moisture content (and corresponding strength) for the subgrade led OECD members to look at the problem of predicting subgrade moisture. By 1973, after a number of meetings and intensive work by a Drafting Group, "Water in Roads: Prediction of Moisture Content in Subgrades" was published. *(1)* OECD member nations consider this milestone report to be a thorough documentation and basic reference on the subject. In an important initial evaluation by the Drafting Group, it is stated that existing prediction theories are often

Figure 1.—Water seepage from joints and cracks downgrade from inflow source.

no more than a guideline and cannot resolve the problem completely, and "the assumptions on which these theories are based are too restrictive insofar as they disregard the existence of certain physical factors (such as, the) waterproof nature of the highway, protection against edge effects, upkeep of these conditions in time, etc." An included note states, "It appears that the waterproof nature of the highway has to be considered with respect to the permeability coefficient of the soil, and the structure of the road." *(1)*

This statement was an accurate prophecy of the more recently recognized problem of surface infiltration volumes, coupled with low outflow rates, as these affect the performance of highways in the United States and other countries. Hydraulic inflow, storage, and outflow properties of pavement structures become important when it is acknowledged that present pavement design procedures are based on the assumption that there is no free water within the structure. It follows that a hydraulic analysis of the pavement structure is seldom made to show that this assumption is realistic. *(4)* Such an analysis would permit a time-quantity study of water from inflow to outflow.

Although the assumption of no free water in the pavement structure has produced some satisfactory designs for many U.S. pavements, it has been less successful for others. Even in the cases of satisfactorily performing pavements, one must always ask whether adequate drainage would provide longer and better service.

A number of field coring investigations of pavements made principally for other purposes (that is, validating design theories) have revealed free water within the pavement structure. Even in some instances where underdrains were in place, deficiencies noted have been as follows *(5)*:

- Discontinuous drainage within the pavement.
- Piping of soil-aggregate materials.

- Clogging of pipes and aggregate drainage units (fig. 2).
- Crushing of pipe outlets by maintenance equipment.
- Inadequate hydraulic capacity of the drainage system.
- Use of high capillarity materials for drainage elements.
- Lack of positive outlets for drainage layers (fig. 3).

These may be considered typical problems of older underdrain systems, but they are not insurmountable. The following examples show how design criteria and construction techniques can minimize most of these problems.

Discontinuous drainage may be the result of either design or construction oversights. During construction, contamination of the top of drainage layers tends to be a major problem. However, this problem can be eliminated just before paving by placing more drain material than needed in the final section, and then scraping off layers which have become contaminated during construction operations. There continues to be a need to impress on contractors the importance of clean drainage materials to the eventual performance of their product, the pavement structure.

Discontinuous drains can also be created by the design of pavement structures having alternating layers of high and low permeabilities. Impervious layers restrict vertical flow and trap surface infiltration water in more pervious layers above them. Lateral drainage may then be required to remove water from the pervious layers. However, the permeability of materials for effective drainage should be over 240 m/day. Unfortunately, most commonly used base and subbase courses have permeabilities ranging from under 0.3 m/day to about 24 m/day. The

Figure 2.—Underdrain deficiency—clogged pipe.

ideal situation, from a drainage standpoint, is for the permeability of pavement layers to increase with depth, layer by layer, to a value equal to or lower than the permeability of the underlying subgrade. Such drainage criteria could be incorporated into a typical flexible pavement design by stating that the permeabilities (k) of layers a_1, a_2, and a_3 should be such that $k_{a_1} < k_{a_2} < k_{a_3} \leq k_{subgrade}$ (fig. 4).

Piping of soil-aggregate materials can best be prevented by the proper design of a graded filter—either with layered aggregates or with newly available engineering fabrics. For aggregates, the relationships of filter materials gradation to adjacent soils are given below *(3)*[3]:

$$D_{15}\,(\text{soil}) \leq \frac{D_{15}\,\text{Filter}}{5} \leq D_{85}\,\text{soil}$$

$$\frac{D_{50}\,(\text{Filter})}{25} \leq D_{50}\,\text{soil}$$

$$\frac{D_{15}\,(\text{open-graded material})}{5} \leq D_{85}\,\text{Filter}$$

[3] D_{15}, D_{50}, and D_{85} refer to that particle size of a material at which 15 percent, 50 percent, and 85 percent of the material, respectively, is smaller in diameter.

A research study at Oregon State University is determining the best use of fabrics in drainage systems. One task in this study is to summarize and evaluate the use of fabrics in European drainage systems and to see if these design criteria are applicable to conditions in the United States.

Clogging of pipes is related to soil erosion and piping problems and can be reduced by using pipes with small slotted openings and designed filtering systems. At least one producer of drainage pipes in the United States will provide pipe on order with slot widths ranging from 0.25 mm to over 2 mm. Small slots in drainage pipes simplify the design of filtering systems. Alternately, fabric wrappings are also effective for reducing particulate infiltration of pipes.

Crushing of pipe outlets can be reduced by installing guard posts at the pipe opening or by using

Figure 3.—Lack of positive outlets for drainage layers causes underdrain deficiencies.

prefabricated metal or concrete pipe headwall and outlets. These outlets must be designed so that wheeled maintenance equipment is not "trapped." Critical pipe loadings usually occur under construction equipment; during installation and backfilling, special care is necessary to prevent underdrain pipe closure.

Inadequate hydraulic capacity of the drainage system may be corrected by the design of new pavements according to a hydraulic analysis of inflow-outflow quantities of pavement structure. More open-graded materials should be used where more drainage capacity is needed. However, these more open-graded materials may need a blanket of filter protection to prevent intrusion. In existing pavements, the problem of low-permeability layers is exceedingly difficult to correct. Efforts may better be directed either toward the installation of new subdrainage systems to intercept surface infiltration at the critical points (edge joints and transverse joints), or toward more intensive maintenance to provide an impervious surface, including well sealed joints and cracks. A thorough hydraulic and economic analysis is needed to determine the best course of action.

Use of high capillarity materials for drainage layers has not been unusual in the past. Subdrainage layers of high capillarity materials are relatively ineffective for removing all detrimental water from the road structure. An example of the problem is given in table 1.

As noted in the table, sands can remain at over 90 percent saturation after drainage. This amount of water is enough to cause high pore pressures due to thermal expansion of the remaining air in the system with corresponding strength reductions in the sand of up to 50 percent for an increase in

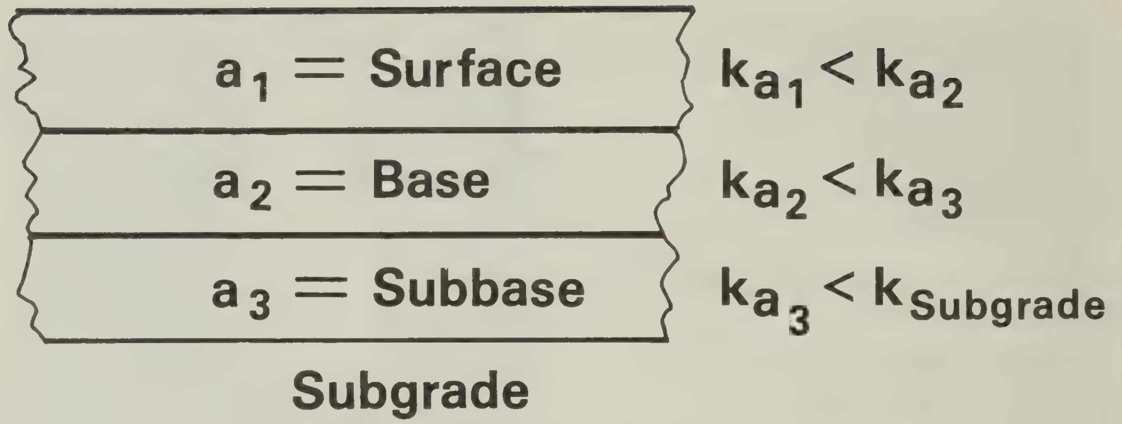


Figure 4.—Permeability (k) of pavement layers where special drainage layers may not be needed.

temperature of 5° C. *(2)* Also, the combination of high capillarity and relatively high permeability (that is, silts and fine sandy gravel) can contribute to severe frost heave and thaw weakening in cold climates. *(3)*

Lack of positive outlets for drainage layers would appear to be an easy problem to solve. Where granular drainage layers extend through the shoulders, the exposed surface may be inadvertently covered with topsoil used to establish an erosion resistant turf. Coordination of landscaping efforts with pavement designers reduces this problem. Other problems related to the lack of positive outlets were discussed earlier in sections on discontinuous drains, pipe crushing, and low

Table 1.—Water retention test (FHWA)

Material	Density (PCF)	Initial saturation	Saturation after drainage
		Percent	*Percent*
Pea gravel	100.7	99.4	8.2
Sand	103.3	98.0	90.7
Sand	101.7	100.0	94.8
25 percent sand and 75 percent pea gravel	113.2	98.6	46.9
25 percent sand and 75 percent pea gravel	100.2	100.0	46.3

permeability drainage layers. A major cause of the discontinuous drain problem is the construction of one or more open-graded layers in a pavement built in a trench section in low permeability soils.

Analysis and Design Procedure

A suggested procedure for an analysis which accounts for all water which can enter the pavement structures, and for the design of drainage for pavement structural sections involves the following steps:

1. Assemble data on highway and subsurface geometry, index properties (including permeability) and performance characteristics of soils and materials, precipitation, and frost penetration. Potential pavement subdrainage problems can often be averted by a simple inspection of the proposed structural geometrics and relative permeabilities of the various pavement components. High permeability materials bounded below and laterally by low permeability materials are a major source of subdrainage problems. Examine the geometrics for possible treatments to intercept rainfall at the surface. This might include changes in cross-slopes, channeling, or inlets at the pavement edge, and shoulder paving to minimize vegetation

growth or accumulation of debris which would otherwise slow the flow of water.

2. Determine the net inflow that must be removed by the drainage system. This should include water from all possible sources, especially edge joints and cracks. Cedergren recommends using a surface infiltration rate equal to from 0.33 to 0.67 multiplied by the maximum rainfall that would be expected to fall during 1 hour in a return period of 1 year, depending on the type and global permeability of pavement surface. *(3)* Groundwater and other sources of water should be added to the surface infiltration. An allowance should be made for any possible natural outflow by downward seepage into the soil beneath the pavement. Potential drainage rates into subgrades having low water tables are given in table 2.

3. Analyze and/or design pavement drainage layers to provide for the rapid removal of the net inflow determined in Step 2. This should include the evaluation of the need for filter layers. Materials having a capillary rise of over 100 mm are probably not suitable as drainage layers because of the large retention of water after drainage of gravity water. This restricts materials for the drainage layers to those having particles larger than 2 mm (No. 10 sieve).

4. Analyze and/or design collection systems to provide for the disposal of water removed by the drainage layers. This includes the location and sizing of longitudinal and transverse collector drains, selection of filter material, and determination of outlet spacing. Daylighted layers should be considered as a possible economic alternative to pipe collectors.

5. Conduct a critical evaluation of the results of Steps 3 and 4 with respect to long term performance, construction, maintenance, and economics of the proposed pavement drainage system.

Table 2.—Possible drainage rates into subgrade for pavement on an embankment

Subgrade permeability (k)	Drainage rate	Typical material
Metres/day	*Litres/day/ 1 lin. metre*	
0.001	1.7	Clayed silt
0.01	16.7	Silts and rock dusts
0.1	167.0	
1.0	1,670.0	Fine sand (clean)
10.0	16,700.0	Course sand (clean)

Typical calculations for an inflow and outflow analysis can be found in "Guidelines for the Design of Subsurface Drainage Systems for Highway Structural Sections." *(3)*

Cost and Performance Data

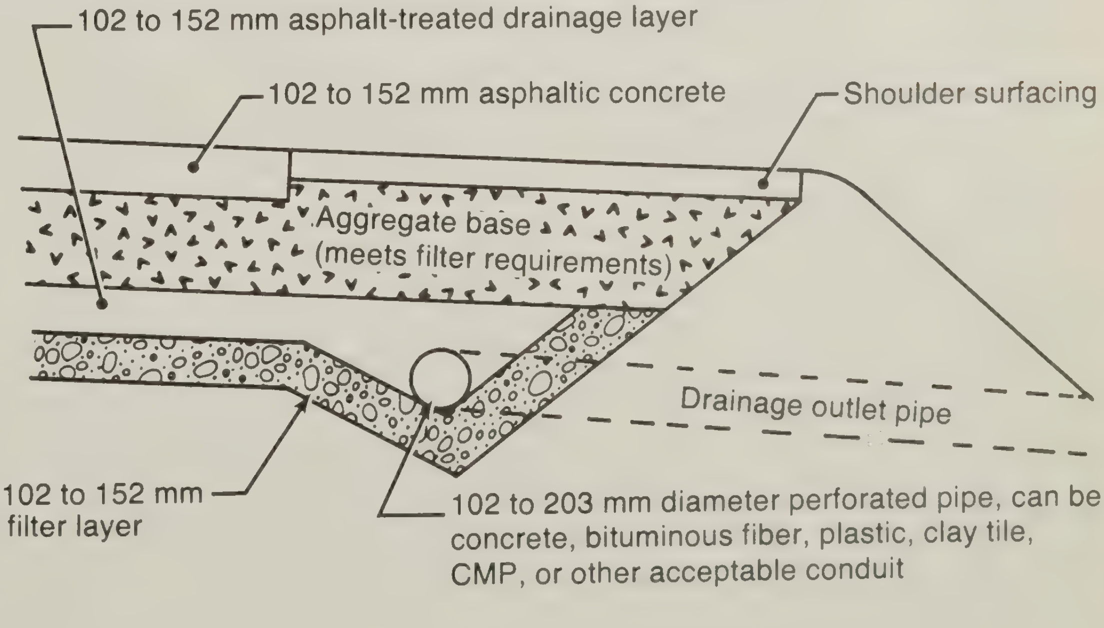
Although design criteria for the drainage of pavement structures should be based on costs versus benefits and compared to the costs of alternative solutions, data are sadly lacking for making economic decisions in this area of pavement design and maintenance. However, there are a few instances where either costs or performance data are available. California has concluded that an open-graded drainage layer with an aggregate filter layer for removing ground water (fig. 5) is cost-effective compared to a single, less permeable layer.

In Louisiana, edge drains installed on two lanes of a four-lane divided highway stopped the faulting of a concrete pavement while on the adjoining, undrained section faulting continued to increase. Through funding of experimental projects, the Federal Highway Administration (FHWA) is currently encouraging the development of much needed data on the relationship of pavement performance to improved drainage of pavement structures.

Recent Efforts to Improve Subsurface Drainage Systems

In the United States, State highway departments and other local jurisdictions are responsible for the design of the structural drainage of pavements. On roads partly funded with Federal funds, plans and specifications for the pavement underdrain systems are approved by FHWA as part of the overall pavement design. However, a 1971

Figure 5.—Two-layer drainage blanket in a flexible pavement system.



survey of the States' design practices showed that the States had not evolved to equal technical capabilities in their approaches to providing subsurface drainage. Trial and error is too often used in solving subdrainage problems. In contrast to the overdesign of some engineering structures for safety considerations, highway underdrain systems have had a low priority and, as a rule, have been underdesigned. *(4)*

In the past few years, FHWA has taken a number of steps to improve subsurface drainage practices in the United States. Some of these steps provide the following:

- Financial support and technical advice to State-initiated research studies on pavement subdrainage. *(4, 6)*
- Direct Federal contract research. *(3, 7)*
- Regional State-Federal workshops. *(5)*
- Development and distribution of information brochures to highway engineers.

The most effective efforts to improve pavement subdrainage practices were the five joint State-Federal regional workshops held in 1973. These were attended by 375 engineers and were useful for identifying and acknowledging pavement subdrainage problems experienced by the States. The clear understanding of the problems as established at the workshops has encouraged many States to begin improving subdrainage system design and construction.

Ten States are currently conducting research on subdrainage problems, and an increasing number of States are installing experimental test sections using fabrics in fabric-pipe-aggregate systems and fabric-aggregate systems. One State is currently studying the performance of twelve 0.8 km long full-scale sections of both drained and undrained pavement structures. *(8)* An important finding from the early part of this study is that the addition of 2 to 6 percent fly ash to an asphalt-treated open-graded material produced a very stable mixture having a permeability of over 914 m/day.

Another State is subjecting both rigid and flexible pavement test sections to repeated loads in a circular test track to determine the relative performance of drained versus undrained test sections. A number of States have installed 48 to 160 km of fabric edge drains along existing pavements.

New techniques in subdrainage are being developed rapidly by the States. To make more engineers aware of these techniques, a second series of State-Federal workshops is planned for the spring of 1979. The program is designed to have those States with the most experience describe both their successes and failures with new subdrainage methods. Further improvements in design criteria are expected to evolve from this second series of workshops.

Additional general information on subsurface drainage can be found in references 9 through 15.

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Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Office of Research, Federal Highway Administration, which includes the Structures and Applied Mechanics Division, Materials Division, Traffic Systems Division, and Environmental Design and Control Division. The reports are available from the address noted at the end of each description.

Concrete Median Barrier Research, Volume 1—Executive Summary (Report No. FHWA-RD-77-3) and Volume 2—Research Report (Report No. FHWA-RD-77-4)

by FHWA Structures and Applied Mechanics Division

These reports describe a comprehensive pooled-fund research study sponsored by 21 States to appraise concrete median barrier (CMB) impact performance. Investigations included 24 full-scale crash tests to evaluate the shape, construction type, and end treatment of various CMB configurations. Theoretical investigations using a crash simulation computer program led to an optimized new CMB shape, Configuration F. The program of crash tests that were conducted compared the behavior of the widely used General Motors and New Jersey CMB shapes and the new Configuration F.

Full-size and subcompact passenger sedans were used in evaluating the performance of the three CMB types during nominal 97 km/h collisions at 7° and 15° impact angles. Barrier profile was found to have greater significance for subcompact vehicle impacts. For the first time, the magnitudes of impact loads were measured during the crash tests conducted on short sections of Configuration F and New Jersey barriers. The measured loads provided an indication of the distribution of the dynamic loading on the barrier—an important factor in determining strength and stability requirements.

Simulation studies of vehicle impacts with vertical and normal CMB installations on pavements having a 10 percent superelevation revealed that a vertical barrier offers better protection for vehicles going down the slope and a normal barrier orientation offers better protection for vehicles going up the slope.

Performance of heavy vehicles in collisions with a CMB was determined from full-scale crash tests using a 18 Mg intercity bus impacting at speeds of 72 and 89 km/h and impact angles of 7° and 15°.

These reports are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161 (Stock Nos. PB 270109 and PB 270110).

Upgrading Safety Performance in Retrofitting Traffic Railing Systems, Report No. FHWA-RD-77-40

by FHWA Structures and Applied Mechanics Division

A promising approach to improved highway safety is the upgrading of substandard older bridge railings with cost-effective retrofit hardware that can be quickly and readily installed on existing bridges to provide currently acceptable structural and safety performance. An indepth study of bridge railing systems in use nationally showed that all of the more than 200 existing

designs in service can be separated into 4 categories on the basis of profile geometry regardless of their safety performance capability. The majority of existing bridge railings fall into two of the categories. Each bridge railing design within a category that is a candidate for upgrading presents common retrofit constraints that are amenable to a common retrofit modification.

Fourteen pre-1973 bridge railing designs, representing 67 percent of the rail length reported in the national survey, were appraised for conformance to current safety performance standards in order to determine specific needs for improvements. Five railing retrofit modifications were designed, fabricated, and installed on test sections of typical nonconforming railings for evaluation through a program of 22 full-scale crash tests with passenger vehicles. The measure of adequacy for the modified bridge railings was the dynamic performance during vehicle collisions.

The primary element of three of the new retrofit modification concepts is a new type of beam rail element, the tubular thrie beam, which is also potentially useful in many other roadside barrier applications.

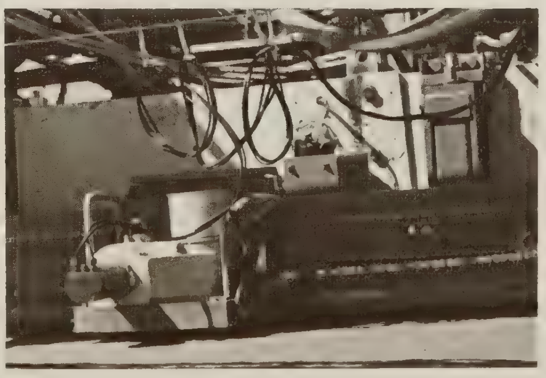
This report is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161 (Stock No. PB 282435).

Development of a Device for Continuous Automatic Monitoring of Consolidation of Fresh Concrete, Report No. FHWA–RD–78–27

by FHWA Materials Division

This report describes the development of a new device for continuous and automatic monitoring of the density of portland cement concrete (PCC). The development of the device from the concept stage to prototype is explained. The report presents the results of laboratory and field evaluations which indicate the device has potential for becoming a powerful quality control tool in PCC construction. The quality of PCC can be increased as water/cement ratios are reduced; however, this increase is only achieved if the concrete is adequately consolidated.

A prototype instrument was developed which uses a nuclear backscatter technique to measure concrete density. The instrument is designed for attachment to a traversing mechanism mounted on the back of a slip-form paver.



The report is available from the Materials Division, HRS–21, Federal Highway Administration, Washington, D.C. 20590.

Installation of Incinerator Residue as Base–Course Paving Material in Washington, D.C., Report No. FHWA–RD–78–114

by FHWA Materials Division

The use of municipal incinerator residue as aggregate in bituminous pavement construction has been evaluated in the laboratory and in the field. A test installation placed in Washington, D.C., in June 1977 consisted of a 114 mm bituminous pavement composed largely of incinerator residue. The base was placed in two lifts and finished over compacted subgrade. The base was covered with 38 mm of a conventional bituminous surface course mixture.

Details of the residue production, laboratory evaluation, asphalt plant operation, placement and finishing of the test installation, and recommendations and precautions for future projects using incinerator residue are given in this report.

Preliminary results indicate that with proper precautions incinerator residue can be used as aggregate substitute or extender in bituminous base construction. Even though incinerator residue may be a technically viable aggregate material, its use will be determined by an interplay of economic, environmental, and energy factors.

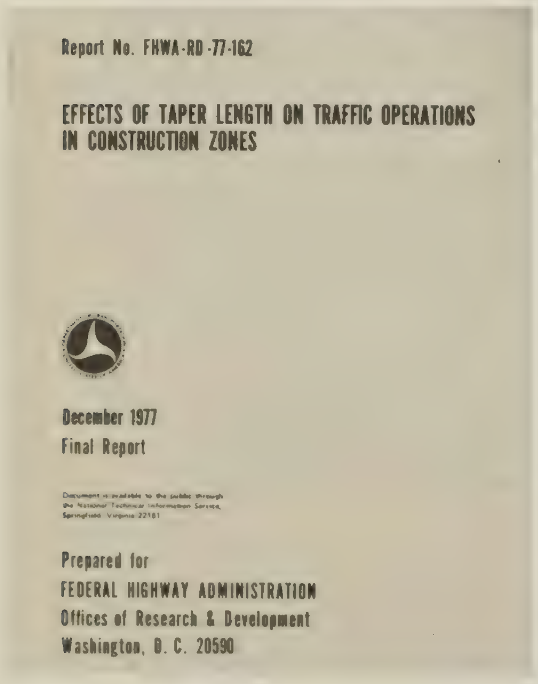
The report is available from the Materials Division, HRS–23, Federal Highway Administration, Washington, D.C. 20590.

Effects of Taper Length on Traffic Operations in Construction Zones, Report No. FHWA-RD-77-162

by FHWA Traffic Systems Division

Two formulas have now been adopted to calculate the required taper length when a lane is to be closed, one of which allows for shorter taper lengths at lower speeds. This report presents the results of field studies that were made to examine the safety effects of using each formula. Vehicle speeds, traffic conflicts, erratic maneuvers, and lane encroachments were collected, day and night, at four construction sites, where design speeds ranged from 24 to 72 km/h. In all but one study, measurements were made using both formulas. Data were collected for trucks and cars at all sites and for buses at two of the sites.

A limited number of copies of the report are available from the Traffic Systems Division, HRS-33, Federal Highway Administration, Washington, D.C. 20590. The report is also available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161 (Stock No. PB 282226).


Report No. FHWA-RD-77-162

EFFECTS OF TAPER LENGTH ON TRAFFIC OPERATIONS IN CONSTRUCTION ZONES

December 1977
Final Report

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

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

Dynamic Sign Systems for Narrow Bridges, Research Summary, Report No. FHWA-RD-78-33

by FHWA Traffic Systems Division

This summary report is the second in a series of reports which summarize completed experiments run at the Maine Facility, a 24 km instrumented two-lane rural highway test site. The experiment summarized in this report tested and evaluated the safety effects of six dynamic sign systems. The systems included signs with flashing beacons, signs with strobe lights which provided a "halo" effect, neon message signs, and bridge illumination. Vehicle speeds and lateral placement were gathered for each sign system and compared against similar measures for a base (passive) sign system. The base system consisted of a lateral clearance warning sign, a narrow bridge sign, and an advisory speed plate. Data were collected under both day and night conditions.

The summary report is available from the Traffic Systems Division, HRS-33, Federal Highway Administration, Washington, D.C. 20590. A more detailed report of the experiment will be available in the next 3 months.

Color and Shape Coding for Freeway Route Guidance, Volume I—Executive Summary (Report No. FHWA-RD-78-61), Volume II—Field Study Results (Report No. FHWA-RD-78-62), and Volume III—Literature Review and Laboratory Studies (Report No. FHWA-RD-78-63)

by FHWA Traffic Systems Division

The purpose of this research was to develop and field test a unique color and coding system to supplement conventional guide signing at problem interchanges. Following a literature review, a series of laboratory studies was conducted to empirically identify the most appropriate color and shape combinations for symbol signs. The symbol signs were used in various ways in the design of five color/shape route guidance systems which were installed and subjected to field evaluation on problem interchanges.

Except for the initial system evaluated, all systems resulted in operational and safety benefits as evidenced by a statistically significant reduction in erratic maneuvers and a significant improvement in other operational measures. The benefits of the color/shape coding concept as applied to freeway route guidance are sufficient to merit further development and testing of such systems.

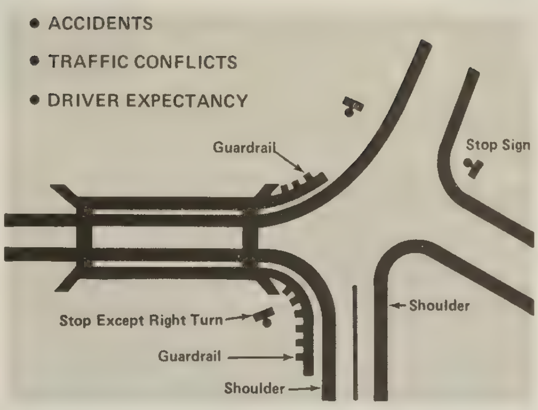
Volume I presents an executive summary of the project activities and results. Volume II contains a summary of the laboratory studies, a detailed description of the systems evaluated along with the results, and guidelines for system design and implementation. Volume III documents the literature review and presents a detailed description of the laboratory studies and results.

These reports are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161 (Stock Nos. PB 282534, PB 282535, PB 282536; set—PB 282533).

Identification of Hazardous Locations, Volume I (Report No. FHWA-RD-77-81), Volume II (Report No. FHWA-RD-77-82), and Volume III (Report No. FHWA-RD-77-83)

by FHWA Traffic Systems Division and Environmental Design and Control Division

These reports describe a method for ranking highway locations by relative hazard. The ranking is accomplished by use of a "Hazard Index" derived from nine selected indicators: (1) number of accidents per year, (2) accident rate, (3) accident severity, (4) volume/capacity ratio, (5) sight



distance, (6) traffic conflicts, (7) erratic maneuvers, (8) driver expectancy, and (9) information system deficiencies.

The concept of the Hazard Index to assess relative hazardousness appears to be valid based on its use and statistical analysis of data from 12 study sites. The research is based on an analysis of the current state of the art for the indicators considered. More extensive evaluations of the procedure developed in this study are planned. The report will be useful to researchers refining and validating methods for hazardous locations but could also be of use to Federal, State, and local personnel involved with the systematic process for safety improvement.

Volume I, **Executive Summary,** highlights study results and conclusions. Volume II, **User's Manual,** provides information and instruction needed to employ the Hazard Index. Volume III, **Final Report,** shows how the Index was developed.

The reports are available from the Traffic Systems Division, HRS-33, Federal Highway Administration, Washington, D.C. 20590.

Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments for Rural Two-Lane Highways, Report No. FHWA-RD-78-51

By FHWA Environmental Design and Control Division

The effect of various delineation treatments on accident rates was assessed by analyzing accident data from more than 500 roadway sites in 10 States for tangent, winding, and isolated horizontal curve sections. Over 13,000 accidents on two-lane highways were involved. Cost-benefit and cost models for evaluating specific delineation treatments were developed. Guidelines were formulated by executing the cost-benefit models for selected delineation treatments.

Among the results of the study, it was concluded that adding a painted centerline to a tangent or winding road section, where no previous delineation treatment existed, reduced the accident rate by approximately 30 percent. This result was statistically significant at the 0.5 level and led to the conclusion that such marking was cost justified on any road likely to have a paved surface. Edgelines, raised pavement markers, and post-delineators are also discussed.

The report is available from the Environmental Design and Control Division, HRS-42, Federal Highway Administration, Washington, D.C. 20590.

Implementation/User Items "how-to-do-it"

The following are brief descriptions of selected items which have been recently completed by State and Federal highway units in cooperation with the Implementation Division, Offices of Research and Development, Federal Highway Administration (FHWA). Some items by others are included when they have a special interest to highway agencies.

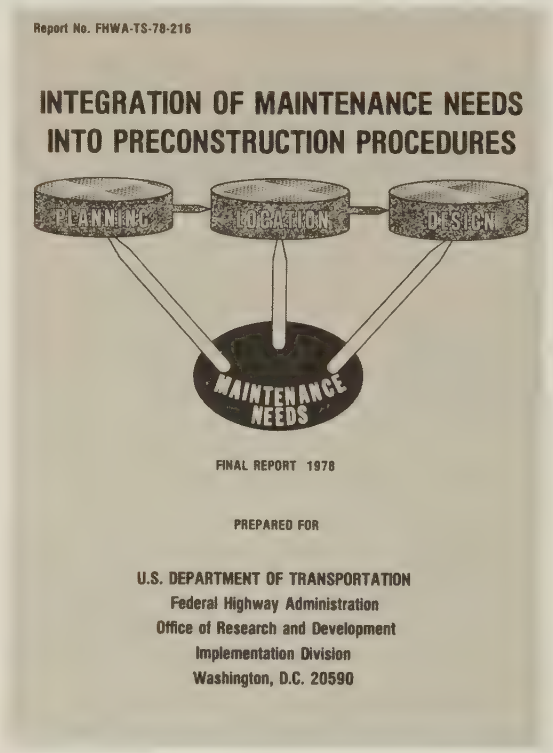
U.S. Department of Transportation
Federal Highway Administration
Office of Development
Implementation Division (HDV–20)
Washington, D.C. 20590

> Items available from the Implementation Division can be obtained by including a self-addressed mailing label with the request.

Integration of Maintenance Needs Into Preconstruction Procedures, Report No. FHWA–TS–78–216

by FHWA Implementation Division

This report was prepared in response to one of the high priority research needs identified in the 1975 Highway Maintenance Research Needs study. Decisions made during the preconstruction process, such as planning, right-of-way acquisition, and design details, may adversely affect future maintenance costs and effectiveness. This report presents a set of guidelines to promote adequate consideration of maintenance requirements during all phases of highway preconstruction activities.



Roadway and bridge design features that affect the normal maintainability of a highway facility are identified. Each design feature is treated as a separate category and includes previous experiences and recommendations for minimizing the maintenance problems. Suggested methods for improving recognition of maintenance problems during preconstruction procedures are also discussed. The report will be of interest to design as well as maintenance engineers in State highway agencies.

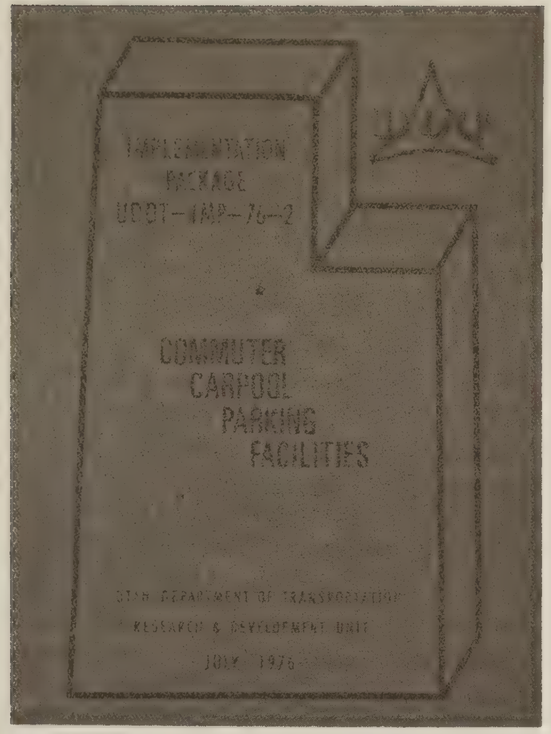
The report is available from the Implementation Division.

Commuter Carpool Parking Facilities, Report No. UDOT–DOT–76–2

by Utah Department of Transportation

This report covers the results of a pilot facility for commuter carpool parking built by the Utah Department of Transportation (UDOT) at American Fork, Utah. Recognizing the increasing number of vehicles being parked near the interchanges along I–15 in Utah, the UDOT evaluated 50 sites to determine where commuter carpool parking facilities should be constructed. Based on the results of the evaluation, the American Fork Interchange facility was constructed. It provided a safe, convenient, illuminated, and well-signed commuter carpool parking facility for 119 vehicles.

This report presents the procedure used to select, design, construct, operate, and maintain the lot at American Fork. It also includes sections on conclusions and recommendations.



A limited number of copies of this report are available from the Utah DOH, 727 West Second Street, Salt Lake City, Utah 84104, Attention: Mr. Dale Peterson. A slide-tape presentation on this subject is available from the FHWA regional offices (see inside back cover), FHWA division offices, and the National Highway Institute.

Engineering Fabrics Implementation Package

by FHWA Implementation Division

Engineering fabrics are being used increasingly as a highway construction and maintenance material in a variety of ways—as filters for subsurface drainage; as separation layers to prevent subgrade contamination of base layers; as subgrade restraining layers for weak subgrades; as earth reinforcement to build retaining walls; as erosion control barriers. Three publications are now available to facilitate the immediate use of fabrics in construction while encouraging the collection of long term data from field installations:

1. **Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads, Report No. FHWA–TS–78–205.** This publication contains current testing, design, and construction procedures employed by the U.S. Department of Agriculture Forest Service. It also delineates fabric manufacturers, types of fabrics available, and information on cost. Although the publication is directed toward the use of fabrics in low-volume roads, the principles it sets forth apply to all roads.

2. **Highway Focus, May 1977.** Highway Focus is a periodical that is published to acquaint field personnel with engineering and construction features not regarded as normal or routine. This issue is devoted entirely to engineering fabric applications on construction projects. It contains eight articles on engineering fabrics.

3. **Sample Specifications for Engineering Fabrics, Report No. FHWA–TS–78–211.** Specifications from Illinois, Alabama, New York, California, the U.S. Army Corps of Engineers, and the U.S. Department of Agriculture Forest Service have been compiled in this publication. They may be used as guidelines by others who are developing specifications for the use of engineering fabrics.

All three publications are available from the Implementation Division.

New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research and Development. Space limitation precludes publishing a complete list. These studies are sponsored in whole or in part with Federal highway funds. For further details, please contact the following: Staff and Contract Research—Editor; Highway Planning and Research (HP&R)—Performing State Highway Department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1A: Traffic Engineering Improvements for Safety

Title: Signing for Low Volume Intersections. (FCP No. 31A1794)
Objective: Develop and validate criteria for the use of two-way stop signs, yield signs, or no signs at low volume intersections.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Expected Completion Date: June 1980
Estimated Cost: $125,000 (FHWA Administrative Contract)

FCP Project 1T: Advanced Vehicle Protection Systems

Title: Assessment of Vehicle Bumper-Guardrail Interaction—Phase I and III. (FCP No. 31T4071)
Objective: Validate program GUARD's predictive capability for effect of bumper design on collision performance and refine existing documentation. Phase I will formulate and execute various simulations using change in bumper height and design. Phase III will include preparation of a parametric study simulation matrix, preparation of a user's manual, and conduct of a workshop on use of program GUARD.
Performing Organization: Chiapette, Welch, and Associates, Palos Hills, Ill. 60465
Expected Completion Date: June 1980
Estimated Cost: $87,000 (FHWA Administrative Contract)

Title: Development of Safer Barriers for Construction Sites. (FCP No. 31T6052)
Objective: Develop new portable barriers and end treatments for use at construction sites so as to provide needed protection to motoring public and construction workers. Upgrade existing barricades to enhance their safety capabilities. Include full-scale impact tests of selected barriers with a school bus and passenger-type vehicles.
Performing Organization: Texas A&M Research Foundation, College Station, Tex. 77843
Expected Completion Date: June 1980
Estimated Cost: $318,000 (FHWA Administrative Contract)

FCP Project 1V: Roadside Safety Hardware for Nonfreeway Facilities

Title: Retrofit Railings for Narrow Through Truss and Other Obsolete Bridges. (FCP No. 31V2014)
Objective: Develop bridge railing systems and other hardware that can be used to retrofit existing bridges in order to protect vital structural members from impacts by vehicles.
Performing Organization: Southwest Research Institute, San Antonio, Tex. 78284
Expected Completion Date: April 1980
Estimated Cost: $201,000 (FHWA Administrative Contract)

FCP Project 1Y: Traffic Management in Construction and Maintenance Zones

Title: Planning and Scheduling Work Zone Traffic Control. (FCP No. 31Y1024)
Objective: Analyze the interrelationships of the traffic control strategy and construction activity with respect to project and public impact. The final product will be a guide that can be used in the early planning and preliminary design phases to estimate the cost and consequences of alternative work zone strategies.
Performing Organization: JHK and Associates, San Francisco, Calif. 94119
Expected Completion Date: January 1980
Estimated Cost: $185,000 (FHWA Administrative Contract)

FCP Category 3—Environmental Considerations in Highway Design, Location, Construction, and Operation

FCP Project 3E: Reduction of Environmental Hazards to Water Resources Due to the Highway System

Title: Study of the Disposal of Recreational Vehicle Toxic Wastes at Roadside Rest Areas. (FCP No. 43E1152)
Objective: Determine the effect of toxic materials in recreational vehicles on septic tank-percolation field wastewater disposal systems

and develop design and operational procedures.
Performing Organization: University of California, Berkeley, Calif. 94720
Funding Agency: California Department of Transportation
Expected Completion Date: June 1980
Estimated Cost: $254,000 (HP&R)

FCP Project 3F: Pollution Reduction and Environmental Enhancement

Title: Planting Techniques and Materials for Revegetation of California Roadsides. (FCP No. 33F1992)
Objective: Investigate the adaptation and establishment of herbaceous and shrub species in the Mojave Desert. Determine what factors influence the natural invasion and establishment of plant materials along highways. Investigate the establishment of ground cover species on slopes with existing herbaceous species.
Performing Organization: U.S. Department of Agriculture, Soil Conservation Service, Lockeford, Calif. 95237
Expected Completion Date: June 1983
Estimated Cost: $298,000 (FHWA Administrative Contract)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4B: Eliminate Premature Deterioration of Portland Cement Concrete

Title: The Properties and Benefits of Super Water Reducers in Maintenance and Construction. (FCP No. 44B1712)
Objective: Identify the areas where the Arkansas State Highway Department would benefit from the use of concrete containing super water reducers—both in the flowing concrete and water reduced modes; define the materials properties of various concretes containing super water reducers; define the economic benefits of their use.
Performing Organization: University of Arkansas, Fayetteville, Ark. 72701
Funding Agency: Arkansas State Highway Department
Expected Completion Date: November 1980
Estimated Cost: $70,000 (HP&R)

FCP Project 4G: Substitute and Improved Materials to Effect Materials and Energy Conservation in Highways

Title: Measuring Rate of Corrosion of Reinforcing Steel in Concrete. (FCP No. 34G3122)
Objective: Develop a nondestructive field instrument and associated methodology to accurately measure the rate of corrosion or reinforcing steel in concrete slabs, and evaluate its applicability to bridge structures.
Performing Organization: National Bureau of Standards, Washington, D.C. 20234
Expected Completion Date: October 1980
Estimated Cost: $250,000 (FHWA Administrative Contract)

FCP Category 5—Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

FCP Project 5D: Structural Rehabilitation of Pavement Systems

Title: Pavement Evaluation and Overlay Design. (FCP No. 25D1262)
Objective: Become familiar with the capabilities of the new FHWA deflection measuring device and use its capabilities to measure and collect data in studying the behavior of different pavement systems under various conditions in order to verify or develop theoretical design procedures.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: August 1980
Estimated Cost: $65,000 (FHWA Staff Research)

Title: Specification Expansion for Fabric Type Filters. (FCP No. 45D3320)
Objective: Establish acceptable standards of filtering capacity and permeability, and formulate testing procedures to assure uniform compliance with such standards.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95805
Expected Completion Date: June 1981
Estimated Cost: $82,000 (HP&R)

FCP Project 5H: Protection of the Highway System From Hazards Attributed to Flooding

Title: Scour Around Bridge Piers. (FCP No. 45H1342)
Objective: Gather field data to validate scour prediction formulas. Observe and evaluate the performance of the scour monitoring system that has been built into the bridge pier in the Homochitto River on Mississippi S.R. 33.
Performing Organization: Mississippi State Highway Department, Jackson, Miss. 39206
Expected Completion Date: January 1988
Estimated Cost: $67,000 (HP&R)

FCP Project 5I: Improved Structural Design and Construction Techniques for Culverts

Title: Evaluation of Coatings for Highway Culverts. (FCP No. 35I3224)
Objective: Review and summarize available information on performance of culvert coatings in current use. Evaluate field performance of and identify new types of culvert coatings including

asphalt, coal-tar epoxy, and reinforced concrete culverts to identify those having economical potential for extending service life of highway culverts.
Performing Organization: PSC Professional Services Group, Warberth, Pa. 19072
Expected Completion Date: February 1980
Estimated Cost: $93,000 (FHWA Administrative Contract)

FCP Project 5K: New Bridge Design Concepts

Title: Measurement and Prediction of Ice Forces on Bridges. (FCP No. 35K1032)
Objective: Develop equipment and procedures for measuring ice forces which may be exerted on bridge piers due to the buildup and breakup of ice.
Performing Organization: U.S. Army Cold Regions Research and Development, Fort Wainwright, Alaska 99703
Expected Completion Date: December 1981
Estimated Cost: $344,000 (FHWA Administrative Contract)

FCP Project 5L: Safe Life Design for Bridges

Title: Corrosion Fatigue Characteristics of Bridge Steels. (FCP No. 35L3022)
Objective: Develop data on corrosion fatigue characteristics in bridge steels, welded connections, and weldments in hostile environments. Develop techniques for prediction of life expectancy in a hostile environment of bridge members containing cracks or crack-type defects. Prepare design recommendations suitable for inclusion in American Association of State Highway and Transportation Officials bridge specifications.
Performing Organization: Lehigh University, Bethlehem, Pa. 18015
Expected Completion Date: June 1983
Estimated Cost: $430,000 (FHWA Administrative Contract)

FCP Category 0—Other New Studies

Title: Vibration Measurement of Truck Cabs and Driver Seats. (FCP No. 20B5124)
Objective: Investigate the effects of various operating conditions on the vibrational environment in the cab and the effects of different seating systems on the amount of vehicle vibration transmitted to the operator.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: October 1979
Estimated Cost: $71,000 (FHWA Staff Research)

Title: Improved Reproducibility of Control Tests for Soils and Aggregates. (FCP No. 40M1604)
Objective: Identify the sources of random variation in the test results and develop improved test procedures and/or testing equipment when possible to improve test reproducibility.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95805
Expected Completion Date: July 1980
Estimated Cost: $77,000 (HP&R)

Title: Rockfall Mitigation. (FCP No. 40M1632)
Objective: Determine causes of rockfall and develop guidelines for the most effective mitigation measures in any given locality and situation.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95805
Expected Completion Date: June 1981
Estimated Cost: $123,000 (HP&R)

Title: Evaluation of Open-Graded Asphalt Friction Courses. (FCP No. 40M2954)
Objective: Evaluate the 7-year performance of existing open-graded asphalt friction courses placed over both asphaltic concrete and portland cement concrete and compare with adjacent control sections of conventional NYS 1A top course mixes.
Performing Organization: New York Department of Transportation, Albany, N.Y. 12226
Expected Completion Date: June 1984
Estimated Cost: $75,000 (HP&R)

Title: Safety and Soundness of Submerged Bridge Timber Piling. (FCP No. 40S8862)
Objective: Develop a nondestructive means for testing and evaluating submerged timber piles, develop and conduct laboratory evaluation tests on new instrumentation, and develop guidelines for use of the instrumentation.
Performing Organization: University of Maryland, College Park, Md. 20742
Funding Agency: Maryland State Highway Administration
Expected Completion Date: April 1981
Estimated Cost: $119,000 (HP&R)

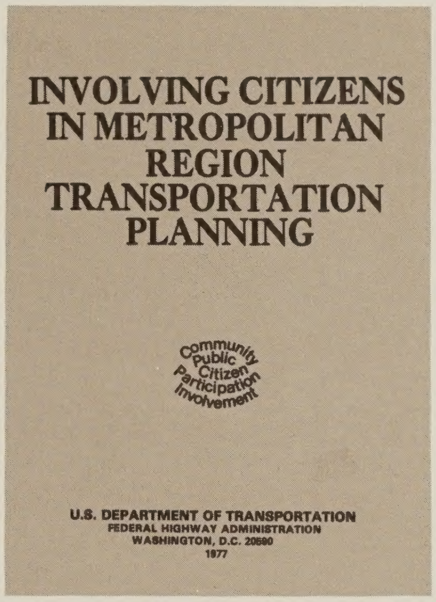
☆U.S. Government Printing Office: 1978—620-103/1

New Publication

Involving Citizens in Metropolitan Region Transportation Planning reports on citizen participation in metropolitan region transportation planning. Six areas that have successfully involved the public in planning were studied. Over 300 interviews were conducted with citizens, elected officials, and public agency personnel in the following areas: Dade County (Miami), Fla.; Harrisburg, Pa.; Minneapolis-St. Paul, Minn.; Raleigh, N.C.; San Francisco, Calif.; and Tucson, Ariz. A major observation was that all of the study regions were developing their processes of planning and community involvement in individualistic and creative ways, usually on a trial and error basis. Thus, the recommendations of this study are very general and can be summarized in five points:

- Changes in the nature of systems planning may be necessary to facilitate participation.
- The skills in human relations needed to involve diverse groups are more important than elaborate identification and classification schemes for these groups.
- Self-selected participants can be generally representative of the public if broad-based efforts are made to stimulate participation.
- Participants can be effectively located through self-selection and volunteering as opposed to depending on leaders.
- Highly structured participation often based on neighborhoods and unstructured participation based on ad hoc meetings throughout the area have strengths and weaknesses depending on circumstances.

The report is intended primarily for those who are trying to integrate citizen input into their local transportation planning process and who are faced with decisions about how to best structure their community participation programs. The report is also intended for people responsible for citizen involvement in other types of planning, as well as researchers studying contemporary citizen involvement.



Chapter I explains the study objectives and includes the research background, study methodology, and a summary of the study findings. Chapter II describes the changing nature of systems planning and implications for citizen participation. Chapter III deals with the participation of multiple publics and the selection of participants. Chapter IV discusses the findings with respect to structure and presents neighborhood-based processes. Chapter V briefly discusses the benefits of an effective public participation program.

This report may be purchased for $3.25 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-002-00104-3).

Federal Highway Administration Regional Offices:

No. 1. 729 Federal Bldg., Clinton Ave. and North Pearl St., Albany, N.Y. 12207.
Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Puerto Rico, Rhode Island, Vermont, Virgin Islands.

No. 3. 1633 Federal Bldg., 31 Hopkins Plaza, Baltimore, Md. 21201.
Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia.

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Delay Measurement at Signalized Intersections

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Improving Urban Traffic Through Truck-Oriented Measures

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