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COVER:
This section of Washington State Route 20 is part of the new "North Cascades Highway" which was completed and opened to traffic in September 1972.

IN THIS ISSUE

Articles

Departments

U.S. Department of Transportation
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Federal Highway Administration
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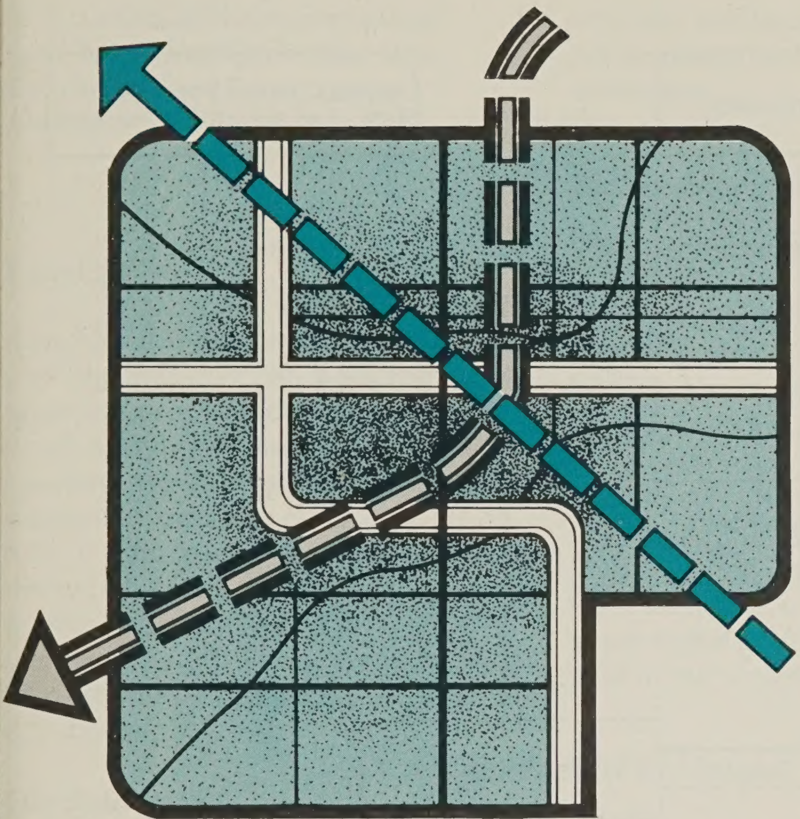
p.1 Urban transportation planning
also Models, Community aggregate planning



Applications of the Community Aggregate Planning Model , key

An Urban Transportation Sketch Planning Procedure , p. 9

by Paul J. Linden

Introduction

In any urban region, planning studies may be carried on at a number of levels of detail. Generally, urban transportation models are designed for the type of issue to be addressed and the number of alternatives to be tested. Three broad levels may be identified: sketch planning, mesolevel planning, and microlevel planning. It is widely accepted that as the level of detail increases, the precision of the resulting analysis increases; however, the time and cost associated with the process skyrockets.

Computerized models have been developed to analyze transportation networks on meso and microlevels of planning where only one or two alternative plans are being analyzed; however, the process takes many months (often years) and is very costly. On the opposite end of the planning process, a sketch planning tool is needed that can analyze and compare many alternative transportation plans quickly and inexpensively.

There are three basic requirements of sketch planning techniques:

- Ease of input preparation.
- Efficient use of computers, for those techniques using computers.
- Relevant and easily understood outputs.

The Community Aggregate Planning Model (CAPM) has been designed to fulfill these requirements. It is a sketch planning tool which compares the economic, social, environmental, and system performance characteristics of different transportation alternatives. CAPM provides a "first cut" look at alternatives so that the number of alternatives can be narrowed down for further, more detailed analysis. It is not meant to supplant traditional urban transportation planning but rather to extend the range of existing procedures. As such it is only one of the tools useful in transportation planning.

Because of the widespread need for sketch planning techniques such as CAPM and the lack of previous experience with their application, the Federal Highway Administration (FHWA) initiated a demonstration project in several urban areas to test CAPM in a working environment. The areas chosen were St. Louis, Mo.; Phoenix, Ariz.; and Cincinnati, Ohio. These cities provided a diverse proving ground for evaluation of the prototype version of CAPM, with direct feedback to aid in the fine tuning or modification of the model system. Details of this demonstration project are presented later in this article.

The CAPM is now operational and is available as part of the Urban Transportation Planning System (UTPS). Developed and maintained by the Urban Mass Transportation Administration (UMTA) and FHWA, UTPS is a collection of computer programs for use in planning multimodal transportation systems.

The CAPM Concept

The basic concept of CAPM is to provide relatively fast processing of a minimal amount of data to provide information about a proposed transportation plan. CAPM's goal is not a detailed analysis of an alternative, but rather a general indication of its merits as compared to other alternatives.

In traditional modeling techniques, base-year data is used to establish relationships and the model is calibrated accordingly; however, CAPM needs no extensive calibration. Initially, the base-year data are set up and run to verify total regional vehicle miles of travel (VMT)—vehicle kilometres of travel (VKT)—and, if necessary, a fine tuning of the regional average work trip time is made. This is the only calibration that is done.

The first important feature of CAPM is that it quickly and efficiently compares two alternatives—usually the existing (base-year) plus one proposed alternative in one run of the program. A second feature is ease of input preparation. The basic geographic analysis units are communities of about 8 to 30 mi^2 (21 to 78 km^2). A major strong point of CAPM is that there is no need to code extensive networks for computer manipulation. The following inputs are necessary for the representation of an alternative for each community:

- Exogenously estimated vehicle trip ends.
- Total lane miles of surface arterials.
- Route numbers, average number of lanes, and centerline miles of each freeway.

Other data necessary for the estimation of the large number of criteria output assume internal default values, although these may be easily changed if desired. Another major feature of CAPM is that its outputs include a large number of evaluation criteria which could be provided directly to

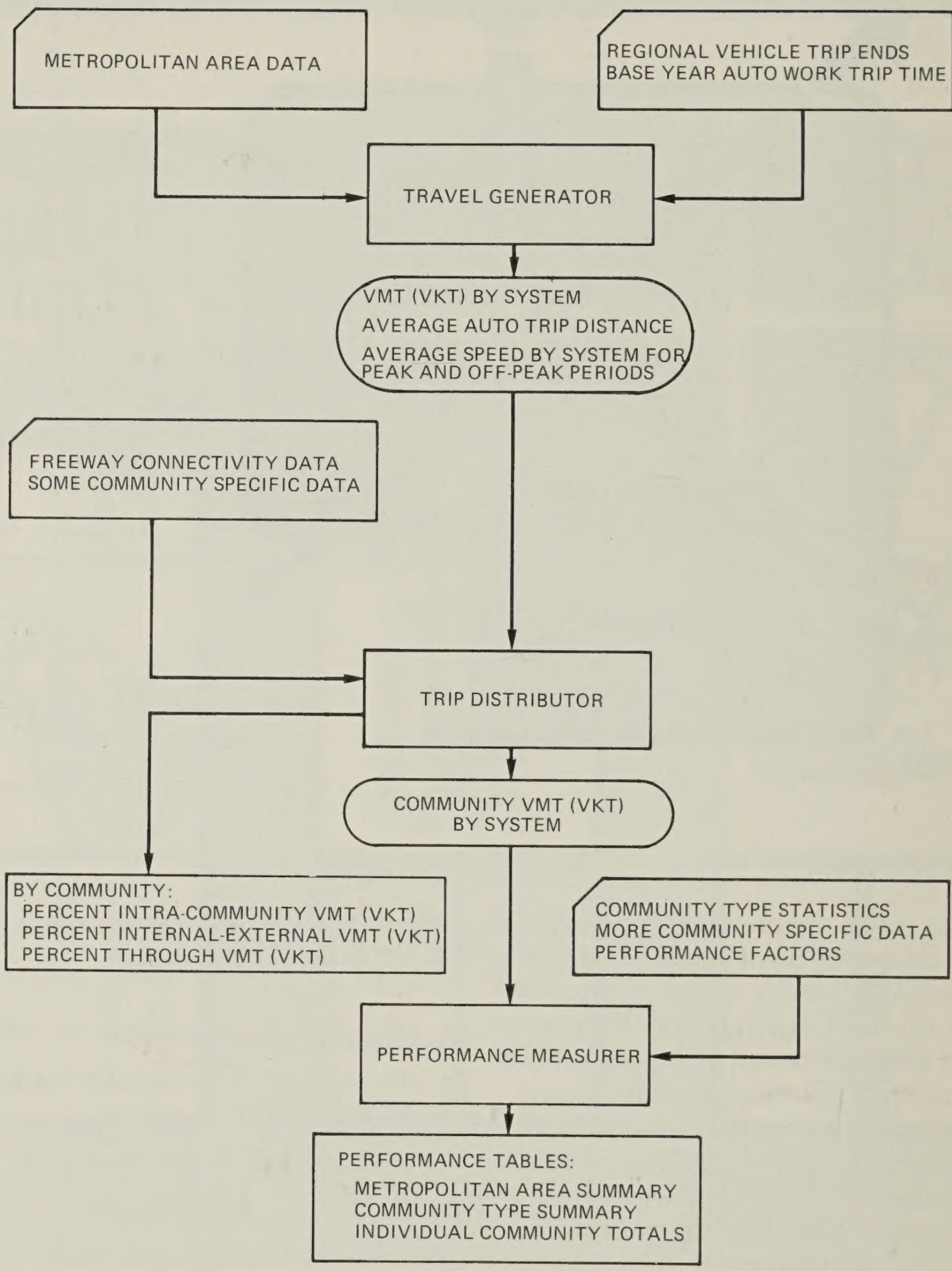


Figure 1.—Community Aggregate Planning Model system.

decisionmakers. These include measures of travel, system performance, environmental/social impacts, and system supply costs. These are output for the base and test alternative in juxtaposition and appear in three separate summary tables:

1. For each individual community.
2. For groups of communities having similar characteristics (for example, all suburbs).
3. For the region as a whole.

The CAPM Process

CAPM includes both an integrated travel distribution/assignment process and a system performance/impact estimation module. As shown in figure

1, it consists of three interrelated modules: Travel Generator, Trip Distributor, and Performance Measurer. (*1*)[1]

Travel generator

Assuming the stability of an input base-year regional work trip time, the travel generator uses a modified version of a direct assignment model (*2*) to compute a system-sensitive estimate of the daily regional average trip distance. This, in turn, is used to estimate the average trip distance for each community by examining its geographical position relative to all other communities. These trip distances are passed to the trip distributor.

Trip distributor

The average trip distance from the generator module is used in an exponential trip distance distribution function to estimate total travel in each community as the sum of three components: (1) Trips with both ends in the given community, (2) trips with one end in the community, and (3) trips with neither end in the community.

A special assignment logic is used to assign each component to the proper highway system. Separate assignments are made for truck and automobile travel. This assignment logic recognizes the connectivity of service provided by the freeway system, and assumes that freeway speeds are twice those on surface arterials. Because this assumption tends to overload freeways, a capacity restraint mechanism has been provided to adjust the volumes on a given community-freeway facility so that its speed in the peak hour will be at least 15 percent higher than the competing surface arterial system in the same community.(*3*) VMT (VKT) in each community on freeways, surface arterials, and locals is passed to the performance measurer for use in impact evaluation.

Performance measurer

Using factors which are input by community type, the VMT's (VKT's) passed from the distributor are split directionally and temporally. By comparing volumes to capacities, speeds are calculated and, in turn, travel-related performance measures and impacts are computed for each direction/time period. These are added (and weighted where appropriate) to yield daily totals. In addition, the direct impacts and costs of going from the base to test system are estimated. (*4*)

CAPM Output

The evaluation measures produced by CAPM are displayed in three reports based on geographical aggregations: metropolitan area summary, community type summary (that is, central business district, central city, suburb, and rural), and community specific reports. Each report is divided into five categories, as shown in table 1, and presents evaluation criteria for the existing (base-year) conditions and one proposed alternative. Optionally, the costs and impacts attributed to vehicle use can be broken down into separate evaluations for automobiles and trucks.

These output measures are designed to be understood by planners, citizens, and decisionmakers with no need for intermediate summarization or interpretation as with conventional network models.

CAPM as a part of UTPS was designed to be used on the IBM System 360/370 computers. The program is written in FORTRAN IV. Core requirements are determined by the number of communities, and machine time is

[1]Italic numbers in parentheses identify the references on page 9

Table 1.—CAPM evaluation measures

SOCIO-ECONOMIC AND SUPPLY DATA

- Population
- Employment
- Land Area
- Freeway Lane Miles (Lane kilometres)
- Percent of Total Arterial Capacity on Freeways
- Surface Arterial Lane Miles (Lane kilometres)
- Freeway Centerline Miles (Kilometres)
- Surface Arterial Centerline Miles (Kilometres)

VEHICLE TRAVEL STATISTICS

- Daily Vehicle Trip Ends
- Average Trip Distance
- Total Vehicle Hours of Travel
- Daily Freeway Vehicle Miles of Travel (VKT)
- Percent of Total Vehicle Miles of Travel (VKT) on Freeways
- Daily Surface Arterial Vehicle Miles of Travel (VKT)
- Daily Local Vehicle Miles of Travel (VKT)
- Daily Total Vehicle Miles of Travel (VKT)
- Vehicle Miles of Travel (VKT)—Percent Through the Community
- Vehicle Miles of Travel (VKT)—Percent Internal-External
- Vehicle Miles of Travel (VKT)—Percent Within the Community
- Peak Hour Total Vehicle Miles of Travel (VKT)

HIGHWAY SYSTEM COSTS AND IMPACTS

- New Freeway Construction Cost
- New Surface Arterial Construction Cost
- Freeway Reconstruction Cost
- Surface Arterial Reconstruction Cost
- Freeway Maintenance Cost
- Surface Arterial Maintenance Cost
- Number of Jobs Displaced
- Land Consumed by New Freeways

VEHICULAR COST AND IMPACTS

- Daily Total Accidents
- Accident Rate
- Total Annual Facilities
- Fatality Rate
- Total Daily Vehicle Operating Cost
- Operating Cost Rate
- Daily Gallons (Litres) Fuel Consumed
- Fuel Consumption Rate
- Daily Kilograms Carbon Monoxide Pollution
- Carbon Monoxide Pollution Rate
- Daily Kilograms Hydrocarbon Pollution
- Hydrocarbon Pollution Rate
- Daily Kilograms Nitrogen Oxide Pollution
- Nitrogen Oxide Pollution Rate

SYSTEM PERFORMANCE

- Weighted Average Daily Total Arterial Volume/Capacity Ratio
- Weighted Daily Average Freeway Speed
- Weighted Daily Average Surface Arterial Speed
- Weighted Daily Average Local Speed
- Weighted Daily Average Total Speed
- Weighted Average Peak Hour Total Volume/Capacity Ratio
- Peak Hour Average Freeway Speed
- Peak Hour Average Surface Arterial Speed
- Peak Hour Average Local Speed
- Peak Hour Average Total Speed

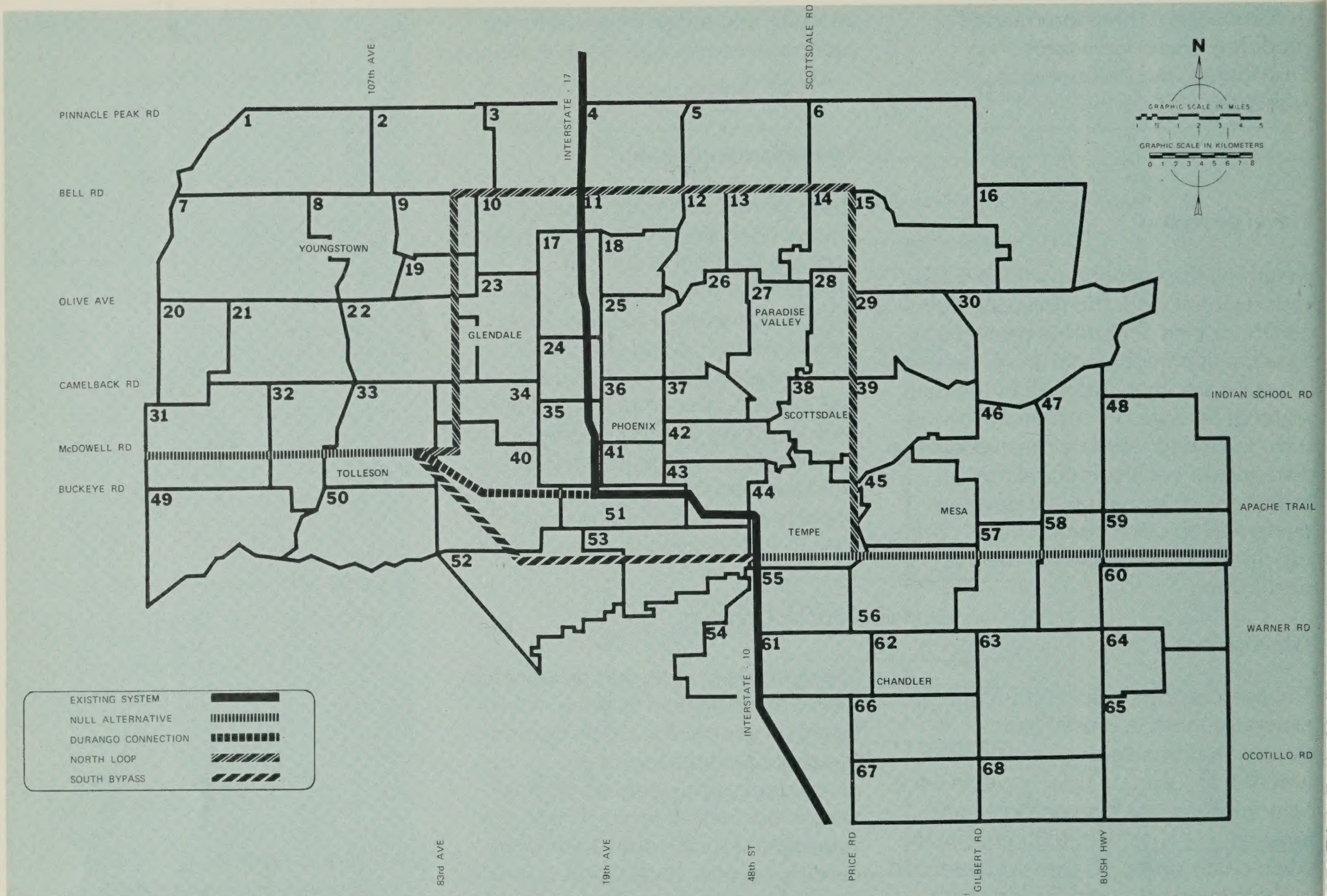


Figure 2.—Phoenix freeway alternatives.

dependent on the complexity of the alternative. Typical core and time requirements are shown in the following table:

Number of communities	Storage (K)[2]	Time[2] (Cpu)
9	132	0 min, 8 sec
68	170	5 min, 45 sec
83	184	9 min, 50 sec

[2] K = 1,024 bytes. Times are given for an IBM 360/65.

The CAPM Demonstration Project

The CAPM demonstration project began in the early stages of the CAPM program design. The purpose of the project was to facilitate the evaluation and testing of the new type of transportation planning model. The demonstration users provided many helpful design recommendations during the development of CAPM. FHWA provided assistance to the demonstration cities during the testing period by both technical visits and limited financial reimbursement. A summary of the users' applications and use of CAPM follows.

Phoenix project

The metropolitan area of Phoenix, located in Maricopa County, Ariz., is a ideal location for the testing of CAPM. The highway system is a regular grid type network covering a basically continuous region. The freeway routes are continuous and relatively straight and the communities are of regular shape and acceptable size. At the time of the CAPM demonstration project, th Maricopa Association of Governments (MAG) was performing the Interstate 1 (I–10) Transportation Corridor Locatio Study and used CAPM to test the four basic alternative alinements for I–10. The four alternatives tested are shown in figure 2 and include a null alternative, the Durango connection, a north loop, and a south bypass.

Input data for CAPM were gathered by an engineering technician at MAG and took about 3 person-weeks to assemble and code. MAG aggregated their 929 Traffic Analysis Zone System encompassing 1,293 mi^2 (3,349 km^2) into 68 CAPM communities, following jurisdictional and census tract boundaries to simplify data gathering. The base-year population was 971,000, with 4.4 million base-daily trip ends. After the base conditions were set up and verified, the MAG transportation planning staff began testing the I–10 freeway alternatives. Data changes to test each of the alternatives took from ½ hour to 2 days depending upon the complexity of the alternative.

Based on a 1995 population of 1.9 million, the total regional VMT would increase from 14 million to around 39 million (22.5 million to 62.8 million VKT) in all alternatives. Excluding the null alternative, the Durango alternative was the cheapest and had the lowest vehicle operating cost; and it resulted in lower fuel consumption than the null alternative. With a new population forecast of 2.8 million people by 1995, the Durango was run again showing the regional VMT increasing to more than 50 million (80.5 million VKT), with speeds dropping and congestion increasing.

In order to test the effect of increased transit usage, transit patronage was increased and the appropriate automobile trip ends were subtracted from the communities served by transit.

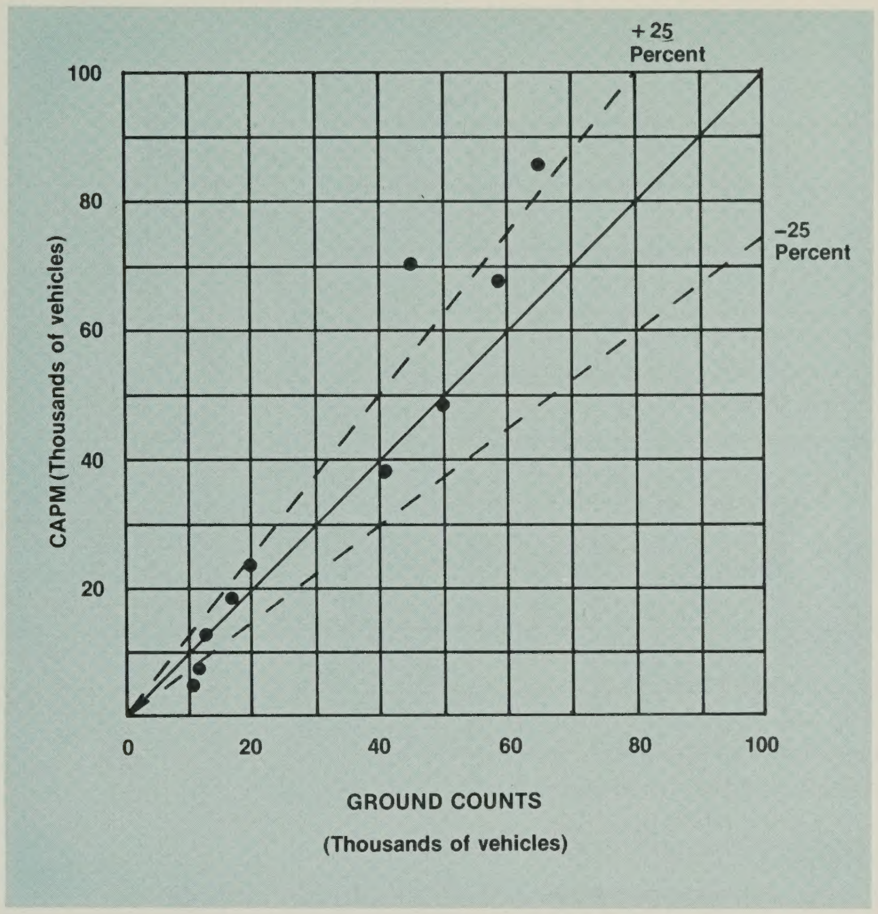


Figure 3.—ADT on freeway segments in Phoenix.

The reduced highway trips resulted in a less than proportional reduction in VMT (VKT) and an increase in system speeds.

As a part of the I–10 study, MAG evaluated various urban forms. One concept tested involved clustering population and employment in much higher densities than currently exist in Phoenix. This resulted in a drop of 2 percent in total VMT (VKT) which was less than expected. MAG therefore experimented with reducing the average trip time, a phenomenon they felt should occur with higher densities. When the average work trip time was reduced from 24 minutes to 18 minutes, the total regional VMT dropped by 20 percent from 50 million to 40 million (80.5 million to 64.4 million VKT); reduction to 12 minutes caused a VMT drop of 40 percent from 50 million to 30 million (80.5 million to 48.3 million VKT).

Although experimentation of this nature produces numerical output, the practice of varying trip time is difficult to justify. One of the major precepts on which CAPM is based is that average over-the-road trip time for work trips remains constant for the region, regardless of long term changes in the urban activity pattern or transportation system. This is supported by several previous studies.(*3*)

Since the predictions of CAPM cannot be verified with future conditions, we must rely on the ability of CAPM to replicate existing conditions as a good

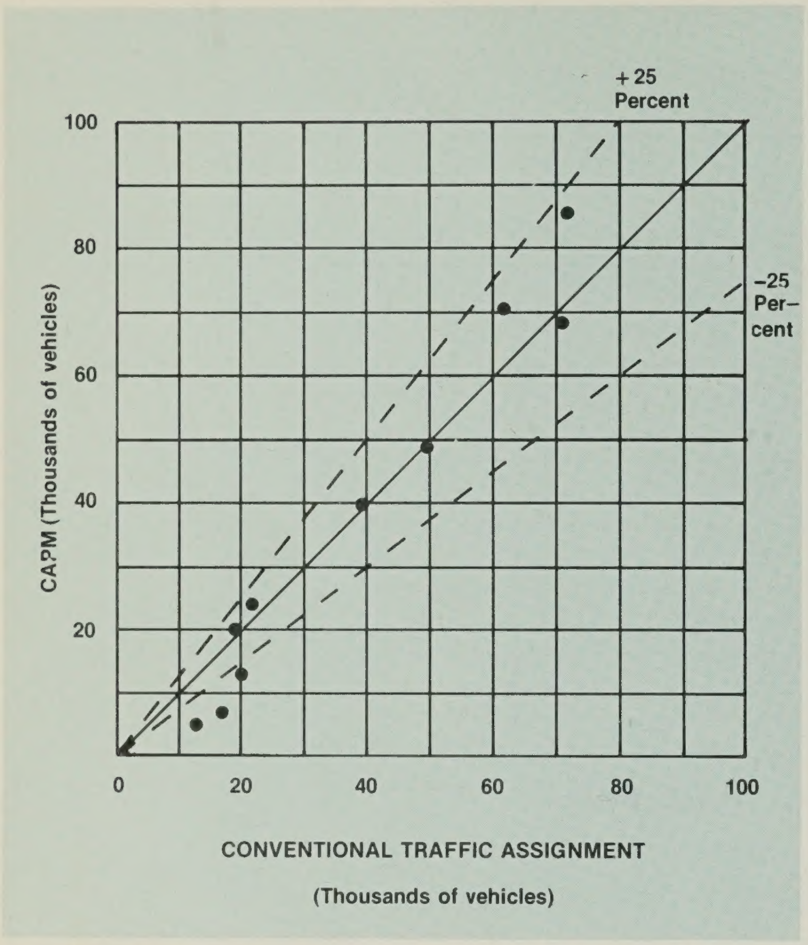


Figure 4.—ADT on freeway segments in Phoenix.

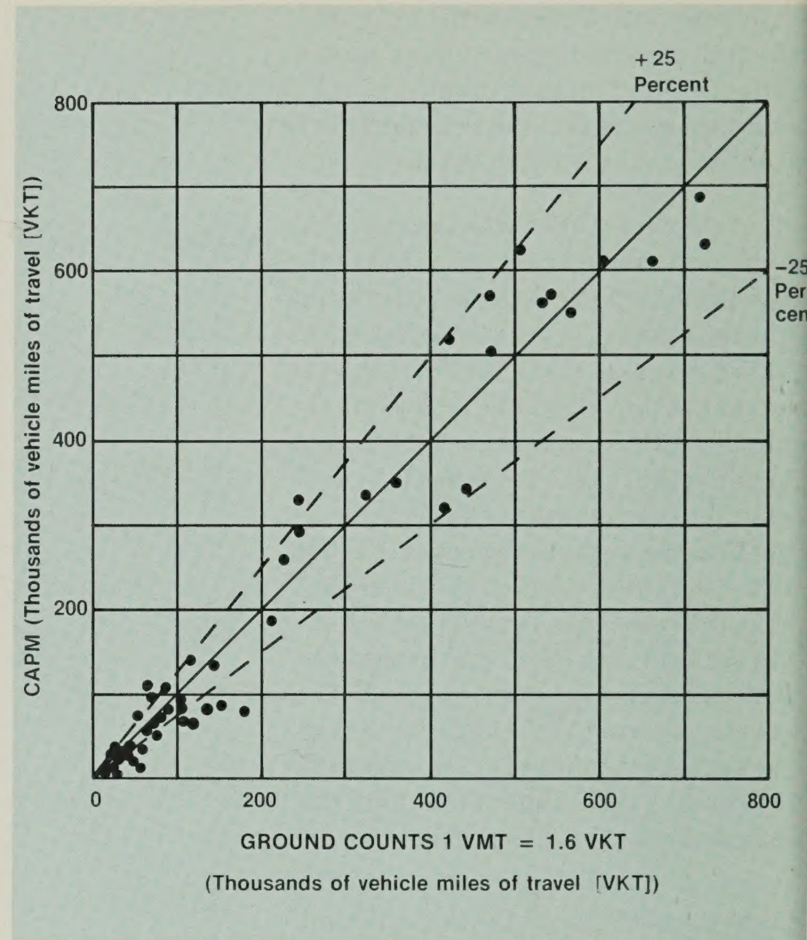


Figure 5.—Total arterial VMT (VKT) by community in Phoenix.

indicator of accuracy. For the Phoenix metropolitan area, consistent data were available from both ground counts and conventional network assignments for the existing (1970 base) test. CAPM results agreed well with observed values at both the aggregate and disaggregate levels. Regionally, the model estimated less than 14 million total VMT (22.5 million VKT) with about 1.3 million VMT (2.1 million VKT) on freeways. Data from ground counts and conventional assignments showed about 13 million total VMT (20.9 million VKT) with 1.25 million VMT (2 million VKT) on freeways.

A comparison of the average daily traffic (ADT) on freeway segments from CAPM and the actual ground counts along freeway segments is shown in figure 3. A comparison of the ADT from CAPM to a conventional traffic assignment is shown in figure 4. The correlations are well within acceptable limits for sketch planning.

Figure 5 shows the total arterial (freeway plus surface arterial) VMT (VKT) of each community output by CAPM compared to actual ground count totals. The inaccuracies were in the lower end of the scale in those communities having less than 60,000 daily VMT (96,500 VKT). Most of these communities were bordering on the outer boundaries of the cordon where travel is more difficult to estimate. CAPM usually underestimates in this area.

Although the Maricopa Association of Governments found that CAPM was no[t] the answer to all their problems, it has proven to be an efficient, valuable tool[.] They are currently using CAPM as one of their tools in a major land use and transportation reevaluation study.

St. Louis project

The East-West Gateway Coordinating Council, the metropolitan planning organization (MPO) of the St. Louis metropolitan area, is using CAPM as a part of an ongoing transportation study.

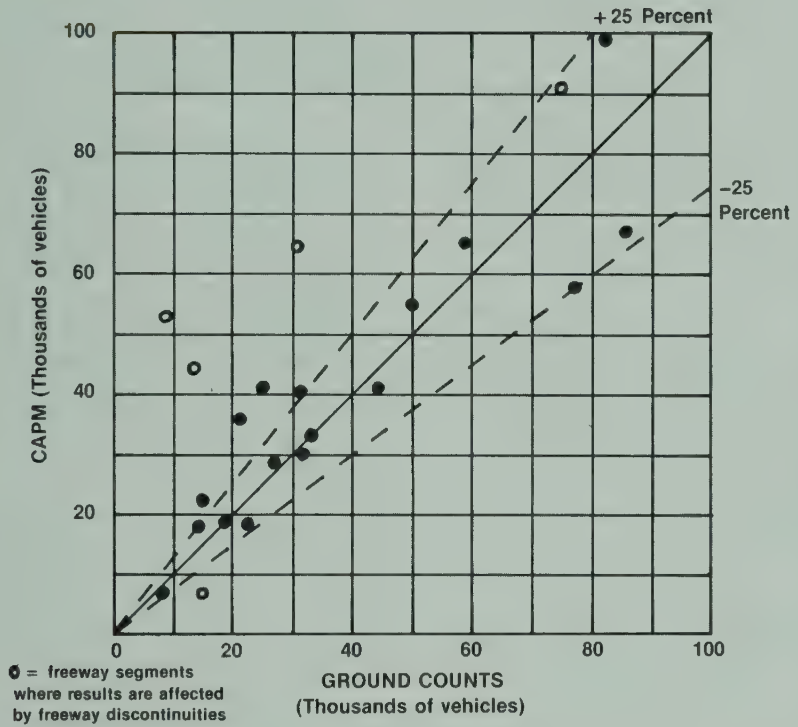


Figure 6.—ADT on freeway segments in St. Louis.

The St. Louis metropolitan area straddles the natural barrier of the Mississippi River and includes parts of two States—Missouri and Illinois. The 1,718 mi^2 (4,450 km^2) that made up the study area were divided into 83 communities for analysis with CAPM. The base-year population was 2.2 million with 6.3 million base-daily trip ends. The internal default data values were used. The freeway system in the 1965 base-year condition was incomplete, with many discontinuities. To add to these difficulties, the available ground count data were for a system which did not exactly match the one used as a base for the model. These problems possibly represent the worst conditions for the model in both operation and testing. However, even under these conditions, regional results were very good and subregionally they were within satisfactory tolerances.

Generally, the results obtained indicated that CAPM was overestimating travel on freeways and underestimating travel on surface arterials. The freeway system discontinuities probably caused this problem. When the base was updated to match a 1970 system (which was more continuous), the model performed more satisfactorily. The model produced 18.9 million total VMT (30.4 million VKT) with less than 4 million (6.4 million VKT) on freeways. Data indicated, for the metropolitan area, 19.7 million total and 3.7 million freeway vehicle miles of travel (31.7 million total and 6.0 million freeway VKT). A comparison of the ADT on freeway segments from CAPM and the actual ground counts along these segments is shown in figure 6. Except for points where there were freeway discontinuities, the model did reasonably well.

The East-West Gateway Coordinating Council had mixed feelings about CAPM. They found that the CAPM estimates of total VMT (VKT) within the region were close to the actual for both 1965 and 1970, but the distribution of VMT (VKT) by community produced some discrepancies. Some of the estimates of VMT (VKT) by community from CAPM differed by more than 30 percent from the ground count totals for the base conditions. This would affect the accuracy of the results in alternative evaluations. These problems are probably caused by a combination of the following conditions which existed in the St. Louis project:

- The region is divided into four parts by three rivers. Therefore, the CAPM assumption of an everywhere continuous surface arterial network does not hold.
- The 1965 freeway system was fragmented, whereas the 1970 system was more continuous producing more reasonable results.
- The 1970 travel data were generated through a series of simulation models, which did not produce good traffic estimates when compared to actual traffic counts through conventional procedures.

• The 1970 trip ends input to the CAPM program were developed from the conventional process.

In addition to alternate highway plan evaluations, CAPM has good potential for evaluating highway related operating strategies. The study in St. Louis tested CAPM sensitivities to four different types of policies: (1) increased freeway speed limit, (2) reduced peak hour travel, (3) effects of 1995 travel demand on the 1970 system, and (4) reduced numbers of vehicle trips due to increased carpooling.

In the analysis of these policies, changes were observed in the performance and impact measures output by CAPM. This indicated that CAPM is sensitive to changes in a variety of policies and therefore holds promise as a valuable sketch planning tool.

Cincinnati project

The city of Cincinnati is located in southwestern Ohio, and the metropolitan region includes parts of Kentucky and Indiana. The Ohio Department of Transportation (ODOT) was responsible for running CAPM with data collection by the Ohio, Kentucky, Indiana Regional Planning Authority (OKI).

The Cincinnati metropolitan area is located on both sides of the Ohio River. The study area is comprised of 729 mi^2 (1,888 km^2) and was aggregated into 65 communities. The base-year population was 1.14 million, with 3.8 million base daily trip ends.

In the Cincinnati project, no attempt was made to analyze future alternatives using CAPM. The approach was to vary the base-year data to show the sensitivity of the program and its parameters to policy variables.

A comparison of the VMT's (VKT's) and ADT's for both the base run and the 1990 alternative run were made through least squares regression. These regressions showed that the VMT's (VKT's) for the base validation run had the same slopes as observed ground counts but varying y-intercepts. The different y-intercept is caused by not including the regional through travel in the CAPM totals. When the through travel is added, the comparison is almost identical. CAPM now includes regional through travel in all instances.

The following benefits and drawbacks of the CAPM process were expressed by ODOT:

Benefits:

• Can serve as a "first cut" evaluation of transportation proposals.

• Provides a quicker means for comparing alternatives than highway assignment.

• Can compare resulting evaluation criteria of one alternative to another.

Drawbacks:

• Too much effort is necessary for input preparation; approximately 90 percent of the 6 weeks required to produce an operational capability in CAPM was spent on data accumulation. Note, however, that conventional techniques may take 10 times as long for data preparation.

• Has difficulty duplicating highway ground counts. In some instances, volumes differ up to 50 percent from base-year ground counts. This resulted from the fact that regional through traffic was not added to CAPM travel outputs in Cincinnati.

• Does not produce carbon monoxide and other pollution concentrations; only the quantity of air pollution emissions is reported. Concentrations are preferred since they form the basis of the National Air Quality Standards.

Other CAPM Applications

After the initial testing of CAPM in the demonstration project, the prototype version was used in several other studies prior to general release on the Urban Transportation Planning System. Comments were received from Indianapolis, Ind., and Tampa-St. Petersburg, Fla., regions on their experience with CAPM.

Indianapolis

The Indianapolis, Ind., Department of Metropolitan Development used CAPM to test four alternative highway systems in the north and northeast sections of the metropolitan area.

For the base (1972) conditions, CAPM produced regional VMT (VKT) only 2 percent above ground counts. Traffic volumes on individual freeway segments also compared favorably. Based on preliminary evaluation of the four alternatives with CAPM, two alternatives were selected for detailed evaluation using conventional planning tools.

Tampa-St. Petersburg

The Tampa Bay region transportation plan is being reevaluated in light of land use alternatives for the year 2000. The Florida Department of Transportation with assistance from Schimpeler Corradino Associates has used CAPM to evaluate the highway portion of the total transportation system.

To increase the model's responsiveness to Tampa's requirements, a small number of modifications were made to the prototype CAPM. Several of these modifications have been incorporated into the current version of CAPM.

For the base conditions, CAPM produced a regional VMT (VKT) estimate within 1 percent of ground counts. The major system responses which were used to determine when acceptable results were obtained are as follows: total vehicle miles of travel (total VKT), vehicle miles of travel (VKT) by functional classification, and average daily traffic on freeway links.

It is encouraging that Tampa Bay, a major discontinuity in the assumed overall continuous arterial system, did not cause any major problems. This results from two conditions: First, the three bridges across the Bay were coded as freeways which, because of their higher level of service, attracted a large portion of those trips crossing the Bay; and second, the computed number of trips crossing the Bay is a very small part of total travel in the region because the Bay is quite large in comparison to the regional average trip distance.

CAPM was also applied to analyze Transportation System Management (TSM) alternatives consisting of actions to insure efficient use of existing roadways and to reduce vehicle use in congested areas. The policies tested included a reduction of freeway speed from 70 mph to 55 mph (112 km/h to 88 km/h) and an increase in auto occupancy from 1.45 to 1.50 persons.

Considering the limited data base and the generally comparative nature of CAPM as a sketch planning model, Florida Department of Transportation and Schimpeler Corradino Associates were impressed with agreement between CAPM output and observed values.

Summary

The Community Aggregate Planning Model is a sketch planning tool. It is an effective way to reduce the number of alternatives, so that other modeling tools may be used for final planning and design estimates.

The CAPM demonstration projects have been successful and have resulted in a number of improvements in the model. Practical experience has shown that reasonable results can be obtained with no changes to the theoretical structure of the model. This is especially encouraging because of the limited data base required for CAPM. A data set for the model system can be put together in from 1 to 2 person-months. This process is enhanced because there is no need to code extensive conventional networks. Adjusting the average work trip time for the given metropolitan area is the only necessary calibration. Changes to test alternatives can be executed in 1 to 2 days depending on the complexity of the system.

The approach used in CAPM differs drastically from conventional planning methods. Because computer costs and data preparation are greatly reduced, many alternatives can be processed within the time and budget required for the conventional analysis of one alternative. A typical case of 68 communities in Phoenix required 5.25 cpu minutes and 168 K of core to execute the Durango alternative on an IBM 360/65 system.

CAPM has proven to be sensitive to data changes in the analysis of highway related policies and the prediction of impacts of highway travel. Presently, CAPM is limited in its ability to account for transit; however, a model which explicitly deals with transit and pricing options is now being developed.

Citizen participation is becoming an important phase in the planning process. CAPM has been designed with relatively simple outputs that can be used directly for evaluation and can be understood by planners, citizens, and decisionmakers.

In conclusion, CAPM represents a new tool which can assist the planner in identifying those alternatives worthy of analysis using conventional mesolevel planning techniques. As such it fulfills its objective and represents an important addition to the tools available to the transportation planner.

Acknowledgment

The author wishes to thank the users of prototype CAPM for providing documentation of their practical experience with the model.

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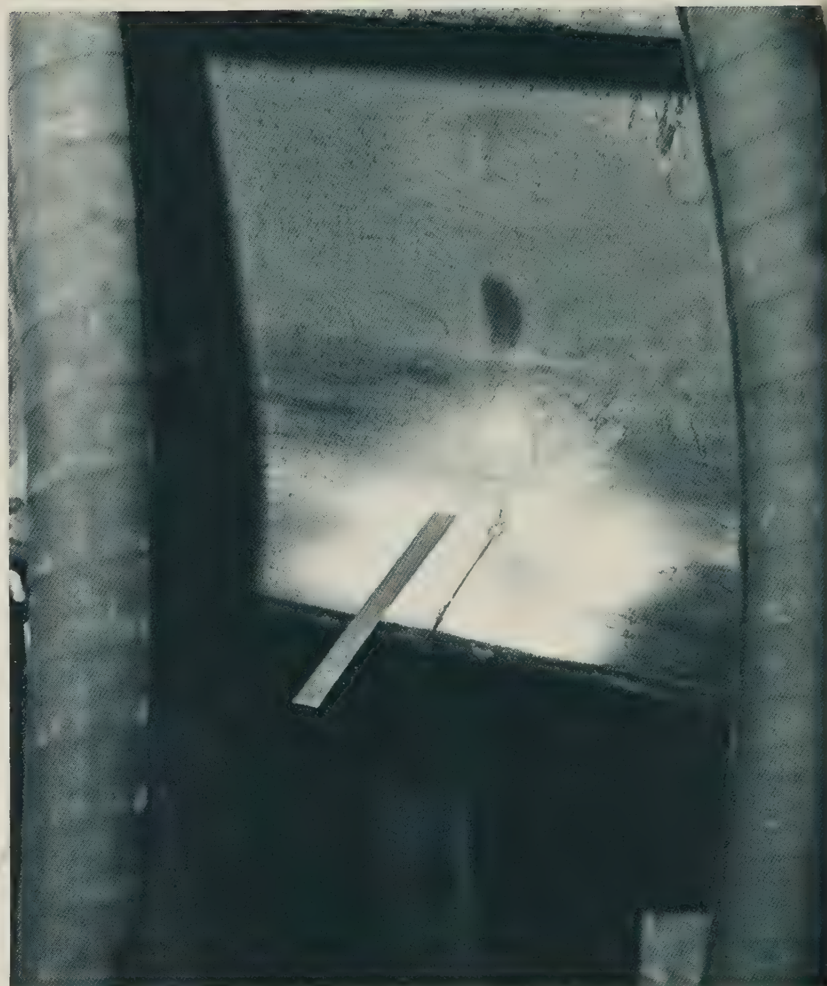
The Effect of Yielding on the Fatigue Strength of Steel Beams

by Charles F. Galambos,
Karl H. Frank,
and Charles H. McGogney



Fatigue crack in test beam.

This article presents the results of laboratory fatigue testing on wide flange rolled beams (W12x40) subjected to sinusoidal constant cycle loading. The main objective of the test was to see whether yielding of a portion of the test specimen would have any effect on the fatigue life. The behaviors of plain beams and beams with partial length welded coverplates were compared. Auxiliary material tests were also made and several nondestructive crack detection and monitoring methods were used.

The major findings of the study were that yielding of the beams had no significant effect on the fatigue life of the coverplated beams, and that the fatigue behavior of all specimens was in good agreement with similar tests by others. It was also concluded that acoustic emission technology may aid in crack detection and crack growth monitoring, and should be pursued further.

Introduction

The effect of repeated loadings on the performance of steel beams has been a subject of research for over a century, yet facets of the problem are still not well understood—or if understood, not universally made known. One facet is the influence of yielding on the fatigue life or service life of steel beams. Such yielding can occur in bridges from an abnormally heavy live load, from fabrication or erection loads, from accidents in fabrication, from vehicles striking bridge members, or from differential foundation settlements. Whatever the cause, it is thought that yielding shortens the fatigue life of the member.

In order to provide some answer to the problem of yielding with reference to differential foundation settlements, a fatigue experiment was designed and conducted at the Fairbank Highway Research Station of the Federal Highway Administration (FHWA). Various means of detecting fatigue cracking were evaluated during these fatigue experiments.

Test Design

The test was of limited scope, involving only two sets of variables: Plain rolled beams, with and without yielding; and coverplated beams, with and without yielding. Fourteen specimens were tested: three identical beams for each variable and two pilot beams.

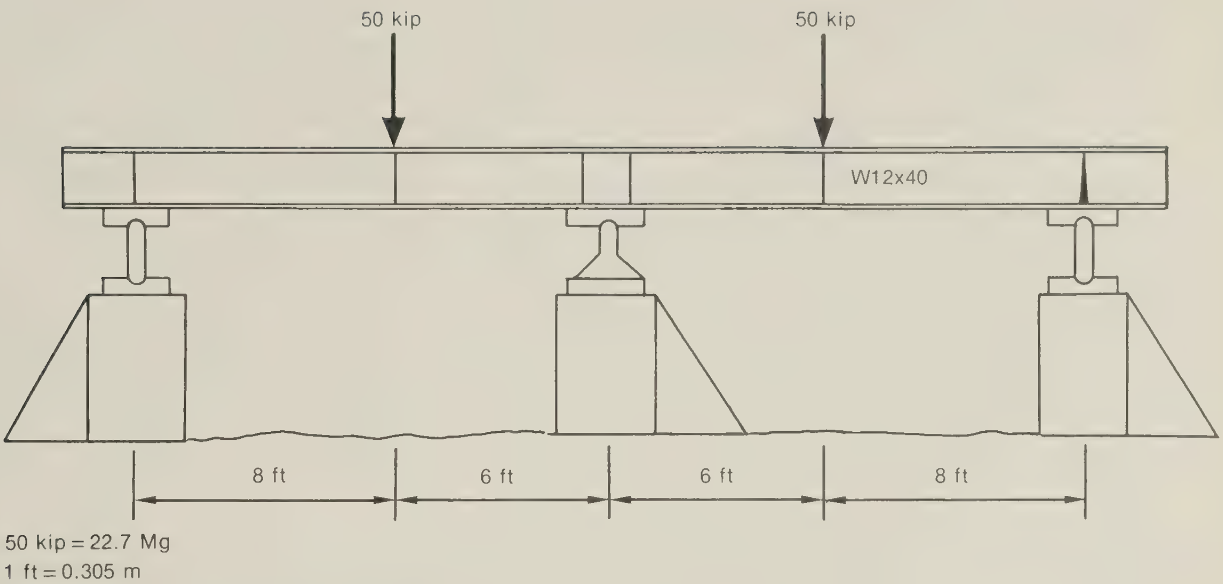


Figure 1.—Two-span continuous test setup.

Because of limited laboratory space and loading capacity, 14-ft (4.3 m) test specimens of W12x40 rolled beams were used in a symmetrical, continuous two-span setup (fig. 1). The coverplated beams had tapered, partial length, 5/16-in (7.9 mm) thick coverplates on the top and bottom. The plates were not welded across the ends. Vertical stiffeners were added at load and support points; the ends of the stiffeners were not welded to the flanges, but were tack welded to the edges of the flanges for fabrication purposes.

The beam designations were as follows:

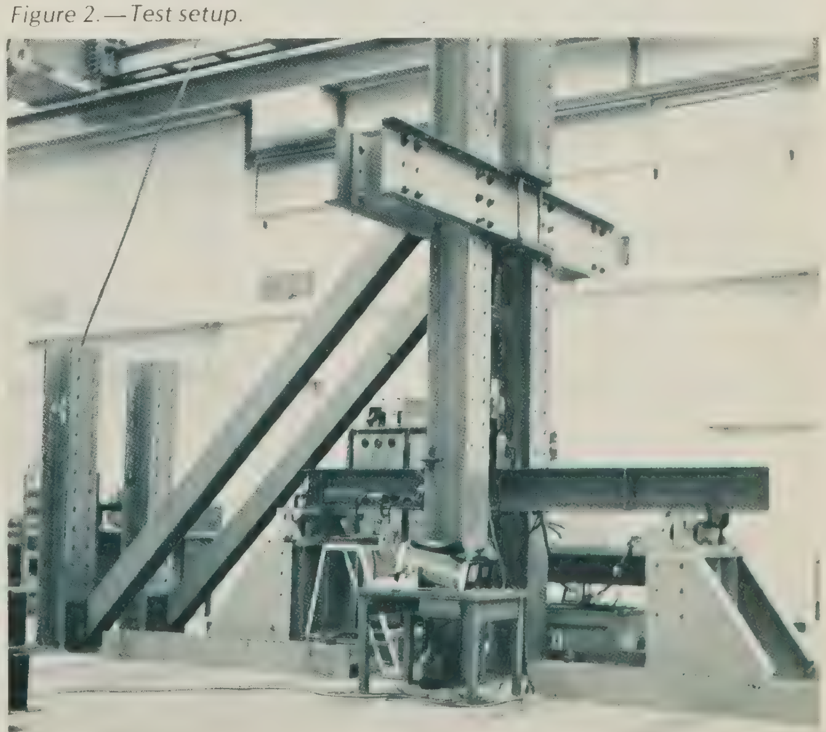
- Beam P1 was plain (without coverplates), heat No. 39P856.
- Beams P2, P3, P4, P5, P6, and P7 were plain (without coverplates), heat No. 37P852.
- Beam C1 had a tapered coverplate, no end welds, heat No. 39P856.
- Beams C2, C3, C4, C5, C6, and C7 had tapered coverplates, no end welds, heat No. 37P852.

The experiment was designed so the area of interest was always near the middle support. The loading caused the upper surface of the beam over the middle support to be in tension making observance of crack initiation and growth easier. Loading of the beams was done with two 50-kip (22.7 Mg) rams powered by an MTS servocontrolled, closed-loop hydraulic system. Although for monitoring purposes the experiment was controlled by strain gages at specific points on the beams, the loading rams were controlled by load cells. A typical test setup is shown in figure 2.

The control section on coverplated beams was 18 in (457 mm) on either side of the middle support, which was 3 in (76 mm) beyond the ends of the coverplates. The loading stresses at this section were controlled to produce the following stresses at the coverplate end: Nominal dead load stress for purposes of experimental setup stability was 2 ksi (13.8 MPa); a sinusoidal fluctuating stress of 18 ksi (124.1 MPa) was superimposed on this, for a maximum stress of 20 ksi (137.9 MPa) tension on the top surface and the same amount of compression on the bottom surface.

On the plain beams, the control section was 3 in (76 mm) beyond the midspan stiffeners—7 in (178 mm) from the midspan of the beams. The live load stress range at the stiffeners on the outside surface of the flange was 20 ksi (137.9 MPa), superimposed on a nominal dead load stress of 2 ksi (13.8 MPa).

Figure 2.—Test setup.



The bending stress range at the inside of the flange surface at the location of the tack welds and stiffener to web welds was 18.3 ksi (126.2 MPa). If any failure was to be experienced in the plain beams, fatigue cracks would most likely start at the tack welds.

Due to problems with one of the rams, the test setup was changed for some of the beams to load with one ram. This was possible only with the beams in the unyielded condition, and the stress distribution pattern was carefully duplicated over the middle portion of the beams. The specimens covered a 10-ft (3.05 m) span between simple supports in the single ram test setup. Four beams were tested in this manner before reassembling the two-span continuous setup for the yielding of the beams.

For the coverplated beams, failure was defined as the number of cycles when a crack reached the edge of the beam. Cracks often formed near all four corners of the coverplate, but one usually progressed to the edge first. For the plain beams, there were no cracks before testing was discontinued near or beyond 2 million cycles.

The *yielded* condition of the beams was defined when the flanges were fully yielded. This was accomplished by (1) shimming up the midspan of the beam, (2) pulling down on the ends with threaded tie rods, and (3) applying the nominal dead load and the live load which produced the same stress ranges that were used in the unyielded beams. In the coverplated beams, the section of interest was at the end of the coverplate; in the plain beams, the yielded section was at the stiffeners. Figure 3 shows the shims used at the center support and figure 4 shows the end tiedowns used to produce the yielded condition.

Test Results

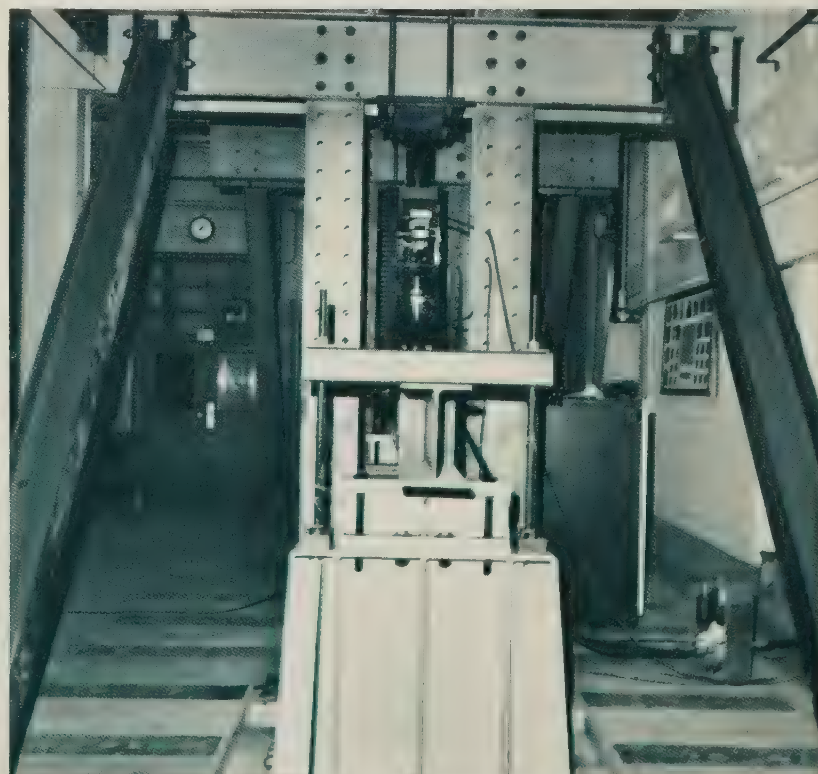
Materials tests

Although all beams were to have come from the same heat of steel, for faster procurement one plain beam and one coverplated beam were from a different heat of steel than the other 12 beams. All material was ordered to ASTM A–36 specification.

In order to have a good record of initial flaw sizes, especially any that might be the result of welding, all coverplate welds were radiographed. No flaws were discovered that had any bearing on the fatigue tests. The longitudinal residual stress in the test beam was determined by sectioning. Two feet (0.6 m) of beam P1 were sectioned in an area which contained no weldments. The strains were measured before and after sectioning with a 10-in (254 mm) Whittemore gage and electric wire strain gages. Since there were some problems with correlating the two sets of readings, the mechanical strain gage readings were considered to represent more accurately the residual stress pattern (fig. 5). The stresses shown have been balanced to provide static

Figure 3.—Shims used at center support.

Figure 4.—End tiedowns.



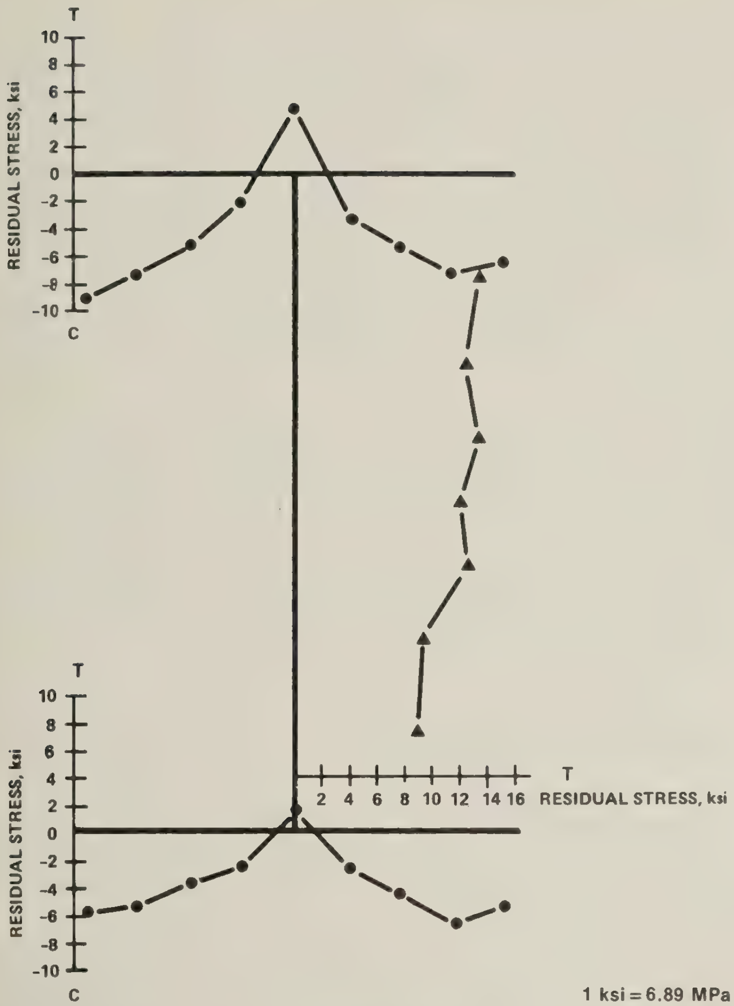


Figure 5.—Residual stresses, W12X40 rolled section.

equilibrium of the cross section. This pattern is typical of rolled wide flange sections.

The Charpy impact notch toughness was determined for the material from three of the test beams: P3, P6, and C1. The results are shown in figures 6, 7, and 8. Note the likeness in the shapes of curves P3 and P6 and the difference in curve C1. Beam C1 is from another heat of steel. Beam C1 would have met the new American Association of State Highway and Transportation Officials (AASHTO) supplemental material longitudinal CVN 15 ft-lb (20.3 J) requirement for 10° F, 40° F, and 70° F (−12.2° C, 4.4° C, and 21.1° C), but beams P3 and P6 would not have met the requirement at 10° F (−12.2° C).

Fatigue tests

Plain beams with stiffeners

Table 1 shows the plain beam test results. Only four plain beams were tested because none of the tests produced any cracks. For various reasons the tests were discontinued at varying cycles ranging from 1.5 million to over 10 million. It was not surprising that no cracks developed at a stress range

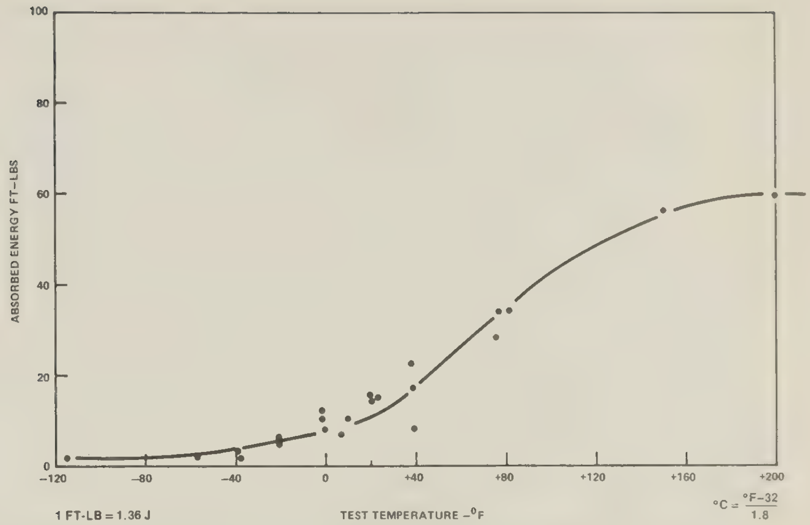


Figure 6.—Impact Charpy V-notch test results, beam P3, flange.

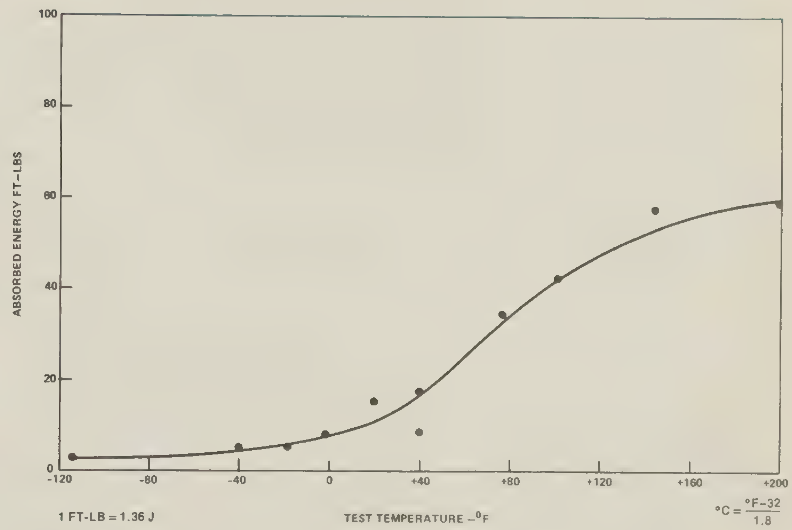


Figure 7.—Impact Charpy V-notch test results, beam P6, flange.

Figure 8.—Impact Charpy V-notch test results, beam C1, flange.

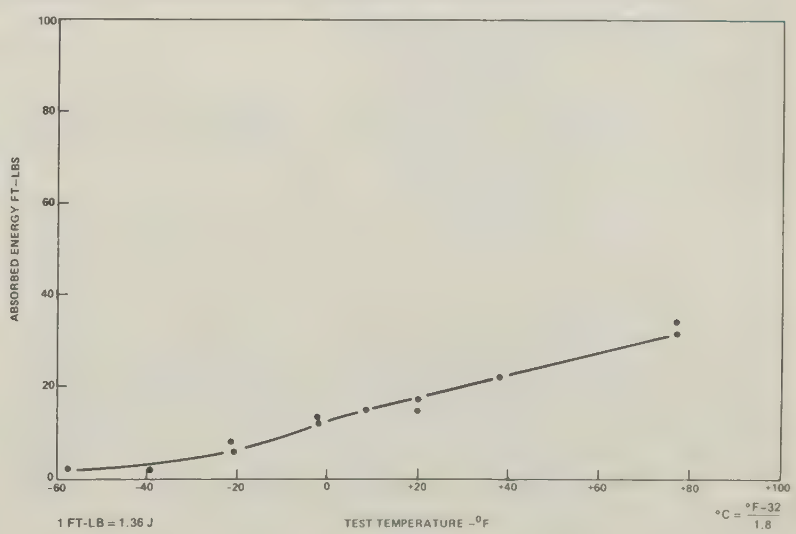


Table 1.—Fatigue test results on plain beams

Beam No.	Testing condition	No. of cycles[1]
P1	Two-span, elastic	1,589,000
P3	Two-span, elastic	1,798,000
P6	Simple span, elastic	10,073,000
P4	Two-span, yielded	2,000,000

[1]Number of cycles when tests were discontinued, no cracks were observed in any beams.

of 18.3 ksi (126.2 MPa), since in other investigations (*1*)[1] similar results were obtained for rolled beams.

Fisher (*2*), in his extensive work on beams with attachments and stiffeners, found that beams with stiffeners fully welded to web and flanges could withstand a similar stress range for over 3 million cycles. The tack welded stiffeners in the present investigation may represent an intermediate condition to the stiffener of Fisher's work. If a tack weld is considered a ¼-in (6.4 mm) flange attachment, Fisher's work showed that for this condition and an 18 ksi (124.1 MPa) stress range, over 3 million cycles were also necessary to cause fatigue crack growth.

Since the beams used showed no fatigue damage after these tests, no further tests were carried out on beams with stiffeners. In order to provide beams with well-defined crack geometrics and locations, artificially induced flaws were made, usually with a saw cut on the edge of the beam; and cyclic testing was continued for the purpose of monitoring crack growth rates and for crack detection experiments. Results from these tests are presented later in this article.

Coverplated beams

Table 2 shows the coverplated beam test results. These results concur with results from tests done at Lehigh University (*1*) and from similar tests conducted at the University of Maryland. (*3*) Partial length coverplates with no transverse end welds were compared. The fatigue tests on the yielded beams generally produced the same results as those obtained in the elastic beam tests. The various test programs had differing moment gradients at the section of interest; only the live load stress range is the common basis of comparison.

The propagation of all cracks was similar: Cracks began at the toes of the fillet welds (or very near the toe, in the weld), grew through the flange in a semicircular shape, and then extended toward the centerline and edge of the beam. As the crack tips approached the web and flange edge, crack growth toward the flange edge accelerated. A view of a typical fracture surface is shown in figure 9.

Crack growth observation

Crack growth measurements were made on a plain beam with a saw-cut-produced edge notch. The measurements were

Table 2.—Fatigue test results on coverplated beams

Beam No.	Testing condition	No. of cycles to failure
C1	Two-span, elastic	627,700
C2	Simple span, elastic	442,500
C4	Simple span, elastic	700,900
C5	Simple span, elastic	574,100
C6	Two-span, yielded	524,600
C7	Two-span, yielded	457,900
C3	Two-span, yielded	458,200

Note: Stress range is 18 ksi (124.1 MPa) at ends of coverplates.

[1]Italic numbers in parentheses identify the references on page 17.

Figure 9.—Cracked beam face.

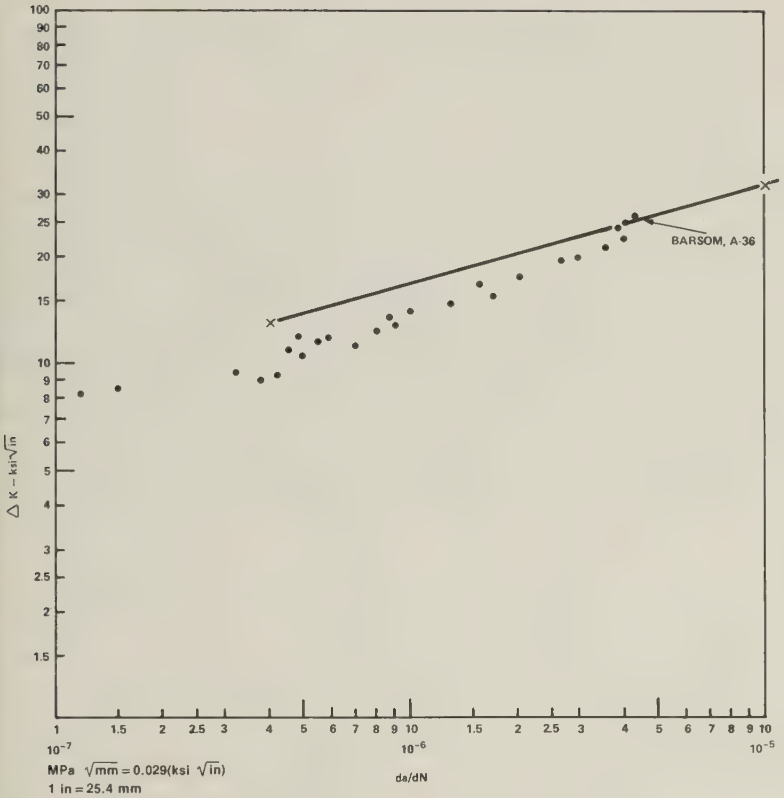


Figure 10.—Comparison of crack growth rates.

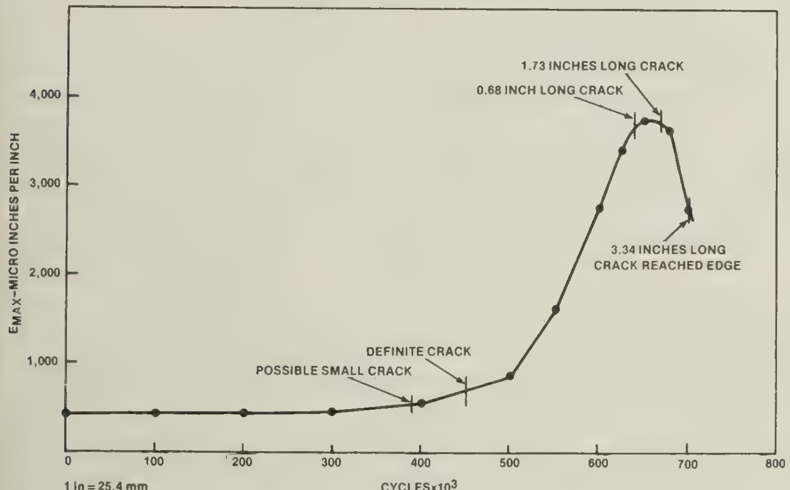


Figure 11.—Crack detection by strain accumulation.

made with a variable power, stereoscopic, zoom microscope. The results were analyzed using fracture mechanics to relate the range of the stress intensity factor, ΔK, to the rate of crack growth. The stress intensity factor was estimated using the equation for an edge crack in a plate. The plate width was taken as the flange width and the stress range of 18 ksi (124.1 MPa)—the outer fiber stress of the beam at the crack location—was used for the calculation of ΔK. A comparison of the measurements with results from previous investigations by Barsom (*4*) is presented in figure 10. The comparison appears to be very good.

Auxiliary Nondestructive Tests

Throughout the fatigue testing, several nondestructive testing (NDT) techniques were tried in order to discover cracks as early as possible and to gain experience in the application of more modern NDT techniques such as acoustic emission.

Strain accumulation

Other investigators (*3*) had reported some success in discovering the onset of fatigue cracking by monitoring the strains accumulated in electric strain gages placed near the areas where cracks were expected. Since in the coverplated beams the crack formation could be expected with reasonable certainty at the toes of the fillet welds, this method was tried on one of the coverplated beams, C4. Gages were placed near each of the four fillet weld terminations, even with the ends of the plates. The gages were directly underneath the toes of the welds on the bottom of the top flange. Minimum and maximum static strain readings were made at intervals during the tests and compared with careful visual inspection of the toe end region. The readings for one gage are presented in figure 11. The figure shows that in a laboratory environment, if it were known exactly where to place the strain gages, it might be possible to indicate crack initiation before a crack is visually detectable.

On the first beam tested, P1, some commercial S/N[2] fatigue gages were tried. These gages work on the principle of accumulating a change in resistance caused by repetitive loading. If they are calibrated with a known crack formation behavior, they can be used to predict fatigue damage. The use of these gages was not successful because of the small strain range used in the fatigue loading. No measurable change in resistance was observed. Recently developed S/N gages employ a strain multiplying device which may help to overcome the small strain limitations. However, no further experimentation with this gage was made in the subsequent tests.

Other NDT techniques

Several more common NDT flaw detection techniques were used throughout the testing of the coverplated beams. These included dye penetrants, magnetic rubber, magnetic particle, conventional ultrasonics, and the recently developed Acoustic Crack Detector/Magnetic Crack Definer (ACD/MCD). (*5*) All of these methods were useful in defining the limits of a crack at any one time, but because one knew exactly where to look, careful visual observation with good lighting and the aid of a pocket magnifier usually resulted in

[2] S/N = Stress versus number of cycles.

the discovery of a crack before its discovery by these other methods.

Acoustic emission

Acoustic emission technology has not been applied widely in structural fatigue applications of highway bridge members. Therefore considerable effort was spent investigating the usefulness of this method for discovering fatigue cracks as early as possible and monitoring crack growth.

The instrumentation used was a Dunegan Series 3,000 system, consisting of a totalizer, audio monitor, log converter, reset clock, pre-amplifiers, and assorted transducers. A strip chart recorder served as the recording device for the acoustic emissions. Later in the study more components were added to the system: two more totalizers, two flaw locators, a voltage control gate, and a memory oscilloscope.

The equipment used in this study makes use of frequency filtering; amplitude discrimination through a variable gain amplifier; spatial filtering using a one-dimensional, time-of-arrival gate; and load related filtering using the load signal to control the duration and location with respect to the load when signals are accepted by the equipment. These various forms of filtering were used to isolate meaningful emissions from extraneous noises in the test setup. The emissions referred to in this study are counts of the number of times the amplified signals exceed a fixed threshold of 1 volt.

One unique part of this limited study was the use of amplified strain gage signals to provide the gating signal for the system. An AC amplifier was used to eliminate drift due to temperature and the resulting signal provided a stable trigger for the gate. This type of gating appears to be a useful way to gate signals from structures tested in the field subjected to traffic loadings.

The instrumentation was first attached to beam P6. Since this beam did not develop any cracks, only the mode of operation was worked out. A more fruitful study resulted from listening for cracks on beam C7, a two-span, coverplated, yielded specimen. Readings were made during the generation of the support settlement by pulling down the ends of the beam. An example of results is shown in figure 12. Most of the noise is generated over the length of the coverplate, where yielding would be expected to occur. These results looked very promising; however, detection of emission during this operation was enhanced by the relatively quiet method of loading the specimen.

The monitoring of emissions during the fatigue testing of beam C7 was continued in the hope of isolating the fatigue crack formation process; but in spite of a great deal of experimentation with settings and transducer locations, it

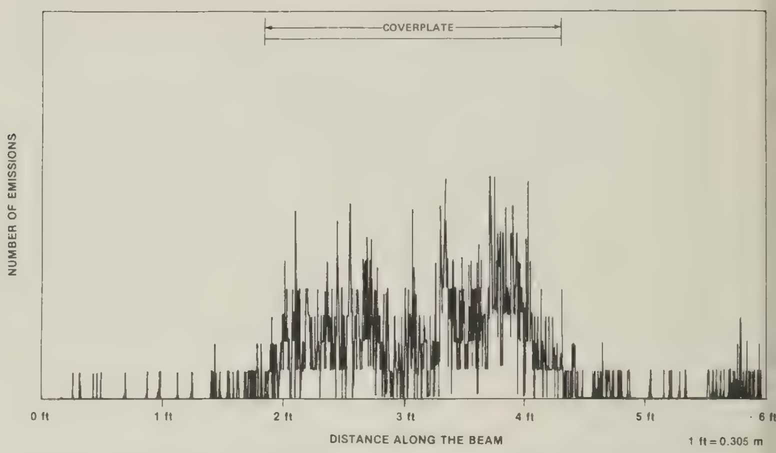


Figure 12.—Acoustic emissions from the yielding of beam C7.

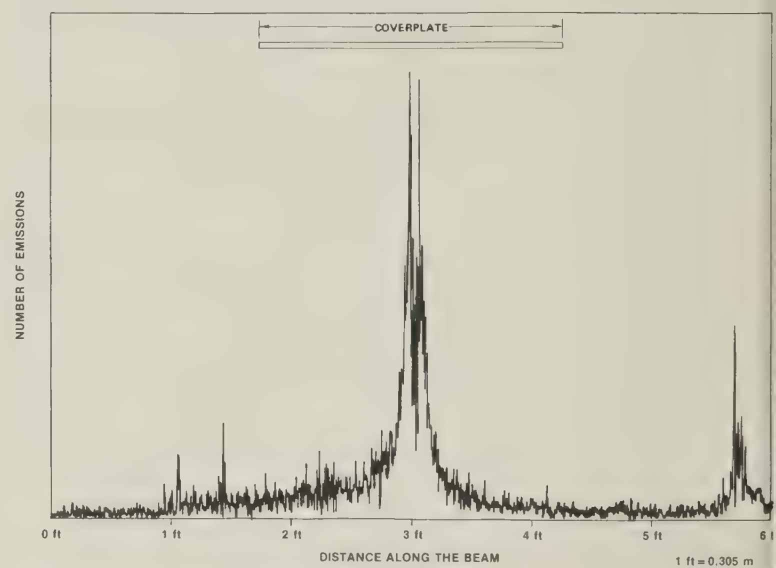


Figure 13.—Acoustic emissions from beam C7.

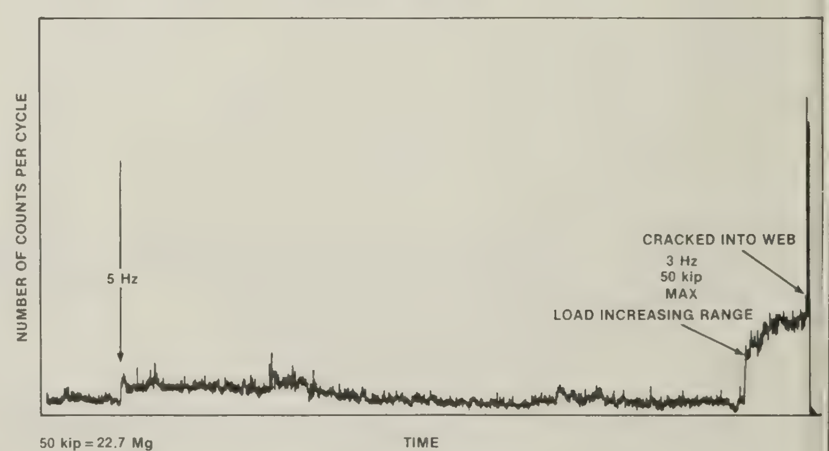


Figure 14.—Acoustic emissions from beam P4.

was never positively established that a crack could be discovered in this way. With two loading jacks and three supports all producing noises, it was impossible to isolate noises from a crack. The middle rocker support was especially troublesome, as shown in figure 13.

Further experimentation with the system was continued on beam P4, where an edge crack had been started on the top flange with a saw cut. Again, it was not possible to isolate the start of crack extension, nor did it prove fruitful to follow crack growth. Only at the end of the experiment when the crack began to extend into the web was there a definable increase in acoustic activity, as shown in figure 14.

The collection of acoustic emissions to discover and monitor fatigue cracks was only marginally successful with this laboratory fatigue experiment. The following parameters were found workable in this setup. The 5- to 6-ft (1.5 to 1.8 m) spacing between transducers appeared satisfactory, and a 60–80 microsecond voltage control gate opening permitted sufficient time to collect emissions on the rise side of the loading cycle. The system gain of 80 to 100 decibels was adequate, and a threshold setting of 0.1 to 0.3 megahertz gave a sufficient window to allow all desirable emissions to enter. Further work in this area is encouraged.

Vibration analysis, Randomdec

A somewhat different approach to flaw detection was tried in the fatigue test of beam P6. The approach consisted of analyzing changes in vibration signatures of a member and relating these changes to crack initiation and growth. The main tool used in the analysis is a process called "Randomdec," short for "random decrements." Randomdec is a method that takes segments of a random time history which start at a constant amplitude, selected by logic circuits, and averages them to form a curve which is called the "Randomdec signature." For single degree-of-freedom linear systems excited by white noise, the Randomdec signature is identical in form to the autocorrelation function; but for multidegree-of-freedom systems and nonlinear systems, it differs in that the cross products (off-resonant vibrations) are absent.

Although it was not possible to detect cracks smaller than about 3/4 in (19 mm), the method did show a difference in crack lengths with increasing stress cycles. A sample of signatures is shown in figure 15. The differences in signatures are obvious, but the meaning of the differences is not. Subsequent Randomdec research will seek to provide more definitive answers.

Summary and Conclusions

This article presents the results of a laboratory fatigue study on W12x40 rolled beams subjected to sinusoidal constant cycle loading. The main objective of the study was to see whether yielding of a portion of the test specimen would have any effect on the fatigue life. Plain beams and beams with partial length welded coverplates were tested.

Auxiliary materials tests and a number of nondestructive crack inspection and monitoring methods accompanied the conduct of the fatigue experiments.

The following conclusions are based on the results of the tests:

- Yielding of the beams had no significant effect on the fatigue life.
- The fatigue behavior of the beams was in good agreement with similar tests by others.
- The single-span, simply supported beam tests correlated well with the two-span, continuous beam tests. The moment gradient for the two types of tests was different and had no effect on the fatigue life; the nominal stress range was the only dominant factor.
- Of the several methods used to try to determine crack initiation, none can be classified as definitely successful. Because the location of possible crack formation was precisely known, visual inspection with nominal magnification was the most successful crack discovery method.
- Crack growth rates as measured in this study agree very well with those measured on mild steels by others.
- Monitoring of crack growth by using acoustic emission technology was only marginally successful, although a mode of operation was established. More work needs to be done on isolating meaningful emissions from background noise.

Acknowledgment

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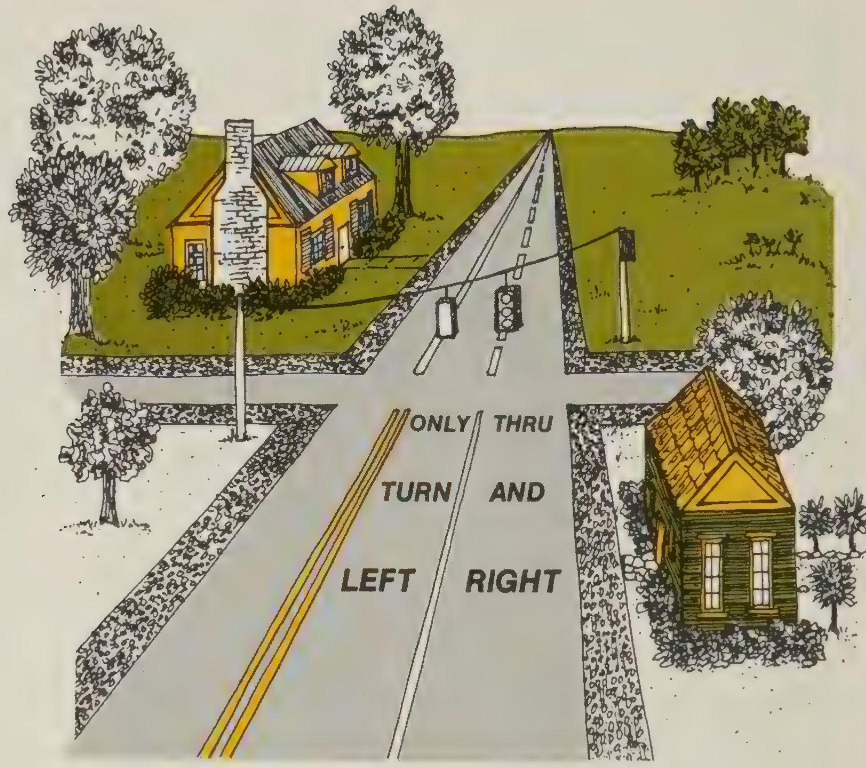
Marking of roads — Codes
Gordon, Donald A.

Studies of the Road Marking Code

by[1] Donald A. Gordon



Background

Road markings and delineations form a code for conveying information to the driver. The basic elements of the code are yellow versus white color, continuous versus broken pattern, and single versus double line. Particular combinations of these elements have specific meanings. For example, a single broken yellow line indicates that traffic on the other side of the line is traveling in the opposite direction and that a driver may pass a car in front, but only with extreme caution. A lane marked by a double broken yellow line carries reversed traffic at different times of the day. The 20 combinations of the 3 elements of the code can deal with 20 basic situations (fig. 1).[2] However, the Manual on Uniform Traffic Control Devices (MUTCD) system excludes the eight mixed yellow and white markings and three of the four broken white combinations. The nine remaining combinations represented in the system are indicated in figure 1. Basic applications of the system are shown in figure 2.

Foreign marking systems, developed independently of our own, are somewhat different. The British, German, Dutch, and Swiss road markings use only white lines. Different meanings are expressed by dashing or doubling the lines. In the United States, separation of flow in opposing directions is indicated by yellow lines, in England and Sweden by broken lines, and in Germany and the Netherlands by both solid and broken lines. Yellow markings designate locations where it is unsafe to pass or change lanes in Finland, Japan, and Switzerland, and to show pavement edges in South Africa, Italy, Israel, and Canada.

Objective of Study 1—Drivers' Understanding of Road Markings

The study objective was to assess drivers' understanding of the U.S. road marking code. Although the code is quite complete and covers most traffic applications, its effectiveness in terms of driver understanding and response remains a question. Essentially, road markings are intended to satisfy the driver's needs and requirements.

The driver's comprehension of road markings was studied by means of a four-part questionnaire. In addition to the driver description sheet, the questionnaire included sections on drivers' needs for various marking applications, drivers' understanding of the marking system principles, and drivers' ability to interpret marking principles in actual road situations shown on movie film.

The questionnaire was administered to two groups. The first consisted of 104 persons in the Offices of Research and Development (R&D), Federal Highway Administration. This group included technicians, group leaders, and secretaries. The second group consisted of 126 Coast Guard recruits and officers stationed at Cape May, N.J., and 24 Federal Aviation Administration employees.

[1] This article is a condensation of the report "Studies of the Road Marking Code," Report No. FHWA-RD-76-59, *Federal Highway Administration*, Washington, D.C., April 1976.

[2] Lines may also be thickened, and the broken lines may be shortened.

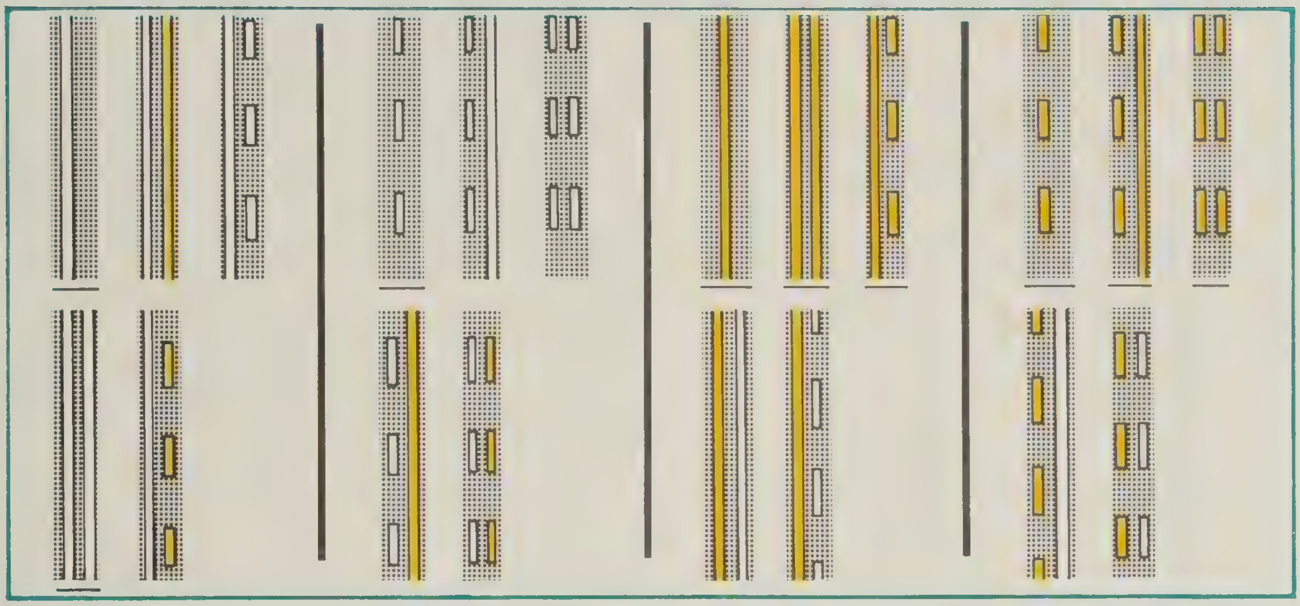


Figure 1.—Possible road marking patterns. The underlined combinations are in the MUTCD system.

Figure 2.—Road marking applications.

Results of Study 1

Drivers graded each marking application in one of four categories: (1) Neither sign nor pavement marking is needed, (2) only a sign is necessary, (3) both sign and pavement markings are needed, and (4) only pavement markings are necessary. The first two categories of response are particularly significant since they indicate disagreement with present marking usage. The third and fourth response categories indicate support for a marking.

Drivers seemed generally satisfied with present road markings. In 5 of the 15 applications that were rated, more than 90 percent of both test groups responded with category 3 or 4, that is, agreed with present marking practices. These applications are listed below and the percentage of agreement in each test group is indicated:

- To show the boundaries of the road at night (R&D—97 percent, Coast Guard—91 percent).
- To indicate the lane borders of a curve at night (R&D—98 percent, Coast Guard—91 percent).
- To show you where to pass (R&D—98 percent, Coast Guard—92 percent).
- To show the boundaries of the road in rain or fog (R&D—96 percent, Coast Guard—92 percent).
- To indicate a pedestrian crosswalk (R&D—95 percent, Coast Guard—96 percent).

These favored applications mainly concern markings used to show the driver's path of travel under adverse conditions or when he or she is performing a difficult maneuver.

Seven of the marking applications were considered troublesome due to the fact that 10 percent or more of both test groups *disagreed* with the present marking practices and answered with response category 1 or 2. These applications and the percentages of disagreement are as follows:

- To advise you where to slow when approaching a toll booth (R&D—36 percent, Coast Guard—25 percent).
- To indicate a narrow bridge (R&D—34 percent, Coast Guard—46 percent).
- To tell you where to stop at a stop intersection (R&D—33 percent, Coast Guard—32 percent).
- To indicate the path on a left or right turn to a cross street (R&D—25 percent, Coast Guard—31 percent).
- To indicate "right and through" by a printed message on the road (R&D—18 percent, Coast Guard—24 percent).
- To indicate obstruction in the road (R&D—13 percent, Coast Guard—16 percent).
- To indicate "left turn only" by a printed message on the road (R&D—10 percent, Coast Guard—16 percent).

These troublesome marking applications attempt to communicate messages which a driver may find difficult to interpret or which he or she may consider unnecessary. These usages might well be reviewed to see if a more effective method of communicating the message can be found.

The remaining three applications were considered favorable by the R&D group (less than 10 percent disagreement) and troublesome by the Coast Guard group (more than 10 percent disagreement):

- To guide you when entering a highway (R&D—6 percent, Coast Guard—13 percent).
- To guide you when exiting from a highway (R&D—6 percent, Coast Guard—18 percent).
- To guide you on lane drops (R&D—5 percent, Coast Guard—11 percent).

Answers to the questions on drivers' understanding of road markings indicated that drivers knew the meaning of the double solid yellow lines and the combined solid-broken yellow lines which prohibit passing. However, most markings were not understood. When asked to give definitions for road markings, many drivers gave wrong or nondefining answers (table 1). A wrong answer was one which was at least partly contradicted by the MUTCD interpretation. The definition "to separate lanes" was a nondefining answer because all types of road markings separate lanes. The single *wide* white marking was wrongly defined by 67 percent of the R&D group and 57 percent of the Coast Guard group; 12 percent of the R&D group and 25 percent of the Coast Guard group gave

Table 1.—Drivers' understanding of road markings

Marking	Wrong answers		Nondefining answers		Total incorrect	
	R&D	Coast Guard	R&D	Coast Guard	R&D	Coast Guard
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Single wide white	67	57	12	25	79	82
Single solid white	63	55	7	19	70	74
Double broken yellow	26	43	5	11	31	54
Single broken yellow	14	21	8	15	22	36
Single broken white	15	18	11	34	26	52
Double solid yellow	5	8	1	0	6	8

nondefining answers. The single solid white marking was wrongly defined by 63 percent of the R&D group and 55 percent of the Coast Guard group and nondefining responses were given by 7 percent of the R&D group and 19 percent of the Coast Guard group. The double broken yellow marking is intended to show that traffic in these lanes reverses direction. Although many subjects gave answers not definitely incorrect, only 13 percent of the R&D group and 3 percent of the Coast Guard group mentioned the essential point that the marking indicates reversible traffic movement. The single broken yellow line signifies that traffic in the adjacent lane is moving in the opposite direction and that passing is permitted in both lanes. Only 27 percent of the R&D group and none of the Coast Guard recruits mentioned these two descriptive items.

Respondents did not recognize that it is illegal to pass on the highway shoulder. A majority thought passing is allowed when the double solid yellow lines or the combination solid-broken yellow lines are on the left. The prohibition against passing on the highway shoulder needs wider publicity.

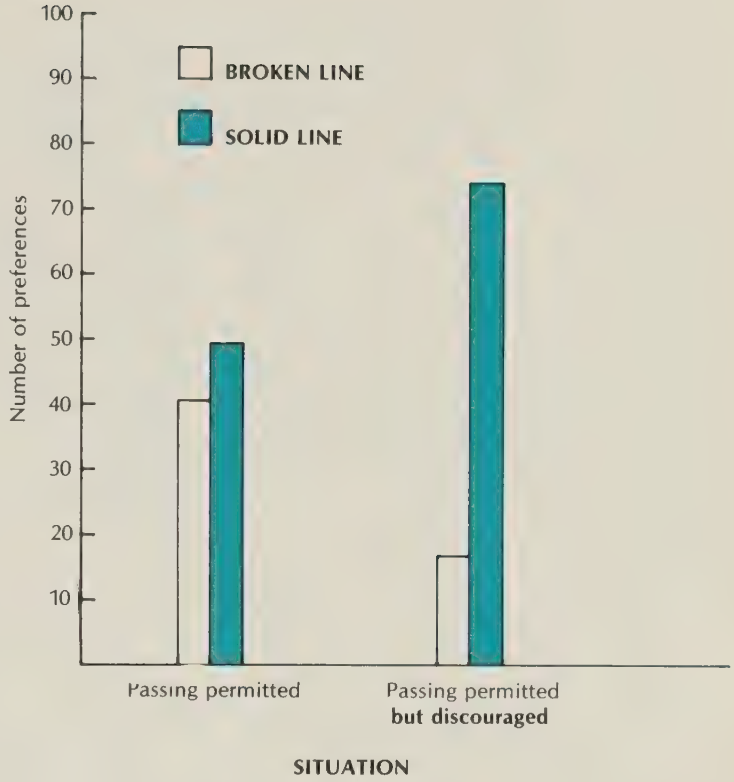


Figure 3.—Lane marking preference shifts associated with changed wording of questions.

Objectives of Study 2

Study 1 indicated drivers' problems in understanding the present road marking system. In Study 2 drivers were asked to design a new and presumably better system. They did this by selecting "the most logical and understandable" markings to fit a variety of common highway situations. Eleven markings were shown, nine of which are listed in the MUTCD (fig. 1). The two markings not in the MUTCD system were a combination solid and broken white marking and a combination solid yellow and broken white marking.

An additional objective of Study 2 was to investigate drivers' associations (stereotypes) related to the elements of the marking code, that is, white-yellow, single-double, and solid-broken lines. The same situation was presented in two ways, one of which was calculated to bring out the stereotype. For example, the subject was asked to suggest a marking for the following situations:

- The center marking of a two-lane highway (one lane in each direction) where traffic heading in both directions is legally permitted to overtake and pass.
- The center marking of an *extremely hazardous* two-lane highway (one lane in each direction) where traffic heading in both directions is legally permitted to overtake and pass. The shift in subjects' answers revealed the population stereotypes associated with hazard on the highway.

Each question of Study 2 was accompanied by a simplified drawing of the vehicle's path and the road position where the judgment was to be made.

The test sample consisted of 23 Baltimore city firemen 24 to 56 years old and 73 Coast Guard recruits 18 to 23 years old. The Coast Guard subjects were part of the group that had been tested in Study 1. All subjects were licensed drivers and had been driving for at least a year.

Results of Study 2

In some cases, subjects' choices coincided closely with the MUTCD recommendations; in others they did not. Choices showing strong agreement with the MUTCD included the single broken white marking used to separate lanes of traffic moving in the same direction, the double solid yellow center marking of a four-lane two-way highway, and the single solid white curb marking. These markings are associated with definite driver actions: The double solid yellow line may not be crossed legally, the single broken white line gives maximum permissiveness for crossing, and the single white curb marking is a logical choice. Yellow could possibly be employed for this last choice, but it usually indicates a "no parking" curb area.

Subjects relied mainly on their recall of prevalent road markings in making their choice of markings. They were asked the question "In selecting your markings, do you feel that you used essentially the same road marking system that

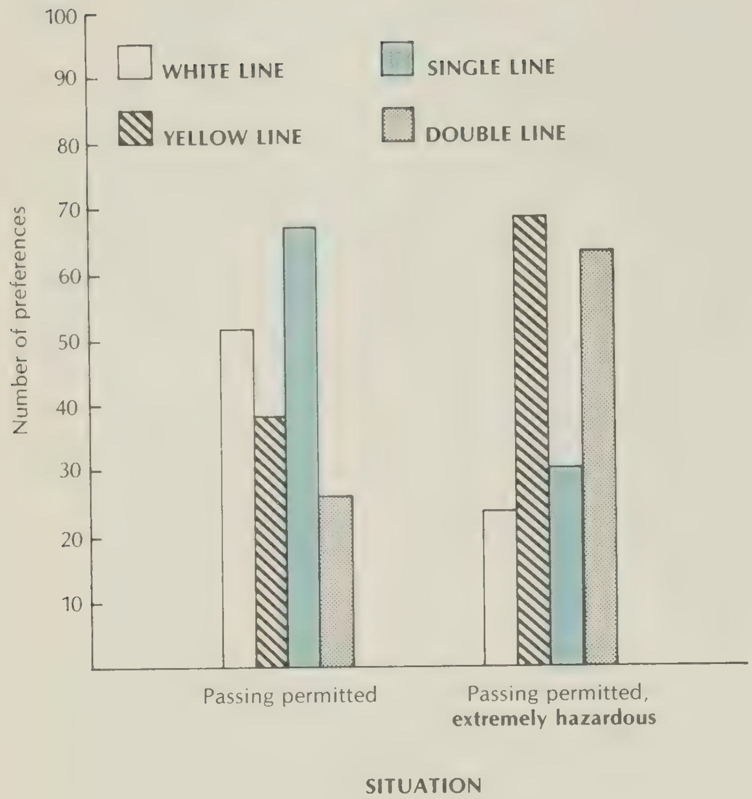


Figure 4.—Lane marking preference shifts associated with changed wording of questions.

you observe on the highways?" Sixty-eight of the 85 persons who responded to the question (10 did not respond) agreed that they chose essentially the same road marking system they observed on the highway.

Two sets of questions were intended to uncover drivers' interpretations of color, broken-solid, and single-double code characteristics. Question 5 asked for the "center marking of a two-lane highway (both lanes in one direction) approaching a fork. NOTE: Passing over the proposed marking is permitted." Question 4 was worded the same way except that the words "but discouraged" were added after "permitted." This change in wording caused a major shift in subjects' answers (fig. 3). Question 5 elicited 41 broken line and 49 solid line marking choices. The addition of "but discouraged" resulted in 17 broken and 74 solid choices. The shift from broken to solid markings exceeds the 0.01 probability by chi-square test of significance. Evidently drivers associated the solid line with discouragement of passing or crossing.

Question 6 concerned "the center marking of a two-lane highway (one lane in each direction) where traffic heading in both directions is legally permitted to overtake and pass." Question 8 was similarly worded, except that the two-lane highway was described as "extremely hazardous." Answers to these questions are revealing. As shown in figure 4, there is a conspicuous shift from white to yellow and from single to double line markings when the situation is described as hazardous. However, yellow color was not evoked by the statement that the highway was two-way.

Application of the Findings

These studies have implications for motorist education and for changes in the design of markings to make them more effective and easier to use. Motorist education may be required where the drivers show a lack of understanding of basic system principles or of specific markings needed for safe travel. The assumption is that the system itself is well designed to convey essential information. If not, changes may be required in the code.

The research findings indicate that the driver could profit from instruction in the meanings of the markings. Seventy percent of the R&D group and 74 percent of the Coast Guard group gave wrong or nondefining definitions of the single solid white line. Over a quarter of the respondents wrongly explained the single solid white lines, the single solid *wide* white line, the double broken yellow, the single broken yellow, and the single broken white lines. Over half the drivers thought the solid white line could not be crossed at a fork and over half the Coast Guard group thought it was not permissible to cross the white line at an intersection. In addition, drivers do not understand coding colors used to show the direction of travel on adjacent lanes. It is necessary to educate drivers on system principles and the prohibition against passing on the road shoulder.

Since drivers did not understand the code meaning of yellow, the use of yellow to show the separation of countermoving traffic should be questioned. In most cases, a two-way road is clearly exhibited to the driver by the nature of the highway and the movement of traffic. Travel direction need not be continually exhibited in situations such as two-way country roads, gores, and passing zones. At critical and dangerous locations, this information is signaled to the driver by the one-way regulatory signs and two-way warning signs presently prescribed in the MUTCD. The use of yellow as center marking on rural and urban roads and incorrectly on pedestrian crossings, gore areas, and parking lots weakens the hazard connotation of the color. Yellow markings should be used only where hazard truly exists—railroad crossings, bus stops, left turn channelizations, dangerous curves, and highway repair areas.

Acknowledgment

The author would like to thank Mr. Joseph Peters and Mr. Ernest Lareau, Traffic Systems Division, Office of Research, FHWA, for their valuable assistance in this study.

Evaluation of Speed Control Signs for Small Rural Towns

by Joseph S. Koziol, Jr., and Peter H. Mengert

This article describes the results of a comprehensive experiment dealing with speed control and driver behavior when approaching and driving through small town speed zones on a high-speed, rural, two-lane highway. The basic objective of the experiment was to develop safe practical traffic control devices which alert drivers to the need for speed reduction when approaching concentrated areas of rural population and invoke voluntary compliance with the speed regulatory devices, thereby increasing safety in vehicle operation. Twelve different configurations of speed limit signs and warning devices were evaluated at the Federal Highway Administration's (FHWA) Maine Facility in the small town of Palmyra, Maine, located along U.S. Route 2. The speed regulation in effect for all sign configurations was 35 mph (56 km/h). Results showed the following:

- **Traffic activated warning signs were the most effective (statistically significant) for both day and night conditions.**
- **During the day, signs with flashing beacons were second in effectiveness.**
- **At night, pavement markings and rumble strips were second in effectiveness.**

Introduction

The problems associated with speed control in small villages and towns in rural areas are familiar to highway and traffic engineers throughout the country. These problems become more acute on two-lane rural roads which also serve as main streets when they pass through rural villages.

The open stretches of roadway through sparsely settled rural America coupled with low traffic volumes are often conducive to high-speed traffic. In addition, the development density or population density of the small towns linked by these two-lane roadways is often not large enough to alert the driver to the need to slow down. Under the ideal situation, the driver should slow down well in advance of the edge of town, that is, *in advance of the location where hazards may actually exist*. However, since no hazard is visually apparent, the driver may delay action beyond the point that allows safe vehicle operation.

Small towns with a two-lane highway "main street" are highly susceptible to this type of potentially hazardous operation. Even where the devices and procedures set forth in the Manual on Uniform Traffic Control Devices

Figure 1.—Test site for Palmyra Town Experiment (sign condition 3 locations shown).

(MUTCD) are strictly applied, the problem of obtaining driver compliance still remains. (*1*) [1]

Little research has been done to evaluate driver compliance with various speed regulations in a small town, two-lane rural highway environment, although hundreds of towns and villages in the United States could benefit from improvements in this phase of speed control. Reported here is an experiment conducted at the FHWA's Maine Facility (*2*) in Palmyra, Maine (population around 100), where 12 different configurations of speed limit signs and warning devices were evaluated.

[1] Italic numbers in parentheses identify the references on page 31.

Test Site Description

The test site for the Palmyra Town Experiment is shown in plan and profile view in figure 1. Twenty-two vehicle detector stations (nodes) were used to completely instrument the roadside providing consecutive vehicle speed profiles. All nodes were 200 or 400 ft (61 or 122 m) apart. The speed zone through the test site was approximately 3,400 ft (1,036 m) long. The total length of the test site, 6,200 ft (1,890 m), included a 1,400-ft (427 m) approach roadway on each end of the reduced speed zone. Two main intersections and several driveways leading to and from private homes and businesses were within the test site boundary.

Sign Configuration

Twelve different sign configurations were evaluated in the experiment. These were tested over 9 separate time periods (2 weeks each) and for each direction of travel (eastbound and westbound), making a total of 18 conditions tested. A pictorial representation of the sign configurations tested and their locations is shown in figure 2. The configurations included passive signs (sign conditions 1, 5, and 8—both directions; sign conditions 2, 3, and 4—eastbound); signs with flashing beacons (sign conditions 2, 3, and 4—westbound); a symbolic advance warning sign (sign condition 6—westbound); traffic activated warning signs (sign condition

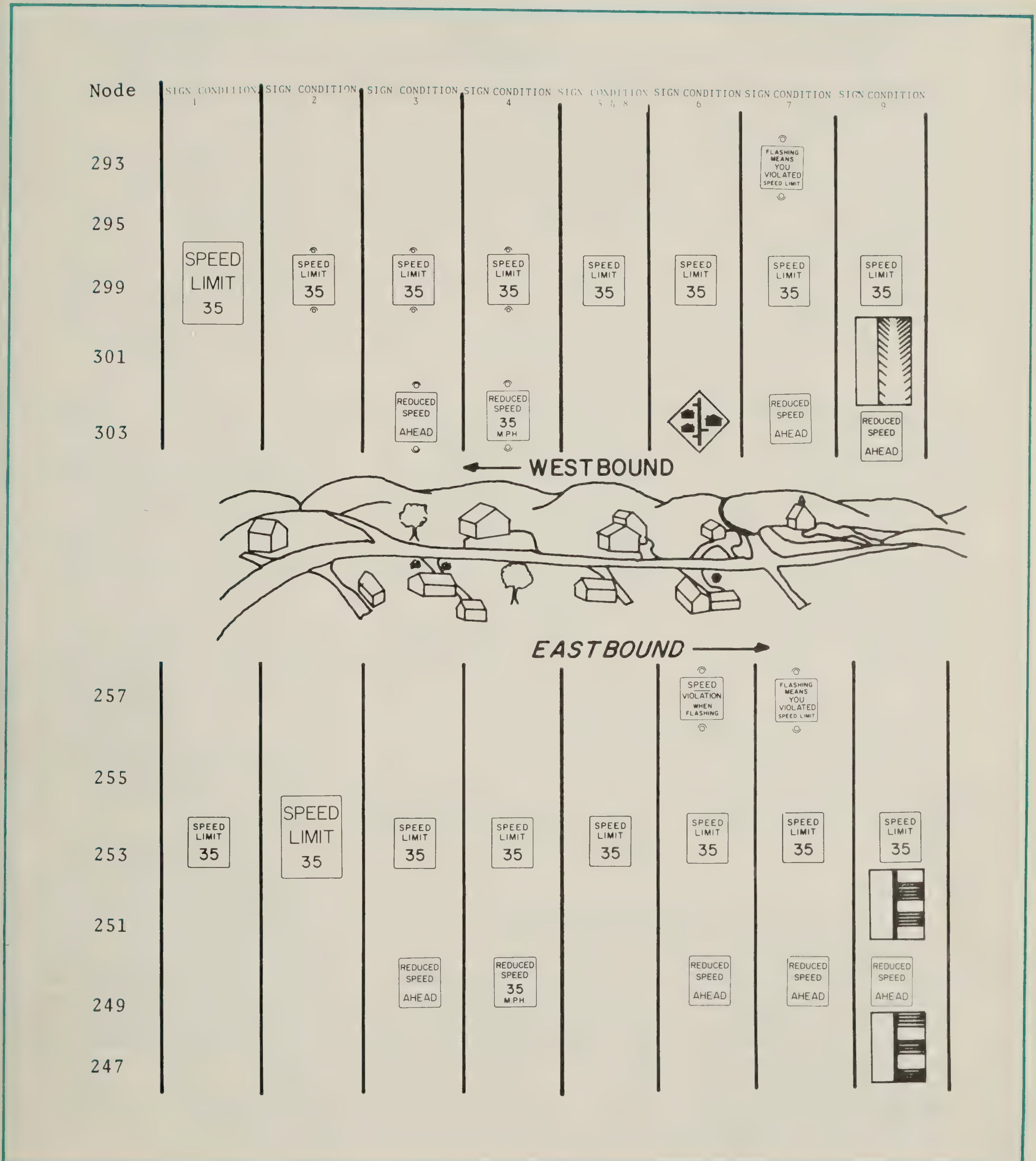


Figure 2.—Sign configuration sequence.

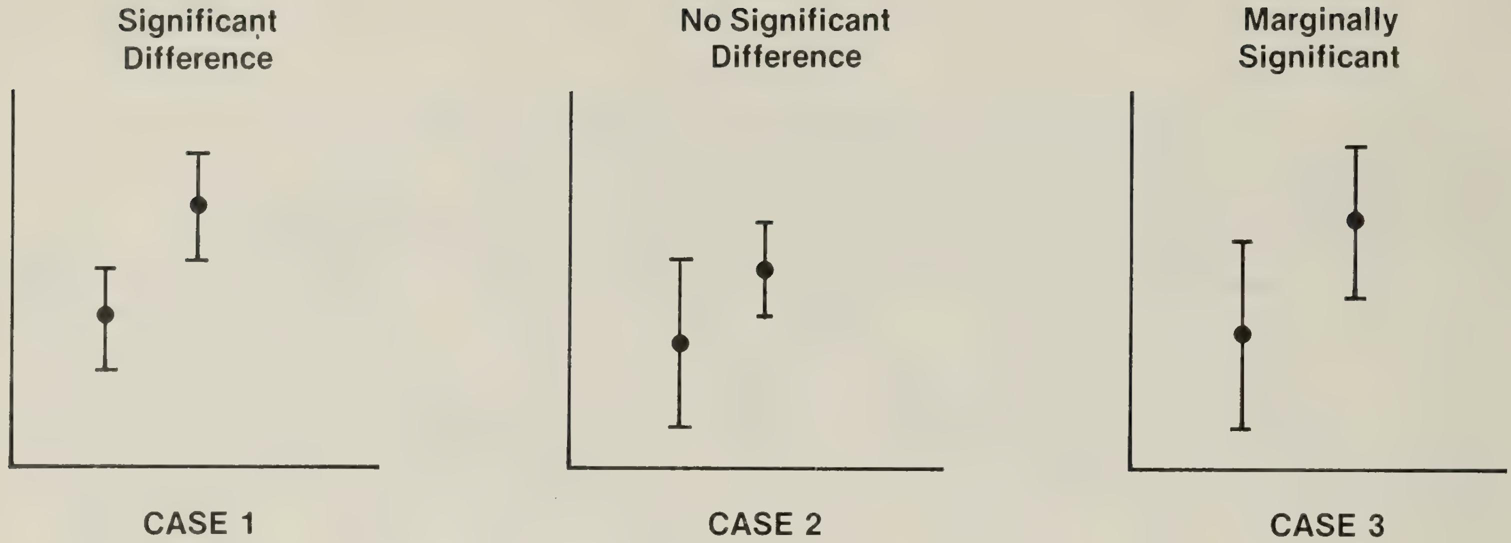


Figure 3.—Error bar overlap interpretations.

6—eastbound; sign condition 7—both directions); rumble strips (sign condition 9—eastbound); and pavement markings (sign condition 9—westbound).

These configurations were selected because of their low cost and high likelihood for acceptance and application by State agencies responsible for speed control and safety on rural highways.

Actual sample sizes collected for each sign condition ranged from 300 to 1,000 for the Day-Auto category, 100 to 200 for the Day-Other category (trucks, buses, and other large vehicles), and 200 to 500 for the Night-Auto category.

Analysis Measures

Three measures of effectiveness were used in comparing the 12 sign configurations: (1) Average compliance to the existing 35 mph (56 km/h) speed limit, (2) speed reduction, and (3) average velocity of those vehicles not in compliance. These measures were chosen because they provide direct indications of speed control and driver behavior characteristics. In addition, the measures are complementary in their treatment of fast- and slow-moving vehicles. Fast-moving vehicles have more potential of scoring high in speed reduction while slow-moving vehicles have more potential of scoring high in compliance. The "average velocity of those vehicles not in compliance" measure is primarily a measure for fast-moving vehicles, since slow-moving vehicles (those traveling less than 35 mph [56 km/h]) were excluded for this measure. This measure also provided an indication of the degree of noncompliance.

Average velocity of all vehicles was not used as a separate measure because the average compliance measure indicates the average velocity of all vehicles.

Analysis Approach

The analysis approach in this experiment compared the sign configurations in terms of the previously described measures of effectiveness. In the comparisons, the effective sign configurations showed more compliance, greater speed reduction, and less average velocity for those vehicles not in compliance. In the following sections, the sign configurations are examined for each data category (Day-Auto, Night-Auto, and Day-Other) in terms of the three measures of effectiveness.

To determine whether one sign condition was statistically more effective than another, error bars were drawn for each measure of effectivenes (figs. 3–6). The center point of each error bar represents the average value o all data collected for a particular measure under a specific sign/traffic condition.

The uncertainty of the average measurement for any sign/traffic condition is indicated by the length of the error bar. The "true" average value of the measure under the experimental conditions will be within the upper and lower values of the error bar 95 percent of the time. This 95 percent confidence range is probably much smaller since it was derived from large sample (greater than 25 data points) formulas and the sample size for each sign configuration in the experiment was much larger thar 25.

To determine whether there is a statistically significant difference in an effectiveness measure between two sign conditions (under the same traffic/daylight conditions), one must examine the overlap of the respective error bars. Figure 3 illustrates the significance of overlapping error bars. If the error bars have no overlap, the statistical significance of the observed difference is very high (Case 1). If the error bars overlap so that the center point (observed mean) of one bar falls within the length of the other, there is no statistical significance in the difference (Case 2). In the intermediate case of overlapping bars (Case 3), a marginally significant difference is suggested.

Comparisons were made between examined sign conditions under similar traffic/daylight conditions. Differences were noted as being significant, not significant at all, or only slightly significant depending on whether error bar comparisons were similar to Case 1, Case 2, or Case 3 as described above.

Results

Day-Auto category

Average compliance

Figure 4 shows the average compliance as a function of sign condition and direction. The most significant feature is that sign configurations (SC) 6 and 7 eastbound (E), 7 westbound (W), and, to a lesser extent, 2W stand out well above the others. In other words, the traffic activated warning signs clearly show better compliance. SC 2W was the first sign tested that had flashing beacons. The relatively high compliance may reflect the novelty effect or the response to implied danger.

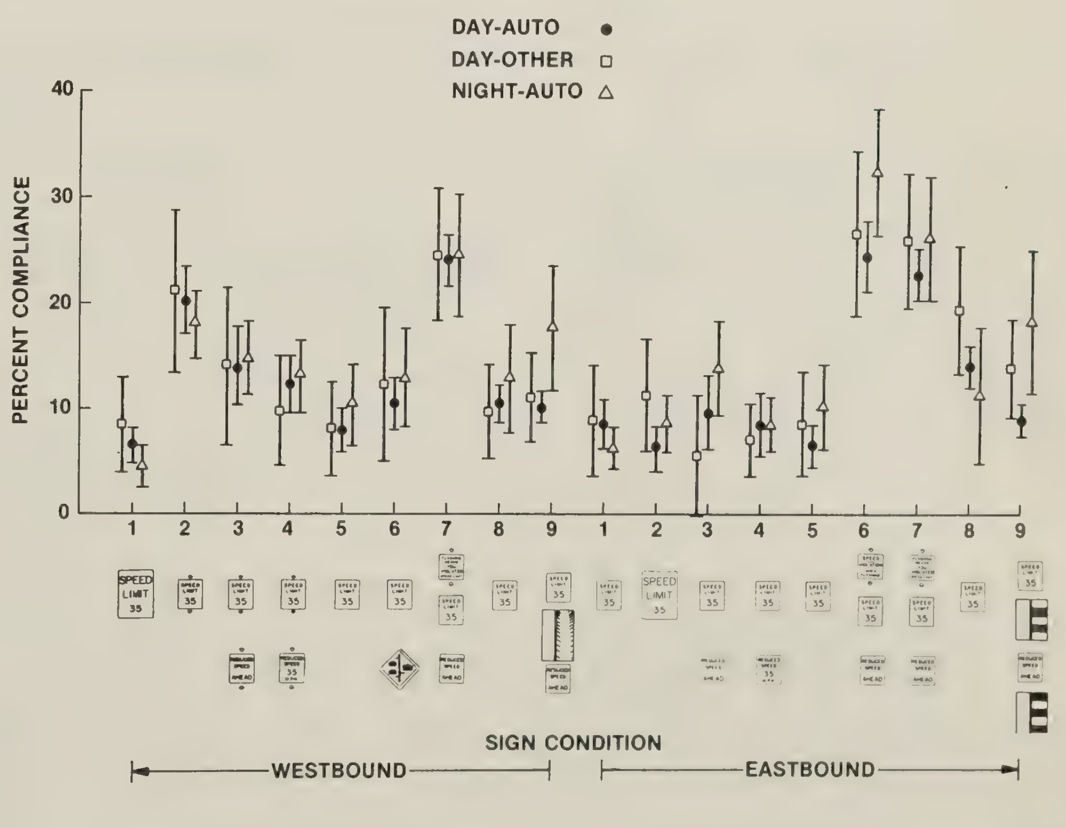
Due to the energy crisis early in 1974, the speed limit outside the Palmyra town limits was changed from 60 mph (97 km/h) to 50 mph (80 km/h). This occurred between testing of SC's 1 and 2. Therefore, for SC 1, automobile drivers tended to enter Palmyra at a higher speed, slow down more through the town, but still go through the town at a higher speed. These effects show up repeatedly in the analysis results below.

Results in the Day-Auto category are as follows (fig. 4):

- For westbound vehicles, the base configurations (SC's 5W and 8W) and the oversize base configuration (SC 1W) are among the least effective with SC 1W receiving the least compliance (due to the higher speed limit in effect).
- The similar compliances evidenced when comparing SC's 5E with 5W, 7E with 7W, and 8E with 8W indicate that any directional (geometric) effects are minimal. In these instances, the same sign configurations were tested at the same time for both directions.
- The addition of flashing beacons to a sign increases the average compliance.
- Enlarging the base configuration sign did not increase average compliance. In fact, the enlarged sign provided practically the lowest average compliance of all sign configurations.
- The wording on the advance warning sign (with or without flashing beacons) may have an effect since SC's 3E and 3W show more compliance than 4E and 4W, respectively. This may be due to a novelty effect since SC's 3E and 3W represent the first time during the experiment that advance warning signs were displayed.
- The symbolic sign (6W), rumble strips (9E), pavement markings (9W), and advance warning signs without flashing beacons (3E and 4E) all show about the same level of compliance as the base configuration.

It is interesting to compare the results of the Day-Auto percent compliance in figure 4 with those received when compliance was defined as having a

Figure 4.—Average compliance versus sign condition, all categories.



speed of less than 40 mph (64 km/h) at the center of town. A plot of the data obtained with this definition of compliance has a shape almost identical to the plot in figure 4, except that the percent compliances are much higher. No sign condition received less than 39 percent compliance and the traffic activated warning signs (SC's 7W, 6E, and 7E) received nearly 80 percent compliance. In figure 4, the Day-Auto category range is 7 to 27 percent compliance. All conclusions drawn from figure 4 still hold, except that sign condition 9W showed some advantage over the base configuration when 40 mph (64 km/h) was the compliance criterion. Also, much stronger evidence of the superiority of the traffic activated warning signs was shown.

Speed reduction

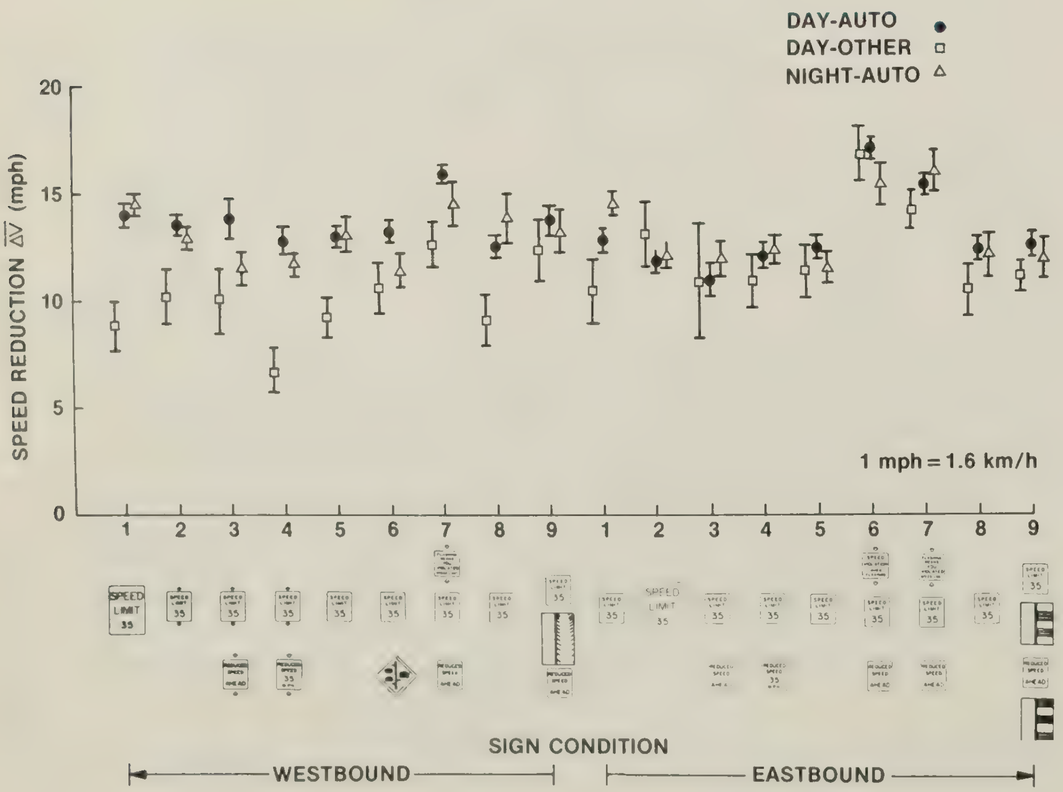
Figure 5 shows speed reduction from a point 400 ft (122 m) before the advance warning sign to the center of town (Node 275 in figure 1) as a function of sign condition and direction. Again, the most prominent feature is the superiority of the traffic activated signs—7W, 7E, and 6E—in achieving speed reduction.

SC's 1E and 1W have a larger speed reduction than all the other signs, except for the traffic activated signs. Again, the higher speed limit in effect for SC 1 explains this result. The large speed reduction together with the relatively low compliance (fig. 4) for SC's 1E and 1W illustrates the complementary effect of the performance measures.

Other notable features displayed in figure 5 are as follows:

- There was more speed reduction in the westbound direction when the same sign configurations were tested during the same time period—SC's 5, 7, and 8.
- Signs with flashing beacons showed more speed reduction than those without, thus reinforcing the compliance results.

Figure 5.—Speed reduction versus sign condition, all categories.



- Enlarging the base configuration sign does not affect speed reduction.
- Wording on the advance warning sign had a mixed effect on speed reduction: Sign 4E showed slightly more speed reduction than 3E, while 3W showed more speed reduction than 4W.
- The symbolic sign (6W), rumble strips (9E), and advance warning signs without flashing beacons (3E and 3W) did not cause much more speed reduction than the base configuration.

Average velocity of vehicles not in compliance

Figure 6 shows the average velocity of those vehicles not in compliance (that is, exceeding the 35 mph [56 km/h] speed limit) as a function of sign condition and direction. The high average velocities for SC's 1E and 1W are readily apparent. As indicated earlier, this is due to the higher speed limit that was in effect when SC's 1E and 1W were tested. Also, at the higher speed limit, the oversize base sign configuration showed slightly less average velocity than the standard size base configuration. This is probably more of a geometry of sampling effect than a sign configuration effect.

The traffic activated warning signs—7W, 6E, and 7E—again demonstrate their superiority (low average velocities). Other points that should be noted are as follows:

- For westbound traffic, the base sign configuration shows slightly higher average velocities than the other configurations (except for SC 1W). This is not true for eastbound traffic.

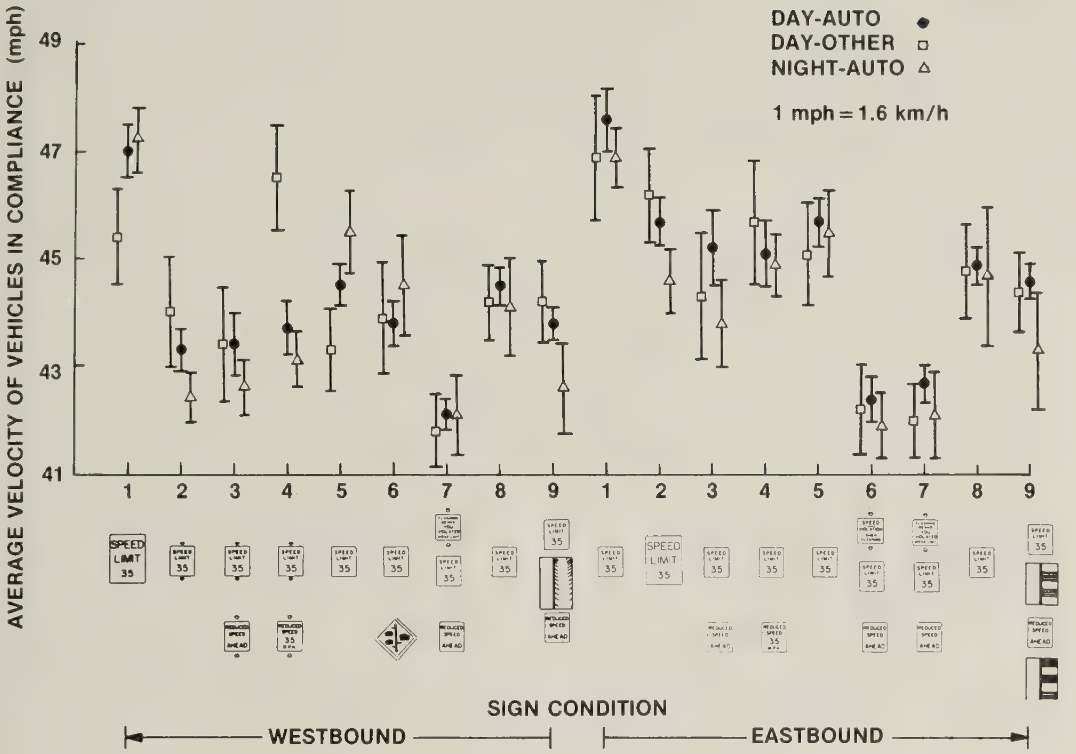


Figure 6.—Average velocity of vehicles not in compliance in speed zone versus sign condition, all categories.

- The signs with flashing beacons (2W, 3W, and 4W) are more effective than all sign configurations except for the traffic activated warning signs.
- The same sign configurations tested during the same time period (SC's 5, 7, and 8) show higher average velocities in the eastbound direction.
- The wording on the advance warning sign has no effect on average velocity of those vehicles not in compliance.
- The rumble strips (9E), advance warning signs without flashing beacons (3E and 4E), and enlarged speed limit sign (2E) all show about the same level of average velocity as the base sign configuration (excluding 1E).
- The symbolic sign (6W) and pavement markings (9W) are slightly more effective than the base configurations and about as effective as the signs with flashing beacons.

Night-Auto category

Average compliance

The Night-Auto category demonstrates results similar to the Day-Auto category for the average compliance performance measure (fig. 4). The most notable is SC 9 in both directions (rumble strips and pavement markings). These are more effective at night than all configurations except the traffic activated warning signs (7W, 6E, and 7E) and the first sign with flashing beacons (2W). The signs with flashing beacons (2W, 3W, and 4W) again display a novelty effect or the response to implied danger.

Curiously, sign 2W (with flashing beacons) gets less compliance at night than during the day while 2E (enlarged base configuration) is more effective at night. Further evidence that flashing beacons are not more effective at night while a *lack* of flashers is more effective is shown by comparing 2W, 3W, and 4W (day versus night) with 5W and 8W (day versus night).

Speed reduction

The only clear effect on speed reduction in the Night-Auto category is the superiority of the traffic activated signs (fig. 5). The apparent effectiveness of SC's 1E and 1W is rejected because the higher speed limit was in effect.

For westbound traffic, the base sign configurations (5W and 8W) show more effectiveness than the signs with flashing beacons (2W, 3W, and 4W). Evidence for any superior effectiveness of the signs with flashing beacons is further contradicted by the fact that SC's 2E, 3E, and 4E (without flashers) are as effective or more effective for speed reduction than 2W, 3W, and 4W, respectively.

The base sign configuration results indicate that westbound traffic slows down more than eastbound traffic (a possible directional or geometric effect); however, the signs with flashing beacons (westbound) are not, as a group, more effective than their counterpart signs without flashing beacons (eastbound).

Finally, the symbolic sign (6W) appears to be the least effective sign configuration at night for speed reduction.

Average velocity of vehicles not in compliance

The effectiveness of the traffic activated warning signs is again confirmed by the average velocity measure in the Night-Auto category (fig. 6).

The signs with flashing beacons show some effectiveness in that the average velocities for SC's 2W, 3W, and 4W are well below 5W and 8W; the same is not true for the eastbound direction. The signs with flashing beacons also show more effectiveness at night (as opposed to day) in terms of average velocity of vehicles not in compliance. But the differential improvement compared to the base signs is not significant. Taking into account the average compliance and speed reduction results, the conclusion is that signs with flashing beacons are about as effective at night as during the day.

The nighttime effectiveness of SC's 9E and 9W (rumble strips and pavement markings) is again demonstrated. Specifically, 9E is significantly better than 1E, 4E, and 5E; and 9W is significantly better than 1W, 5W, 6W, and 8W.

Day-Other category

Average compliance

"Other" vehicles are defined as vehicles longer than 20 ft (6 m): trucks, buses, or other large vehicles. Drivers of such vehicles can be expected to follow a specific behavior pattern because truck drivers' speeds are largely determined by the geometry of the roadway. In other words, truck drivers tend to travel as fast as they can, gathering speed going down hills and losing it going up. Therefore, the effect of speed control signs is greatly counteracted by the truck driver's desire not to lose his momentum or to slow down when approaching a hill.

The traffic activated warning signs show some special effectiveness even for truck drivers (fig. 4). An attempt to comply—to the extent the drivers feel is feasible—is evidenced for all signs. In general, truck drivers behave very similarly to automobile drivers in terms of average compliance.

Speed reduction

For the speed reduction measure, the Day-Other category shows some insensitivity of truck drivers to signs (fig. 5). The superiority of the traffic activated signs is evident but not to the same degree as for the other data categories. Sign 7W is the most effective westbound sign condition but almost equivalent to 9W. In the eastbound direction, 6E is significantly better than all other signs, but sign 7E is not significantly better than 2E. The anomalous effect that 4W is significantly and strikingly lower than all other sign configurations is also shown in figure 5.

Average velocity of vehicles not in compliance

The average velocity measure for the Day-Other category once again illustrates the superiority of the traffic activated signs (fig. 6). The effectiveness of the other signs is quite low. This is probably due partly to the effect of road geometry and partly to the decreased sample size. The anomalous effect of SC 4W in the speed reduction measure is brought out since 4W also has the second highest average velocity (second to 1E).

Summary

Day-Auto category

Only the traffic activated signs showed a definite superiority. Their effectiveness is significantly higher than all other configurations. The signs with flashing beacons showed some indication of being effective, but not as effective as the traffic activated warning signs and not under all conditions. The pavement markings were only marginally more effective than the base configuration. The enlarged base configuration sign, advance warning signs—verbal and symbolic—and the rumble strips were all comparable to each other and to the base configuration in terms of effectiveness.

Night-Auto category

The major difference for the Night-Auto category was the effectiveness of the pavement markings and rumble strips. Only the traffic activated warning signs showed more effectiveness. The pavement markings and rumble strips were about equal in effectiveness.

Day-Other category

Once again, the traffic activated warning signs showed definite superiority. The other sign configurations were either no more effective than the base configuration or the variability in the data (because of smaller sample sizes and geometric effects) masked any difference. There was a definite similarity between the responses for "autos" and "other" vehicle types.

Conclusions

The following results of the experiment were found:

- Traffic activated warning (speed violation) signs were the most effective signs (statistically significant) tested and will reduce speeds by 3 to 4 mph (4.8 to 6.4 km/h) more than passive signs.
- Signs with flashing beacons were next in effectiveness during daylight but they will reduce speeds by only 1 to 2 mph (1.6 to 3.2 km/h) more than passive signs.
- Pavement markings and rumble strips followed traffic activated signs in effectiveness at night as measured by the percent of drivers who comply with the speed limit.
- The addition of flashing beacons to a sign increases its effectiveness, but not significantly.
- Signs with flashing beacons were about as effective during the day as at night.
- Very few differences were found between the various passive signs tested.
- Drivers of large vehicles responded similarly to the sign conditions examined as drivers of automobiles.
- No sign achieved as much as 30 percent compliance to the existing 35 mph (56 km/h) speed limit.
- Forty miles per hour (64.4 km/h) appears to be a more realistic speed limit for small towns located along a high-speed highway.

No attempt was made during the evaluation to define absolute criteria for the measures of effectiveness since this was considered beyond the scope of the experiment. This experiment was primarily intended to obtain basic performance data and to evaluate the relative effectiveness of the 12 described sign configurations. It is recommended that highway engineers and planners extend the present effort and determine the requirements for wide application of the new signing configurations by assessing the results presented in this article together with cost/benefit trade offs.

A detailed report on the Palmyra Town Experiment will be published by the Department of Transportation's Transportation Systems Center during 1977. This report will provide detailed information on the test site, all sign configurations, experiment variables, data collection procedures, and data analysis procedures. In addition, further analysis will be conducted and presented in the report, including a study of early compliance, late compliance, the 15th, 50th, and 85th percentile speed profiles, and unsafe headways.

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Algorithms
Freeway incident detection
Authors

Improved Freeway Incident Detection Algorithms

by Samuel C. Tignor and H. J. Payne

This article presents the results of a study on the development of improved incident detection algorithms for freeway surveillance systems. A total of 10 algorithms were defined, calibrated, tested, and evaluated. False alarm levels previously experienced with incident detection algorithms have been significantly reduced as a result of this new research. New algorithm results are also presented relative to sensor configuration, geometric anomalies, and weather considerations. This study was performed under FCP Project 1C, "Analysis and Remedies of Freeway Traffic Disturbances."

Introduction

One of the problem areas within the Federal Highway Administration's (FHWA) Federally Coordinated Program of Research and Development (FCP) is Project 1C, "Analysis and Remedies of Freeway Traffic Disturbances." (*1, 2, 3*)[1] This project includes the development of freeway management systems to detect, locate, and respond to freeway incidents. The components of a freeway management system include information gathering, data processing and decisionmaking, and response techniques. The development of improved incident detection algorithms is of great importance to the development of useful freeway management systems.

This article describes the results of research recently obtained on the development of improved incident detection algorithms. An incident detection algorithm is a specific logical and analytic procedure used along with data obtained from freeway surveillance traffic detectors to ascertain the presence or absence of a capacity reducing incident. An incident detection algorithm is only a part of the operational freeway management system and the other components of th system are vital if the system is to be effective. These components and their relationship are indicated in figure 1. The portion relating to electronic incident detection is enclosed in a dashed line box.

The Problem

A freeway incident causes a discontinuity in traffic densities both upstream and downstream of the incident location. As shown in figure 2, the density after the incident occurs, d_3, is greater than the before density, d_1. Th density immediately downstream of th incident site, d_2, falls below the origin density, d_1. Lighthill and Whitham

[1] Italic numbers in parentheses identify the references on page 40.

showed theoretically that when the state of traffic flow changes, as it does when an incident is present, shock waves occur. (*4*) They further showed that the speed of the shock wave is a function of the ratio of flow and density.

Automated freeway incident detection has typically been based on the use of inductive loops installed in the pavement every one-half mile (0.8 km) along the freeway. Some systems have loops installed in all lanes and others in only the center lane. The inductive loops are connected with a computer which interrogates each loop every few milliseconds to ascertain the presence or absence of a vehicle. This real-time data is processed by the computer using predefined detection algorithms to determine if an incident or flow discontinuity has occurred.

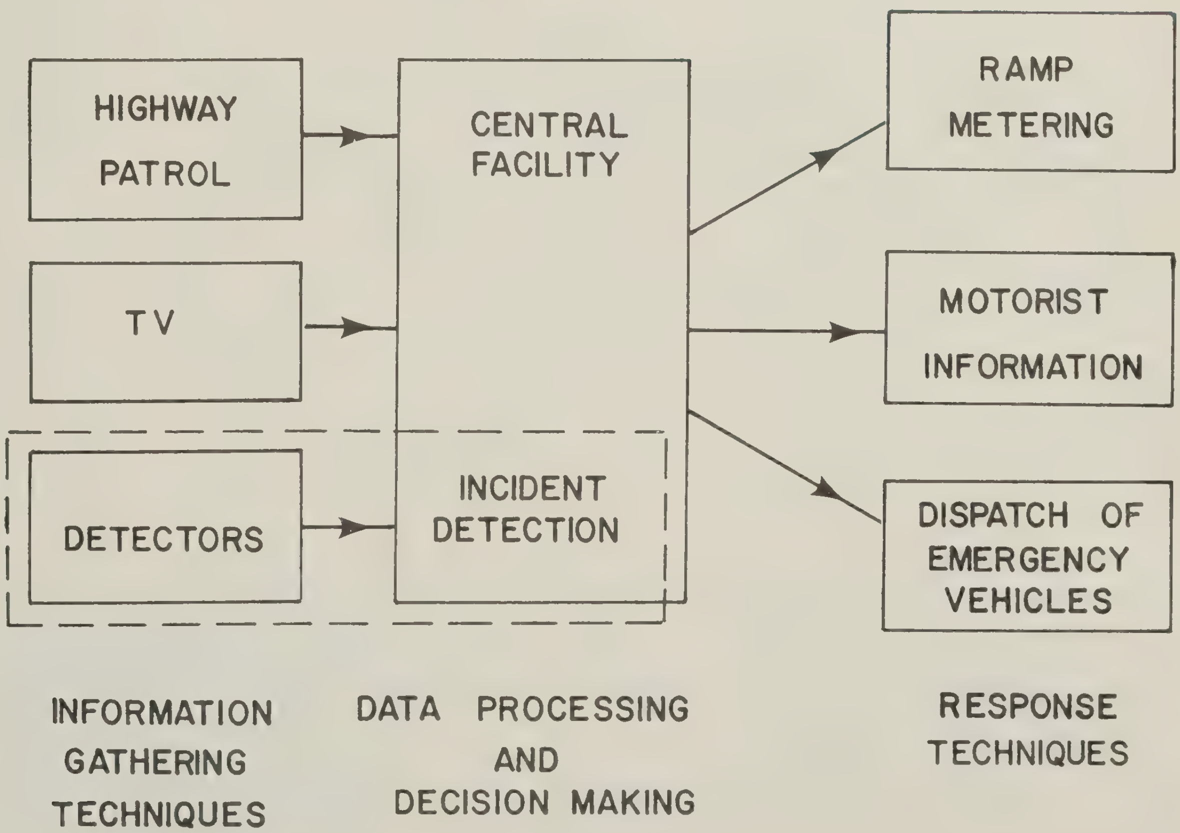
Since Lighthill and Whitham's work, various kinds of detection algorithms have been hypothesized and used for detecting freeway incidents. The use of most of these algorithms has been seriously handicapped because of excessive false alarms. When an incident detection algorithm is executed, four outcome possibilities arise, including false alarms (fig. 3). The relative frequencies with which these possibilities occur for a given algorithm largely determine its acceptability as a good algorithm. Generally, the fraction of incidents detected can be increased only at the expense of an increase in the false alarm rate as well. Therefore, when selecting an incident detection algorithm, there is a trade off between false alarms and detected incidents. Another important performance measure is the response time of the algorithm, that is, the time between the occurrence of an incident and the time the algorithm produces an incident signal.

Previously Used Algorithms

Automated incident detection systems have been proposed by various researchers since 1961. One of the first systems was installed by the Port of New York Authority in the Lincoln Tunnel. (*5*) The algorithm used was based on identification and tracking of individual vehicles through the tunnel to determine the number of vehicles within subsections of the tunnel. This procedure, although useful in tunnel applications, is not useful for detecting freeway incidents.

In 1968, the Texas Transportation Institute experimented on the John C.

Figure 1.—Components of a freeway management system.



Lodge Freeway in Detroit with six different incident detection algorithms based on macroscopic traffic flow parameters. (6) In this research, the detection of an incident was based on a preselected threshold which was related to the alpha risk shown in figure 3. All six algorithms demonstrated some ability for detecting incidents, but because of high false-alarm rates, the algorithms would need much refinement before they could be used operationally.

One of the most widely used algorithms was developed by the California Department of Transportation. Roadway occupancy—the percent time a roadway sensor indicates the freeway is occupied by vehicles—is the basic traffic measure used. This model, commonly called the "California model," contains the following three test conditions which must be met before an incident is signaled. (7)

(1) $occ(i,j+1)-occ(i,j) \geqslant K_1$

(2) $\dfrac{occ(i,j+1)-occ(i,j)}{occ(i,j+1)} \geqslant K_2$

(3) $\dfrac{occ(i-1,j)-occ(i,j)}{occ(i-1,j)} \geqslant K_3$

Where,

$occ(i,j)$ = Occupancy measured over time interval i at sensor j (fig. 2).

$j+1$ = Upstream sensor station.

j = Downstream sensor station.

Constants K_1, K_2, and K_3 = Predefined, station-specific thresholds, each of which must be exceeded before an incident is detected.

The California model has been described by Payne, who evaluated a number of existing algorithms, as being one of the best performing incident detection algorithms. (7)

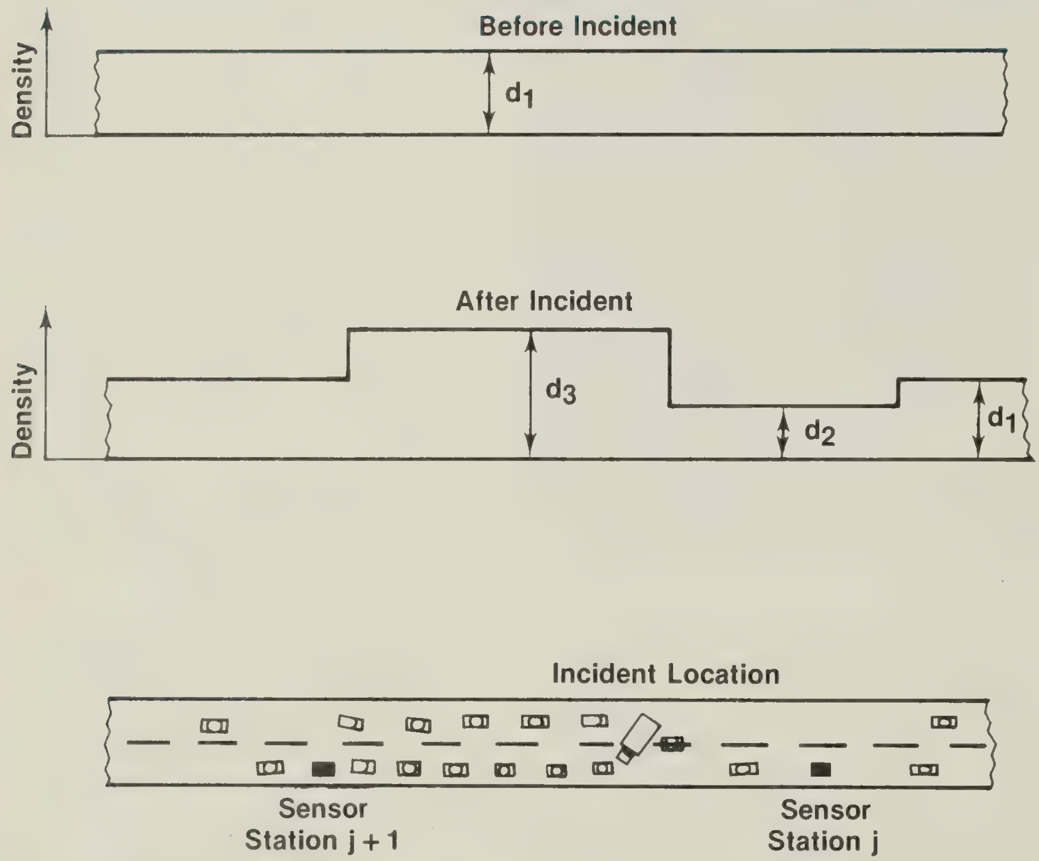
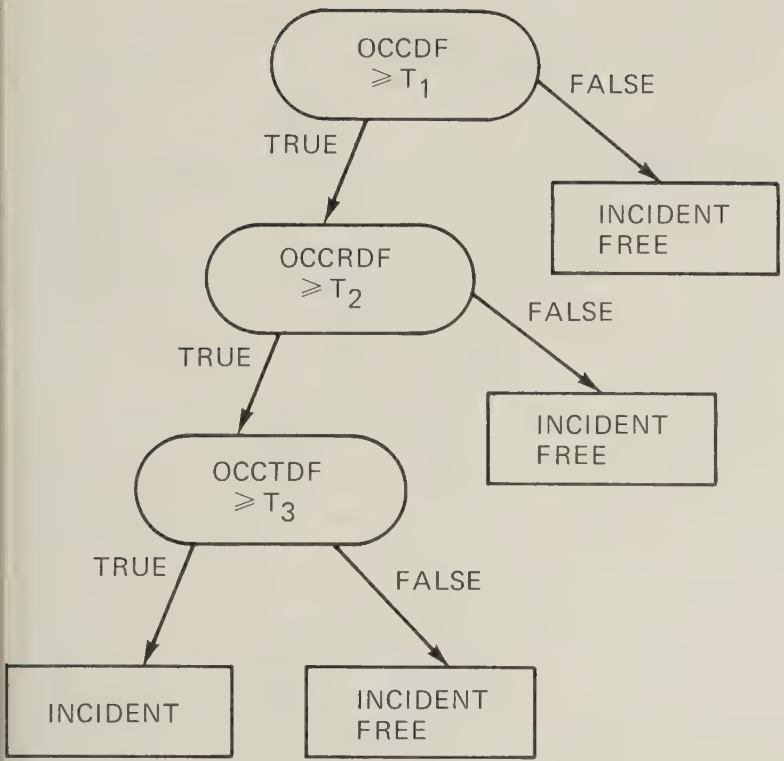


Figure 2.—Traffic density conditions before and after incident.

Figure 3.—Results of executing an incident detection algorithm

CONDITION INDICATED BY ALGORITHM	ACTUAL CONDITION: INCIDENT-FREE	ACTUAL CONDITION: INCIDENT PRESENT
INCIDENT-FREE		MISSED DETECTION (α RISK)
INCIDENT PRESENT	FALSE ALARM	CORRECT DETECTION



OCC = MINUTE AVERAGE OCCUPANCY (EXPRESSED AS A PERCENTAGE)

OCCDF = OCC (UPSTREAM) - OCC (DOWNSTREAM)

$$\text{OCCRDF} = \frac{\text{OCCDF}}{\text{OCC (UPSTREAM)}}$$

OCCTDF = [OCC(DOWNSTREAM, TWO MINUTES AGO) -OCC (DOWNSTREAM, NOW)] / OCC (DOWNSTREAM, TWO MINUTES AGO)

T_1, T_2, T_3 = THRESHOLDS

Figure 4.—The California algorithm shown as a binary decision tree.

In 1970, Cook and Cleveland reported the results of their evaluation of a double exponential smoothing model. (*8*) They found there was a definite advantage in considering more than the last one or two occupancy data observations when trying to determine the current traffic flow trends. In this method, a tracking signal is used which considers the statistical magnitude of data noise before a decision is made that an incident has occurred. The traffic parameter occupancy is smoothed as follows:

$$S1(t) = \alpha\, occ(t) + (1-\alpha) S1(t-1)$$

$$S2(t) = \alpha\, S1(t) + (1-\alpha) S2(t-1)$$

Where,
$S1(t)$ = Single exponential smoothing formula for the time interval t.
$S2(t)$ = Double exponential smoothing formula for the time interval t.
$occ(t)$ = Occupancy for time interval t
α = Smoothing parameter.

With the results of these two formulas, a predicted linear forecast of occupancy for the time interval $t+1$ can be made. For each time interval t, a tracking signal is computed for the purpose of determining if the observed value of occupancy could have occurred by chance or if it reflects the presence of a roadway incident. Cook and Cleveland concluded that of all incident detection models they evaluated, the exponentially smoothed occupancy model was the most effective.

The incident detection models discussed above have been used by operating agencies. However, other algorithms have been developed for special applications. Dudek et al. developed and evaluated two algorithms for detecting incidents occurring under low volume conditions, whereas Tignor recommended a single exponential smoothing model for these low volume traffic conditions. (*9, 10*) Sakasita and May used a simulation model to develop and test three incident detection algorithms under various flow conditions at four sensor spacings. (*11*) Dudek and Hesser also presented findings relative to determining the sensor spacing for incident detection systems. In addition, they evaluated an incident detection model based on the use of the statistical standard normal deviate method. (*12*) Many of these algorithms are variations of the ones used by operating agencies.

Although the above discussion indicates that sufficient research has been performed, the number of false alarms generated by the algorithms is still a problem. One of the major aims of the research reported in this article was to reduce or solve this problem.

Development of Improved Algorithms

The FHWA Office of Research recognized the need for further improvements in incident detection algorithms. These improvements include the need for better false alarm performance and research showing the effect of sensor configuration, geometrics, and adverse weather on algorithm performance. In addition, it would be helpful to operating agencies if the lane or lanes where the incident is located could be automatically identified.

In December 1973, the Federal Highway Administration awarded a contract for a research study to develop improved incident detection algorithms. This study made use of an empirical and analytic approach based on data obtained from the Los Angeles and Minneapolis freeway surveillance systems. A total of 153 incident and 30 incident-free data sets stored on magnetic tapes were used in the study. In general, each incident data set contained 1-minute averages of occupancy, volume, and speed for each of three stations upstream and two stations downstream of the incident location. These averages were updated every 20 seconds for approximately 2 hours. Each incident-free data set was approximately 3 hours long and covered all stations for the section of freeway identified.

Incident detection

The initial effort in the research study evaluated the performance of existing incident detection algorithms. As indicated earlier, Payne et al., concluded that the exponential smoothing and California algorithms were good performers and easy to use. (*7*) Also, occupancy and volume were found to be the traffic features that are most effectively used in incident detection algorithms.

During the research, a total of 10 incident detection algorithms were developed, calibrated, tested, and evaluated. For simplicity, all new algorithms were presented and described as binary decision trees. A binary decision tree consists of one or more logical decisions grouped together in a treelike structure. Each logical decision is based upon a comparison of a traffic feature and a threshold value. The consequence of a logical decision is to progress to a succeeding logical decision or to the termination of the process by making a final decision. Figure 4 shows the California algorithm structured as a binary decision tree.

Table 1 identifies the traffic features and characteristics of the 10 algorithms developed and tested. Each of the 10 algorithms employs a binary decision tree structure and generalized computer software which can be easily used for the most complicated algorithms. Figure 5 is an example of the decision tree used for algorithm 9, a somewhat involved algorithm. (The binary decision trees for the other algorithms shown in table 1 can be reviewed in reference 13.)

Because of the large amount of real-time data that was included in the Los Angeles and Minneapolis data bases, special calibration software was developed. The objective of the

Table 1.—Characteristics of the 10 new incident detection algorithms

Algorithm number	Features used[1]	Comments
1	OCCDF, OCCRDF, DOCCTD	Essentially the California algorithm
2	OCCDF, OCCRDF, DOCCTD	Essentially the California algorithm with an incident continuing state
3	OCCDF, OCCRDF	Same as algorithm 2, but without DOCCTD check
4	OCCDF, OCCRDF, DOCC	Same as algorithm 2, but use of DOCC replaces use of DOCCTD
5	OCCDF, OCCRDF, DOCCTD	Essentially the California algorithm with a check for persistence
6	OCCDF, OCCRDF	Algorithm 3 with a check for persistence
7	OCCDF, OCCRDF, DOCC	Algorithm 4 with a check for persistence, *best simple algorithm*
8	OCCDF, OCCRDF, DOCC, DOCCTD	Has form of algorithm 4 plus check for compression wave and persistence, *especially effective in "stop-and-go" traffic*
9	OCCDF, OCCRDF, DOCC, DOCCTD	Algorithm 8 without a persistence check, *especially effective in "stop-and-go" traffic*
10	OCC, OCCTDF, DOCC, SPDTDF	Distinguishes two traffic regimes (light and moderate) for purposes of detecting incidents

[1]The features OCCDF, OCCRDF, and DOCC are defined in figure 4. DOCCTD is the relative temporal change in downstream occupancy, that is, DOCCTD equals occupancy at downstream station 2 minutes ago minus occupancy at downstream station now, divided by occupancy at downstream station 2 minutes ago. SPDTDF is similarly defined in terms of the volume divided by occupancy ratio at the upstream station.

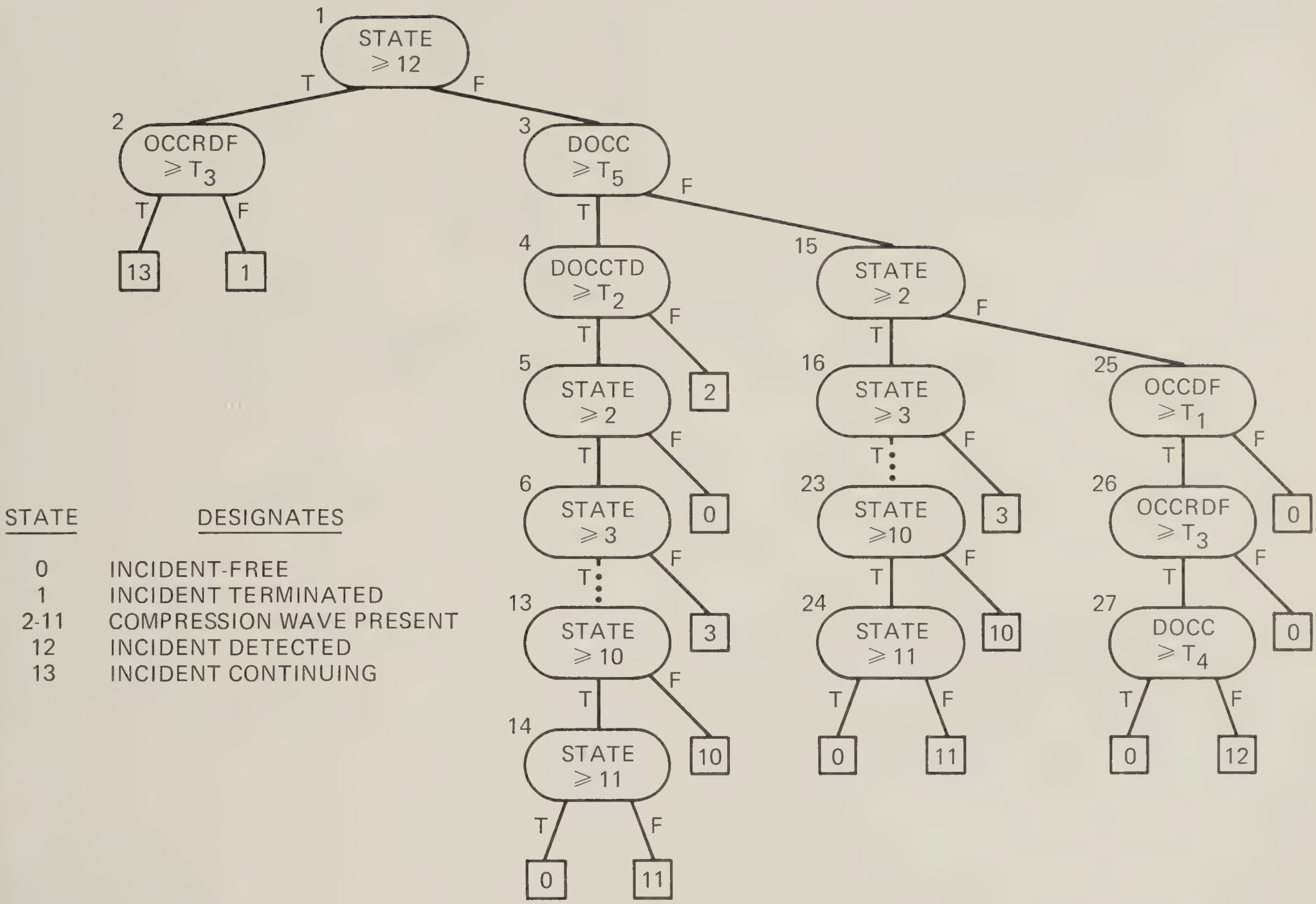


Figure 5.—Decision tree for algorithm 9, 30-second updating, 5-minute suppression.

calibration was to determine the threshold values needed in each logical decision included in the algorithms developed (fig. 4). After determination of the threshold values, the individual performance of the algorithms could be determined. The performance criteria included both detection and false alarm rates (fig. 3). False alarm rates are the total number of algorithm-generated false alarms divided by the total number of tests performed by the algorithm. Figure 6 shows the comparison of the performance of the California algorithm, the double exponential smoothing algorithm, and algorithm 9. Algorithm 9 is a significantly better performer at the 0.01 level of significance than either of the other two algorithms. For most levels of detection, algorithm 9 has a lower level of false alarms. (Other algorithm performance comparisons are also presented in reference 13.)

Detection persistence and compression waves

As stated earlier, an incident detection algorithm is a specific, logical, and analytic procedure used to detect the presence or absence of a capacity reducing incident. Incident detection algorithms are very sensitive to traffic conditions. As interpreted by the algorithms, traffic conditions sometimes look as if an incident is present when, in fact, one is not. There are two cases of this phenomenon which occur most frequently.

In one case, many flow disturbances in incident-free traffic are short-lived and, while they may produce one or two incident signals, the signals do not last since a real capacity reducing incident is not present. In this research, a persistence check was developed which

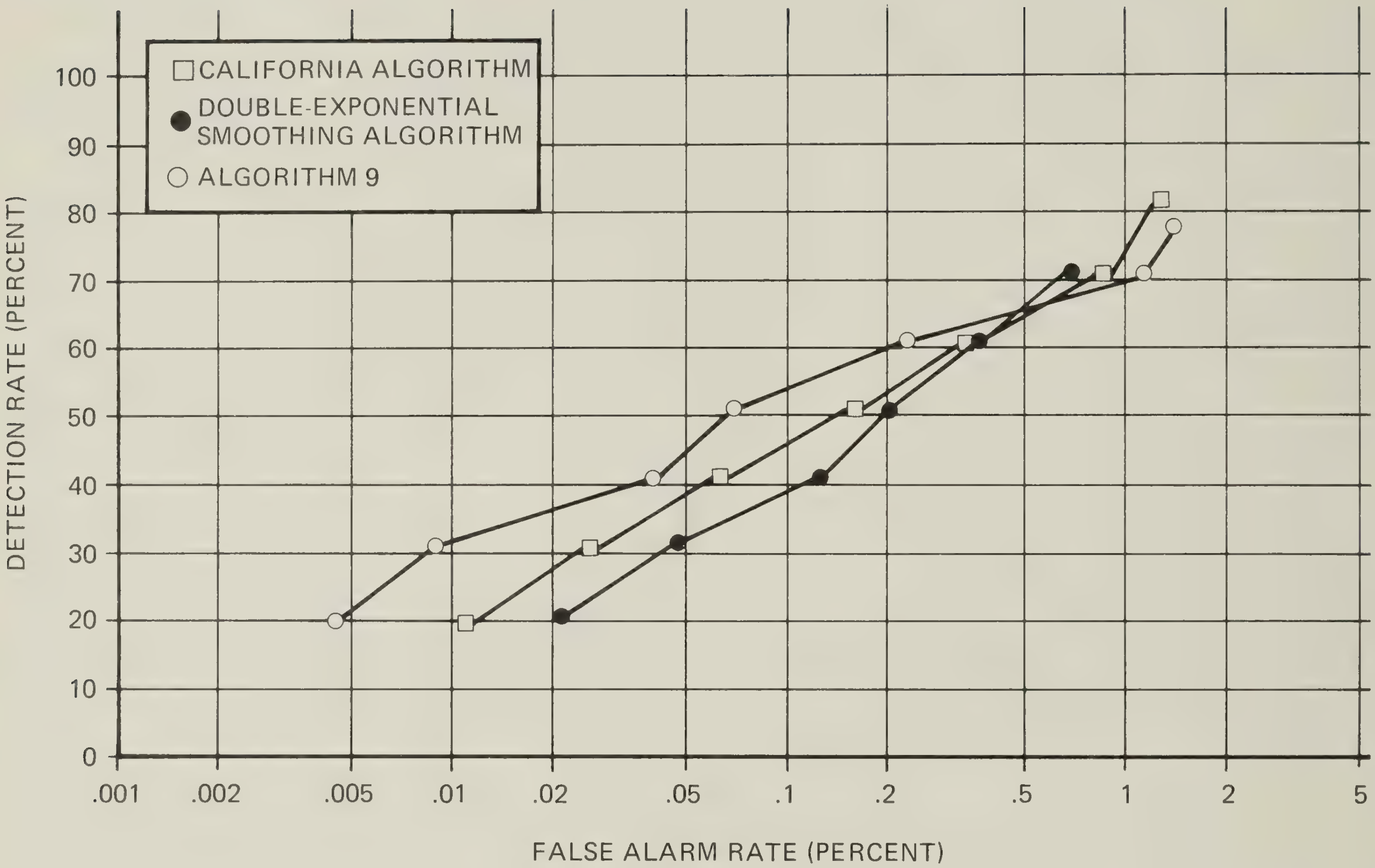


Figure 6.—Comparison of performance for three algorithms.

requires a traffic discontinuity to continue for two or more algorithm iterations or time periods. Algorithms 5 through 8 incorporate the persistence check (table 1). (References 13 and 14 provide the flow charts and coding for the persistence feature.)

In the second case, compression waves in heavy traffic, such as occur in stop-and-go traffic, can also appear to algorithms as incidents when, in fact, none are present. Typically, compression waves are manifested by a sudden large increase in occupancy which moves through the traffic stream from 5 to 15 mph (8 to 24 km/h) in a direction counter to the traffic flow. The clue to the presence of a compression wave is a large increase in occupancy at one station followed by a large increase in occupancy at the next upstream station within the time interval required for the compression wave to reach the upstream station. Both algorithms 8 and 9 contain the compression wave feature (table 1). The primary logic used in detecting the presence of a compression wave is based on DOCCTD, the relative temporal difference in downstream occupancy (fig. 5). The 5-minute suppression feature of algorithm 9 prevents false alarms while compression waves are moving through the given freeway section.

Examination of the algorithm false alarms when the compression wave feature is used indicates that false alarms due to compression waves are relatively few. Most false alarms appear to be related to bottlenecks and appear specifically at the head of the queue. Thus the use of the compression wave feature was very successful.

Sensor configuration

Both the configuration of sensor placement and sensor spacing influence the speed with which freeway incidents are detected. Part of the Los Angeles data—35 incident data sets—was obtained from a 4-mile (6.4 km) segment of the San Diego Freeway which had sensors in all lanes spaced about one-half mile (0.8 km) apart. Using this data, both sensor configuration and spacing were investigated relative to their effect on algorithm performance.

Three sensor configurations were investigated. In configuration A, all lanes had a sensor every one-half mile (0.8 km); in configuration B, one lane in each direction contained a sensor every one-half mile (0.8 km); and in configuration C, all lanes were instrumented with sensors every mile (1.6 km). Since little sensor configuration data is available, results were generally inconclusive. However, it was found that for a given detection rate, the false alarm rates for configuration A were about one-half those for configurations B and C. (*13*) Response time results showed no consistent pattern, but other research has shown that sensor spacing has an effect on detection time.[2] (*10, 15*)

Geometrics

Traffic flow irregularities result not only from incidents, but also from certain combinations of traffic demands and geometric conditions. These traffic flow irregularities can result in false alarms. Since false alarms are undesirable, an effort was made to determine if algorithm correction factors or threshold changes could be used to adjust for geometric anomalies.

Certain combinations of traffic demands and geometrics yield consistent differences in occupancies at adjacent sensor stations. If the upstream occupancy is consistently greater than the downstream occupancy, false alarms increase; whereas, when the downstream occupancies tend to be greater than those upstream, incident detection is more difficult. A candidate solution was the hypothesis that if the occupancy values could first be adjusted statistically to correct for the geometric anomalies before being used by the detection algorithm, there would be fewer false alarms and an increase in the detection of incidents. Because of a limited geometric-type data base, the results obtained were statistically inconclusive; however, the results suggested that the statistical normalization of the upstream and downstream occupancies is a reasonable approach to the problem solution. (*13*)

Weather considerations

One of the main uses of the Minneapolis data bases was to ascertain if different algorithm thresholds are required for snowy weather. In order to answer this question, the Minneapolis data base was evaluated individually on both the clear and snowy weather data. Even with weather adjusted thresholds, the algorithm detection performance was not significantly improved and false alarms did not decrease. (*13*) Thus, special snow thresholds for incident detection algorithms are not necessary.

User Guidelines

An important requirement of the final research report was that it include guidelines for users for integrating the algorithms into real-time system software. (*14, 16*) In using the guidelines, users must first identify the incident detection algorithm that will best meet their needs (table 1).

Table 2.—Candidate threshold sets for algorithm 2

Threshold set	Thresholds			Performance on Los Angeles data base		
	T_1	T_2	T_3	Detection rate	False alarm rate	Mean-time-to-detect
				Percent	*Percent*	*Minutes*
1	5.3	0.308	0.061	82	1.294	0.85
2	5.8	0.340	0.112	71	0.901	1.99
3	7.7	0.498	0.049	61	0.309	3.33
4	5.0	0.563	0.013	51	0.222	5.09
5	9.6	0.617	0.075	41	0.070	5.18
6	15.3	0.637	0.245	31	0.015	6.00
7	13.0	0.710	0.192	20	0.004	7.77

FORTRAN coding is then written for the algorithm selected. Sample coding instructions are provided for each of the 10 algorithms shown in table 1. Candidate threshold values are then selected from a table, an example of which is shown in table 2 for algorithm 2. In using this table, the user would select the threshold set and

[2] "Toward Automatic Incident Detection on the North Central Expressway," by C. L. Dudek and H. Whitson, Dallas Freeway Corridor Study Report RF 953-7, prepared for the Federal Highway Administration. Not yet published.

corresponding threshold values, depending on the detection and false alarm combination which best meet the requirements of the surveillance system being used. For example, if the user desired a false alarm rate no greater than 0.25 percent, he would select threshold set 4 from table 2. After the threshold values are selected, they are also coded into the FORTRAN software. For those users who prefer to calibrate the threshold values to their own freeway system, calibration software has also been developed. However, in most applications, the candidate threshold values can be used directly as provided. (*14*)

User software recommendations and guidelines have also been developed for geometric problems, to detect malfunctioning sensors, to solve or minimize anomalies, and to identify the lanes affected by capacity reducing incidents. (*14*)

Next Phase

In this research study, a major consideration was to develop incident detection algorithms that would detect real-world freeway incidents. Emphasis was placed on obtaining real-time incident and incident-free traffic data from operating surveillance and control systems. Thus, a total of about 200 real-time data sets were obtained and used. The 10 incident detection algorithms developed and reported in this article have already been tested under nearly real-life surveillance system conditions.

However, the users of incident detection algorithms are operating freeway surveillance and control systems. Consequently, the next phase of this research is being performed by a State agency. The Illinois Department of Transportation is currently undertaking a 24-month effort which will evaluate and document the technical acceptability and ease of implementing the new algorithms on an operational freeway surveillance and control system. This research will be performed at the Chicago Freeway Surveillance and Control System.

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[3]Reports with PB numbers are available in paper copies and microfiche from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

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Recent Research Reports

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.

Lateral Support Systems and Underpinning—Volume I (Report No. FHWA-RD-75-128), Volume II (Report No. FHWA-RD-75-129), Volume III (Report No. FHWA-RD-75-130), and Concepts for Improved Lateral Support Systems (Report No. FHWA-RD-75-131)

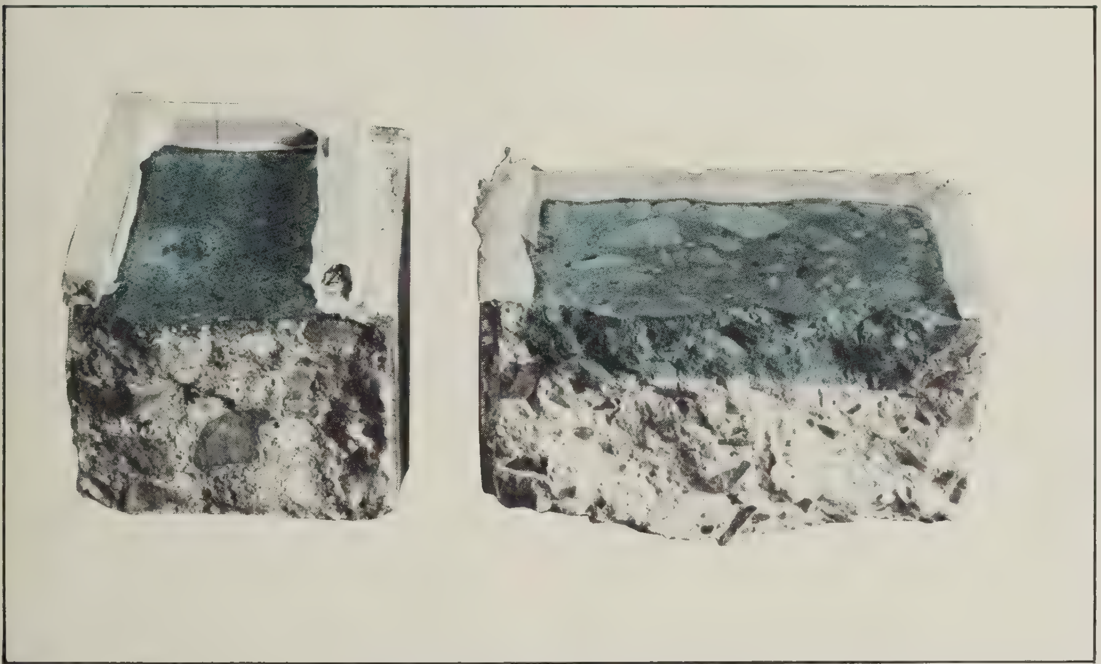
by FHWA Structures and Applied Mechanics Division

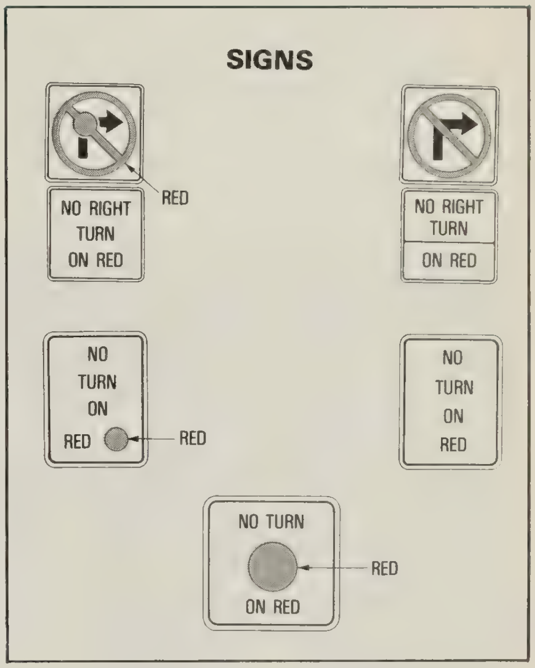
Lateral support systems for deep excavations and underpinning of adjacent structures are often required with cut-and-cover or soft ground tunneling. These reports present information from a state-of-the-art review as an aid to practicing engineers and contractors engaged in the design and construction of these structural features.

Volume I, **Design and Construction**, is a summary of Volumes II and III and includes discussions on displacements, lateral earth pressure, ground water, passive resistance, stability analysis, bearing capacity, soldier piles, steel sheet piling, diaphragm walls, bracing, tiebacks, underpinning, grouting, and ground freezing. Volume II, **Design Fundamentals**, emphasizes geotechnical aspects, provides detailed explanations of design methods, and gives attention to those parameters which contribute to excessive displacements of adjacent ground. Volume III, **Construction Methods**, presents cost comparisons of alternate methods of open excavation support construction and discusses factors affecting their implementation. Also, an attempt is made to balance operational construction considerations with corresponding engineering considerations. **Concepts for Improved Lateral Support Systems** suggests improvements for existing systems and recommendations for future research using both analytical procedures and new construction techniques.

These reports are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161 (complete set, Vols. I, II, and III—Stock No. PB 257209; Vol. I—Stock No. PB 257210; Vol. II—Stock No. PB 257211; Vol. III—Stock No. PB 257212; and Concepts for Improved Lateral Support Systems—Stock No. PB 255706).

You Should Know About





Internally Sealed Concrete: Materials Characterization and Heat Treating Studies, Report No. FHWA–RD–77–16

by FHWA Materials Division

Internally sealed concrete is a relatively new concept in which small spherical wax particles are mixed with the conventional components of portland cement concrete. After the concrete has cured, heat is applied and the wax melts and flows into the capillaries and bleed channels of the concrete. When it cools, the wax solidifies in the capillaries and bleed channels creating an internally sealed concrete which water and chloride cannot penetrate.

This report describes the processes necessary for efficient experimental construction of bridge decks using internally sealed concrete. The principal areas reported are the development of safe, efficient field heating systems; and definitions of the engineering properties of the particular internally sealed concrete specified for the experimental projects. The report also presents changes made to correct cracking problems encountered in early testing as well as several heating equipment experiments which document the development and evaluation of both small, single-pass, fast-heating equipment and equipment which slowly heats a large area at once. Also included in the report is an analysis of two prototype internally sealed decks built in 1975 and heat treated in 1976.

The report is available from the Materials Division, HRS–20, Federal Highway Administration, Washington, D.C. 20590.

Right Turn on Red, Volume 1 (Report No. FHWA–RD–76–89) and Volume 2 (Report No. FHWA–RD–76–90)

by FHWA Traffic Systems Division

Right turn on a red traffic signal (RTOR) has gained wide acceptance and use by the States in the last few years. However, there is still disagreement on whether, where, and how RTOR should be implemented. The objectives of the study presented in these reports were to determine whether RTOR should be permitted and to prepare guidelines for determining inclusion or exclusion of RTOR. The study included field data collection and computer simulation analyses, accident analyses, driver and pedestrian attitude surveys, legal and law enforcement analyses, and a signing needs evaluation.

Volume 1, **Final Technical Report**, contains the complete documentation of the technical studies and recommendations. It also includes implementation guidelines and recommended changes to the Manual on Uniform Traffic Control Devices. Volume 2, **Executive Summary**, highlights the important findings and recommendations.

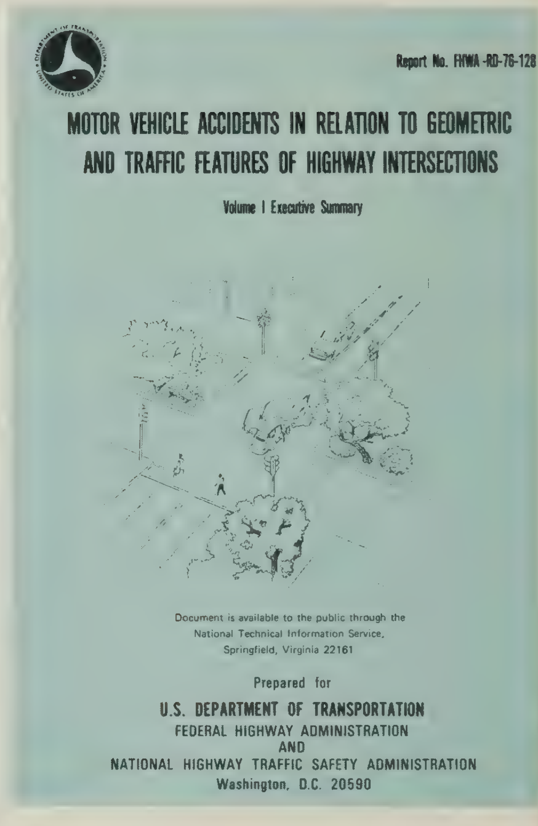
Both volumes are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161 (Vol. 1—Stock No. PB 262255; Vol. 2—Stock No. PB 262256).

Organizing and Operating a Vanpool Program

by the Virginia Highway and Transportation Research Council

This report identifies the various elements of vanpool programs and describes the procedures necessary for employers and agencies to implement a vanpool program. The concept of vanpools is introduced and benefits to management and employees are identified. The benefits include reduced need for parking, reduced traffic congestion, and lower commuting costs. There is a discussion on employer concerns about vanpool implementation such as legal aspects and insurance costs. The steps necessary to implement a pilot vanpool program are described in detail: selecting a vanpool coordinator, van acquisition, insurance and legal requirements, and establishing operating procedures. In addition, the State's role in vanpool programs is identified and includes supportive legislation, incentive programs, information services about vanpools, and programs by State agencies to demonstrate benefits and establish costs and procedural experience.

The report is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161 (Stock No. PB 264635).



Motor Vehicle Accidents in Relation to Geometric and Traffic Features of Highway Intersections—Volume I (Report No. FHWA-RD-76-128), Volume II (Report No. FHWA-RD-76-129), and Volume III (Report No. FHWA-RD-76-130)

by FHWA Environmental Design and Control Division and National Highway Traffic Safety Administration's Accident Investigation Division

This report establishes relationships between intersection geometry and traffic and motor vehicle accident rates for several groups of intersections sharing common design features. The results presented were based on a detailed onscene inventory of the geometry, design features, and traffic counts of 558 intersections coupled with police reports of 4,372 accidents at these intersections during a 3-year period. Several design features and traffic characteristics were found to be accident-related. The report presents the effectiveness of countermeasures for these troublesome features in terms of accident reduction and accident cost.

Volume I, **Executive Summary**, highlights the study results and recommendations. Volume II, **Research Report**, provides details on the methodology, analysis, and results. Volume III, **Appendices**, provides supporting data for the study area; sampling, data collection, and analysis methods; and study results.

All of the volumes are available from the Environmental Design and Control Division, HRS–41, Federal Highway Administration, Washington, D.C. 20590.

Effects of Highway Construction and Use on Big Game Populations, Report No. FHWA–RD–76–174

by U.S. Forest Service for FHWA Environmental Design and Control Division

This report presents the effects of right-of-way fences and highway traffic on pronghorn antelope, mule deer, and elk. During a 5½-year period, at least 153 antelope, 561 mule deer, and 10 elk were killed by vehicles along a 55-mile (88.5 km) section of I–80 west of Laramie, Wyo. Since antelope are reluctant to jump fences and use underpasses, I–80 is a barrier to them and they can be managed by woven wire fences. Mule deer jump right-of-way fences but can be forced to use underpasses by using deerproof fencing. Proper management can provide safe deer crossings and increase the safety of motorists. Since elk are large, they present a greater hazard to motorists and should be discouraged from crossing highways by proper fencing and road location. New techniques using heart-rate telemetry show great potential for use in further studies of animal behavior in relation to the ever-increasing activities of man.

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

Federal Highway Administration Regional Offices:

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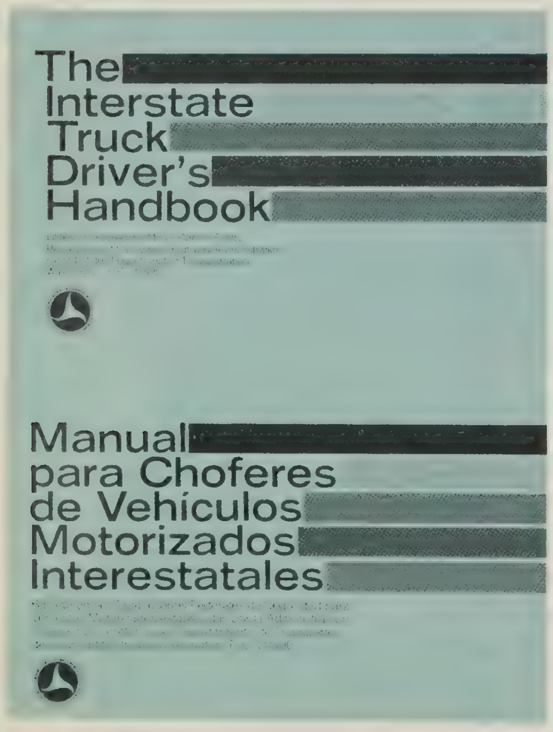
No. 15. 1000 North Glebe Rd., Arlington, Va. 22201.
Eastern Federal Highway Projects.

No. 19. Drawer J, Balboa Heights, Canal Zone.
Canal Zone, Colombia, Costa Rica, Panama.

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. These items will be available from the Implementation Division unless otherwise indicated.

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



The Interstate Truck Driver's Handbook

by the Regulations Division, FHWA Bureau of Motor Carrier Safety

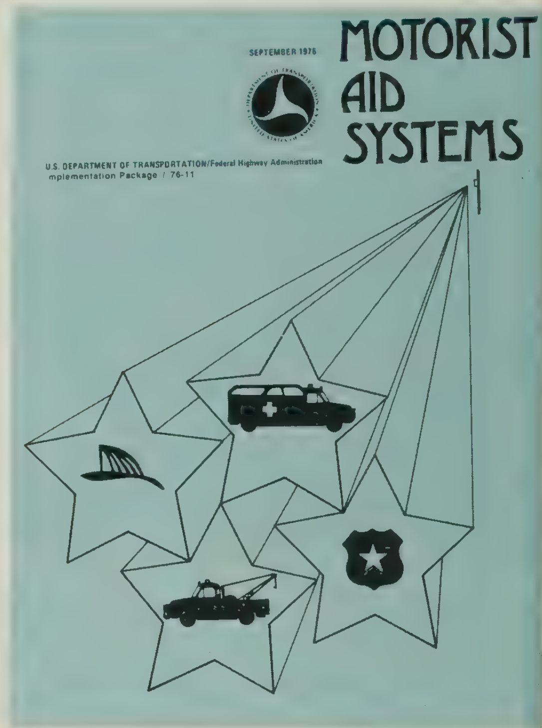
This handbook has been designed as an aid to understanding the Federal Motor Carrier Safety Regulations (FMCSR). It is an easily understood summary of the regulations that interstate truck drivers must meet. Sections are included on meeting qualifications, driving safety, hours of service, care of the truck, and transporting hazardous materials. The handbook is only a guide to the FMCSR and should not be used for strict legal interpretation of the regulations. The exact wording of each of the regulations appears in the Federal Motor Carrier Safety Regulations, Code of Federal Regulations, Title 49, Transportation, Parts 390–397.

Both English and Spanish versions of the handbook are available from the Regulations Division, HMC-22, Bureau of Motor Carrier Safety, Federal Highway Administration, Washington, D.C. 20590.

Motorist Aid Systems, Summary

by the FHWA Implementation Division

To be responsive to the needs of disabled motorists, a motorist aid system must bring the existence of a disabled motorist to the attention of those responsible for and capable of providing help, ascertain the type of service required, and quickly provide the appropriate response. The basic elements incorporating the functions of a motorist aid system are detection, definition, dispatch, service, and recording.



This summary presents an overview of a Motorist Aid Systems Study conducted for the FHWA Implementation Division. The study defined and evaluated the current state of the art for motorist aid systems. The documentation of the study includes the following reports: FHWA Policy Report, State-of-the-Art Report (Implementation Package 76-11), and Motorist Aid Systems Bibliography (Implementation Package 76-12). A slide presentation entitled "Motorist Aid Systems—A Brief Review" is also available.

The summary, reports, and slide presentation are available from the Implementation Division.

A Traverse Adjustment Computer Program: User's Manual, Implementation Package 76–4

by the FHWA Implementation Division

The solution and balancing of traverse problems using computers offers several advantages over manual methods. The most important single advantage is the speed of calculation and the resulting lack of tedious manual calculations. This permits the engineer to select a number of different balancing methods for the same traverse problem and compare the results.

The computer program described in this manual can solve traverse problems by any one of seven different modes, including two correction and four adjustment methods. The two most significant of these methods—distance correction and weighted least square adjustment—are described in detail in this report. The other five methods are conventional and mentioned only briefly.

The report is available from the Implementation Division.

Highway Air Quality and Highway Noise Notebooks

by FHWA Implementation Division

The assessment and mitigation of air quality and noise impacts related to highways are relatively new and dynamic areas in the process of highway development. In an effort to disseminate the most current information in the air quality and noise fields to the working level in the State highway and the FHWA field offices, notebooks have been prepared. These notebooks serve a three-fold purpose: (1) as a ready reference guide for those dealing in air quality and highway noise on a daily basis; (2) as an instructional tool for new personnel unfamiliar with current technology in these fields; and (3) as a systematic means to disseminate newly developed information.

The notebooks are available from the Implementation Division.

Fundamentals of Air Quality, Implementation Package 76–5

by FHWA Implementation Division

This manual is a training text which is based on the 1972 FHWA Air Quality Manuals, Volumes I through VIII; Turner's Workbook of Atmospheric Dispersion Estimates; and training materials from the initial series of Highway Air Quality Workshops. Current state-of-the-art technical information has been incorporated.

In addition to being a training tool, this text is a basic reference manual for dealing with the problem of highway air pollution. Basic information on air pollutants, meteorological terms and factors related to pollutant dispersion, and analysis of highway air quality impact assessment are covered.

The text is available from the Implementation Division.

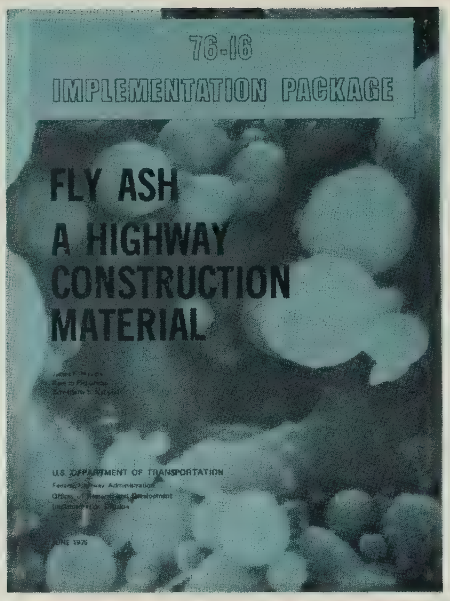
Evaluation of Minor Improvements, Grooved Pavement, (Supplemental Report) Part 8

by the California Department of Transportation in cooperation with FHWA

This report presents an evaluation of the effectiveness of longitudinal grooving in reducing wet pavement accidents on freeways in Los Angeles County, Calif. A "before and after" technique was used in the evaluation of 322 lane-miles (518 lane-km) of grooved portland cement concrete pavement on State freeways; 750 lane-miles (1,207 lane-km) of ungrooved portland cement concrete were used as a control. Accidents (fatal and injury only) were evaluated for a 2-year before and after period on both the grooved and ungrooved sections of freeway.

A different method was developed to predict wet pavement accident rates after grooving on future projects. The method depends on accounting for any trends in the wet and dry pavement accident rates that have occurred in the past.

The report is available from the Implementation Division.



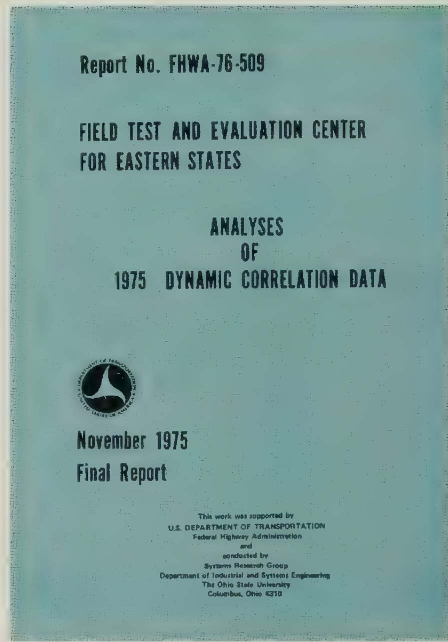
Fly Ash—A Highway Construction Material, Implementation Package 76–16

by the FHWA Implementation Division

Fly ash exhibits unique engineering properties. It is a pozzolanic material and has a light unit weight which makes it useful for highway construction. Its large-scale use will help solve a national waste disposal problem. It is estimated that there are 500 million tons (450 million tonnes) of fly ash in stockpile in the United States, and another 30 million tons (27 million tonnes) are being added each year. Current use is about 5 percent of the annual production, whereas in Europe about 60 percent is being used for construction purposes.

This design and construction manual describes the use of fly ash in aggregate treated base course, soil stabilization, embankments, structural backfill, and grouting mixtures. Guidelines are provided for fly ash evaluation, mixture design, structural design, and construction procedures. This manual should be of interest to research, design, and construction engineers in highway construction agencies, particularly in those localities where fly ash is readily available from large electric power generating stations.

The manual is available from the Implementation Division.



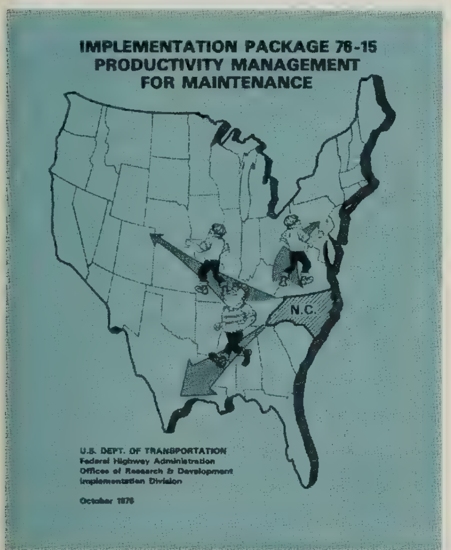
Analyses of 1975 Dynamic Skid Correlation Data at the Field Test and Evaluation Center for Eastern States, Report No. FHWA–RD–76–509

by the Ohio State University and the FHWA Implementation Division

Fifteen skid measurement systems from the Eastern States were evaluated and calibrated at the Field Test and Evaluation Center for Eastern States. This report summarizes the analyses of the dynamic correlation data collected for each system during April through August 1975. The analyses included two major factors: (1) The average skid number variation over the entire period, and (2) the short term skid number variation relative to long term variation. These two factors are examined for their relation to long term variation (time), pad wear, and both ambient and pavement temperatures.

The report also includes the results of an independent study concerned with the procedures used in the correlation program itself. The question of errors introduced as biases in computing the skid number from tractive force and skid trailer dynamic load is examined. This report should be of direct interest to those persons working in the pavement skid resistance measurement field.

The report is available from the Implementation Division.

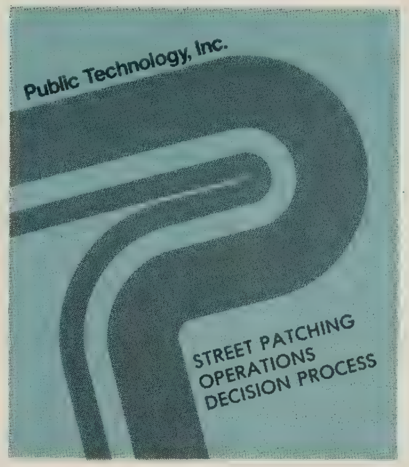


Productivity Management for Maintenance, Implementation Package 76–15

by North Carolina Division of Highways for FHWA Implementation Division

When highway maintenance operations in North Carolina began to feel the constraints of tight money, inflation, and the energy crisis, their Department of Transportation authorized a new branch to focus on productivity. This report describes how the Productivity Management Branch was organized and how it approached productivity improvement. A brief report of 27 studies completed to date is provided. One of these studies indicates a 60 percent reduction in the material costs for bituminous surface patching and another predicts a 67 percent productivity gain for the bituminous crack-pouring operation. The structure and operation of the field productivity teams are emphasized.

The report is available from the Implementation Division.



Street Patching Operations Decision Process

by Public Technology, Inc.

This report describes a method for managing street patching operations. The Street Patching Operations Decision Process was developed to enable local governments to evaluate changes in operations and equipment. It has been tested by street departments in a number of cities with favorable results.

The process considers three basic components of street patching operations: labor, materials, and equipment. It allows a jurisdiction to determine and analyze its current street patching costs and to evaluate the impact of proposed changes in these three areas. Through analysis of current costs and performance in street patching operations, opportunities for cost reduction or performance improvement are suggested. The cost impact of an equipment change or a crew size change and an evaluation of combined changes in all three areas are presented as examples of the application of the process. This manual is a useful tool to highway agencies in evaluating current operations in terms of labor, materials, equipment, and the estimated operating costs of proposed changes.

The manual is available from Information Director, Public Technology, Inc., 1140 Connecticut Avenue, NW., Washington, D.C. 20036.

Pile Driving Analysis, Implementation Packages 76–13 and 76–14

by the Texas Transportation Institute and Goble and Associates

In recent years, a new tool, the Wave Equation, has been developed for analysis of pile driving problems. It can be used to predict the compressive and tensile driving stresses in piles and to estimate the soil resistance acting on a pile at the time of driving.

Two FORTRAN computer programs, the TTI and WEAP Programs, have been developed to perform a computer wave equation analysis of piles driven by air/steam and diesel hammers. The TTI Program (Implementation Package 76–13) provides an introduction to the wave equation concept and is best suited for the analysis of air/steam hammers. The WEAP Program (Implementation Package 76–14) is used for analyzing all types of hammers and theoretically will yield more accurate results for a diesel hammer analysis. Each package includes three manuals and a printed script for a slide-tape presentation. The manuals will be of particular interest to those involved in the design and construction of pile foundations.

The manuals are available from the Implementation Division and the slide-tape presentation is available from FHWA regional offices (see p. 45).

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: Passing and No-Passing Zones—Signs, Markings, and Warrants. (FCP No. 31A1673)
Objective: Develop and evaluate improved criteria for establishing passing, no-passing, and restrictive passing zones; traffic control devices; and warrants for urban and rural two-lane highways to be considered for inclusion in the American Association of State Highway and Transportation Officials policy and the Manual on Uniform Traffic Control Devices.
Performing Organization: Texas A&M Research Foundation, College Station, Tex. 77843
Expected Completion Date: March 1978
Estimated Cost: $149,000 (FHWA Administrative Contract)

FCP Project 1E: Safety of Pedestrians and Abutting Property Occupants

Title: Identification and Feasibility of Demand Incentives for Nonmotorized Transportation. (FCP No. 31E3043)
Objective: Identify and evaluate demand incentives for encouraging bicycle and pedestrian activities in urban areas for utilization trip purposes.
Performing Organization: Barton Aschman, Minneapolis, Minn. 55155
Expected Completion Date: October 1978
Estimated Cost: $212,000 (FHWA Administrative Contract)

FCP Project 1G: Safer Traffic Guardrails and Bridge Railings

Title: Lower Service Level Highway Bridge Railings—Performance and Design Criteria. (FCP No. 51G2081)
Objective: Identify and document performance and design criteria for bridge railing systems for roadways offering various levels of service. Develop and validate at least one design for the lower service level using computer simulation and full-scale testing.
Performing Organization: Southwest Research Institute, San Antonio, Tex. 78284
Expected Completion Date: June 1978
Estimated Cost: $195,000 (NCHRP)

FCP Project 1L: Improving Traffic Operations During Adverse Environmental Conditions

Title: Evaluation of an Earth Heated Ramp. (FCP No. 31L7014)
Objective: Document and evaluate the construction and operation of a ramp heated by ammonia-filled pipes conducting stored earth heat energy. Monitor ambient weather conditions and temperatures throughout the heat pipe system for three winter seasons.
Performing Organization: West Virginia Department of Highways, Charleston, W. Va. 25305
Expected Completion Date: November 1978
Estimated Cost: $58,000 (FHWA Administrative Contract)

FCP Project 1T: Advanced Vehicle Protection Systems

Title: Laboratory Evaluation of Existing Breakaway Structures. (FCP No. 31T5012)
Objective: Evaluate existing breakaway sign and luminaire supports by analysis, laboratory pendulum test, and full-scale test. Improve the breakaway performance where feasible without degradation of fatigue life in accordance with American Association of State Highway and Transportation Officials criteria.
Performing Organization: Ensco, Inc., Springfield, Va. 22151
Expected Completion Date: October 1978
Estimated Cost: $174,000 (FHWA Administrative Contract)

FCP Project 1U: Safety Aspects of Increased Size and Weight of Heavy Vehicles

Title: Reduction of Adverse Aerodynamic Effects of Large Trucks. (FCP No. 31U3012)
Objective: Develop methods to minimize the adverse effects of truck-induced aerodynamic disturbances, splash, and spray.
Performing Organization: Systems Technology, Inc., Hawthorne, Calif. 90250
Expected Completion Date: July 1979
Estimated Cost: $491,000 (FHWA Administrative Contract)

FCP Category 2—Reduction of Traffic Congestion, and Improved Operational Efficiency

FCP Project 2D: Traffic Control for Coordination of Car Pools and Buses on Urban Freeway Priority Lanes

Title: Evaluation of Preferential Lanes for High Occupancy Vehicles at Metered On-Ramps. (FCP No. 32D1514)
Objective: Evaluate the effects of implementing a series of ramp meter bypass facilities on the Golden State Freeway (I–5) in Los Angeles to determine changes in vehicle occupancy, air quality, energy conservation, and public attitudes.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95814
Expected Completion Date: May 1978
Estimated Cost: $149,000 (FHWA Administrative Contract)

FCP Project 2L: Detection and Communications for Traffic Systems

Title: Detection and Communications for Traffic Systems. (FCP No. 32L1132)
Objective: Develop and fabricate self-powered vehicle detector (SPVD) prototype sensors using the Honeywell SPVD design as a baseline.
Performing Organization: Naval Surface Weapons Center, Silver Spring, Md. 20910
Expected Completion Date: February 1978
Estimated Cost: $120,000 (FHWA Administrative Contract)

Title: Development of a Wide Area Detector. (FCP No. 32L1152)
Objective: Demonstrate the use of an automatic surveillance system.
Performing Organization: Jet Propulsion Laboratory, Pasadena, Calif. 91109
Expected Completion Date: March 1978
Estimated Cost: $345,000 (FHWA Administrative Contract)

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

FCP Project 3F: Pollution Reduction and Visual Enhancement

Title: The Effect of Highway Operation Practices and Facilities on Elk, Mule Deer, and Pronghorn Antelope. (FCP No. 33F2042)
Objective: Evaluate various methods of detecting large animals on the highway and various radio telemetry techniques used to monitor the activities of big game species. Assess the effectiveness of deerproof fence and determine the impact of snow fencing on game species.
Performing Organization: U.S. Forest Service, Laramie, Wyo. 82071
Expected Completion Date: March 1979
Estimated Cost: $150,000 (FHWA Administrative Contract)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4C: Use of Waste as Material for Highways

Title: Guidelines for Recycling Pavement Materials. (FCP No. 54C3033)
Objective: Develop guidelines for recycling pavements in consideration of various recycling techniques, equipment needs, environmental effects, energy conservation, mix design methods, and types of additives. Evaluate the practicality of the guidelines.
Performing Organization: Texas A&M Research Foundation, College Station, Tex. 77843
Expected Completion Date: January 1979
Estimated Cost: $200,000 (NCHRP)

FCP Project 4D: Remedial Treatment of Soil Materials for Earth Structures and Foundations

Title: Stabilization of Oklahoma Soils with Hydrated Calcitic Lime: An Evaluation. (FCP No. 44D3184)
Objective: Investigate the effects of time and weather on the engineering properties of soil lime mixtures used in Oklahoma road construction.
Performing Organization: Oklahoma Department of Highways, Oklahoma City, Okla. 73105
Expected Completion Date: June 1978
Estimated Cost: $62,000 (HP&R)

FCP Project 4E: Techniques to Determine Critical Terrain and Environmental Features by Remote Sensing

Title: High Resolution Sensing Techniques for the Study of Landslide Potential. (FCP No. 34E2142)
Objective: Investigate new approaches to better defining discontinuities and inhomogeneities in soil/mass which influence slope stability. Investigate new and

developing techniques for measuring soil, rock, water, and air mixtures to document boundary, internal, and external influence for slope stability analyses.
Performing Organization: National Bureau of Standards, Boulder, Colo. 80203
Expected Completion Date: October 1978
Estimated Cost: $196,000 (FHWA Administrative Contract)

FCP Project 4G: Substitute and Improved Materials to Reduce the Effects of Energy Problems in Highway Costs

Title: Design of Emulsified Asphalt Paving Mixtures. (FCP No. 24G1073)
Objective: Develop a rational mix design procedure for durable emulsified asphalt paving mixtures. Ascertain the cost-energy savings of using emulsified asphalt pavements as opposed to hot plant mix asphalt concrete pavements.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: September 1979
Estimated Cost: $100,000 (FHWA Staff Research)

Title: Evaluation of Aggregate Shape and Surface Roughness as Related to Frictional Characteristics. (FCP No. 24G2021)
Objective: Develop method to quantitatively measure aggregate shape and surface roughness characteristics to evaluate relative importance in the development of frictional forces. Study surface features such as asperity height, width, spacing, density, area, and composition with rapid scan surface analyzer.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: September 1978
Estimated Cost: $173,000 (FHWA Staff Research)

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

FCP Project 5B: Tunneling Technology for Future Highways

Title: Measuring and Testing Techniques for the Determination of In Situ Stress in Soil Masses. (FCP No. 35B2522)
Objective: Develop and manufacture improved, more reliable, and practical field measuring instruments for routine determinations of the state of stress in natural soil masses.
Performing Organization: Foundation Sciences, Inc., Portland, Oreg. 97310
Expected Completion Date: October 1978
Estimated Cost: $360,000 (FHWA Administrative Contract)

FCP Project 5D: Structural Rehabilitation of Pavement Systems

Title: Pavement Condition Measurement Needs and Methods. (FCP No. 35D4042)
Objective: Develop procedures for collecting pavement condition data from inventories for managerial decisions. Include selection and application of measurement equipment and data processing, storage, and retrieval methodology.
Performing Organization: Pennsylvania Department of Transportation, Harrisburg, Pa. 17120
Expected Completion Date: March 1978
Estimated Cost: $64,000 (FHWA Administrative Contract)

FCP Project 5F: Structural Integrity and Life Expectancy of Bridges

Title: Extending the Service Life of Existing Bridges by Increasing Their Load Capacity. (FCP No. 35F2152)
Objective: Develop innovative methods to economically and rapidly upgrade and increase the load carrying capacity of geometrically inadequate and structurally unsound bridges.
Performing Organization: Byrd, Tallamy, McDonald, and Lewis, Falls Church, Va. 22042
Expected Completion Date: May 1978
Estimated Cost: $96,000 (FHWA Administrative Contract)

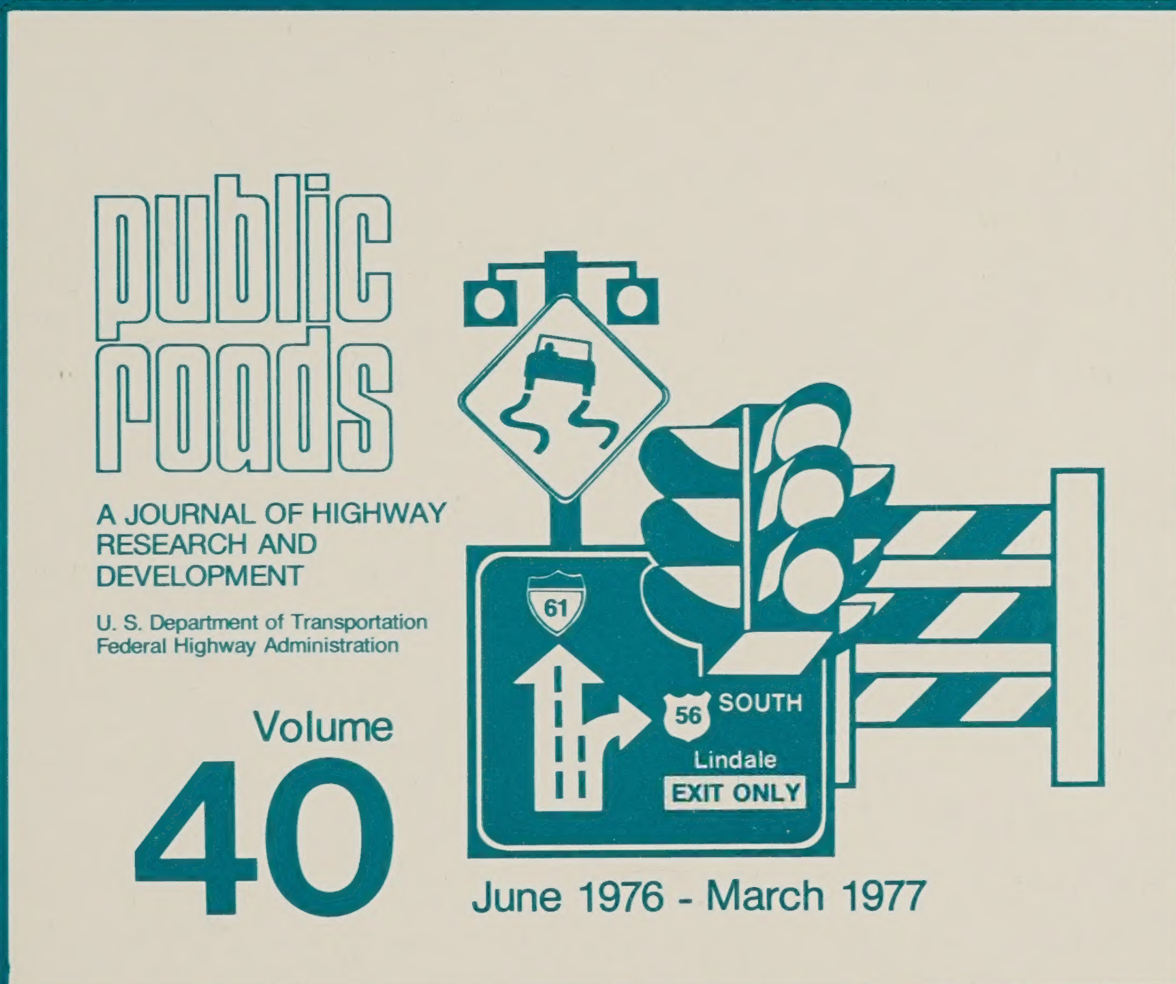
Title: Bridge Girder Butt Welds' Resistance to Brittle Fracture Corrosion. (FCP No. 45F2302)
Objective: Evaluate electroslag and submerged arc butt weldments for their fracture toughness, fatigue, and corrosion properties in two grades of bridge steels.
Performing Organization: Michigan Department of State Highways, Lansing, Mich. 48904
Expected Completion Date: September 1979
Estimated Cost: $220,000 (HP&R)

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

Title: New Structural Concepts for Culvert Installations. (FCP No. 35I3211)
Objective: Develop new structural concepts for increasing the span of corrugated metal culverts. Evaluate the feasibility of using soil stabilization for more economical culvert structures.
Performing Organization: Civil Engineering Laboratory, Port Hueneme, Calif. 93043
Expected Completion Date: July 1978
Estimated Cost: $98,000 (FHWA Administrative Contract)

☆U.S. Government Printing Office: 1977—720-212/3

TITLE SHEET, VOLUME 40



The title sheet for volume 40, June 1976–March 1977, of Public Roads, A Journal of Highway Research and Development, is now available. This sheet contains a chronological list of article titles and an alphabetical list of authors' names. Copies of this title sheet can be obtained by sending a request to the managing editor of the magazine, U.S. Department of Transportation, Federal Highway Administration (HDV-10), Washington, D.C. 20590.

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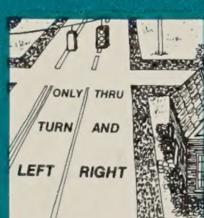
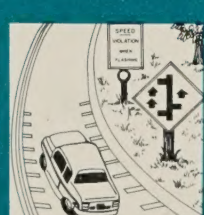
in this issue

Applications of the Community Aggregate Planning Model
An Urban Transportation Sketch Planning Procedure

The Effect of Yielding on the Fatigue Strength of Steel Beams



Studies of the Road Marking Code



Evaluation of Speed Control Signs for Small Rural Towns

Improved Freeway Incident Detection Algorithms

public roads

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