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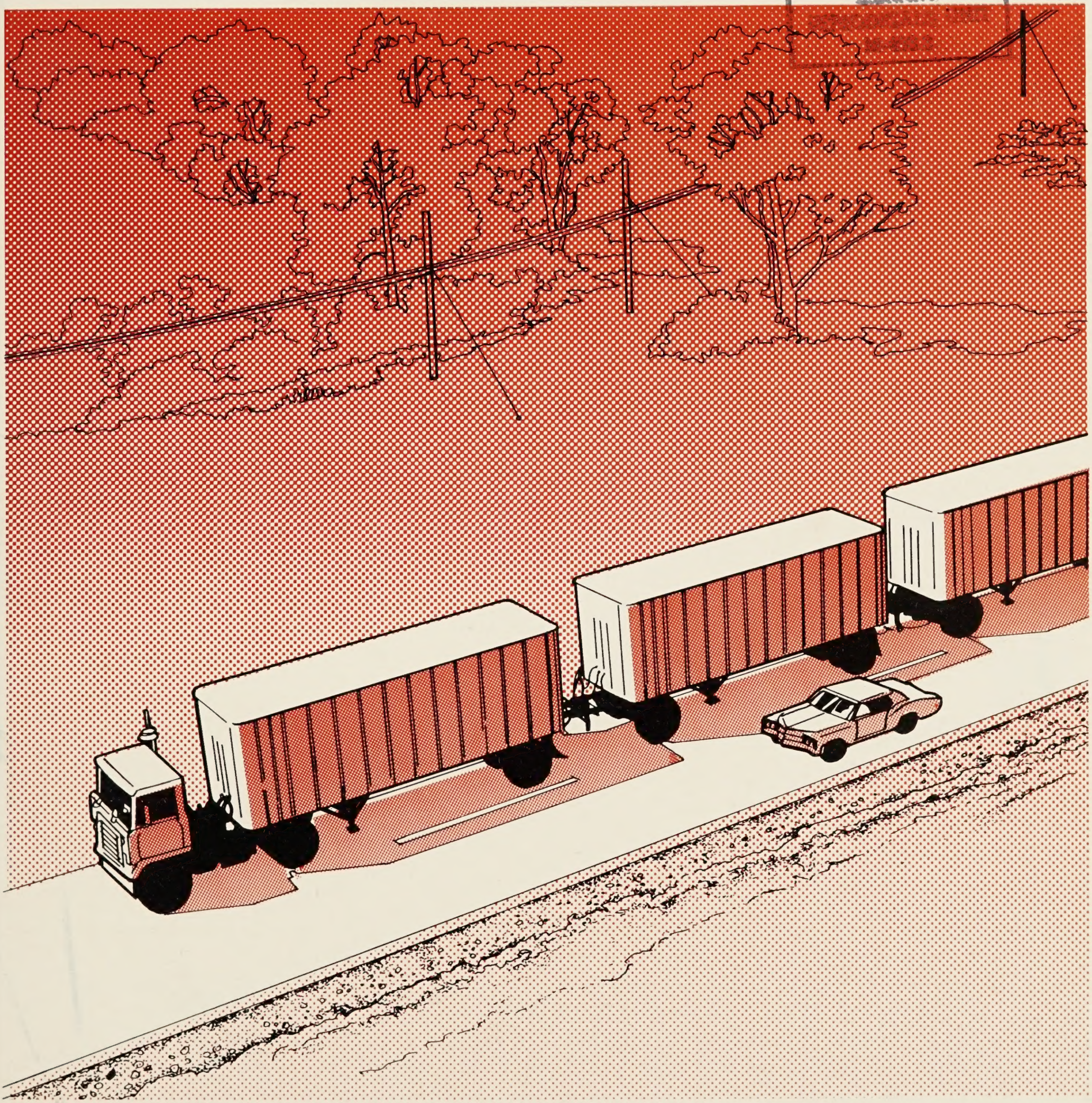

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IN THIS ISSUE

Articles

Departments

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Reorganization of the Federal Highway Administration's Offices of Research and Development

In July 1982 the Federal Highway Administration (FHWA) Offices of Research and Development were reorganized and renamed the Offices of Research, Development, and Technology (RD&T). The purpose of the reorganization was to reflect changing programs and priorities and emphasize the importance of the technology transfer process, improve management communications and operations, and accommodate necessary personnel reductions.

Major features of the new organization, shown in the chart below, include the following:

• The National Highway Institute (NHI) was transferred intact from the staff of the Federal Highway Administrator to the Associate Administrator for RD&T because of the close relationship between NHI's and RD&T's missions, especially in technology transfer functions. The change also allows a more efficient sharing of personnel and administrative operations.

• A Science Advisor position was established. The incumbent advises and assists the Associate Administrator on technical issues and represents FHWA in various national and international scientific activities.

• An Office of Operations Staff was created and includes budget, program analysis, personnel, publications, and related functions.

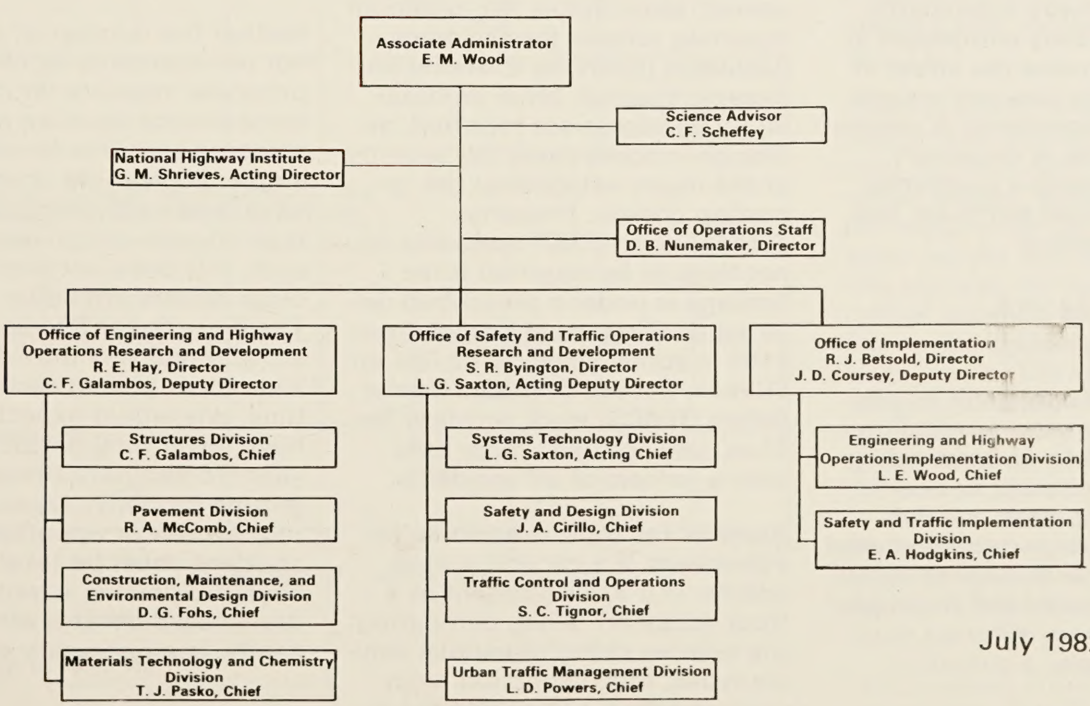
• Three major offices were created—Office of Engineering and Highway Operations Research and Development (structures, materials, and hydraulics), Office of Safety and Traffic Operations Research and Development (operational safety, traffic engineering, and supporting systems and technology), and Office of Implementation (technology transfer and related coordination). The remaining line staff were organized into 10 divisions that are functionally alined to better parallel the programs and organizational structure of the other FHWA operating offices.

• Management levels below the division level, such as groups, were eliminated.

• The mechanical, electronics, computer, and publication functions previously under one division were reassigned as follows:

Mechanical—Materials Technology and Chemistry Division,
Electronics—Systems Technology Division,
Computer—Safety and Traffic Implementation Division, and
Publications—Office of Operations Staff.

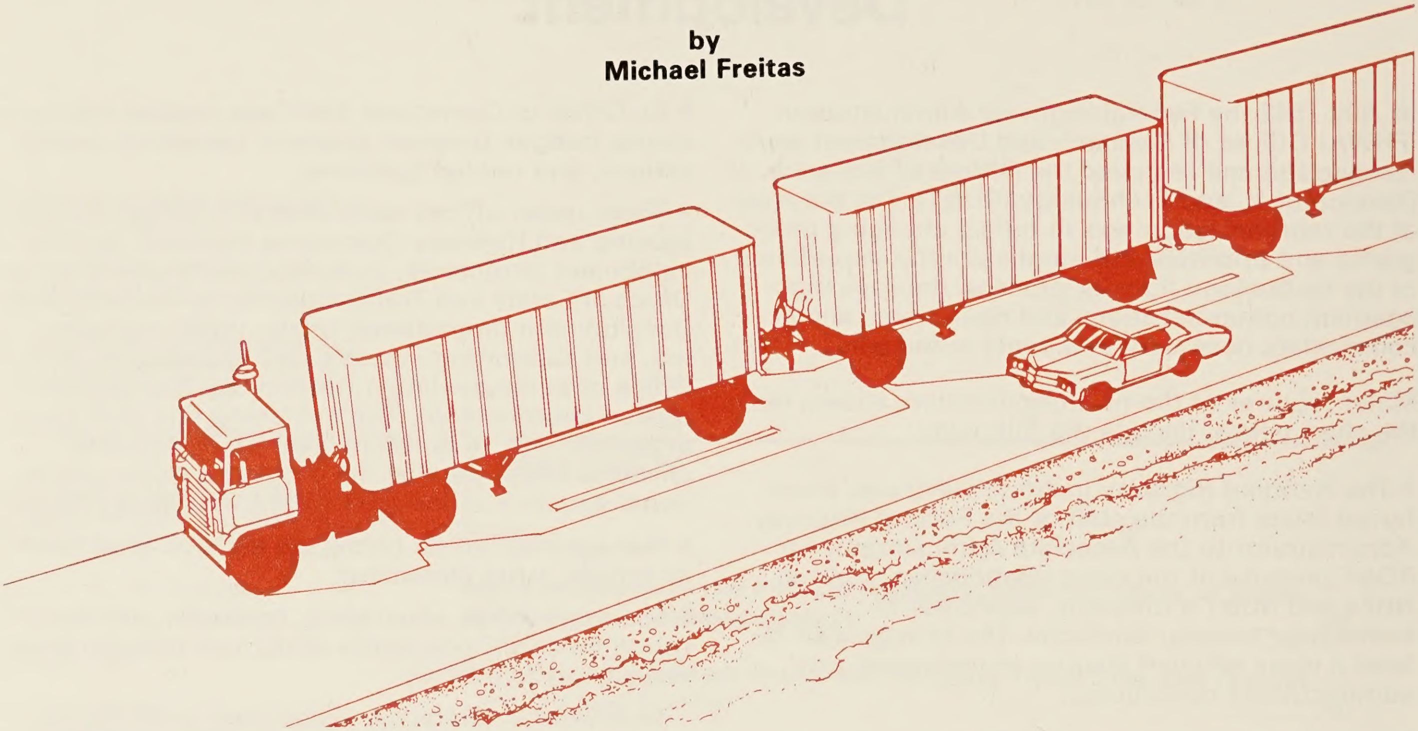
Offices of Research, Development, and Technology



July 1982

A Review of Accident Research Involving Truck Size and Weight

by
Michael Freitas



The most obvious method of determining how various highway, driver, and vehicle factors contribute to highway accidents is by collecting and analyzing accident data. This method has been used in several studies, including a Federal Highway Administration (FHWA) study completed in 1980, to determine the effect of increased truck size and weight on accident experience. A review of these studies is necessary, however, to resolve conflicting study results and put them into proper perspective.

Accident Research Terminology

One source of confusion in accident research is the terminology used. Without an understanding of similar terms such as accidents, accident rates, involvements, fatalities per accident, and injury rates, it is difficult to understand study results and thus compare results from different studies. For example, a simple definition of a motor vehicle accident might be any collision of a motor vehicle and some other object or vehicle with enough force to damage the motor vehicle(s) or the object struck or to injure occupants of the motor vehicle(s) involved. Most States set minimum reporting criteria for accidents. Accidents involving a fatality are always reported. Most nonfatal injury accidents are reported, although in some cases the severity of the injury establishes the reporting criteria. Property-damage-only (PDO) accidents do not have to be reported if the damage is under a prescribed dollar value. This value ranges from $100 in some States to $2,000 for FHWA's Bureau of Motor Carrier Safety (BMCS) truck accident file. Thus, any accident study uses only a sample of all accidents.

Another key term is accident involvement. If a car and a truck collide, is it a car accident or a truck accident? When comparing the relative safety of various vehicle types, this distinction is important. When comparing the accident experience of cars versus trucks or trucks of various configurations, it is appropriate to use involvements in accidents. Thus, an accident involving three vehicles would be counted as three involvements.

Neither the number of accidents nor involvements alone is an appropriate measure for most safety comparisons because neither measure accounts for risk. For example, 80-year-old drivers may have fewer accidents in a year than 30-year-old drivers; however, this does not mean that older drivers are better drivers. There are fewer 80-year-old drivers and typically they drive fewer kilometres (miles) each year; thus, one would expect them to have fewer total accidents in a year. To compare these two groups properly, exposure, the relative risk or opportunity for an accident, must be taken into account. Exposure, a term that has drawn considerable attention recently, is a necessary element for comparing accident experience. Commonly used exposure measures are number of vehicles, vehicle-kilometres (vehicle-miles) of travel, cargo kilogram-kilometres (ton-miles) of travel, and passenger-kilometres (passenger-miles) of travel. It is essential to select the proper exposure measure for a specific safety assessment.

Exposure is used to calculate accident and involvement rates. Accident rate is the number of accidents divided by the exposure measure. Involvement rate is the number of accident involvements divided by the exposure measure. These rates can be compared to determine the relative safety of various vehicles, highway sections, and drivers.

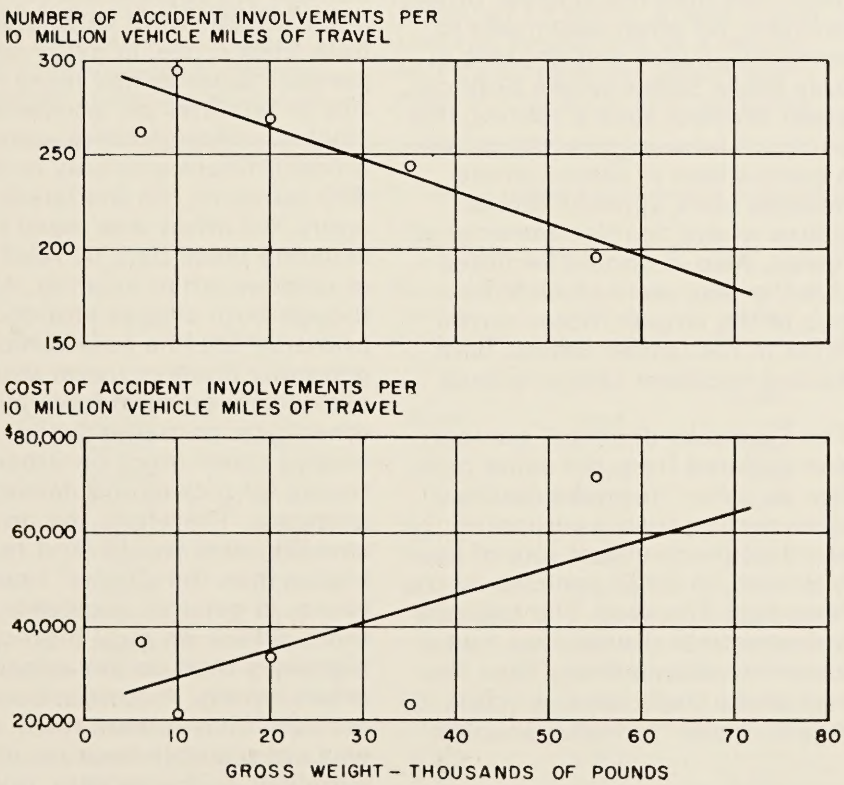
Appropriate measures for severity comparisons might be injuries or fatalities per accident. However, these variables do not measure the probability of an accident, but only the probability of an injury or fatality given an accident occurs. The variables are very useful for evaluating the crashworthiness of vehicles or the performance of roadside barriers.

The incidence of severe accidents is measured by fatality rates, fatal accident rates, injury rates, and injury accident rates. Injury rate is the total number of injuries divided by the appropriate exposure measure. Fatality rate is the total number of fatalities divided by exposure. Injury accident rate and fatal accident rate, however, are the total number of accidents in which an injury or fatality occurred, respectively, divided by exposure.

Key Accident Research Studies

Following is a review of 10 key accident studies relating to increased truck size and weight. In general, the trucks involved were large—not small vans, panels, or pickups—and included single-unit trucks with at least six tires and gross weights of more than 4.5 Mg (10,000 lb) empty and 9.1 Mg (20,000 lb) loaded and all combination trucks (singles [tractor-semitrailer], doubles [tractor-semitrailer-full trailer], and triples [tractor-semitrailer-two full trailers]).

Figure 1.—Gross vehicle weight of trucks related to the number and cost of accident involvements in Illinois, 1958. (1)



1 mile=1.61 km

1,000 lb=0.45 Mg

Some of the following studies cited were part of general economic reviews of increased truck size and weight that used available accident data for a safety assessment. Others are general truck accident studies in which the major issue was truck safety; hence, size and weight were just two of many variables examined for their safety effect. Finally, some studies were specifically designed to assess the effect of increased truck size and weight on accidents.

General size and weight studies

In 1964 the Secretary of the U.S. Department of Commerce submitted to Congress an economic assessment of increased truck size and weight that included a chapter on safety. (*1*)[1] Included in that chapter was an analysis of truck accidents by gross weight. The analysis indicated that the accident involvement rate of trucks decreased as weight increased. An analysis of accident costs, however, indicated that the cost of accidents increased with increasing weight (fig. 1).

Unfortunately, only registered weight was available for the analysis. No data were available on actual weight. Because there is little relationship between registered weight and actual weight, this analysis did not address the critical issue of the effect of loading on the accident experience of large trucks. The registered weights of most tractor-trailer combinations are similar, but their actual weights can vary by more than 22.7 Mg (50,000 lb).

Because all truck types with registered weights from less than 4.5 Mg (10,000 lb) to greater than

[1] Italic numbers in parentheses identify references on page 52.

31.8 Mg (70,000 lb) were included in the analysis, the data did not necessarily indicate the effect of weight. To examine the effect of weight on accident experience, it would be necessary to control for truck type. Because all trucks were included in this analysis, the data more likely indicated the effect of truck type rather than weight. Additionally, because the analysis included a range of truck types with various kinds of usage, it was simultaneously an analysis of road type because large combination trucks tend to travel on rural, high-design highways, while smaller, single-unit trucks tend to travel on urban highways, including city streets.

Such variance in usage would explain the apparent discrepancy between accident involvements and accident costs previously noted. The lighter or smaller trucks primarily travel on roads with a high incidence of accidents; the larger trucks travel primarily on roads with a low incidence of accidents. However, accidents tend to be less costly on urban roads and on roads without controlled access because of lower travel speeds.

A classic study on the economics of increased truck size and weight also discussed safety. (*2*) The only data available for study came from turnpikes on which the "turnpike double" was allowed to operate and from a test operation of "turnpike doubles" and "triples" conducted by the State of Idaho. The "turnpike double" is a tractor pulling two 12.2 to 13.7 m (40 to 45 ft) trailers. The "triple" is a tractor pulling three 8.2 m (27 ft) trailers. Both of these vehicles are approximately 30.5 m (100 ft) long and should not be confused with the more common "western double," which is a tractor pulling two 8.2 m (27 ft) trailers and is usually 19.8 m (65 ft) long. The analysis of the Idaho and turnpike data indicated that these very long and heavy combination trucks had good safety records. For example, one carrier reported his turnpike doubles experienced one accident per 2 400 000 trailer-km, or 1 200 000 vehicle-km (1,500,000 trailer-miles, or 750,000 vehicle-miles). This compared with an accident frequency for all trucks of one accident per 435 000 km (270,000 miles). The difficulty in generalizing from the turnpike and Idaho test data is that the very long and heavy combination trucks involved do not necessarily represent typical truck operations. Such combinations usually are operated under special permit or special regulations to insure their safe operation. Only modern, well-maintained equipment is used, and operators usually are experienced drivers with excellent driving records. Also, these combination trucks travel almost exclusively on high-design facilities with controlled access.

In 1969, FHWA examined the accident experience of both "western doubles" and "turnpike doubles."[2] The "western doubles" information was provided by two major interstate carrier firms. Involvement rates for both singles and doubles operated by these two firms were computed and compared. In all cases the doubles had a lower accident involvement rate than the singles. Unfortunately, no effort was made to compare singles and doubles in only those States where both operate. Without such a control, this comparison was, to some extent, a comparison of States where doubles were allowed versus States where doubles were not allowed. Also, it should be noted that the data were provided by two of the largest motor carrier firms in the United States, both having excellent safety records.

The "turnpike doubles" comparison suffered from the same problem as other "turnpike doubles" analyses because it compared the accident involvement rate of doubles with all other vehicles on the New York Thruway. The analysis indicated that the doubles had a lower involvement rate than the rest of the traffic stream (table 1). Again, these "turnpike doubles" operated under a special set of restrictions designed to enhance their operational safety.

General truck accident studies

In 1971 a statistical analysis of truck accident involvements was conducted using accident data from several States and from the BMCS accident file. (*3*) Accident and matching exposure data also were obtained from three turnpikes. The turnpike data, primarily the data from the Indiana Turnpike, provided additional insight into the issue of truck size. The accident involvement rates of singles and doubles on the Indiana Turnpike were computed, and, as shown in previous studies, the doubles (12.2 m [40 ft] long) had lower involvement rates than the singles. Again, the operation of these doubles is tightly controlled on the Indiana Turnpike to insure safe operation.

In this same study, the accident severity of singles and doubles also was compared using BMCS accident data. Casualty rates (the number of people killed or injured per accident) were calculated for both truck types. In every comparison, doubles had more injuries or fatalities per accident than singles, although there were significant differences only in the injury category, not the fatality category. No effort was made to separate these data by road type or rural or urban location. Although both singles and doubles primarily are line haul vehicles, generally doubles travel almost exclusively on rural freeways and other rural primaries while singles travel more on urban routes for pickup and delivery purposes. Therefore, the doubles' severity rates would tend to be higher than the singles' rates because, in general, accidents are more severe on rural high-speed highways than on low-speed urban streets. A comparison of accident involvement rates, which was not possible because of insufficient exposure data, might have favored doubles because rural freeways and other rural primaries generally have the lowest involvement rates.

[2] "Review of the Safety and Economic Aspects of Increased Vehicle Sizes and Weights," unpublished report, *Federal Highway Administration,* Washington, D.C., September 1969.

Table 1.—Accident involvements of "oversized" doubles on the New York Thruway compared with involvements of all vehicles using the Thruway[1]

Year	Vehicle involvements		Vehicle-miles operated		Involvement rate per 1 million vehicle-miles	
	Doubles	All vehicles[2]	Doubles	All vehicles	Doubles	All vehicles
			Thousands			
1963	19	7,012	10,972	2,767,338	1.7	2.5
1964	19	7,324	13,400	3,005,818	1.4	2.4
1965	28	7,826	16,501	3,227,595	1.7	2.4
1966	27	8,013	18,313	3,378,501	1.5	2.4
1967	33	8,439	20,397	3,533,673	1.6	2.4
1968	52	8,804	26,890	3,728,089	1.9	2.4
6-year total	178	47,418	106,473	19,641,014	1.7	2.4

[1] "Review of the Safety and Economic Aspects of Increased Vehicle Sizes and Weights," unpublished report, *Federal Highway Administration*, Washington, D.C., September 1969.
[2] The numbers of *vehicle involvements* in accidents for vehicles of all types were estimated from actual numbers of *accidents*, which were furnished.

1 mile = 1.61 km

In 1975, BMCS accident data were used to analyze severity rate as a function of truck weight. (*4*) Car-truck accidents were examined, and injuries per accident and fatalities per accident were calculated for both truck and car occupants. A clear relationship was found between truck weight and the fatality rate for car occupants. Unfortunately, these data, as in previous analyses, included a range of truck and road types, making it impossible to assess the effect of truck weight alone.

In a similar analysis conducted in 1977, BMCS data again were used to examine the effect of certain variables on the number of car occupant fatalities in car-truck accidents. (*5*) Several variables were considered, including year of accident, urban or rural location, roadway, and truck type and weight. A contingency table analysis was used to predict the probability of a fatality. It was found that the probability of a fatality could be predicted accurately from the location and the roadway (as described by the number of lanes). Once the location and roadway combination was known, the probability of a fatality did not vary significantly with truck type or weight. This conclusion supports the need to control for road type and location when comparing the accident experience of trucks or other vehicles.

Specific size and weight safety studies

Doubles/singles comparisons

In 1977, BMCS analyzed accident and vehicle-kilometre (vehicle-mile) data submitted by seven large motor carrier firms for a 7-year period. (*6*) A comparison of accident and severity rates of singles and doubles showed no differences (table 2). Again, no effort was made to separate data by region of the United States to assure equal exposure of the two truck types. Also, the seven carrier firms surveyed were among the largest common and private carriers in the Nation and, as such, operated modern, well-maintained equipment driven by experienced drivers and had active safety programs. Although

Table 2.—Safety comparison of doubles versus singles (*6*)

Year	Truck type	Accidents per million vehicle-miles	Injuries per million vehicle-miles	Fatalities per million vehicle-miles	Property damage per million vehicle-miles	Injuries per accident	Fatalities per accident	Property damage per accident
					Dollars			*Dollars*
1976	Doubles	0.572	0.307	0.066	0.0043	0.537	0.116	7,500
	Singles	0.848	0.605	0.056	0.0060	0.713	0.066	7,100
1975	Doubles	0.733	0.483	0.030	0.0075	0.660	0.041	10,240
	Singles	0.707	0.566	0.079	0.0058	0.800	0.111	8,162
1974	Doubles	0.590	0.495	0.050	0.0039	0.838	0.085	6,665
	Singles	0.880	0.688	0.046	0.0057	0.783	0.052	6,440
1973	Doubles	0.761	0.492	0.041	0.0047	0.646	0.054	6,224
	Singles	0.940	0.723	0.078	0.0066	0.769	0.082	7,002
1972	Doubles	0.660	0.550	0.048	0.0035	0.833	0.073	5,269
	Singles	0.795	0.745	0.081	0.0041	0.937	0.101	5,217
1971	Doubles	0.640	0.554	0.049	0.0042	0.865	0.076	6,506
	Singles	0.768	0.699	0.049	0.0050	0.910	0.064	6,442
1970	Doubles	0.624	0.533	0.062	0.0037	0.853	0.100	5,972
	Singles	0.963	0.925	0.070	0.0052	0.961	0.073	5,305
1969	Doubles	0.529	0.495	0.039	0.0022	0.935	0.074	4,201
	Singles	0.845	0.997	0.064	0.0039	1.180	0.076	4,624

1 mile = 1.61 km

the data are representative of large, modern truck fleets, they do not necessarily represent that portion of the truck population with older, poorly maintained equipment, inexperienced drivers, and no safety programs. In addition, these carriers run their trucks loaded about 95 percent of the time. As discussed later in this article, there is evidence that combination trucks, especially doubles, may experience serious safety problems when empty.

Recently the accident data of another large motor carrier firm was analyzed as part of a court case involving the use of doubles.[3] Highway links where this firm ran both singles and doubles were selected for study, but the report did not present criteria used in the selection. For each link, an equal number of trips involving singles and doubles were matched, and the firm's records were searched for accidents occurring on these trips. In this way, accident rates for the two truck types could be calculated with the exposure being controlled for road type, urban or rural location, and region of the United States (table 3). The analysis indicated that for this carrier firm there was no difference in the accident experience of singles and doubles. Again, however, these data may represent accurately this firm's experience with the operation of doubles but not represent the overall experience of doubles. Like most other common carriers, this firm ran virtually no empty trucks.

Table 3.—Accidents for singles and doubles[1]

Truck type	Total trips	Total miles	Total fatal accidents	Total injuries	Total accidents
Singles	188,296	56,100,018	1	27	100
Doubles	188,296	56,100,018	1	17	106

[1] John Glennon, "Matched Pair Analysis," unpublished report, *Consolidated Freightways Corporation*.

1 mile = 1.61 km

Table 4.—Accident involvement rates of singles and doubles (*7*)

Type of rate	Singles	Doubles	Rates significantly different[1]
Per 100 million vehicle-miles			
Accident involvements	146.4	148.9	No
Injuries	62.1	63.5	No
Fatalities	3.8	5.3	Yes
Per 100 million ton-miles			
Accident involvements	14.70	11.0	Yes
Injuries	6.30	4.7	Yes
Fatalities	0.38	0.4	No

[1] Significantly different at the 0.05 level.

1 mile = 1.61 km
1 ton = 0.91 Mg

An analysis conducted for FHWA in 1978 used data from the State of California to assess the relative safety of singles and doubles. (*7*) Accident data from 1974 were combined with estimates of truck exposure to calculate accident and injury rates based on vehicle-kilometres (vehicle-miles) of travel. Estimates also were made of average cargo weight to evaluate the safety of the two vehicles based on cargo kilogram-kilometres (ton-miles) of travel. The analyses indicated that on a vehicle-kilometre (vehicle-mile) basis, the only significant difference was a higher fatality rate for doubles. In the kilogram-kilometre (ton-mile) comparison, the only significant differences were a higher accident rate and injury rate for singles. These figures are shown in table 4.

The accuracy of the exposure estimates used in this study is questionable. The accident data came mostly from rural locations while the classification counts used to estimate exposure came from both rural and urban locations. If only rural classification counts had been used, the exposure estimate would have been different, which would have changed the findings of the study. Because there are some urban accidents in the data base, it is not clear which method of calculating exposure would have been most appropriate.

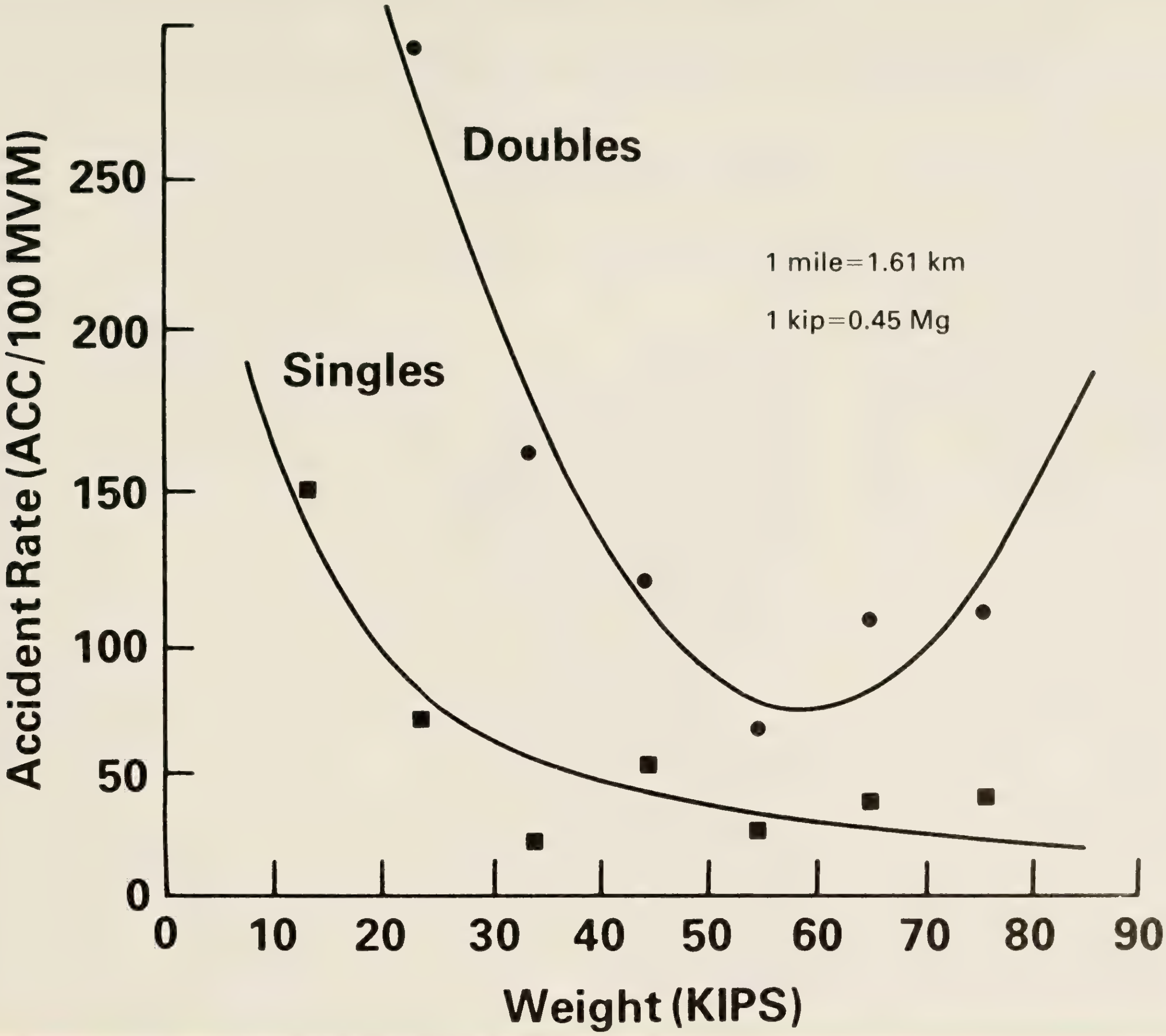
Comprehensive truck-accident study

In 1975, FHWA initiated a comprehensive study to assess the effect of truck size and weight on accident experience. (*8*) Steps were taken to avoid some of the problems inherent in previous truck accident research.

Six States—California, Nevada, Texas, Michigan, Pennsylvania, and Maryland—were selected for study based on annual truck exposure, historical accident records, and kinds of vehicles allowed to operate. Within these six States, 78 road segments were selected to represent a range of road types (freeway, primary, and secondary) and locations (urban and rural). Historical accident experience was used as a site selection criterion to avoid a bias toward either high- or low-accident sites. Truck volumes also were checked to insure reasonable volumes.

[3] John Glennon, "Matched Pair Analysis," unpublished report, *Consolidated Freightways Corporation*.

Figure 2.—Accident rates versus gross vehicle weight for singles and doubles. (*8*)



Exposure data were developed from several sources. State average daily traffic data were used as the base. Photographic classification counts were made every 3 months at each site to determine the distribution of truck types. At sites with truck scales or truck stops, more detailed information concerning vehicle dimensions, weight, and driver characteristics were collected periodically by field investigators to calculate vehicle-kilometres (vehicle-miles) of travel for a variety of vehicle and driver descriptors.

Each week field investigators reviewed police reports for truck accidents that occurred within the boundaries of any of the sites and investigated these accidents in detail. Investigators visited the sites, contacted the people involved in the accident, and, if possible, inspected the truck involved in the accident. Data were collected on the truck, the other vehicle(s), all drivers, the location, and the dynamics of the accident.

Accident and exposure data were collected for 1½ years in 1976–1977. The final accident file consisted of 2,112 records of trucks involved in 1,816 accidents. (*8*) When an accident involved more than one large truck, a record was established for each truck. Consequently, even though the report uses the term "accidents," these are really truck accident involvements. Most of the analyses compared truck accident involvement rates.

This comprehensive effort resulted in two major findings. First, doubles had a significantly higher accident involvement rate than singles (table 5). Second, empty combination trucks, particularly empty doubles, had a substantially higher accident involvement rate than loaded combinations (fig. 2).

Table 5.—Distribution of accident rates for singles and doubles by roadway type (*8*)

Truck type	Rural Freeway	Rural Nonfreeway	Urban Freeway	Urban Nonfreeway
Singles	110	99	214	93
Doubles	228	468	388	428

Although doubles may be operated safely under controlled conditions (for example, rigid permit regulations or active fleet safety efforts), when operated under a variety of conditions by a variety of operators with no special controls, the first finding indicates that doubles appear to have unique safety problems. The second finding indicates that operating empty doubles may be especially hazardous. When loaded, there is less difference in the accident experience of singles and doubles. The fact that large common carriers rarely run empty vehicles may account, in part, for the difference in the results of this study and those in the BMCS analysis (*6*) and the motor carrier firm analysis.[4] As a result of these findings, ongoing work has been redirected to emphasize braking and handling capabilities of empty and near-empty doubles and singles.

Other interesting findings in this FHWA study include the following:

- Doubles have a significantly higher kilogram-kilometre (ton-mile) accident involvement rate than singles on urban freeways and rural nonfreeways. There is no significant difference on other road types.
- There is no significant difference in the accident rate of tractor-trailer combinations with conventional tractors and those with cab-over-engine tractors.
- There is no significant difference in the accident rates of tractor-trailer combinations with 12.2 m (40 ft) trailers and those with 13.7 m (45 ft) trailers.
- Truck drivers under age 20 have the highest accident rate, followed by drivers 20 to 29 years of age, and 60 years and older.
- There is no significant difference between drivers of singles and drivers of doubles in terms of age, professional experience, or experience in their kind of truck.
- Combination trucks with dump- or tank-type trailers have the highest accident rates.
- At freeway interchanges, trucks have more accidents at offramps than at onramps.

[4]John Glennon, "Matched Pair Analysis," unpublished report, *Consolidated Freightways Corporation.*

Conclusion

The available research on large truck safety is not always congruent for several reasons. Often, apparently conflicting results actually involve different issues or different populations of trucks. Also, the quality of the data or analysis is sometimes questionable. It does seem clear, however, that larger and heavier trucks can be operated safely, but under certain conditions, larger trucks do have real safety problems. It is imperative that these problems be addressed and that acceptable solutions be developed so that these highly productive trucks can be operated safely on our Nation's highways.

REFERENCES[5]

(*1*) "Maximum Desirable Dimensions and Weights of Vehicles Operated on the Federal-Aid System," House Document No. 354, 88th Cong., 2d sess., August 1964.

(*2*) R. Winfrey et al., "Economics of the Maximum Limits of Motor Vehicle Dimensions and Weights, Volumes 1 and 2," Report Nos. FHWA–RD–73–69 and –73–70, *Federal Highway Administration*, Washington, D.C., September 1968. PB No. 231519.

(*3*) R. E. Scott and J. O'Day, "Statistical Analysis of Truck Accident Involvements," *National Highway Traffic Safety Administration*, Washington, D.C., 1971.

(*4*) Thomas N. Herzog, "Injury Rate as a Function of Truck Weight in Car-Truck Accidents," *National Highway Traffic Safety Administration*, Washington, D.C., 1975.

(*5*) James Hedlund, "The Severity of Large Truck Accidents," *National Highway Traffic Safety Administration*, Washington, D.C., 1977.

(*6*) "Safety Comparison of Doubles Versus Tractor Semitrailer Operation," *Federal Highway Administration*, Washington, D.C., 1977.

(*7*) Hugh McGee, Martin Reiss, and Chang Yoo, "Comparison of California Accident Rates for Single and Double Tractor-Trailer Combination Trucks," Report No. FHWA–RD–78–94, *Federal Highway Administration*, Washington, D.C., March 1978.

(*8*) G. R. Vallette et al., "The Effect of Truck Size and Weight on Accident Experience and Traffic Operations, Volume 3: Accident Experience of Large Trucks," Report No. FHWA/RD–80/137, *Federal Highway Administration*, Washington, D.C., July 1981. PB No. 82 139726.

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

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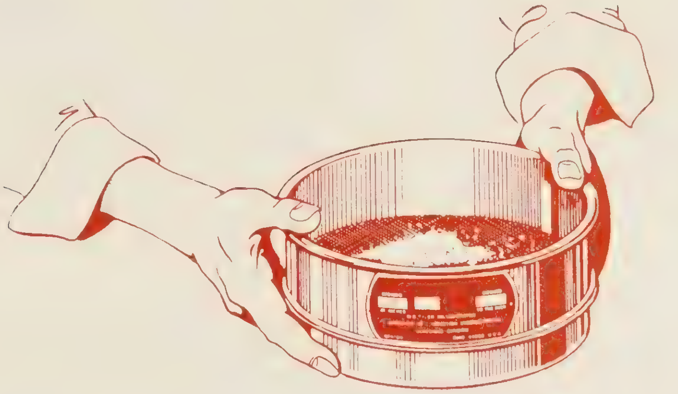
Aggregate Gradation Control: Part II— A Model Aggregate Gradation Control Program

by
Peter A. Kopac, Jose I. Fernandez, Stephen W. Forster, and Terry M. Mitchell



Introduction

This is the conclusion of a two-part article on a Federal Highway Administration (FHWA) field investigation of aggregate gradation control. Part I, published in the June 1982 issue of *Public Roads* (*1*)[1], presented an analysis of the relative costs of current gradation control programs of State highway agencies. (*2*) The analysis indicated that quality assurance-quality control (QA–QC) programs in which the contractors or producers perform most of the gradation testing are more economical than the more widely used "traditional" programs in which the State highway agencies perform most of the testing.

As a result of the analysis, a model aggregate gradation control program was developed by combining some new concepts with the most favorable and economical features of the State programs that were studied. (*2*) This article, Part II, describes this model program.

Key Considerations in Developing the Model Program

Economy

The primary objective of a gradation control program should be to promote and maintain aggregate quality with respect to gradation. Many kinds of gradation control programs can maintain acceptable aggregate quality, but an *economical* gradation control program should maintain quality while minimizing the testing-related costs for all parties involved.

[1] Italic numbers in parentheses identify references on page 60.

Point of delivery

Because a gradation control program should promote and maintain the quality of the delivered aggregate, acceptance testing should be performed whenever possible at the point of delivery—that point where the aggregate is incorporated into the concrete mixture, or into the project in the case of unbound aggregate. Although gradation control testing should be performed at various stages in the production, transportation, and handling of the aggregate, it is suggested that State highway agencies not prescribe the details of such testing. Aggregate producers should be free to perform whatever testing they find consistent with process control and the protection of their contractual interests. State highway agencies also should be concerned primarily with protecting their contractual interests, and this can be done best by testing at the point of delivery.

For aggregates being used directly as base, subbase, or shoulder material, point of delivery is the project site itself. For aggregates being used for portland cement concrete or for bituminous concrete, point of delivery is the concrete plant. If possible, aggregate should be sampled at the plant at the last feasible point (for example, at a hopper or conveyor belt) before the aggregate is used. This way the effects of handling the aggregate in the production, transportation, and storage stages would be reflected in the test results.

Testing at the aggregate source, although convenient and popular in many States, does not always reliably indicate product gradation at the point of use. Material that is found acceptable at the aggregate production plant may not be within the specified gradation range when it arrives at the construction site or the concrete plant. By accepting the aggregate at the point of use only, State highway agencies are not involved with intermediate points of testing and rely on contractors to insure that the aggregate processing will result in the specified material.

Contractor quality control

A distinction must be made between acceptance testing and process control testing. All process control testing should be performed by the contractor so that contract responsibilities are maintained. The contractor's own forces or those of the subcontractor or supplier may be used to perform the process control functions. The services of an independent testing laboratory also may be used. In any of these cases, the contractor is still responsible for insuring adequate process control.

State highway agency quality assurance

A State highway agency could perform all acceptance testing independently of a contractor's process control testing. However, by using a QA–QC approach, test results from the contractor's quality control program can be used directly for acceptance if the results can be validated by a concurrent program of quality assurance that includes verification testing. This approach results in the least amount of duplication.

Verification test results should not be used directly for acceptance. They should be used only to verify and maintain the reliability of the contractor's test data. Material acceptance would be affected by verification test results only if the test results consistently, and excessively, varied from those of the contractor, indicating poor reliability of the contractor's data.

Acceptance criteria

Establishing gradation tolerances for acceptance of delivered aggregate is not the same as establishing gradation tolerances for acceptance of concrete mixtures. Gradation tolerances for aggregate generally include a wide band of acceptance percentages whereas gradation tolerances for mixtures must conform to a target or design percentage. The problem is more complicated in the case of aggregate acceptance.

Many aggregate gradation acceptance plans include terms such as "substantial compliance" or "reasonably close conformity" without defining them. In setting tolerances for acceptance of aggregate gradation, both the magnitude and frequency of the noncompliance must be considered. For the purpose of this model program, the magnitude of the aggregate's nonconformance to specification limits is measured in terms of Tolerance Increment Factors (TOL's). As illustrated in figure 1, TOL's are expressed as percentages and represent the increments of tolerance based on percentage of total test sample weight. TOL's are applied to each end of the specified gradation range for each sieve size. It is postulated that the maximum allowable nonconformance for any single test is 2 TOL's from the prescribed limits of the gradation range. More stringent tolerances also are applicable based on frequency of noncompliance as discussed later. For the sake of simplicity, the model program structure refers only to TOL's without designating their specific values. Specific TOL values of 2 percent for the minimum sieve size and 4 percent for most other sieve sizes are suggested. However, State highway agencies that have studied aggregate variability resulting from sampling and testing error may want to assign values more suited to their particular situations. Although a new concept, the use of TOL's in the specifications clearly delineates the consequences for various degrees of deviation from the allowable gradation bands.

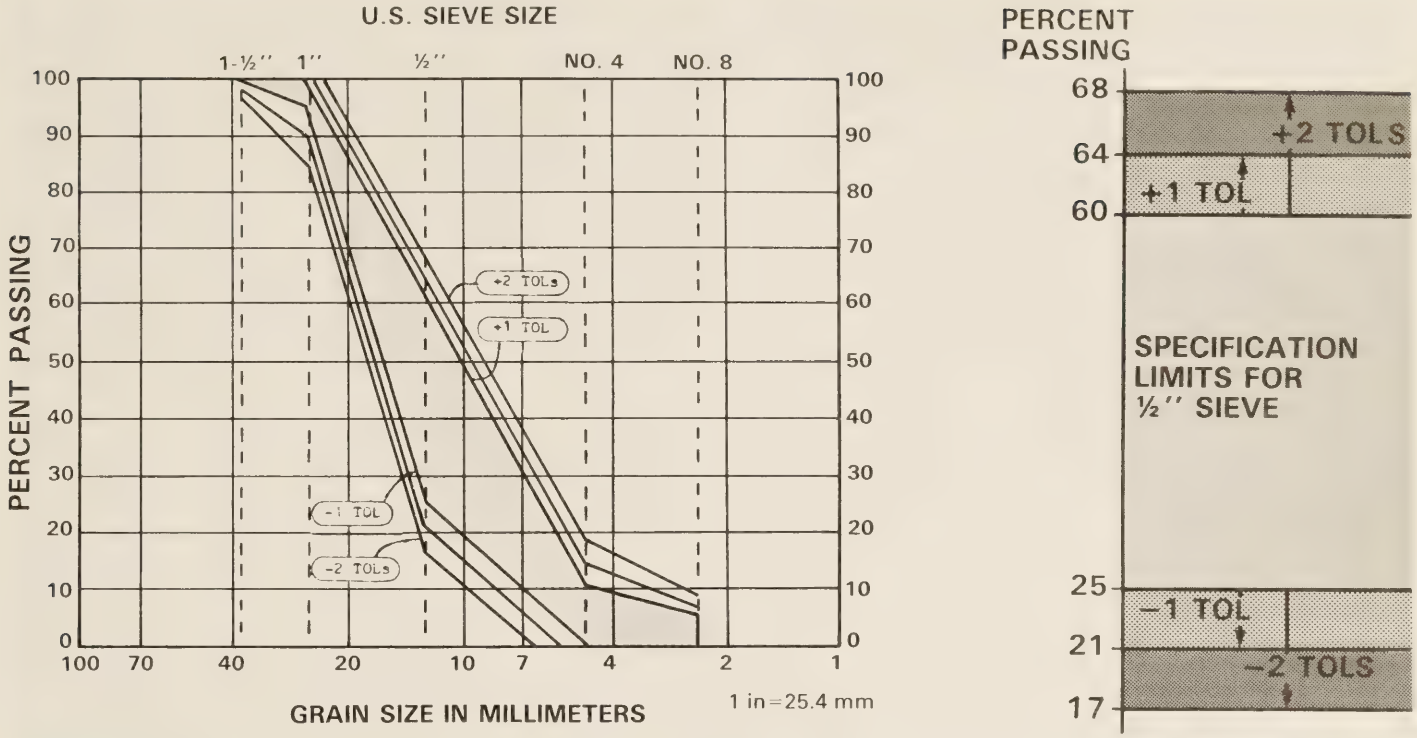
Similar criteria are applied when comparing quality control tests with verification tests to determine the reliability of the contractor's quality control program. In comparing the results of quality control tests and verification tests, the difference between results for the same sieve size generally should be within 1 TOL and in all cases within 2 TOL's. This means that up to one increment of tolerance would be considered normal, but no more than two increments would be acceptable if the contractor's results are to be considered reliable.

Treatment of noncompliance

In the FHWA field investigation it was found that without a method for evaluating "substantial compliance," State highway agency personnel are unwilling to apply a price reduction to what is perceived as a "minor" deviation from the prescribed gradation limits. Price adjustments, however, usually are necessary to encourage the contractor to maintain adequate gradation control. State highway agencies should vigorously enforce their price adjustment policies if their gradation control programs are to be effective and fair to all contractors. The model gradation control program attempts to lessen this subjective element by quantifying not only the magnitude but also the frequency of deviation from the nominal gradation range.

The model program's price adjustment approach involves assigning a unit value to the quantities of aggregate to be used in each particular application within the scope of the contract. Such unit values should be assigned by the State highway agency for inclusion in the contract documents and could be related to the replacement costs or the expected loss of serviceability of the product or portion of the structure in which the aggregate is used. Using this approach, outright rejection could require removal and replacement of the defective material, while price reduction provisions would entail progressively greater reductions of payment based on the cor-

Figure 1.—The effect of TOL's on a gradation band.



responding unit value, depending on the severity of noncompliance. The payment reduction percentages suggested in the model program are guidelines only; each State highway agency should tailor the price reduction provisions to its individual situation. In keeping with the differentiation of contractual relationships, the State should not attempt to assign responsibility for the nonconforming aggregate which resulted in price reductions.

Model Program Structure

The model aggregate gradation control program that was developed based on the preceding key considerations is summarized in figures 2 and 3. The program places responsibility for process control on the construction contractor and prescribes the minimum amount of testing that must be performed by the contractor. Also, the program emphasizes point-of-use testing to minimize sample transportation costs while allowing the contractor's test results to be used, subject to adequate reliability, for acceptance.

Some of the major requirements of the model program follow.

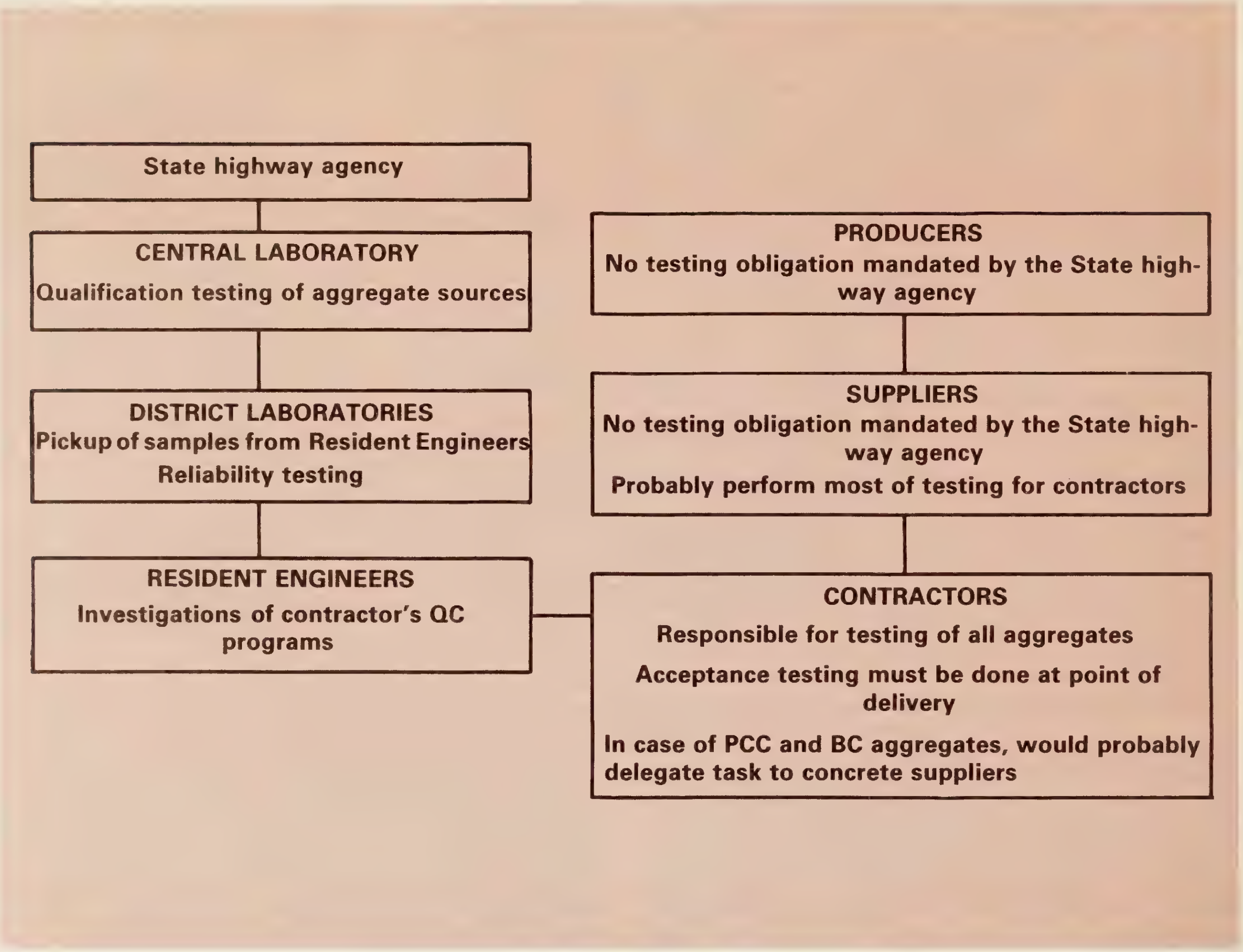
Place of sampling

Aggregate samples shall be taken at the last feasible point before using the aggregate or mixing it with other ingredients. When aggregates are used for base, subbase, or shoulder material, sampling shall be performed at the project site, and the sample shall be taken either from the truck before the aggregate is unloaded or after it is spread on the roadway but before it is compacted. When aggregates are used for portland cement concrete, samples shall be taken from the conveyor belt used to load the mixer feed bins or, if practical, from the discharge end of the mixer feed bins. Aggregates used for bituminous concrete mixes shall be sampled at the conveyor belt carrying the individual aggregate classes into the cold-feed blend. All samples shall be split to provide material for verification testing by the State highway agency.

Sampling and testing frequency

For aggregates used for bituminous concrete or portland cement concrete construction, one set of "startup" samples (a set is three samples taken at the same time) shall be taken and one sample tested within the first 30 minutes of operation of the concrete plant each day. Rapid drying methods will be permitted for this test. If this initial test shows the aggregate to be nonconforming and the results are confirmed by retesting as described below, adjustments may be made, a new set of samples taken, and one sample tested within 30 minutes after adjustments are made. The test results of the first set of samples would be marked clearly with the time period represented and the adjustments that were made based on the test results. The test results of

Figure 2.—Schematic diagram of the model gradation control program.



the first set would not be considered in the acceptance criteria, but the results of the second set would be. Two additional sets of samples shall be taken at random each day—one during the morning hours and one during the afternoon hours. If a set of samples is taken after startup adjustments, it shall be considered the morning sample.

For aggregates used as base or subbase material, a set of samples shall be taken and one sample tested from one of the first three trucks each day, with an additional set of samples taken approximately every 900 Mg (1,000 tons) or fraction thereof delivered the same day.

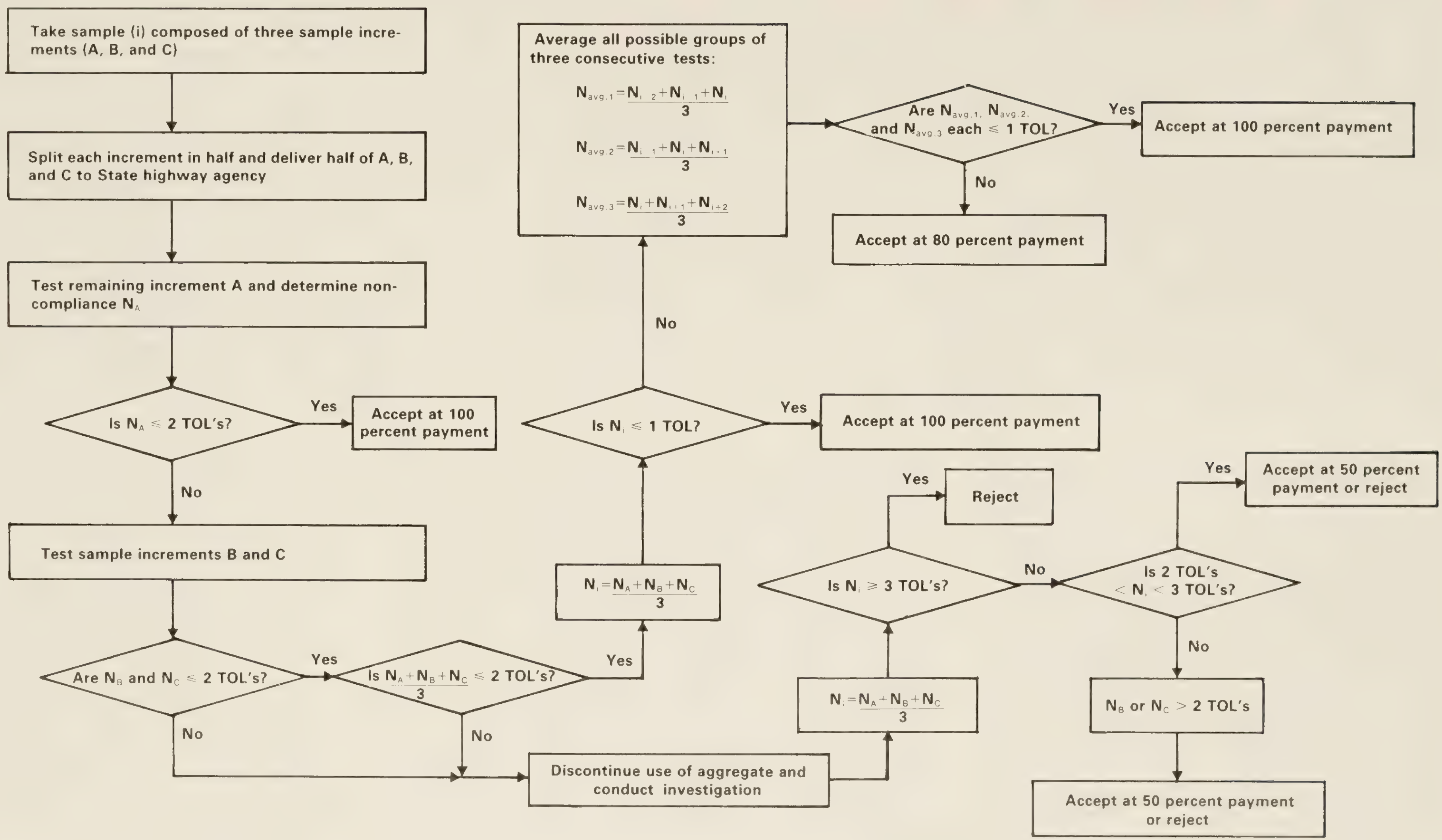
For aggregates used for road shoulders, one set of samples shall be taken from one of the first three trucks each day, and one additional set of samples shall be taken at random during the day each day.

All sampling shall be performed by the contractor or an authorized representative. Before testing, all samples shall be split using an approved splitting device. One-half of each sample shall be placed in a tight burlap or heavy plastic bag, tied with a nonremovable closure, identified, and immediately delivered to the designated representative of the State highway agency at the project site. The other half of one of the samples in a set shall be tested as soon as possible but at least within 2 hours after sample collection. The halves of the other two samples of the set shall be stored temporarily for retesting, if necessary.

Retesting by the contractor

If test results indicate a noncompliance of more than 2 TOL's with respect to any size of the gradation specification, the two other samples of the same set shall be tested immediately. If both of these samples show the aggregate to have a noncompliance of no more than 2 TOL's with respect to all sieve sizes, the results of the tests on all three samples of the set shall be averaged, sieve by sieve. If the resulting averages show the aggregate to

Figure 3.—Flow chart showing acceptance and payment criteria for model gradation control program.



have a noncompliance of no more than 2 TOL's with respect to all sieve sizes, only the average will be considered for the project records. If either of the other two samples, or the average of the three samples, shows noncompliance of more than 2 TOL's with respect to any sieve size, the contractor immediately shall discontinue using the aggregate until an investigation and corrective measures can be undertaken. In all cases, the results of all three tests shall be submitted together.

QA testing by the State highway agency

The State technicians shall test, at random, 1 sample out of every 10 sets of samples submitted by the contractor. In addition, one sample out of each set for which results were averaged by the contractor shall be tested. In general, these verification tests by the State highway agency should be completed within 3 days, and in all cases within 1 week, of receipt from the contractor of the last sample of each group of 10 sets.

If the State's test results consistently agree with the contractor's, within 1 TOL with respect to all sieve sizes, the reliability of the contractor's QC program shall be considered good. If a discrepancy of more than 1 but no more than 2 TOL's with respect to any sieve size is observed, the reliability of the contractor's QC program shall be considered only fair and the State's testing frequency shall be increased to one sample out of every five sets of samples (including one sample retroactive to the middle of the previous 10-set period) until three consecutive samples fall within the definition of good reliability. If a discrepancy of more than 2 TOL's with respect to any sieve size is observed or whenever three consecutive samples fall within the characteristics of fair reliability, the reliability of the contractor's QC program shall be considered poor. Verification testing will be increased and the matter shall be referred to the Resident Engineer responsible for the project for possible payment reduction. Depending upon the results of the investigation, the State highway agency shall have the option of performing all QC testing and assessing a penalty against the contractor for having to do so.

Acceptance criteria

Aggregate acceptance shall be based only on the contractor's test results, with the State's test results being used only to verify the reliability of the contractor's results. Aggregate showing noncompliance of 1 TOL or less with respect to all sieve sizes shall be accepted without question. Aggregate showing noncompliance of more than 1 TOL but no more than 2 TOL's with respect to any sieve size also shall be accepted without question if the averages of the test results sieve by sieve, for all possible groups of three consecutive tests including the test in question, yield an average noncompliance of no more than 1 TOL with respect to all sieve sizes.

When the averaging requirements are not met, the aggregate could still be accepted subject to price reduction. However, when the results of a single test show any nonconformance of more than 2 TOL's with respect to any sieve size, the Resident Engineer may, based on the specific test results (including the results of the retest samples), reject the aggregate or accept it subject to price reduction.

When the contractor's test results show good reliability, acceptance decisions can be based only on the contractor's results. When the contractor's test results show fair or poor reliability, the Resident Engineer should request the State laboratory to test specific samples to determine if a price reduction for the aggregate is applicable, in addition to the possible penalty for poor reliability.

In any event, if the results of tests on any single set of samples, verified by the test on one of the State's split samples, show a nonconformance of 3 TOL's or more on any sieve size, the Resident Engineer should immediately reject the aggregate and direct its removal and replacement.

Payment criteria

Price reductions shall apply to aggregate delivered when the contractor's test results show poor reliability as well as to accepted but nonconforming aggregate. Table 1 shows the possible price reductions for these two cases.

A price reduction of 10 percent (based on the assigned unit prices) shall be applied to aggregate delivered when the contractor's quality control program shows poor reliability. This provision shall be applied regardless of the actual test results obtained by the contractor.

Table 1.—Basic price reduction levels for the model program

State's reliability (verification) tests	
	Percent reduction
Good reliability	0
Fair reliability	0
Poor reliability	10
Contractor's acceptance tests	
	Percent reduction
Single test:	
Nonconformance < 2 TOL's	0
More than one test required:	
Nonconformance ≤ 1 TOL	0
1 TOL < nonconformance ≤ 2 TOL's	20
2 TOL's < nonconformance < 3 TOL's	50 or reject
Nonconformance ≥ 3 TOL's	reject

A price reduction of 20 percent shall be applied to aggregate showing nonconformance of more than 1 TOL but no more than 2 TOL's with respect to any sieve size and which failed to meet the acceptance criteria for the average of all possible groups of three consecutive tests including the test in question as defined above.

A price reduction of 50 percent shall be applied for accepted aggregate showing noncompliance of more than 2 TOL's but less than 3 TOL's with respect to any sieve size. The same 50 percent reduction will be applied to any aggregate, if accepted, delivered before operations are stopped when any retest sample in a set shows noncompliance of more than 2 TOL's with respect to any sieve size. It should be noted that any aggregate for which the 50 percent reduction applies also could be rejected by the Resident Engineer, based on the specific test results and the results of the retest samples.

Finally, no payment will be made for any aggregate showing noncompliance of 3 TOL's or more with respect to any sieve size. Such aggregates should be rejected and replaced unless it is determined that the quantities involved are very small and will not significantly compromise the safety, function, or durability of the structures in which the aggregate will be used.

The price reduction scheme discussed above is very basic and has few distinct payment levels. A State highway agency, however, may want to make finer distinctions among quality levels and thereby develop a scheme having more payment levels. This can be done by making a distinction between aggregate showing a nonconformance on one sieve size only and aggregate showing nonconformances on two or more sieve sizes. (In the model program, the largest nonconformance governs for acceptance and payment purposes.)

Summary and Discussion

The model aggregate gradation control program presented in this article incorporates the most desirable features of the State programs investigated in the FHWA study. The overall costs of the model program should be comparable to, or perhaps slightly higher than, those of the contractor-oriented (State B) gradation control program investigated in Part I of this article. The responsibility for testing and place of testing are the same in the model program and the State B program and therefore should result in similar labor costs. The key to economy in labor costs appears to be in effectively integrating gradation testing activities by contractor technicians with other responsibilities. One area where the model control program might yield slightly higher costs than the State B program is verification testing because the model program incorporates a slightly more involved plan of verification testing by the State. This is justified, however, because of enhanced reliability of the contractor's test results.

The model program introduces several new features. Although none of these features is absolutely essential, there are good reasons for their use and they should be considered. (If a State highway agency desires, individual features may be replaced with more commonly accepted methods.) One of these new features is the use of TOL's to allow for gradation variability resulting from gradation sampling and testing error. Their use enables the State highway agency to treat out-of-specification gradations as objectively as possible. Another unique feature is the application of price reductions when the State's verification test results disagree with the contractor's results. Instead of applying verification price reductions, the State could either shut down the contractor's operation or assign its own full-time inspectors to the work at the contractor's expense. The State highway agency should not have to incur additional costs because of inaccurate or faulty contractor testing and certainly should not direct process control operations.

A final unique feature is acceptance of the gradation of bituminous concrete aggregate before it has been incorporated into the mix. Although improper mixing proportions may occur after the aggregate has been sampled, this feature has been found acceptable for portland cement concrete and is appealing because larger sample sizes, and therefore greater accuracy, are possible.

The Federal Highway Administration is encouraging State highway agencies to consider the ideas contained in this model program. FHWA's Office of Implementation is soliciting State highway agencies to conduct economic analyses of their own gradation testing programs, as outlined in Part I of this article, and to try the model program (or similar contractor control programs already in use in some States) in one or more districts in their States.

REFERENCES

(*1*) Peter A. Kopac et al., "Aggregate Gradation Control: Part I—An Analysis of Current Aggregate Gradation Control Programs," *Public Roads*, vol. 46, No. 1, June 1982, pp. 13–24.

(*2*) Jose I. Fernandez, "Economic Analysis of Aggregate Gradation Control Programs," Report No. FHWA/RD–82/048, *Federal Highway Administration*, Washington, D.C., May 1982.

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The MAXBAND Program for Arterial Signal Timing Plans

by

S. L. Cohen and J. D. C. Little

This article discusses the MAXBAND model, a portable bandwidth optimization computer program written in FORTRAN IV that can be used to develop signal timing plans for signalized arterials and simple networks of three intersecting arterials. The program can optimize signal offset, cycle length, and left turn phase sequence. The program has several features that can improve the efficiency of timing plans. These features include varying the progression speed on individual street segments, advancing the start of green at each intersection to allow queue clearance, and permitting the user to specify the weighting of the bands in each direction on two-way arterials to give preference to the direction of heavier traffic flow.

Introduction

Maximizing green bandwidth has been the most widely used method for developing signal timing plans for signalized arterials. This method is relatively straightforward and has been popular because it is based on street geometry and does not require traffic data, making it easier to use than delay optimization programs such as TRANSYT. (*1*)[1] Field observation of bandwidth optimized signal systems indicates the systems perform well. (*2*)

In simple cases, such as one-way progression or equal signal spacing, good results may be obtained manually using time-space diagrams. However, in more complicated situations, such as two-way progression with unequal block spacing or determining other parameters (left turn phase sequence and cycle length) in addition to offset, using time-space diagrams becomes prohibitive. Thus, several computer programs (*3*)[2] have been developed in the past few years to handle more complicated cases. The most recent program to be developed is MAXBAND. (*4*)

MAXBAND is based on a maximal bandwidth criterion that enables the common cycle length, offsets, and left turn phase sequence at each intersection to be computed to maximize a weighted sum of the through green bandwidths in each direction. (*5*) The percentage of green time for each phase may be entered by the user or computed by the program using a method in which the user enters volumes and capacities. (*6*) If the user enters green times, no traffic data are required to execute the program.

[1] Italic numbers in parentheses identify references on page 65.

[2] "Timing Support Programs–SIGART," Section 6, unpublished report, *JHK & Associates,* Alexandria, Va.

Program Features

MAXBAND has the following features that increase its utility and improve the efficiency of the signal timing it computes:

- The program uses an input structure, based on the widely used SOAP program (*7*) that is designed to analyze intersection design and signal timing.
- The program allows the design speeds to vary on each block within fixed limits set by the user. This capability can improve substantially the efficiency of bandwidth solutions by taking advantage of the observation that drivers will make limited changes to their speeds to adjust to signal timing.
- The program has a green advance feature, which may be set by the user, that allows the mainline green at a given intersection to be started early. Green advance allows a standing queue formed from the secondary flow of an upstream intersection to be discharged.

• The program can select the arterial left turn phase sequence pattern at each intersection, which maximizes the through green band. The selection can be made from four possible patterns: lead-lead (leading left turns in both directions); lead-lag (leading green inbound, lagging green outbound); lag-lead (lagging green inbound, leading green outbound); and lag-lag (lagging left turns in both directions). The user may limit which patterns are to be tried. The left turn phase times do not need to be the same in both directions.

• Because the program maximizes the weighted sum of the bandwidth in each direction, the user may adjust the weighting factor to give preference to either direction.

• The program can select, from a continuous range specified by the user, the common cycle time that optimizes the weighted sum of bandwidths on an arterial or a triangular network of three intersecting arterials.

• The user may specify green phase time. Using this alternative, the program can be executed using only geometric data Because traffic data are expensive to collect, this will result in a substantial savings over a program like TRANSYT, which requires traffic data.

Program Formulation

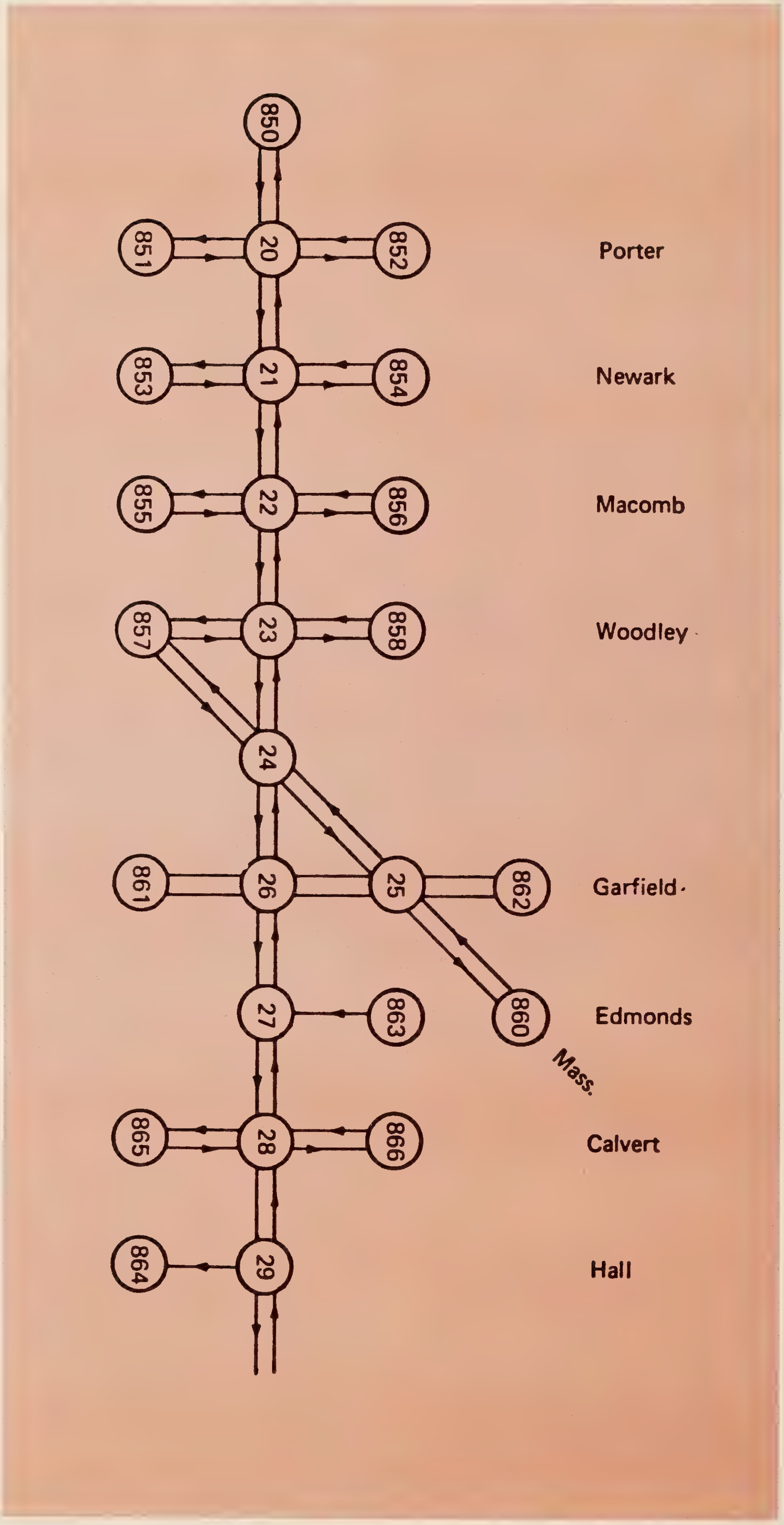
The mathematical formulation of the MAXBAND program is derived from the following observations:

1. The sum of the offsets around any closed loop in the network must be an integer multiple of the cycle length. (*8*) For example, in figure 1 a closed loop is from node 21 to node 22 and back to node 21.

2. The bandwidth in either direction on a two-way arterial cannot exceed the shortest green time on the arterial facing in that direction.

It then can be shown that the maximal bandwidth problem can be stated as a mixed integer linear programing problem: Find the

Figure 1.—Link-node diagram for Wisconsin Avenue arterial, Washington, D.C.



values of the bandwidth in both directions, the cycle length, the offsets, and the phase sequence to maximize the objective function given by the weighted sum of the bandwidth in both directions subject to the two constraints above.

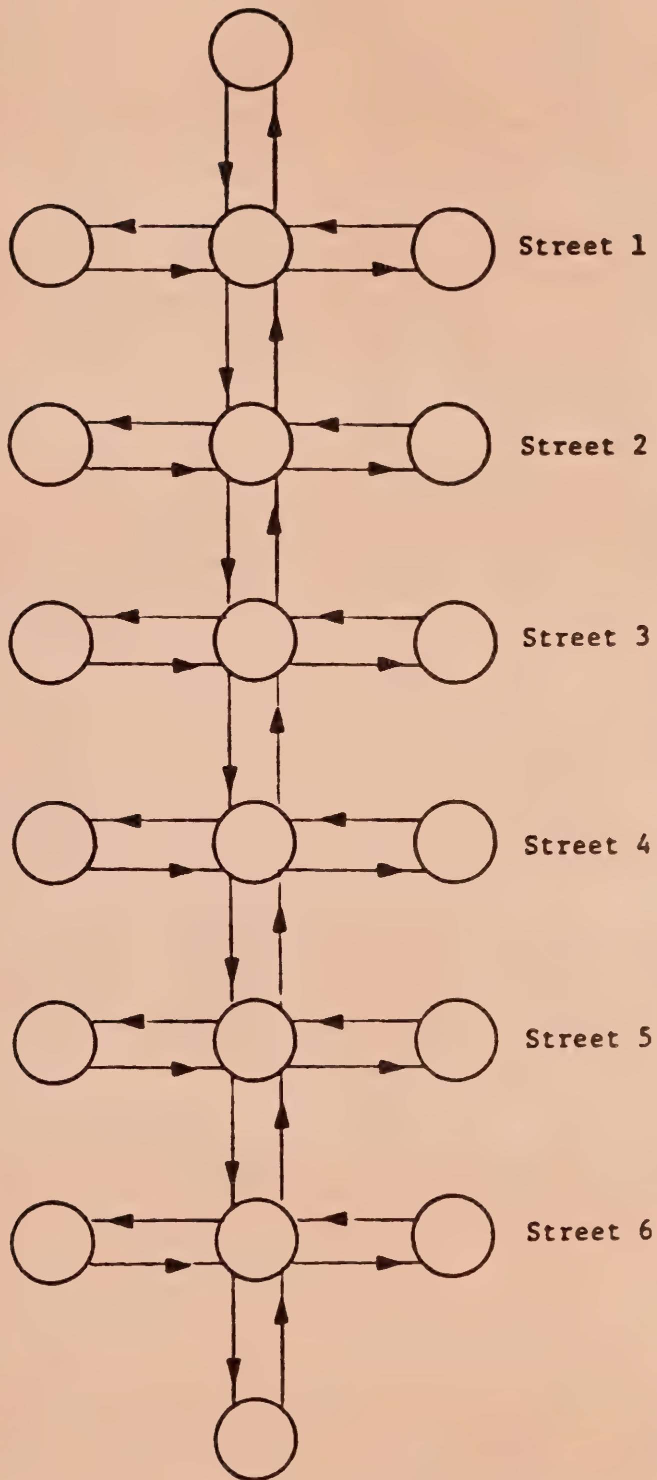
Two sets of integer variables are involved—the integers introduced through the first constraint and a set of two integers introduced at each intersection to represent each possible left turn phase sequence pattern. The variables in this latter set are restricted to values 0 or 1 so that there are four possible combinations—0–0, 1–0, 0–1, and 1–1— each of which represents one of the four possible phase patterns on the arterial at each intersection. Details of the mathematical formulation and solution process may be found in reference 5.

Comparison With Other Programs

At present, MAXBAND has been compared with other approaches in only two instances. The network shown in figure 1 consists of nine intersections on Wisconsin Avenue in Washington, D.C., between and including Hall and Porter Streets. A morning peak data set for this network was obtained from the District of Columbia Department of Transportation. MAXBAND was used to compute the offsets on the arterial, using the cycle length, green times, and phase sequences in existence when the data were collected. The resultant MAXBAND timing plan then was run on the NETSIM traffic simulation model and the results were compared with a NETSIM run of the existing timing plan. (*9*) The results for the measure of effectiveness of average speed, shown in table 1, indicate that the MAXBAND program improved the existing plan, especially in the southbound direction (equal weighting was assumed for the bandwidths in both directions).

Figure 2 shows an arterial that was used to compare the effectiveness of three programs—TRANSYT, PASSER–II, and

Figure 2.—Link-node diagram for test scenarios.



MAXBAND—for developing signal timing plans for arterial systems.[3] Scenarios were developed to test the response of the programs to independent variables such as block spacing and demand levels, both on the arterial and side streets. The signal timing parameters computed by all three programs included cycle length and offsets. In addition, green phase times were optimized as a part of the TRANSYT runs. The scenarios were restricted to two-phase operation and the cycle lengths ranged between 30 and 120 seconds.

The results for the two scenarios of differing block spacing and demand levels are shown in table 2 for the entire arterial including the side streets and for the arterial street only. Before comparing the results it should be noted that (1) the TRANSYT model adjusted the input green times to optimize delay at each intersection while MAXBAND and PASSER–II maintained the input green times, which probably explains much of the differences seen between the TRANSYT and MAXBAND results; and (2) the range of cycle lengths scanned was much larger than PASSER–II was designed for. In these two scenarios and others[4], PASSER–II chose a relatively large cycle length compared with the other programs when given a large range to scan. The much larger value of cycle length computed by PASSER–II may partly explain why the other two programs gave relatively better results. Based on this rather limited sample, it may be concluded that the MAXBAND program did well.

Table 1.—Simulation run using NETSIM to compare MAXBAND settings with existing settings on Wisconsin Avenue, Washington, D.C.

Link	Vehicle-miles		Vehicle-minutes		Average speed	
	Existing settings	MAXBAND settings	Existing settings	MAXBAND settings	Existing settings	MAXBAND settings
					Miles/hour	*Miles/hour*
(20,21)	110.6	111.0	303.1	300.6	21.90	22.40
(21,22)	46.2	46.4	197.8	181.1	14.00	15.40
(22,23)	62.9	63.8	254.2	224.1	14.90	17.10
(23,24)	114.7	115.1	637.1	518.1	10.80	13.30
(24,26)	37.2	37.7	185.0	155.2	12.00	14.60
(26,27)	75.2	78.5	207.0	208.9	21.80	22.50
(27,28)	60.4	61.7	211.5	191.2	17.10	19.40
(28,29)	88.1	91.8	297.7	302.9	17.80	18.20
ϵ	595.3	606.0	2,293.4	2,082.1	15.57	17.46
(29,28)	59.4	59.1	222.3	212.7	16.00	16.70
(28,27)	47.5	48.0	149.3	146.1	19.10	19.70
(27,26)	62.9	62.0	188.6	190.4	20.00	19.50
(26,24)	17.3	16.7	55.7	53.1	18.60	18.90
(24,23)	91.5	91.5	248.8	244.5	22.10	22.50
(23,22)	48.2	48.6	204.3	256.1	14.20	11.40
(22,21)	34.9	34.7	139.0	115.9	15.10	18.00
(21,20)	90.7	92.8	278.7	253.5	19.50	22.00
ϵ	452.4	453.4	1,486.7	1,472.3	18.25	18.47

1 mile=1.61 km

Table 2.—Simulation comparisons of TRANSYT, MAXBAND, and PASSER–II

Program	Cycle length	Measures of effectiveness							
		Number of stops per vehicle		Delay per vehicle		Average speed		Fuel efficiency	
		A[1]	B[2]	A	B	A	B	A	B
	Seconds			*Seconds*		*Miles/hour*		*Miles/gallon*	
Scenario I									
TRANSYT	30	1.98	2.01	21.62	17.07	18.8	18.8	13.52	13.96
MAXBAND	51	1.89	1.67	24.39	14.20	17.9	19.3	13.16	14.26
PASSER–II	65	2.45	1.70	35.00	19.20	16.6	18.5	12.43	13.88
Scenario II									
TRANSYT	35	2.19	1.90	22.20	17.13	18.1	18.7	13.16	13.84
MAXBAND	33	2.53	1.49	26.39	13.61	17.5	19.5	12.97	14.25
PASSER–II	90	2.91	2.16	46.84	31.45	14.0	15.3	11.06	12.11

[1] For both arterial and side streets.
[2] For arterial only.
1 mile=1.61 km
1 gal=3.8 L

[3] W. K. Kittelson et al., "Application of Existing Strategies to Arterial Signal Control—First Interim Report, Volume 1: Functional Description of Signal Control Techniques," unpublished report No. FHWA/RD–80/110, *Federal Highway Administration*, Washington, D.C., April 1980.

[4] Ibid.

Availability

The MAXBAND program that is available from the Federal Highway Administration free of charge is operational on IBM or AMDAHL equipment and requires 294K bytes of core storage (overlaid). With minor program modifications, it could be operational on most other computers with equivalent capabilities. A source tape, including two sample data sets, and a three-volume set of reports, including a users manual, may be obtained by writing the Urban Traffic Management Division, Offices of Research, Development, and Technology, Federal Highway Administration, Washington, D.C. 20590.

REFERENCES

(*1*) D. I. Robertson, "TRANSYT: A Traffic Network Study Tool," TRRL Report LR 253, *Transport and Road Research Laboratory*, Crowthorne, Berkshire, United Kingdom, 1969.

(*2*) R. D. Desrosiers and C. H. Leighty, "Traffic Flow Responses to Unannounced Increases in Progression Speeds of Signal Systems," *Public Roads*, vol. 34, No. 1, April 1966, pp. 1–4, 13–15.

(*3*) C. J. Messer, R. H. Whitson, C. L. Dudek, and E. J. Romano, "A Variable Sequence Multiphase Progression Optimization Program," Highway Research Record 445, *Highway Research Board*, Washington, D.C., 1974, pp. 24–33.

(*4*) J. D. C. Little, M. D. Kelson, and N. H. Gartner, "MAXBAND: A Program for Setting Signals on Arteries and Triangular Networks," Transportation Research Record 795, *Transportation Research Board*, Washington, D.C., 1981, pp. 40–46.

(*5*) J. T. Morgan and J. D. C. Little, "Synchronizing Traffic Signals for Maximum Bandwidth," Highway Research Record 118, *Highway Research Board*, Washington, D.C., 1966, pp. 24–47.

(*6*) F. V. Webster, "Traffic Signal Settings," Road Research Technical Paper No. 39, *Her Majesty's Stationery Office*, London, 1958.

(*7*) "Signal Operations Analysis Package, Volumes 1–5," Report No. FHWA–IP–79–9, *Federal Highway Administration*, Washington, D.C., July 1979.

(*8*) J. D. C. Little, "The Synchronization of Traffic Signals by Mixed Integer Linear Programing," *Operations Research*, Vol. 14, 1966, pp. 568–594.

(*9*) "Traffic Network Analysis with NETSIM, A User Guide," Report No. FHWA–IP–80–3, *Federal Highway Administration*, Washington, D.C., January 1980.

S. L. Cohen is a mathematician in the Urban Traffic Management Division, Offices of Research, Development, and Technology, Federal Highway Administration. He was contract manager for FHWA research on optimal signal timing for arterial signal systems. Dr. Cohen has worked for FHWA since 1970 in the areas of traffic simulations, signal optimizations, and traffic data collection.

J. D. C. Little is Professor of Management Science at the Sloan School of Management, Massachusetts Institute of Technology. Dr. Little's interests include the application of mathematical programing techniques to the optimization of traffic signal settings. He currently is working on a project for FHWA to expand the capabilities of MAXBAND to include delay optimization.

Progress Report on the CMD: A Device for Continuous Monitoring of the Consolidation of Plastic Concrete

by
Terry M. Mitchell

Introduction

In the March 1979 issue of *Public Roads*, the Federal Highway Administration (FHWA), Office of Research, reported the development of a new device—the Consolidation Monitoring Device (CMD)—for monitoring the degree of consolidation of newly placed concrete. (*1*)[1] The CMD can be mounted on a slipform paver and will continuously and automatically monitor the degree of consolidation or densification of the concrete. The 1979 article included a discussion of the need for density monitoring, a description of the device's design and operation, and the results of initial laboratory and field evaluations.

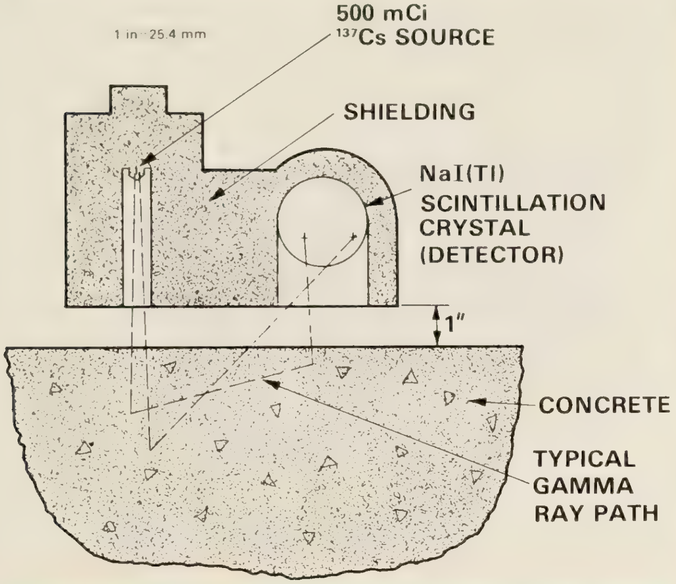
Since 1979, development of the CMD has continued. Field trials completed by the Iowa and Illinois Departments of Transportation (DOT's) uncovered a problem with the original design, namely the sensitivity of the density reading to the device's height above the concrete pavement. Under FHWA contract the prototype CMD was modified to automatically correct the density reading for height changes. A simple capacitance distance gaging system that compensated for height changes was incorporated into the CMD and a second generation prototype CMD is now being constructed. This article summarizes the Iowa and Illinois field trials, development of the height compensation system, and future plans for the CMD.

The CMD

The CMD's source/sensor unit, shown schematically in figure 1, contains a 500 millicurie Cesium–137 (500 mCi ^{137}Cs) source and a radiation detector—a thallium-activated sodium iodide (NaI(Tl)) scintillation crystal and a photomultiplier tube. The amount of gamma radiation scattered by the concrete back into the detector is proportional to the density of the concrete. This same technique is already widely used by transportation agencies in commercially available, portable nuclear gages to control compaction of (1) soil and soil aggregate in pavement structures, (2) bituminous concrete pavements, and (3) portland cement concrete pavements and bridge decks.

[1] Italic numbers in parentheses identify references on page 72.

Figure 1.—Backscatter measurement with CMD source/sensor unit.



The CMD's source/sensor unit is connected by a cable to its control and readout unit, located typically on the operator's deck of the slipform paver. The prototype CMD's control and readout unit (fig. 2) includes a meter display of concrete density, high and low density alarms, and a strip chart recorder to permanently record the density and the transverse and longitudinal positions of the source/sensor unit over the pavement surface. More detailed descriptions of the prototype CMD's design and operation are available in references 1–3.

The source/sensor unit is mounted and positioned on a slipform paver by a traversing mechanism (fig. 3). A carriage holds the source/sensor unit and supports it on wheels that roll on a horizontal guide beam. The guide beam is attached to the paver by three or more adjustable mounting mechanisms that enable vertical and angular positioning of the beam. The source/sensor unit of the original CMD had to be maintained at 25 ± 2 mm (1 ± 0.08 in) above the concrete surface to measure the density correctly. Although such a spacing is fairly easy to maintain on some slipform pavers, it is not possible, in practice, on others, as will be shown later in this article.

The CMD has a number of potential applications based on its ability to detect density irregularities while concrete is still plastic and before large volumes of defective concrete are in place. It can be used to detect malfunctions of individual vibrators on pavers, to evaluate the adequacy of vibrator spacings and operating frequencies, and to compare the effectiveness of external (pan) vibrators with that of groups of internal (spud) vibrators. It also has potential for detecting changes in the composition of concrete, particularly air contents well above or well below specified amounts. As a process control tool, it should enable contractors and State highway agencies to avoid multimillion dollar construction problems and lawsuits that can result

Figure 2.—Control and readout unit, original design.

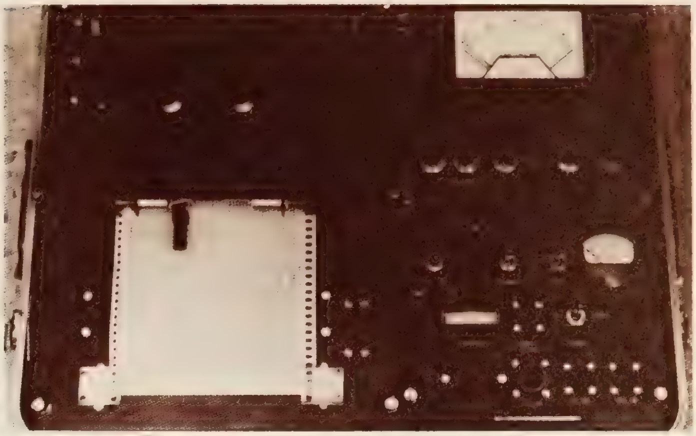
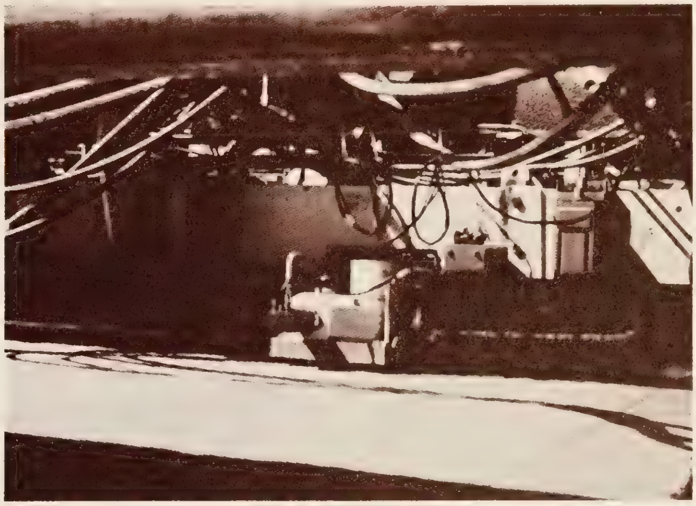


Figure 3.—Source/sensor unit and traversing mechanism.



from placing defective concrete. Finally, density control could become an integral part of a new quality assurance system that would allow agency acceptance of new concrete pavement at the time of construction, that is, without waiting for 28-day strength test results.

Field Trials

Although the original development contract for the CMD included an extensive field evaluation, additional field trials were conducted in 1978 under FHWA contract by the Iowa and Illinois Departments of Transportation. The purpose of the field trials was to determine the usefulness, fieldworthiness, and adequacy of the prototype CMD design. In each State, construction projects involving at least 8 lane km (5 lane miles) of paving were selected for the CMD trial. The Iowa researchers also planned a study to compare the effectiveness of internal and external vibrators.

After a 1-week laboratory familiarization study, the Iowa researchers began evaluating the CMD on an 11.9 km (7.4 mile) nonreinforced concrete pavement project on State highway 44, about 80 km (50 miles) west of Des Moines, Iowa. Although the slipform paver used on this project was manufactured by the same firm as the one used in the original research, the configurations of the two pavers differed considerably around the extrusion meter. The extrusion meter support channel on this paver was too low to satisfactorily mount the CMD's guide beam. Angle-iron mounts had to be welded on the paver at several places before the mounting for the guide beam and traversing mechanism was satisfactory.

Because of the nature of the mounting, the researchers reported considerable difficulty in maintaining the 25 mm (1 in) air gap between the source/sensor unit and the concrete surface. The guide beam supports had to be readjusted as often as every 20 minutes. The gap variations also made it difficult to evaluate the device's accuracy and precision. (Iowa's data indicated that a 3 mm (0.12 in) change in the air gap would produce a 1 percent change in the density reading.) Other minor problems were spurious spikes in the strip chart density record (probably electrically caused) and the awkwardness of handling the heavy (80 kg [177 lb]) source/sensor unit in the field.

The vibrator comparison study showed that the external vibrator gave densities of 2 210 to 2 310 kg/m^3 (138 to 144 lb/ft^3) over the entire project. Mechanical problems with the internal vibrators severely limited their use during the project, and therefore a real comparison of the effectiveness of the two kinds of vibrators was not possible. The limited amount of data indicated that concrete densities obtained midway between the vibrators were typically 16 to 48 kg/m^3 (1 to 3 lb/ft^3) lower than the densities at the vibrators. The vibrators were spaced 460 to 760 mm (18 to 30 in) apart.

Because of the varying air gap problem, the Iowa researchers concluded that the CMD was not ready for general use. They recommended that the air gap be measured continuously and either the density reading be automatically corrected to compensate for changes in the gap or the air gap be maintained constant at 25 mm (1 in) by automatically moving the source/sensor unit up and down.

Following the Iowa study, the Illinois DOT conducted a field trial on a continuously reinforced concrete pavement project on U.S. 36 south and west of Jacksonville, Ill. The slipform paver used on this project was manufactured by another firm and differed considerably from the one used in the original research study. Mounting the CMD guide beam was even more difficult than on the Iowa project. Figure 4 shows a side view of the final mounting arrangement before the start of paving. The CMD's guide beam could not be mounted directly on the extrusion meter support channel because of the location of the extrusion meter itself and of a walkway across the back of the paver. Three rectangular steel braces were welded to an auxiliary 380 mm (15 in) channel beam. As shown in the figure, the braces were hooked over the extrusion meter support channel, and the CMD's guide beam was mounted on the auxiliary channel beam.

Figure 4.—CMD attachment to paver, Illinois field trial, side view.

Because of this mounting arrangement, the CMD's guide beam was located about 1.5 m (5 ft) back from the extrusion meter support channel and the CMD's ability to maintain the constant 25 mm (1 in) air gap above the concrete was reduced. Again air gap adjustments were necessary as often as every 20 minutes, and the Illinois researchers concluded that automatic compensation of the CMD's density reading for air gap changes was necessary.

The Illinois researchers also studied concrete densities obtained at and between internal vibrators. Their results were almost identical to those of the Iowa researchers. With a uniform spacing of 610 mm (24 in) between vibrators, they found that concrete densities midway between the vibrators typically were 16 to 48 kg/m^3 (1 to 3 lb/ft^3) lower than the densities at the vibrators. The researchers also used the CMD to determine when individual vibrators were functioning properly; several vibrators were replaced during the paving when malfunctions were indicated.

The Illinois researchers concluded that, with automatic compensation for the air gap changes, the CMD would have great potential for producing uniform consolidation in concrete pavement.

Air Gap Compensation

The Iowa and Illinois field trials confirmed that the CMD needed to be modified to compensate for the variations in the air gap. As the Iowa researchers had noted, there were two obvious options: (1) sense the gap size and modify the traversing mechanism to allow continuous vertical adjustment of the source/sensor unit to maintain the required 25 mm (1 in) gap, or (2) continuously sense the gap size and electronically correct the density value displayed on the readout unit to reflect the actual density—the density at a 25 mm (1 in) gap size. The first option was likely to make the traversing mechanism more complex as well as heavier; if a suitable gap sensor were available, the second option appeared much easier.

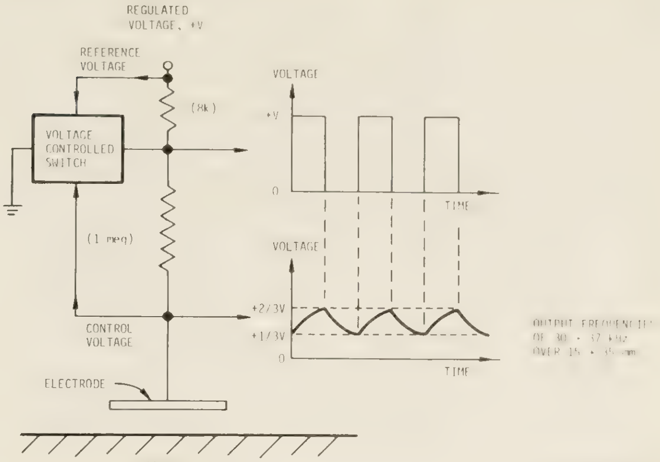
Therefore another FHWA contract study was undertaken to find a suitable gap measuring technique, develop a sensor, and modify the original readout unit to automatically compensate the density reading for the changes in the gap. The results of the study are summarized here and discussed in detail in reference 4.

The contract specification required that the modified CMD accurately monitor density while the air gap varied from 15 to 35 mm (0.6 to 1.4 in). Initial data indicated that the original CMD's density reading decreased by 6 kg/m^3 per 1 mm (1.0 lb/ft^3 per 0.1 in) increase in the air gap. The data also indicated a linear relationship between density reading and air gap over the 15 to 35 mm (0.6 to 1.4 in) range.

To monitor air gap size, the capacitance between a small, copper-sheet electrode mounted below the CMD's source/sensor unit and the concrete surface was measured. The measurement relies on the fact that capacitance is inversely proportional to the distance between the two plates of a parallel-plate capacitor. The capacitance is measured continuously by the circuit shown in figure 5. The concrete acts as the lower plate, a conductor at ground potential. The capacitor is alternately charged and discharged by the voltage-controlled switch; changes in the capacitance, caused by changes in the air gap, are reflected in the charge and discharge time of the capacitor between one-third and two-thirds of the supply voltage. The output of this circuit is an oscillating signal whose frequency, 30 to 37 kHz, varies with the capacitance value.

The capacitance probe consists of a 100 × 180 mm (4 × 7 in) copper sheet and an electrical guard plate, which are encapsulated in silicone rubber. The probe, which acts as the upper plate of the capacitor, is shown in figure 6, and in place on the CMD carriage in figure 7. As stated previously, the concrete acts as the lower plate of the capacitor. No grounding wire is necessary from the CMD because electrical continuity is achieved through the paving machine. Changes in the concrete mix do not affect the air gap measurement nor does the presence of a water film on the concrete surface.

Figure 5.—Capacitance measurement circuit.



1 mm = 0.04 in

Figure 6.—Capacitance probe (shown with electrode facing up).

Figure 7.—Capacitance probe in place on carriage.

Integrating the capacitance probe compensation signal with the CMD's uncompensated density signal required additional electronic circuitry. The two signals had to be summed to produce a density signal that is not affected by changes in the size of the air gap (fig. 8). The 30 to 37 kHz output from the capacitance air gap measurement first passes through a frequency-to-voltage converter, which produces a direct current voltage proportional to the air gap size. Because the CMD's uncompensated density signal varies linearly with the air gap, the capacitance probe's output also had to be linearized as follows: As the capacitance probe output voltage passes preset electronic switch points, different resistors are introduced into the circuit to change the gain and raise the voltage to the linearized output line. Nine gain regimes are necessary to adequately simulate linearization. Figure 9 shows the original capacitance probe output voltage curve and the linearized output voltage, both plotted against air gap size.

The modifications to the original CMD's electronics were completed with the addition of temperature compensation, to keep the capacitance probe output constant over 5° to 45° C (41° to 113° F), and the circuitry to sum the capacitance probe and uncompensated CMD signals. A time constant also was applied to the air gap signal to match the time constant selected for the CMD density signal.

The display panel of the CMD's readout unit was modified to provide a meter display of the air gap size. A switch on the panel allowed the air gap compensation to be switched so that either the uncompensated or the compensated CMD density could be fed into the density meter and strip chart recorder. Connections on the panel also allowed both the air gap size and the uncompensated density to be transmitted to an auxiliary strip chart recorder external to the control and readout unit.

Laboratory evaluation

The effectiveness of this air gap compensation was examined in the laboratory using a variable height test stand. A hydraulic cylinder and hand pump were used to raise and lower the CMD's source/sensor unit over the specified 15 to 35 mm (0.6 to 1.4 in) air gap above a concrete sample. Figure 10 shows a strip chart record of the compensated and uncompensated density readings while the air gap was increased from 15 to 35 mm (0.6 to 1.4 in). The figure clearly shows that the density reading is automatically corrected to compensate for the changes in the air gap over the specified range.

Field test

The evaluation of the air gap compensation system was completed with a brief field test in August and September 1980 on a reinforced concrete pavement project on U.S. 219, about 50 km (30 miles) south of Buffalo, N.Y. The guide beam mounting area of the slipform paver (the extrusion meter area) differed

Figure 8.—Scheme for density compensation.

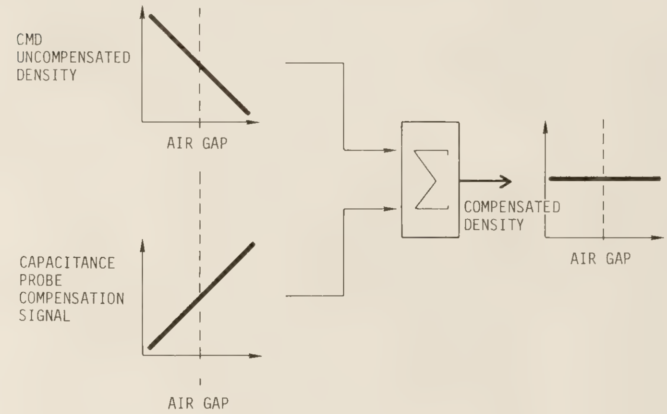


Figure 9.—Original and linearized output voltages as a function of air gap.

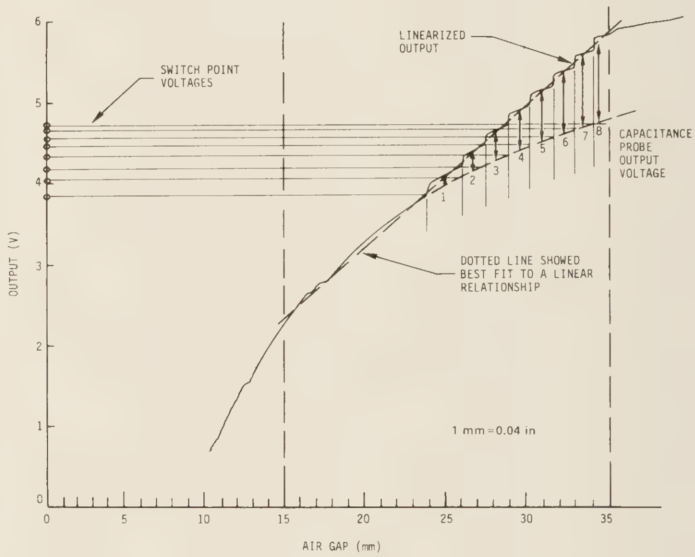
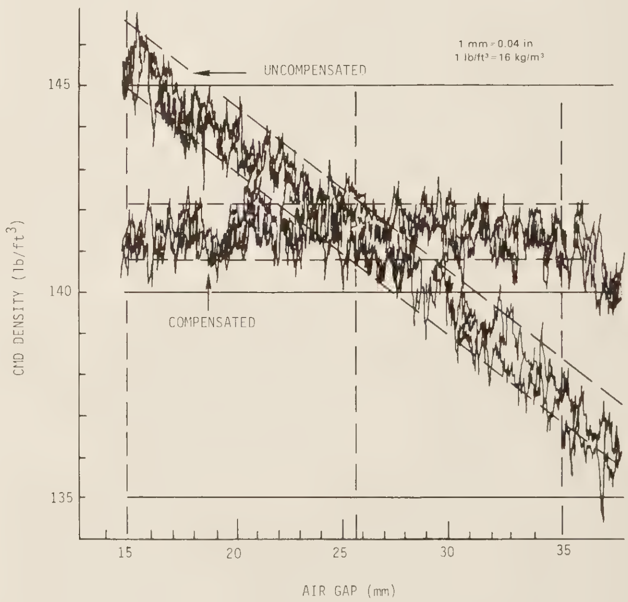


Figure 10.—Comparison of compensated and uncompensated CMD densities as a function of air gap.



from the configuration in all three previous field trials, so again the researchers had installation problems. In this case, the mounting brackets were modified and part of a vertical I–beam on the paver was cut away to satisfactorily mount the guide beam.

No attempt was made during this trial to correlate the CMD density readings with results obtained by other conventional tests, for example, rodded unit weight, weighed density, and core density. Such correlations had been established in the original CMD development study. (*1, 2*) The present field trial was aimed at demonstrating the effectiveness of the air gap measurement and the compensation of the CMD density readout.

The data indicated that the air gap compensation worked well over the entire 15 to 35 mm (0.6 to 1.4 in) range and over the entire period of the field test. Both construction-produced variations in the air gap and intentional tilting of the guide beam were adequately compensated for in the CMD's density reading. Limited comparisons between the CMD readings and density readings by commercially available, static nuclear density gages showed good agreement.

The records of the air gap provided by the auxiliary recorder suggested another possible application of the capacitance probe. These plots showed a substantial increase in air gap, lasting approximately 0.3 m (1 ft), every 4.9 m (16 ft) of slipform paver travel. Because the CMD was rigidly attached to the paver's extrusion meter, such an increase corresponds to a slight depression in the concrete itself. Further investigation showed actual depressions in the concrete, typically 5 mm (0.2 in) deep and coinciding with the overlap of the steel wire reinforcing mesh embedded in the concrete (the mesh sections were 4.9 m [16 ft] long and overlapped by about 0.3 m [1 ft]). The researchers suggested that the depression might be caused by increased vibration and consolidation around the overlap.

The detection of the depressions at the mesh overlap points suggested that the capacitance probe might be useful for monitoring the smoothness of newly placed concrete pavement. Capacitance probes of the type used in the CMD would be very inexpensive. Assuming immediate feedback on pavement smoothness could be used by a contractor to improve control of the paver and finishing operations, a series of such probes with associated data processing electronics could be a very useful tool.

The CMD's Future

Early in 1981, the prototype CMD was returned to FHWA's Office of Research. Several instrumentation problems—breakdown of the strip chart recorder and the appearance of large spikes, apparently electrically generated, in the density readings—indicated that the first generation prototype was showing signs of age. Two major reworkings of the electronics since the initial fabrication had reduced the prototype's reliability. It was decided, therefore, to construct a second generation prototype with the following objectives:

- Improve the electronics by using the latest technology in established reliability electronic components.
- Replace obsolete major components such as the strip chart recorder.
- Redesign the panel of the control and readout unit to simplify standard operation and to make the CMD operable by inspector-level personnel.
- Redesign the guide beam to allow installation and full traverse on both 3.7 and 7.3 m (12 and 24 ft) wide slipform pavers. (The guide beam for the first generation prototype will operate only over the shorter distance.)

The construction of the second generation prototype is scheduled for completion during the spring of 1983. Field trials by State highway agencies will be scheduled for the 1983 construction season.

Two additional research studies have resulted from the CMD's successes and other construction control needs. In the first study a device for mounting on compaction rollers is being developed to monitor the density and temperature of asphalt concrete during compaction. Much of the nuclear and electronic technology used in the CMD will be used in designing the new device, although some changes will be required to allow the instrument to be used both on full-depth and thin (25 to 50 mm [1 to 2 in]) overlays. Infrared thermometry is the method of choice for the temperature measuring system.

This study includes development of a prototype device, laboratory evaluations, and field trials on three paving projects. The field trials will include comparisons of the new device's density data with densities obtained from cores and by static nuclear gages. The study is scheduled for completion late in 1982. Additional field trials by State highway agencies will be scheduled for the 1983 construction season.

The second study, scheduled to begin in the fall of 1982, will develop equipment for monitoring pavement surface smoothness during construction. Currently, surface smoothness measurements, for defining the rideability of new concrete pavement, are made on the hardened concrete. When rough areas are encountered, they must be ground down.

The grinding equipment is expensive to purchase ($150,000) and operate (perhaps $50,000 a year to maintain the diamond cutting edges), and grinding is very labor intensive. Therefore, development of a surface profilometer that would determine smoothness while the pavement surface is still workable is desirable. The accuracy and low cost of the capacitance probe developed for the air gap measurement in the CMD suggest capacitance to be a promising technique for a profilometer for plastic concrete. The research will include an examination of capacitance as well as acoustic, optical, and other promising techniques, followed by the development of a prototype profilometer.

Summary and Conclusions

Development has continued on the CMD, a nuclear backscatter device to continuously and automatically monitor the degree of consolidation of plastic concrete. Initial field evaluations by State highway agencies confirmed the device's potential as a quality control tool but indicated that additional equipment development was needed. The major design shortcoming, the sensitivity of the device's density reading to changes in the air gap between the device and the pavement, was effectively eliminated by adding a simple gap-measuring device and automatically compensating the density reading for air gap changes. A second generation CMD is currently under construction.

FHWA's Offices of Research, Development, and Technology believe the CMD offers highway agencies and contractors a valuable tool for controlling the quality of concrete pavement as it is being placed. The real test, however, is costs and benefits. For both contractors and State highway agencies, materials and construction defects can create million-dollar problems. Small investments in equipment, such as the CMD, for monitoring quality before kilometres (miles) of defective concrete are in place, quickly pay for themselves. Furthermore, better control of consolidation should increase average pavement life and stretch highway agencies' limited maintenance and reconstruction dollars.

REFERENCES[2]

(*1*) T. M. Mitchell, P. L. Lee, and G. J. Eggert, "The CMD: A Device for Continuous Monitoring of the Consolidation of Plastic Concrete," *Public Roads,* vol. 42, No. 4, March 1979, pp. 148–155.

(*2*) P. L. Lee and G. J. Eggert, "Development of a Device for Continuous Automatic Monitoring of Consolidation of Fresh Concrete," Report No. FHWA–RD–78–27, *Federal Highway Administration,* Washington, D.C., March 1978. PB No. 285966.

(*3*) P. L. Lee and G. J. Eggert, "Instrument Manual for Prototype Concrete Consolidation Monitoring Device," Report No. FHWA–RD–78–96, *Federal Highway Administration,* Washington, D.C., May 1978. PB No. 290735.

(*4*) G. J. Kirby and R. W. Lusignea, "Improvement of Device (CMD) for Monitoring the Consolidation of Plastic Concrete," Report No. FHWA/RD–81/117, *Federal Highway Administration,* Washington, D.C., August 1981. PB No. 82 132390.

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

Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Federal Highway Administration, Office of Engineering and Highway Operations Research and Development (R&D) and Office of Safety and Traffic Operations R&D. The reports are available from the address noted at the end of each description.

Curbside Pickup and Delivery Operations and Arterial Traffic Impacts, Report No. FHWA/RD–80/020

by FHWA Office of Safety and Traffic Operations R&D, Urban Traffic Management Division

This report presents an analysis of curbside pickups and deliveries (PUD's) of freight in urban areas. Data were collected in six cities on the characteristics of the PUD trip, the parking of the delivery vehicle, the kind and size of the business, and the impact of double parking on arterial traffic performance. These data were analyzed and tools were developed to predict PUD demand, parking patterns, and resultant traffic impact under various conditions. These tools were used to test various traffic engineering strategies to improve the level of service on arterials. The report recommends the most practical strategies for demonstration, including improved management of curb-space use, improved signing and striping, signal timing adjustments, and enforcement levels.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 225914).

Luminous Requirements for Traffic Signs, A Comparison of Sign Performance and Requirements, Report No. FHWA/RD–81/158

by FHWA Office of Safety and Traffic Operations R&D, Systems Technology Division

To be effective, a traffic sign must transmit information to an approaching driver in enough time for the driver to gather and process the information and react appropriately. This report presents the results of a study of 11 new retroreflective traffic control signs to determine driver detection and recognition/message comprehension distances at night. Environmental effects were minimized by restricting the study to straight roads with homogeneous, nondistracting sign surroundings. Detection and recognition distances of the study subjects were compared with analytically determined detection and recognition distances. All signs were detected at the required distance, but some messages were not comprehended at the required distances.

Speed recommendations are not provided or evaluated in this report. Because of the many variables that influence sign visibility, a more detailed study is investigating sign retroreflective requirements under various conditions.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 176553).

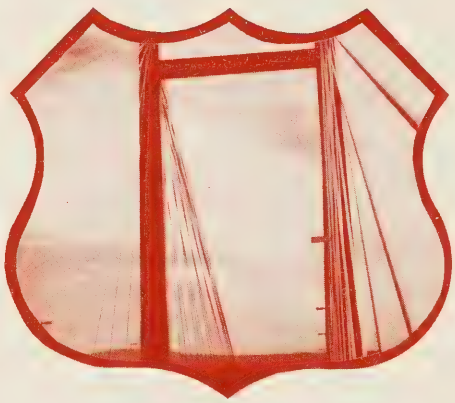
San Antonio Motorist Information and Diversion System, Report No. FHWA/RD–81/018

by FHWA Office of Safety and Traffic Operations R&D, Urban Traffic Management Division

This report documents a study to evaluate the effectiveness of a low-cost motorist information diversion system in San Antonio, Tex. The system was implemented in 1977 as a demonstration program to alleviate congestion and reduce accidents on I–35 in San Antonio near the central business district. As part of the program, I–35 traffic was rerouted around the business district and a low-cost changeable message sign system was used to divert freeway traffic and manage traffic during freeway maintenance.

The report also discusses the lessons learned from the demonstration program and provides recommendations for future urban motorist information diversion systems.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 131574).



Analytical Study for Fatigue of Highway Bridge Cables, Report No. FHWA/RD–81/090

by FHWA Office of Engineering and Highway Operations R&D, Structures Division

Designers of cable-stayed highway bridges must consider the significant resonant vibration motions that may be induced in individual cables at certain critical wind velocities. Such vibrations may result in an accumulation of bending stress cycles at the fixed ends of long, flexible cables sufficient to cause fatigue failures of component wires in the cables.

This report describes an analytical investigation of the complex fatigue crack initiation and propagation mechanism in small diameter, high-strength steel wires in large cables subject to wind-induced vibration. The bridge cable aerodynamic response formulas presented in the report provide the design engineer with methods for computing vibration frequencies, critical wind velocities, cable deflections, and cable bending stresses. Formulas are presented for the fatigue analysis of individual wires in a bridge cable based on a linear elastic fracture mechanics methodology. Guidelines are provided for estimating the fatigue life of the cable, and example calculations are shown for stay cables of an existing highway bridge.

The report also includes a discussion on the fatigue testing of wires and cables and an outline of recommended additional analytical and experimental research on the subject.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 245672).

Flexible Pavement Overlay Design Procedures, Volume 1 (Report No. FHWA/RD–81/032) and Volume 2 (Report No. FHWA/RD–81/033)

by FHWA Office of Engineering and Highway Operations R&D, Pavement Division

These reports provide rational procedures based on elastic layer theory for designing flexible overlays for existing flexible pavements. The design procedures and analytical techniques presented predict the structural fatigue of flexible overlays from various geometric, material, loading, and environmental conditions.

Volume 1, **Evaluation and Modification of the Design Methods,** describes the development of new computerized design procedures based on a combination and modification of several existing flexible pavement overlay design methods. The new procedures incorporate the latest developments in flexible pavement evaluation and overlay design. Overlay thickness is determined by a fatigue distress function derived from American Association of State Highway Officials Road Test data. The required inputs for the new overlay design procedures include pavement dynamic deflection measurements; limited pavement crack survey data; projected traffic in terms of equivalent 80 kN (18 kip) axle loads; and material characterization (measured layer thicknesses and estimates of (1) Poisson's ratio for each layer, (2) the stress dependency relationship of base and subgrade moduli, and (3) the asphalt modulus-temperature relationship). Guidelines are presented for quantifying these parameters in the absence of laboratory test data. Environmental factors are provided for adjusting deflection measurements made at various times of the year.

Volume 2, **User Manual,** presents detailed instructions for obtaining the necessary input data and for entering the data into the computerized design program. Comparisons between the new design procedures and other overlay design methods presently used by three States show that the new procedures can be more economical because pavement evaluations and overlay thickness designs are made for each location where dynamic deflection measurements are taken. This permits the design engineer to consider alternate, more cost-effective remedial strategies, such as improved drainage, recycling, or reconstruction, where very thick overlays would otherwise be required.

The reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 82 136672 and 82 136680).

The Effect of Truck Size on Driver Behavior, Report No. FHWA/RD–81/170

by FHWA Office of Safety and Traffic Operations R&D, Safety and Design Division

The increased size and weight limits for trucks today have raised several safety issues, including possible handling and braking problems, performance on grades, traffic impedance, and sign blockage. However, the effect of these larger trucks on the drivers of adjacent vehicles has not been widely discussed or studied.

This report discusses the effect of truck size on the behavior of drivers who interact with trucks in selected roadway situations. Truck length/configuration was studied in freeway entrance merge, mainline lane change, and narrow bridge situations, while truck width was studied in a rural two-lane, two-way passing situation. Microscopic traffic measures were collected and erratic maneuvers and truck type were observed for the length/configuration studies. In the truck width passing study, an impedance factor was used to induce passing of an experimentally widened vehicle.

The report suggests that automobile drivers do not perceive differences in truck size or at least do not react unusually to these differences.

Limited copies of the report are available from the Safety and Design Division, Office of Safety and Traffic Operations Research and Development, Federal Highway Administration, Washington, D.C. 20590.

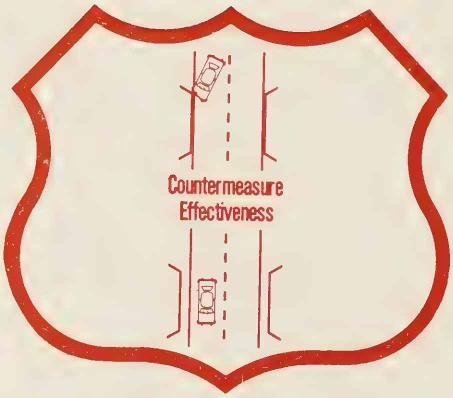
Model System for Evaluating Safety Projects Using State Record Systems, Report No. FHWA/RD–81/186

by FHWA Office of Safety and Traffic Operations R&D, Safety and Design Division

This report presents the results of a study on the adequacy of existing recordkeeping systems for evaluating highway safety programs. The kinds of highway safety-related data collected by States are presented in the report as are the methods used to collect and store the data.

A model system developed under this study to store, maintain, and retrieve safety data and evaluations of projects is described in the report. The model system addresses the problem of matching hazardous sites with similar sites where safety projects have been implemented and evaluated. Also, the model system can perform project evaluations using existing recordkeeping systems of States.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 202516).



Estimating the Safety Benefits for Alternative Highway and/or Operational Improvements, Volume I—Research Summary, Report No. FHWA/RD–81/179

by FHWA Office of Safety and Traffic Operations R&D, Safety and Design Division

This report presents the results of a study to evaluate the safety of various highway design improvements and to develop techniques for predicting accident frequency and severity. A total of 326 test and control sites in Alabama were studied to determine the effect of 14 different safety improvements. Parametric and nonparametric statistical tests were used to estimate accident frequency and severity reduction so that safety improvement funds could be allocated more accurately. The ratio of property damage only accidents to total accidents—the severity ratio—was used to estimate severity reduction. Generally, the confidence intervals for these estimates were quite wide. A dynamic programing procedure was developed to translate the estimates into budget allocation policy.

Limited copies of the report are available from the Safety and Design Division, Office of Safety and Traffic Operations Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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

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

U.S. Department of Transportation
Federal Highway Administration
Office of Implementation
Washington, D.C. 20590

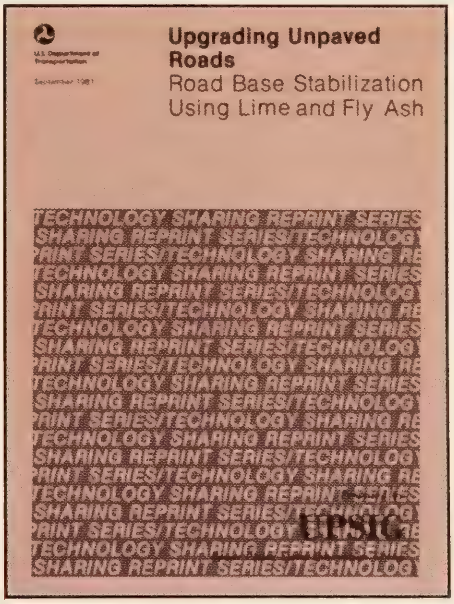
Items available from the Office of Implementation can be obtained by including a self-addressed mailing label with the request.

Upgrading Unpaved Roads—Road Base Stabilization Using Lime and Fly Ash

by Upper Plains States Innovation Group

In the United States, over 70 percent of the total road kilometres (miles) are unpaved. Most of these roads are under the jurisdiction of county and other local governments. As maintenance and construction needs continue to increase, local highway agencies are searching for new ways to improve the serviceability of unpaved roads and to decrease construction and maintenance costs.

Stabilization, particularly lime-fly ash-aggregate (LFA) stabilization, has proven to be a cost-effective method for upgrading unpaved roads and improving performance and serviceability. This report is intended to help practicing road superintendents determine whether LFA base stabilization with an asphaltic surface seal is a cost-effective approach for upgrading local unpaved roads.



Limited copies of the report are available from the U.S. Department of Transportation, Technology Sharing Office (I–40), Washington, D.C. 20590.

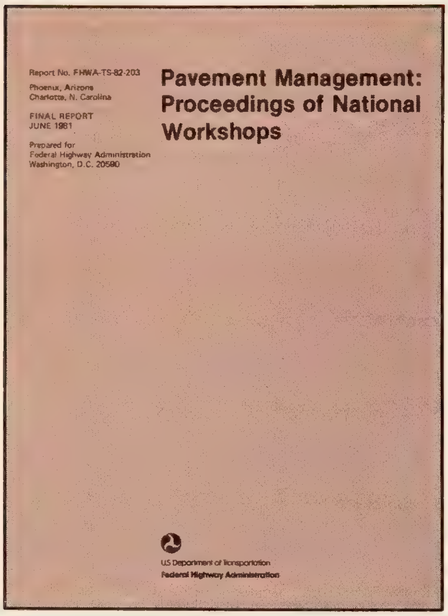
Roadway Delineation Practices Handbook, Implementation Package 81–5

by Office of Implementation

This handbook provides practical guidelines for the proper application of available delineation systems. Although the handbook is not intended to be a state-of-the-art report, it does provide an overview of current developments in roadway delineation techniques. Current and newly developed devices, materials, and installation equipment are discussed in terms of demonstrated or anticipated performance based on actual experience or field/laboratory tests.

The handbook is intended primarily for design, traffic, and maintenance engineering personnel. The uses, materials, application procedures, service life, and maintenance of painted markings, thermoplastic and other durable markings, raised pavement markers, and post delineators are presented as well as administrative and management considerations.

Copies of the handbook may be purchased for $4 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00198–5).



Pavement Management: Proceedings of National Workshops, Report No. FHWA–TS–82–203

by Office of Implementation

Two national workshops on pavement management were conducted by the Transportation Research Board for the Federal Highway Administration. The workshops addressed pavement management processes including information acquisition and processing, planning and programing, design, construction, maintenance, rehabilitation, and field monitoring.

This report contains the proceedings of both workshops and provides valuable information for improving the pavement management practices of an organization, particularly for developing and implementing a pavement management subsystem to improve the scheduling of maintenance and rehabilitation projects. Highlights and major recommendations of the two workshops are provided. Pavement management considerations, definitions, benefits, and implementation procedures also are discussed. The need to make better pavement management decisions, provide feedback on the consequences of those decisions, consider alternative practices, and strive for consistent decisions at different levels within an organization using objective criteria were emphasized at the workshops.

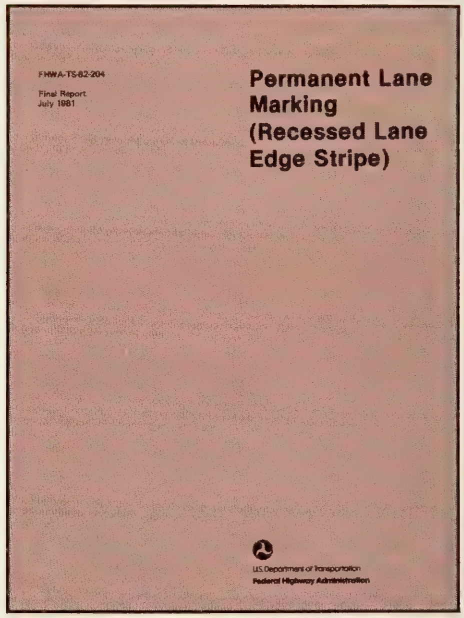
Limited copies of the report are available from the Office of Implementation.

Permanent Lane Marking (Recessed Lane Edge Stripe), Report No. FHWA–TS–82–204

by Office of Implementation

Maintaining adequate roadway delineation on mountain passes during winter is a continual problem because conventional traffic paint cannot withstand sanding operations, studded tires, chains, and snowplowing. This report summarizes a study to evaluate different methods of cutting recessed skip-stripe grooves and various pavement marking materials placed into the recesses to find a permanent marking system.

Only one method of grooving was found that produced the desired recess shape at a reasonable cost. All three of the marking materials survived for 3 years, but none produced the desired wet-day or wet-night visibility needed for adequate lane delineation.



The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 105446).

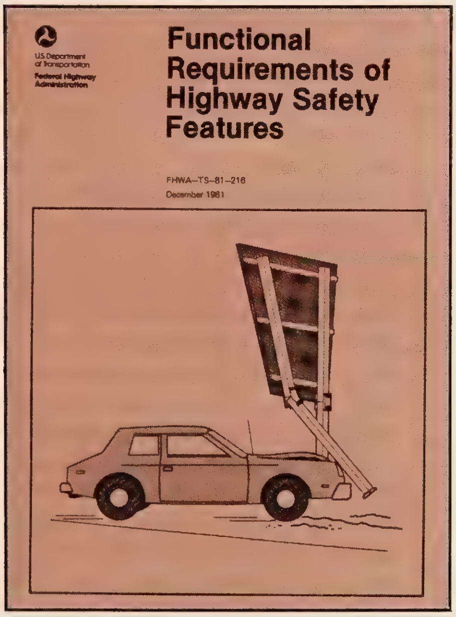
Functional Requirements of Highway Safety Features, Report No. FHWA–TS–81–216

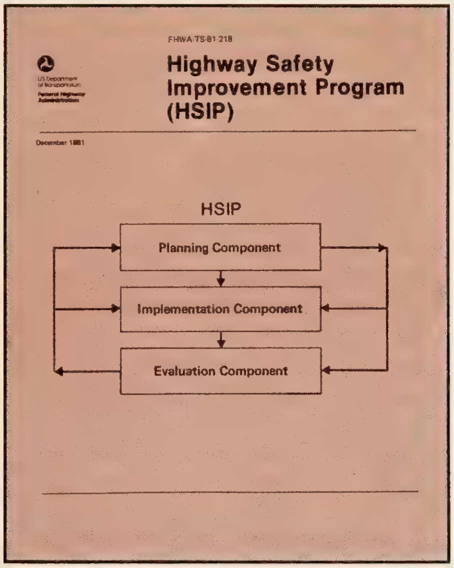
by Office of Implementation

In 1978 FHWA conducted a nationwide safety review to determine the degree to which design and construction of highways and highway safety upgrading projects adhered to the principles in the American Association of State Highway and Transportation Officials' report *Highway Design and Operational Practices Related to Highway Safety* (Yellow Book). During the review, operational and maintenance practices on all kinds of highways were observed. Because it was found that the purposes and performance requirements of highway safety features were not understood clearly, this training notebook was developed for construction and maintenance personnel.

The notebook describes how various highway safety features work and why they are used, identifies the factors that will adversely affect the intended performance of each feature, and illustrates, through examples of good and bad installations, what field personnel should look for to identify safety problems in the field installations.

Copies of the notebook may be purchased for $7.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00237–0).





Highway Safety Improvement Program (HSIP), Report No. FHWA–TS–81–218

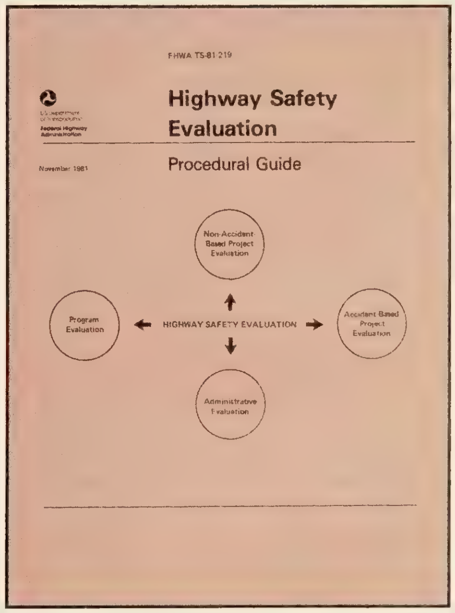
by Office of Implementation

This manual provides State and local highway agencies guidelines for developing and implementing a highway safety improvement program that best meets their capabilities and needs. The manual describes how to plan, implement, and evaluate a highway safety improvement program that complies with *Federal-Aid Highway Program Manual 8–2–3*; select the most appropriate procedures based on an agency's objectives, resources, and highway system; and use current information on reporting requirements, funding sources, and practices of other highway agencies.

Copies of the manual may be purchased for $7.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00241–8).

Highway Safety Evaluation, Procedural Guide, Report No. FHWA–TS–81–219

by Office of Implementation

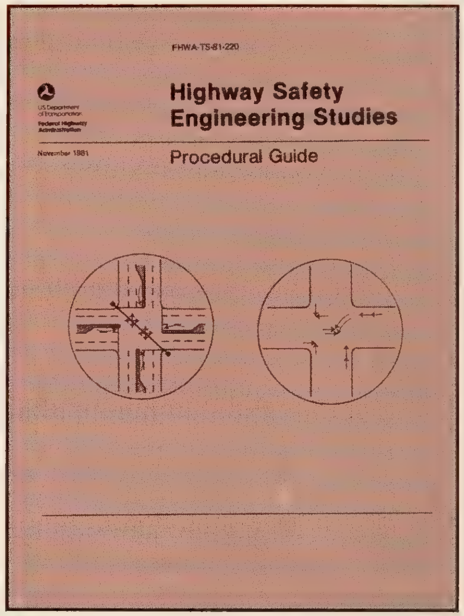


This guide describes procedures for evaluating highway safety programs and projects. The guide describes how to select appropriate measures of effectiveness and efficiency for evaluating safety improvements using either accident data or alternate measures of hazard reduction; evaluate safety improvements and use the results to recommend improvements for other safety problems; organize and manage evaluation processes for providing feedback on the effectiveness of safety projects to the planning and implementation components of the safety program; and perform program effectiveness and administrative evaluations.

Copies of the procedural guide may be purchased for $9.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00242–6).

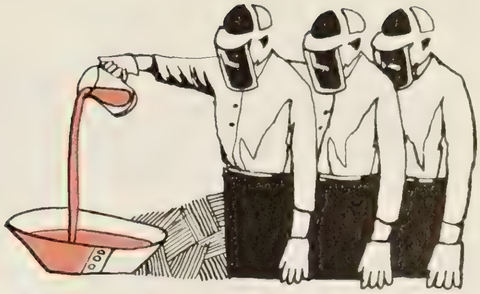
Highway Safety Engineering Studies, Procedural Guide, Report No. FHWA–TS–81–220

by Office of Implementation



This guide describes how to plan and conduct an effective highway safety engineering investigation of an identified hazardous location, using appropriate procedures and techniques; select the most appropriate procedures and techniques required for investigations, considering agency size and type; identify safety deficiencies and feasible countermeasures to alleviate the hazardous situations; and select a safety project based on safety objectives.

Copies of the procedural guide may be purchased for $11 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00240–0).



New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research, Development, and Technology. 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 or Transportation 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 1P: Visual Guidance for Night Driving

Title: Study of Procedures Related to Efficiency of Raised Pavement Marker Systems. (FCP No. 41P3112)
Objective: Develop quantitative information on the interaction of the service lives, costs, installation techniques, roadway environments, and accident prevention potentials of raised pavement markers used in Texas.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1984
Estimated Cost: $160,000 (HP&R)

FCP Category 2—Reduce Congestion and Improve Energy Efficiency

FCP Project 2K: Metropolitan Multimodal Traffic Management

Title: Improving Traffic Signal Timings. (FCP No. 42K2162)
Objective: Develop procedures for improving signal timing plans and conduct field studies to evaluate the consequences of improved signal timing.
Performing Organization: University of California, Berkeley, Calif. 94720
Funding Agency: California Department of Transportation
Expected Completion Date: February 1984
Estimated Cost: $137,000 (HP&R)

Title: Fuel Consumption and Emission Values for Traffic Models. (FCP No. 32K2211)
Objective: Measure fuel consumption and emissions for the full range of vehicle performance capabilities of vehicles representative of the U.S. automobile fleet from 1979 to 1985. Convert these measurements into tables and equations for incorporation into various traffic models.
Performing Organization: Oak Ridge National Laboratory, Oak Ridge, Tenn. 37830
Expected Completion Date: January 1984
Estimated Cost: $279,000 (FHWA Administrative Contract)

FCP Project 2L: Detection and Communications for Traffic Systems

Title: Visual Incident Detection Evaluation Operation (VIDEO). (FCP No. 42L1042)
Objective: Develop the image transmission phase of the SCAN project and extend its concept to cover permanent station location within a system concept. Test the field applicability of television surveillance using low-frame rate samples of real-time images processed at the roadside.
Performing Organization: Maryland Department of Transportation, Baltimore, Md. 21211
Expected Completion Date: November 1983
Estimated Cost: $443,000 (HP&R)

FCP Project 2P: Improved Utilization of Available Freeway Lanes

Title: On-line Freeway and Street Corridor Control. (FCP No. 42P4074)
Objective: Consolidate and extend theoretical base for on-line systemwide control, develop field evaluation methodology, and experiment with and evaluate most promising on-line systemwide control scheme.
Performing Organization: University of California, Berkeley, Calif. 94720
Funding Agency: California Department of Transportation
Expected Completion Date: December 1983
Estimated Cost: $178,500 (HP&R)

FCP Category 4—Improved Materials Utilization and Durability

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

Title: Performance of Three Bridges in Permafrost Areas. (FCP No. 44D4104)
Objective: Evaluate the design and performance of three bridges in the permafrost areas of central Alaska.
Performing Organization: Cold Regions Research and Engineering Laboratory, Juneau, Alaska 99801
Funding Agency: Alaska Department of Transportation and Public Facilities
Expected Completion Date: September 1983
Estimated Cost: $16,000 (HP&R)

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

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

Title: Evaluation of Design Practices for Riprap Used in Protection of Highway Crossings. (FCP No. 35H1212)
Objective: Determine by field evaluation and collection of hydraulic data the applicability of available riprap design procedures and provide guidelines for comprehensive design methods.
Performing Organization: U.S. Geological Survey, Reston, Va. 22092
Expected Completion Date: April 1985
Estimated Cost: $340,000 (FHWA Administrative Contract)

FCP Project 5L: Safe Life Design for Bridges

Title: Characterization of Acoustic Emission Signals. (FCP No. 35L2102)
Objective: Identify and characterize acoustic emission signals. Gather and evaluate laboratory test data on typical bridge steel specimens and components of bridge field tests. Develop acoustic emission systems and sensing elements for analyzing the acoustic emission signal needed to identify the acoustic emission source mechanism.
Performing Organization: United Technologies Research Center, East Hartford, Conn. 06108
Expected Completion Date: January 1984
Estimated Cost: $138,700 (FHWA Administrative Contract)

Title: Application of Bridge Formula to Truck Weight Enforcement. (FCP No. 35L3022)
Objective: Develop a simple, economical, and practical method of applying the bridge formula at weigh stations for truck weight enforcement. Prepare a users manual to include step-by-step procedures for weigh station operators using portable scales as well as platform scales.
Performing Organization: Chi Associates, Inc., Arlington, Va. 22201
Expected Completion Date: August 1983
Estimated Cost: $88,000 (FHWA Administrative Contract)

FCP Category 6—Improved Technology for Highway Construction

FCP Project 6D: Structural Rehabilitation of Pavement Systems

Title: Evaluation of Subsurface Road Drainage Systems. (FCP No. 46D3424)
Objective: Evaluate the performance of experimental pavement sections having an incorporated drainage layer and compare with that of conventional dense-graded pavement designs.
Performing Organization: New Jersey Department of Transportation, Trenton, N.J. 08628
Expected Completion Date: March 1987
Estimated Cost: $103,000 (HP&R)

FCP Category 0—Other New Studies

Title: Evaluation of Experimental Test Sections. (FCP No. 40M3013)
Objective: Validate the use of high-pressure liquid chromatography for asphalt analysis to predict the serviceability and longevity of pavements.
Performing Organization: Montana State University, Bozeman, Mont. 59717
Funding Agency: Montana Department of Highways
Expected Completion Date: September 1988
Estimated Cost: $63,000 (HP&R)

Title: An Evaluation of Epoxo 300–C Nonskid Coating for Use on Bridge Decks. (FCP No. 40M5784)
Objective: Test effectiveness and durability of Epoxo 300–C, a two-part epoxy nonskid coating, on steel grid, steel plate, and portland cement concrete sections of a bridge deck.
Performing Organization: Mississippi State Highway Department, Jackson, Miss. 39205
Expected Completion Date: May 1984
Estimated Cost: $17,000 (HP&R)

Title: Specially Constructed Bridges. (FCP No. 40M5794)
Objective: Evaluate bridge deck materials (watertight bridge expansion joints, waterproofing membranes, and treated structural and reinforcement steel) and construction practices that protect against premature deterioration. Perform surveys of techniques implemented by the Kentucky Department of Transportation.
Performing Organization: University of Kentucky, Lexington, Ky. 40506
Funding Agency: Kentucky Department of Transportation
Expected Completion Date: January 1987
Estimated Cost: $281,000 (HP&R)

Instructions to Authors

All articles proposed for publication in *Public Roads* magazine are reviewed for suitability by the technical editors; authors are notified of acceptance or rejection.

Recent issues of the magazine should be reviewed for kind of articles, style, illustrations, tables, references, and footnotes. *Public Roads* follows the U.S. Government Printing Office Style Manual.

Submission of Manuscripts

Authors in the Washington, D.C., area should submit two copies of the manuscript to the editor.

Editor, *Public Roads* Magazine
(HRD–10)

Federal Highway Administration
Offices of Research, Development, and Technology
Washington, D.C. 20590

Authors outside the Federal Government, or in State, city, or local government agencies, should submit two copies of the manuscript through appropriate Federal Highway Administration Regional Offices (see page 84).

Manuscript Treatment

Manuscripts should be typewritten (on a Vydec disk or with an optical character reader element, if possible), double spaced, with at least 1-inch margins on 8 ½- by 11-inch paper. Excluding art, one magazine page equals about three pages of manuscript. End each page with a completed paragraph. Type main headings flush left in initial capital letters.

Subheadings should be flush left, and only the first letter of the first word capitalized. The first page of each article should contain the title and the name of each author. If the article has been presented at a meeting, that should be indicated in a footnote at the bottom of the title page. Each page of the text should be numbered in the upper right corner. Because the Federal Government does not endorse products or manufacturers, avoid trademarks and brand names in articles unless their use is directly required by the objectives of the article.

Biography

A brief biography should be supplied. This should include the author's present position and responsibilities and previous positions relevant to the subject matter of the article. Biographies are limited to 100 words.

Tables

Nonessential technical tables should not be included in the article. Each table should be typed on a separate page and be identified by an Arabic number and a caption. The table should be cited in the text. Details of data already presented in tables or charts should not be repeated in the text.

Illustrations

Illustrations or figures should be referenced in the text, and numbers and captions should be assigned to each. All captions should be typed on a separate page. Organize the text so that illustrations can be scattered throughout the article. Avoid referencing several illustrations in one page to prevent problems in the layout. Black and white glossy photographs of good quality are preferred; however, color photographs and art are acceptable. Display art, which introduces the article and is run with the byline, may be a photograph, graphic representation, or an idea that can be drawn by an artist. Send legible copies of illustrations when the manuscript is sent for review. Send original artwork to the editor after being notified that the article has been accepted for publication.

Metrication

Under present law and FHWA regulation, *Public Roads* is required to show in the text metric (SI) units of measurement followed by their English equivalent in parentheses. In figures and tables, indicate equivalent units in a legend (for example, 1 in=25.4 mm or 1 km=0.6 mile); it is not necessary to show metric or English equivalents for each point plotted or quantity tabulated.

References

Number references consecutively in the body of the text according to the order of their appearance. Each reference number should be enclosed in parentheses and underlined. Copyrighted material referenced and quoted will require copyright releases. Unpublished material referenced in the text will be described in a footnote. Type references on a separate page under the heading REFERENCES, numbering them in the same manner as in the text and sequentially listing them.

Galley Proofs

Galley proofs will be sent to authors for their inspection.

For further information, contact the editor: (703) 285-2104.

Federal Highway Administration Regional Offices:

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

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

No. 4. Suite 200, 1720 Peachtree Rd., NW., Atlanta, Ga. 30367.
Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee.

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No. 6. 819 Taylor St., Fort Worth, Tex. 76102.
Arkansas, Louisiana, New Mexico, Oklahoma, Texas.

No. 7. P.O. Box 19715, Kansas City, Mo. 64141.
Iowa, Kansas, Missouri, Nebraska.

No. 8. P.O. Box 25246, Bldg. 40, Denver Federal Center, Denver, Colo. 80225.
Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming.

No. 9. 2 Embarcadero Center, Suite 530, San Francisco, Calif. 94111.
Arizona, California, Hawaii, Nevada, Guam, American Samoa.

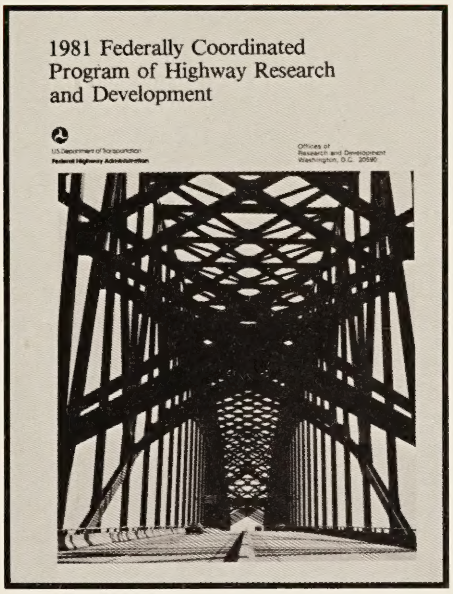
No. 10. 412 Mohawk Bldg., 222 SW. Morrison St., Portland, Oreg. 97204.
Alaska, Idaho, Oregon, Washington.

No. 19. Regional Engineer, Federal Highway Administration, APO Miami, Fla. 34002.
Canal Zone, Colombia, Costa Rica, Panama.

☆U.S. Government Printing Office: 1982—361–783/105

New Publication

The Offices of Research, Development, and Technology (RD&T), Federal Highway Administration (FHWA), have released their fiscal year **1981 Annual Report on the Federally Coordinated Program (FCP) of Highway Research and Development.**



The 36-page report briefly describes the goals and programs of the FCP and FCP accomplishments in highway research and development during FY 1981. Specific accomplishments in safety research, traffic operations research, environmental research, materials research, structural research, highway construction, and highway maintenance are cited. The report is prefaced by a message from Federal Highway Administrator R. A. Barnhart.

While supplies last, individual copies of the report are available without charge to highway-related agencies and universities. Requests should be sent on agency or institution letterhead to the Federal Highway Administration, Offices of Research, Development, and Technology, Operations Staff, Washington, D.C. 20590. Copies of the report are on sale for $4.75 by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00457–1).

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Public Roads

A Journal of Highway Research and Development