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Fringe parking near an interchange.



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Highway Interchange Area Development

BY THE OFFICE OF
RESEARCH AND DEVELOPMENT
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Reported by¹ FLOYD I. THIEL, Economist
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Introduction

LAND USE problems are directly related to the amount and rate of land development. At present in the United States, the fast pace of land development is apparent and land use problems are becoming more numerous and serious. These land use problems are the result primarily of an increasing population, a rising standard of living, and an increasingly complex society (1).²

Opportunity and a problem

Land use problems in areas near the interchanges of controlled-access highways are especially numerous and intense. Interchange areas are not ordinary places. Because of the special advantages of accessibility, more economic activities are attracted to them than to areas not served by an interchange. This economic attraction constitutes both an opportunity and a problem, or at least a potential problem. There is almost universal agreement that the opportunity for economic development that interchanges offer should be used. Interchanges can serve as an instrument to open up new areas for sound economic growth, to revive the economic vigor of places that need economic revival, and perhaps to be the nucleus for a new kind of community. If this development needs to be planned so that it will continue to be economically sound over a period of time and so that the purpose of the interchange can be met.

Changes in land use occurring after a highway is built may impair the usefulness of the highway. Ribbon developments are an example. The goal of interchange area planners is to take advantage of the opportunity for economic development and at the same time to guide or even restrain development that may be incompatible with the interchange or with other development in the interchange area.

Guidance for interchange development

Considerable attention has been given to land development problems and opportunities in interchange areas. Several planning groups

A synthesis of reports on studies defining the problem of land use development of areas near interchanges, the approaches to controlled-access highways—development that often causes traffic congestion on the interchanges—is presented in this article. The location of an interchange can be the stimulus for nearby economic development; but this development can be the source of problems if it is not planned and controlled in relation to the traffic-carrying capacity of the interchange.

In the completed studies, attention was focused on the complexity of the problem related to the development of interchanges; land use controls now in force were analyzed; and suggestions as to the type of controls that might be effective were proposed. The author discusses these study findings and suggests that controls combining eminent domain techniques and police power might be the most appropriate ones for many areas. Suggestions also are made as to the guidance that State highway agencies could provide local communities confronted with interchange problems.

Areas requiring more research before definitive solutions can be formed are discussed; some are: Traffic generation characteristics of different land uses, service facility land requirements, compatibility of different land uses, effectiveness of different controls, and means for using available information to protect the capacity of the interchange.

and at least 17 State highway departments, in cooperation with the Bureau of Public Roads, have either conducted or sponsored research to find ways for maximum opportunities for economic development and to avoid land use problems in interchange areas. (A brief description of interchange studies sponsored by State highway departments and the Bureau of Public Roads is presented at the end of this article.) Analyses of all aspects of the interchange problem have been made in some of these studies and in others only certain aspects have been considered, such as the amount of space needed for highway-oriented businesses in interchange areas. Some of the more promising findings and recommendations from completed studies are described in this article, and a few suggestions are made for dealing with interchange matters. Also, attention is called to aspects of the interchange land use problem that appear to need additional research effort.

Summary

Location of a highway interchange near a community may or may not be beneficial and could be the source of a potential problem. Benefits from economic activity can be

realized only when development of land use near an interchange is orderly; this requires planning. Information gathered in interchange studies made to date have been useful for—

(1) Focusing attention on land development in interchange areas; (2) providing a priority system that can be used to determine interchange areas where the need for establishment of some control on land use is critical; (3) showing the complexity of the problems in the interchange area, particularly those related to traffic generated some distance from the interchange; (4) analyzing land use controls—on this basis suggestions have been made on the possible use of new methods such as issuing licenses on a need-to-be-there basis or establishing criteria for determining traffic generation for different land uses; (5) evaluating the effectiveness of different land use controls in interchange areas—eminent domain was more effective than police power; and (6) providing guidelines that can be useful for determining space availability and space needs for highway services and other uses.

One of the shortcomings of some completed interchange studies has been the failure to consider what can be done in the absence of land use planning in the interchange area. For areas unprotected by local land use planning, it seems reasonable to freeze any

¹Presented at the 44th annual meeting, Highway Research Board, Washington, D.C., January 1965.

²References indicated by italic numbers in parentheses are listed on p. 164.

future development near an interchange when the expected volume of traffic would exceed the capacity of the interchange ramps. Such a provision could be enforced in different ways; for example, by not permitting construction of additional driveways onto the feeder road near the interchange.

More information is urgently needed, particularly on other facets of the problem. Information is needed on the volumes and types of traffic generated by different land uses near interchanges, as well as the amount of interchange space needed for service stations, motels, and other uses. The compatibility or incompatibility of different land uses should be determined. Confirmation is also required as to whether it is good practice, as supposed, to have similar uses such as highway service facilities located in one quadrant of an interchange and different uses such as industrial facilities located in another quadrant. Information is also required as to whether well-planned, pleasant-appearing interchanges do in fact have a better economic future than poorly planned ones, and as to whether more attention should be given to planning for such highway needs as rest areas and placement of signs indicating the location of highway services.

Studies in depth, as well as surveys of broad coverage, are needed to gain the information required for adequate planning of land use controls at interchange areas. Surveys of a fairly large number of interchanges should be helpful in the selection of interchanges for analysis in depth, and information could also be obtained from the surveys on such aspects of the problem as number of driveway openings near interchange ramps and nearby highway service facilities. To the extent possible, research findings should be quantified; that is, given in percentage changes of land development, lineal feet or square feet needed for highway services, cost of controls through eminent domain procedures, and/or percentage of zoning appeals granted.

Interchange Development Problems

The nature and seriousness of interchange area development problems have been highlighted effectively during the past 4 years or so by individuals and organizations. One writer has described the freeway program as an ". . . unqualified success with the exception of the interchange areas . . ." (2). Another has likened freeways to people, suggesting that they both pass through youth, maturity, and finally old age. But interchanges reach the age of senility, he claims, more from the increase in traffic volumes than from the passage of time (3).

The economic problem that unsightly interchanges may pose for local areas and the opportunity interchanges afford for economic betterment often have been emphasized. A half-dozen States have issued booklets calling attention to the interchange as a valuable economic asset. For maximum benefit from an interchange, according to

one account, planning must keep pace with economic development. If planning lags, the resultant development may be haphazard and poorly conceived. But no need exists to ". . . overplan for development, beyond any possible potential . . ." (4). Interchanges are the *new four corners* (5) or *your new front door* (6) and you cannot afford anymore to show your cluttered backyards, your garbage patches to America. So reads the literature intended to focus enough attention on the interchange area development problem to encourage constructive action.

One of the most successful efforts to highlight the interchange problem was the 1961 Highway Research Board Symposium on Land Use and Development at Highway Interchanges, reported in HRB Bulletin 288. The reports presented have caused much attention to be given to the highway interchange land use problem, and they also have provided an analysis of several aspects of the problem that still seems appropriate, such as the description and evaluation of controls, the description of the land to be demanded and supplied at interchanges, and the need for user services.

A complex problem

The true causes of the interchange problem are complex. Interchanges that have little economic development nearby may be congested with traffic; on other interchanges that are surrounded by development traffic may be moving satisfactorily. One of the most baffling aspects of this problem is the varying amounts of traffic generated some distances away that rely on the interchange for access. If it were not for the remotely generated traffic, the interchange problem would be almost as simple as permitting only those land uses that would not generate more traffic in the area than could be served by the interchange. Actually, even without the traffic generated from remote locations, two phases of the problem are formidable. Accurate information is needed on: (1) Normal traffic-generating characteristics and (2) traffic generated near the interchange but not using it.

A fairly common hypothesis made for most interchange studies is that, without some form of land use planning publicly enforced, interchange areas may be developed in an undesirable way—economically, esthetically, and in traffic generation. This hypothesis appears to be generally valid, but the fact that often it does not apply illustrates the complexity of the interchange area development problem. In a study in Texas, Professor Adkins failed to find any serious interchange problem in areas having no land use controls; these interchanges were subject only to market restraints. The results of the Texas study have caused some speculation concerning the possibility that the free market may work satisfactorily, and that land uses for which the owners can afford to be near interchanges will be suitable. In evaluating the absence of congestion reported in the Texas study, the effect of frontage or service roads

must be considered. For example, ". . . Houston, where there is no zoning ordinance and the Gulf Freeway is solidly lined with commercial and industrial uses, congestion at intersections was noticeably absent, even under the most heavy conditions of use. This might be partially attributed to the fact that this freeway, like many of those in Texas, is continuous collector-distributor roadways on either side of it which take a portion of the total transportation corridor demand."

The complexity of the interchange problem is also suggested by the needs of different highway users. For example, one of the most commonly suggested ways of easing traffic congestion problems at interchanges is to limit access for some distance along the feeder road. But for highway users desiring to leave the highway only far enough to obtain food and fuel, such access controls simply lengthens the distance the user has to go for this service (8).

To discern the relationship between elements of the complex land use interchange problem, several researchers have resorted to simulation models. Simulation models have been used in research completed or underway at the University of Washington, Pennsylvania State University, University of West Virginia, and the University of Virginia. Variables analyzed, in an attempt to predict development at interchange areas, have included population of the nearest urban place, population of the interchange area, traffic on the feeder road, age of the interchange, freeway capacity, land area available for development, and characteristics of the adjoining land. Some models have been used only to predict limited information, such as the need for service stations or motels. An adequate testing of these models has not been possible because of the lack of detailed information, especially data on traffic, land use, and population for the appropriate areas.

Development Controls Available

Problems related to attempts to control economic development by public decree were obvious as long ago as 1763, when King George III attempted to arrest the westward movement in America by forbidding settlements beyond the sources of rivers flowing into the Atlantic (1, Delafons p. 16). But difficulties of enforcement have not prevented land use controls from being used, and the adoption of land use planning measures has increased significantly in recent years. At present, more than 90 percent of the 1,355 cities that have a population of more than 10,000 people have an official planning agency (9).

Controls available in interchange areas have been surveyed often. Results of a survey by the Pennsylvania Department of Highways showed that, in the 36 States from which responses were received, little control of land use was provided explicitly for interchanges beyond extending access controls some distance—from 100 to 1,000 feet—along the feeder road. In a 1961 survey on the use protection provided at interchanges, 17 States reported using some access control

feeder roads (10). Data in this survey so showed that 22 States had no interchange and use controls planned or in effect. The urban nature of the State sometimes was used as a reason for not providing guides or controls on interchange area development. Differences in land use controls in urban and rural areas also were reported in a recent ASHO-NACO survey³ of counties. Twenty-five pertinent questions were asked, such as land use control techniques as zoning, subdivision regulations, driveway controls, setbacks, access regulations near interchanges, building codes, and mapped highway finances. Affirmative responses from urban counties were about 43 percent compared with about 22 percent for the rural counties. The 1,200 counties through which the Interstate System passes have more selected land use control measures than the other 1,800 counties; affirmative responses for the counties through which the Interstate System passes were 27 percent compared with 20 percent for other counties. Differences in land use controls by counties are shown in table 1.

Some interesting differences by States and regions were shown by the survey data. For example, the Western States of California, Washington, Nevada, and Oregon rank first, second, fourth, and fifth, respectively, in land use controls. As shown in figure 1 and table 1, Florida and Maryland also rank high, third and sixth, in having land use control measures.

Table 1.—States having land use controls, by percentage of counties responding affirmatively to 25 questions¹

State	Responses from—			
	All counties in State	Interstate counties ²		
		All	Urban ³	Rural
	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Alabama.....	13	14	26	11
Arizona.....	29	32	72	23
California.....	58	64	81	58
Colorado.....	28	36	55	28
Florida.....	35	38	52	28
Georgia.....	18	26	66	18
Idaho.....	14	22	41	16
Illinois.....	22	29	51	21
Indiana.....	25	35	45	32
Iowa.....	19	27	37	24
Kansas.....	16	30	55	23
Kentucky.....	14	19	42	16
Maryland.....	45	54	60	50
Michigan.....	25	28	30	25
Minnesota.....	22	26	34	24
Mississippi.....	11	16	32	14
Missouri.....	11	17	40	9
Nebraska.....	5	18	44	8
Nevada.....	35	40	54	35
New Jersey.....	31	31	31	29
New York.....	19	24	28	21
North Carolina.....	10	9	23	4
Ohio.....	31	40	59	34
Oregon.....	35	39	63	31
Pennsylvania.....	18	19	31	15
South Carolina.....	5	8	37	2
South Dakota.....	10	9	19	6
Tennessee.....	13	20	61	15
Texas.....	10	13	17	10
Utah.....	30	31	58	22
Virginia.....	28	34	64	30
Washington.....	48	51	64	45
Wisconsin.....	22	33	40	28
Wyoming.....	7	7	9	5
AVERAGE.....	22.4	27.6	44.7	22.3
MEDIAN.....	20	27	43	22

Application of Controls

Everyone can agree that interchange areas should be neat and orderly. Nearly everyone would also agree that some type of public planning or land use control ordinarily is needed to assure that the development attracted to interchange areas proceeds in an orderly way. But there is no general agreement as to whether State or local governments should be responsible for guiding development in interchange areas; neither is there agreement on the general type of land use controls most appropriate for interchange areas, such as the use of police power or eminent domain.

Local or State controls

Land use controls such as zoning, subdivision regulations, and building codes generally have been administered by municipal or county governments. But land use controls available for use by local governments do not automatically ensure orderly development in interchange areas. Local land use protection devices may not be responsive to need for providing protection near highways,

¹ Questions involved such techniques as zoning, building codes, long-range plans, driveway controls, subdivision regulations, setback ordinances, and mapped highway ordinances.

² Interstate counties are those crossed by or adjacent to an Interstate highway.

³ Urban counties are those that: (1) are part of a Standard Metropolitan Statistical Area, or (2) had a 1960 population of 100,000 or more and had an increase in population of 50 percent or more from 1950 to 1960, or (3) had a population increase of 100 percent or more from 1950 to 1960, or (4) in 1960 were 70 percent or more urbanized (more than is typical for the United States).

even though more than purely local interests are involved when an Interstate highway is built.

Apparently because of the problems arising when different agencies are responsible for building highways and for guiding development near highways, considerable thought has been given to providing land use control beyond or in the absence of control established by municipalities or counties. Many plans have been proposed or put into practice; they range from the existing situation in which land use controls generally are provided locally to plans for State administered zoning—sometimes accompanied by other police powers. Attention has also been given to possible establishment of interchange districts to guide development and highway strip zoning. In a few States, such measures have been enacted or are being seriously considered.

A standard feature of any plan to provide land use controls, either through interchange districts, strip zoning, or other State action, is use of local initiative to the fullest extent possible. This can be done in several ways: By excluding local areas or interchange districts from Statewide zoning if local planning of development is satisfactory; by changing

local control only to the extent of referring rezoning questions to a State agency; by giving local governments a specified period of time to zone or provide other land use controls in interchange areas; by leaving zoning matters generally to localities, except where local practice and State interests are clearly incompatible.

To combine State leadership with local initiative, local interests must be considered as soon as possible. Highway plans are more likely to be respected by local groups if these plans have been made a part of the local land use plans. This has been proved in different locations. In Duluth, Minn., for example, planning of several interchanges on Interstate 35 has been integrated with local planning, and local streets have become frontage roads along part of the Interstate System. Coordinated planning of this type, in which city planners share in the decisions on highway location and alignment, is expected to continue to receive local support. This type of planning will contribute to orderly development in the interchange area. Other areas where effective coordination of interchange and local planning have been reported or planned include the State of Illinois and Tulsa, Okla. Result of

For this survey by the American Association of State Highway Officials and the National Association of County Officials, much of the tabulation and analysis was done by Philip Patterson, a student employee of the Bureau of Public Roads during a part of 1963 and 1964.

University study report, "... typically, building departments and planning staffs do not make systematic checks of land use against the zoning map. Public prosecutors act only when requested to do so either by the administrative unit concerned or by a complaining citizen." (12, pp. 10-23.)

New Orleans and Philadelphia had a similar pattern of zoning appeals and exceptions. Of 363 cases studied in a recent year in New Orleans, 90 percent were granted. Of 256 cases heard in Philadelphia, only 47 were denied. Interestingly, for the 30 persons appearing in person, each appeal required an average of 18 minutes for hearings compared with 3½ minutes on appeals when no person appeared (1, pp. 88-90, Delafons).

The advantages of having zoning controls are also obvious. Zoning can slow the pace of development until more intensive measures can be provided, and it can affect the density of development. Zoning can also be especially effective in helping to stabilize land use after redevelopment of an area.

Subdivision regulations, another police power, are also being used to a considerable extent, though not so widely as zoning. Subdivision regulations are used primarily because they affect developers at a time when they are still able to make changes in the subdivision and then pass any increased cost along to the buyers.

The power of eminent domain, involving the payment of public money for certain property rights, can also be effective for controlling land usage when it involves such techniques as development rights, easements, purchase and leaseback, and condemnation of excess land. The primary advantage of eminent domain is simple enforcement. Because an agreement by which landowners transfer redevelopment or other rights has the power of a contract, violations of these rights are not likely to occur.

Disadvantage of eminent domain

The main disadvantage of controlling land use by eminent domain is the high cost. For example, costs for redevelopment have ranged from 13- to 84-percent of the market value in fee simple along parts of the Mississippi River Parkway in Wisconsin and along some parts of the Natchez-Trace Parkway in the South (12, p. 37). And, an easement for building high-rise apartments on a 47-acre site along the Potomac River near Washington, D.C., was valued at \$750,000 by a jury even though the cost of the property in fee simple had been only \$650,000 a short time previously. When the cost of purchasing certain rights, in order to control the use of the land, approaches the cost of purchasing the property in fee simple, generally it is preferable or the public agency to purchase the property outright; later, if all or part of the property is sold, development controls such as restrictive covenants can be imposed.

Best controls

A combination of police power and eminent domain techniques appears to be the best

Table 2.—Rank of States according to land use controls in effect, by counties ¹

State	Responses from—			
	All counties in State	Interstate counties ²		
		All	Urban	Rural
	<i>Rank</i>	<i>Rank</i>	<i>Rank</i>	<i>Rank</i>
California.....	1	1	1	1
Washington.....	2	3	4	3
Maryland.....	3	2	8	2
Nevada.....	4	5	13	4
Oregon.....	5	6	6	7
Florida.....	6	7	14	11
Ohio.....	7	4	9	5
New Jersey.....	8	13	26	9
Utah.....	9	14	10	18
Arizona.....	10	12	2	16
Colorado.....	11	8	11	10
Virginia.....	12	10	5	8
Indiana.....	13	9	16	6
Michigan.....	14	18	28	13
Wisconsin.....	15	11	20	12
Illinois.....	16	17	15	19
Minnesota.....	17	20	24	15
Iowa.....	18	16	22	14
New York.....	19	21	29	20
Georgia.....	20	19	3	21
Pennsylvania.....	21	25	27	25
Kansas.....	22	15	12	17
Idaho.....	23	22	19	23
Kentucky.....	24	24	18	22
Tennessee.....	25	23	7	24
Alabama.....	26	29	30	27
Missouri.....	27	27	21	29
Mississippi.....	28	28	25	26
Texas.....	29	30	33	28
North Carolina.....	30	31	31	33
South Dakota.....	31	32	32	31
Wyoming.....	32	34	34	32
Nebraska.....	33	26	17	30
South Carolina.....	34	33	23	34

¹ Tabulated from the number of affirmative responses made to 25 questions on land use controls, involving such techniques as zoning, building codes, long-range plans, driveway controls, subdivision regulations, setback ordinances, and mapped highway ordinances.

² Interstate counties are those crossed by or adjacent to an Interstate highway.

answer for controlling economic development near interchanges. Professor Horwood suggests a combination of zoning, land redesign, and the acquisition of access rights. Acquisition of access rights ordinarily is less expensive than most other eminent domain techniques of land use control, and this control can be effective if used carefully. For example, access rights can be purchased to control industrial or other uses considered potentially hazardous to interchange traffic capacity, and the landowner will be free to develop the land for some other use. An example of an apparently successful combination of the police power and eminent domain has been reported from Tennessee. There, if a building permit is requested that would interfere with future highway building, the land involved is acquired by the highway agency (13). Such a fusing of police power controls and eminent domain seems to provide optimum protection for both the public interest and the private property owners' rights.

Certain land use controls that are being adapted from other situations also may be helpful in the interchange problem. For example, a concept has been formed from studies in Minnesota and Illinois that only those uses requiring highway location should be permitted in such locations. This concept has a precedent in the formation of Waterfront Districts, by which a harbor or other such facility is recognized as being a natural

resource in which the community has a vested interest. In the same way, an Interstate highway could be recognized as a transportation resource in which the entire community has an interest. Another possible approach, which is not new, is to use development performance standards to limit the amount of traffic by controlling large traffic generators. These performance standards could be developed along the lines of the standards now employed to determine when establishments exceed permitted generation levels of smoke, sewage, odors, or noise.

Priorities for Interchanges

Providing land use planning for all interchange areas seems to be an almost overwhelming task. However, the task becomes manageable when it is taken up one part at a time. If the parts of the interchange problem are to be taken in logical order, suburban interchanges near the fringes of urban centers deserve attention first. Near these interchanges, development of land is more likely to be uncoordinated than in urban or rural areas. In rural areas, land development problems can be expected to be fairly mild. But some pressure for economic development may be exerted for land near urban interchanges. However, near urban interchange areas, general land use controls are probably available

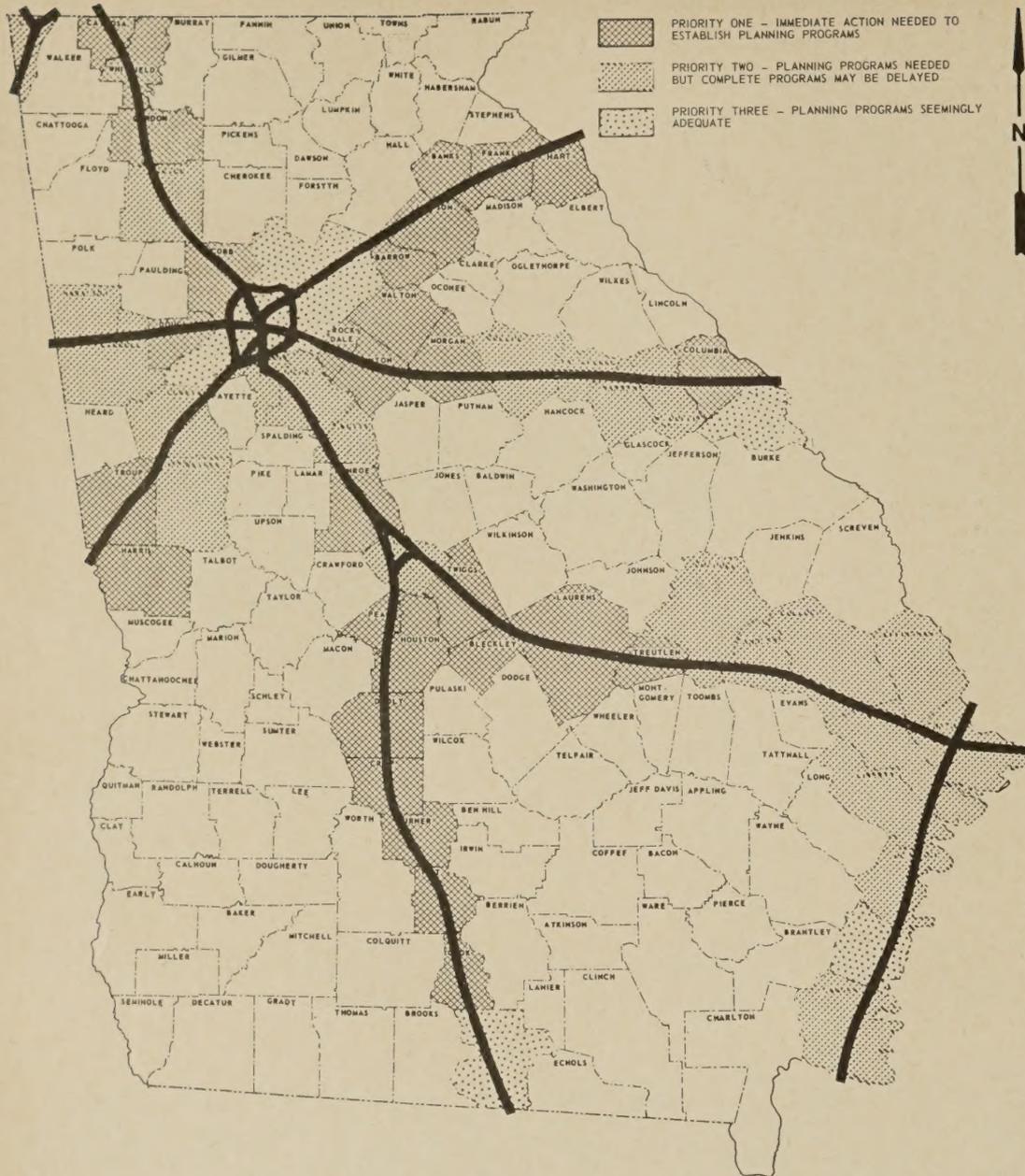


Figure 2.—Priorities for county planning in Georgia for land use planning controls along the Interstate System.

and the use permitted of the surrounding land probably has been established.

The usefulness of a system of priorities that focuses attention on the interchanges and on the land use problems that need solution first have been demonstrated by the procedure followed in the Georgia study. Interchanges were analyzed according to their location (urban, rural, suburban) and the type of cross-road (primary, secondary, etc.); from this information a priority system was developed to indicate how critical the need was for county planning. Counties in priority one are those in which parts of the Interstate System have been completed or are due for completion by 1965 and in which unincorporated areas are not subject to planning commissions. Priority two generally includes counties in which none of the Interstate System will be completed until after 1965. Priority three includes counties that have programs deemed adequate for controlling land use. Fast action on the interchange land use problem is needed: 50

percent of the 58 Georgia counties through which the Interstate System passes have been placed in priority one. That is, the Interstate System passes through these counties but they do not have adequate land use planning protection. Only 10 percent of the 58 counties were judged to have adequate land use control programs (14). The priorities assigned to Georgia counties crossed by the Interstate System and Georgia counties that have planning commissions are shown in figures 2 and 3.

Priorities of a somewhat similar type have been developed in studies in Pennsylvania, Michigan, and Minnesota, and by the committee of AASHO-NACO, referred to previously. In Pennsylvania, interchanges have been listed according to whether they will be located in cities, boroughs, first class townships, or second class townships. In addition, highway locations and county planning commissions have been related to one another on maps, as illustrated in figure 4.

The interchange priorities system for Michigan involves redesign and reconstruction of interchanges rather than land planning in the surrounding area. Some of the conditions justifying redesign could have been prevented or alleviated sooner by land use planning for example, a sudden jump in traffic volume caused by the change in nearby land use could have been prevented or controlled by land use planning (3, Neve, p. 3).

In the Duluth, Minn., study already referred to, a priority system has also been established for land use planning. The priority system consists of: "Immediate Actions Prior to Interstate Construction; Actions with Interstate Construction; and Future Actions." (15). And the AASHO-NACO survey of interchanges has provided general information showing the land use planning techniques being used in fast growing and/or urban areas having Interstate routes. The interchange land use problem in these counties might be regarded as high priority because interchange problems in these counties are expected to be more critical than they are in rural areas.

Space Needs at Interchanges

The crux of the interchange problem seems to be how much of the land made available for development at interchanges will be used and the type of use to which it will be put. Professor Garrison has estimated that by 1980 intensive land development will occur near the interchanges of large metropolitan areas but that in small urban centers the available land near interchanges will exceed the demand (16). Space needed for residential development is expected to far exceed that for the other specified uses—industry and shopping centers. Although the space needed for shopping centers is by far the smallest of the three uses, it needs to be carefully coordinated with interchange plans because of the traffic generating characteristics (large volumes) of shopping centers.

Highway services

Space needs for highway services in interchange areas have received special attention. For example, in studies in Minnesota the amount of space used for highway services has been related to the traffic volumes along the highway. By using this information and traffic projections for 1975, the amount of space needed for highway service near certain interchanges has been estimated. For example, an expected 45,850 average day traffic in 1975 will require about 4,400 lineal feet for highway service at one interchange in Duluth.

Pennsylvania researchers have gathered information from interchange sites concerning the relative frequency of service stations, restaurants, and motels. This relationship is 21:14:10—that is, 21 service stations to 14 restaurants to 10 motels. And in a study in Wisconsin, auto service and food service were reported to be 66 percent of all roadside

establishments (10, p. 43). Obviously existing space allocations near interchanges can be of only limited usefulness in estimating space needs for highway services because of the apparent tendency of some oil companies to obtain more space for service stations than will be needed in the immediate future. In addition to the amount of space allocated to highway services, interchange land use planners need to know the preferred location for highway services in relation to the interchange. Several studies have been completed that indicate the most desirable location for highway services is the first quadrant of an interchange on the right side of an urban area. Apparently this location is favored because of the ease with which service facilities can be reached without the need to make left turns, even on a diamond interchange. The first quadrant on the right side of an approach to an urban center also is desirable (7, p. 13).

Frontage roads, in some places, have been used in an efficient way to provide space for highway services—such usage has been reported in the Duluth area and in many areas in Texas. In some places the frontage roads also serve as traffic reservoir areas, which helps to alleviate traffic backup on exit ramps (17). But a continuing problem exists in relation to frontage roads: They may magnify roadside control problems in non-urban areas where strict land use controls are not in effect.

An Answer for All Interchanges

The bulk of the 14,000 Interstate interchanges will be located in rural areas. In many of these rural areas, little land use planning exists beyond crop rotation, and no agency or individual is available to administer and use planning legislation even if it were to be enacted.

Some thought has been given as to what can be done to provide effective land use control in the absence of land use planning by local authorities. In some States, such as California and Florida, legislation has been enacted to establish interchange districts on a limited basis. In other States, the State highway agency is relied on to help administer or police subdivision regulations, roadside zoning, driveway controls, or some similar land use control measures. Another land use control measure considered for application to rural interchange areas would have the State freeze existing land use near interchanges until acceptable land use controls could be established, either by the local government or the State. The effect of such a freezing or fixing of existing land use would probably be very similar to the effect of agricultural zoning. Control of land use either by creation of interchange districts or freezing probably would curtail and delay land development activity near rural interchanges.

An alternate plan would permit economic development in an interchange area until traffic on the feeder road and/or at the interchange approached the design volume. When this occurred, it seems reasonable to

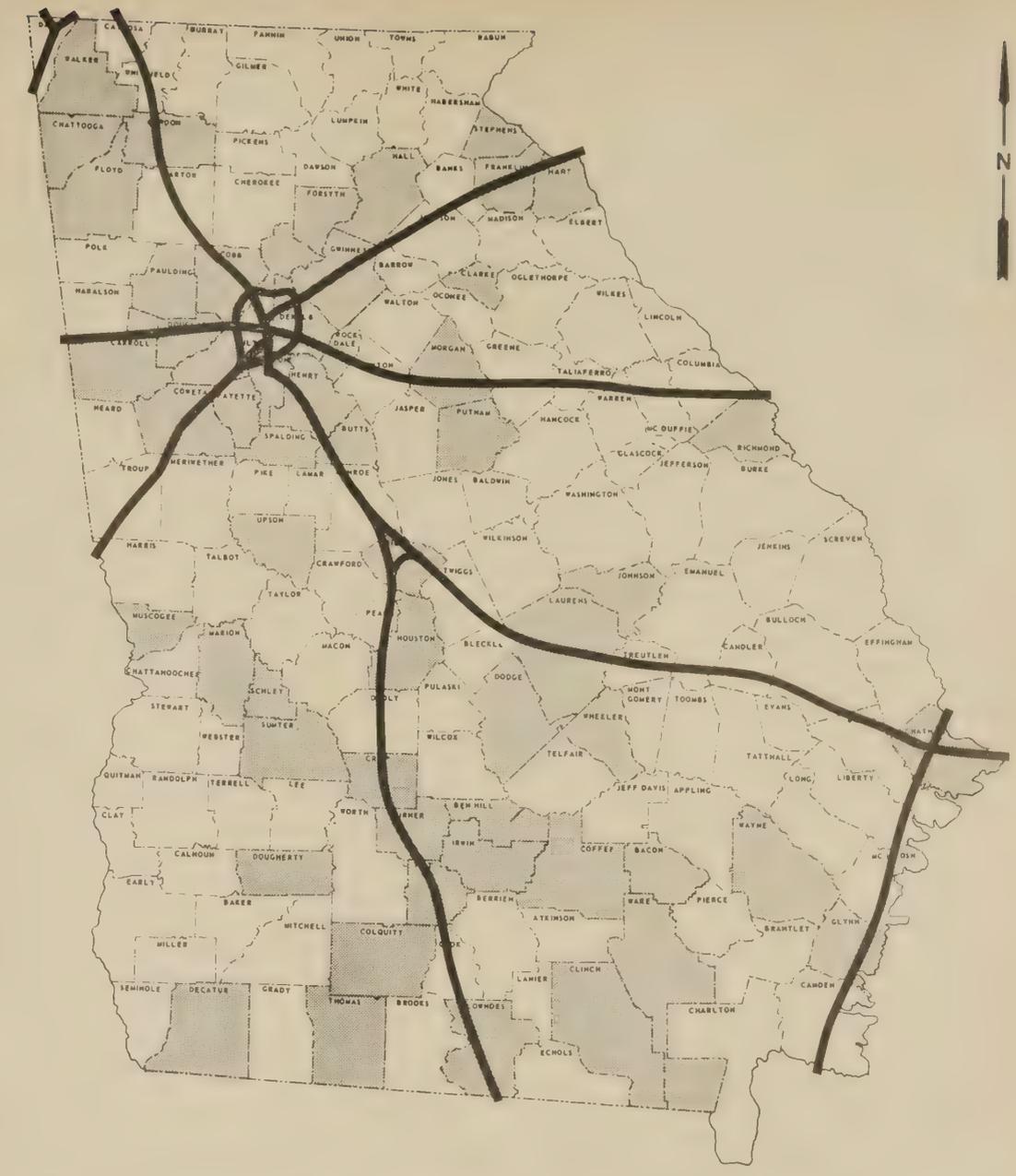


Figure 3.—Georgia counties having official county or joint city-county planning commissions.

expect that highway builders would take action to prevent further deterioration at the interchange. The action to take is a problem. In the past, development of land use near interchanges has not been sufficiently controlled and the solution to the resultant traffic problems in some places has required that the interchange be redesigned. A better approach would seem to be the imposition of measures to control development beyond the expected accommodation of the highway facility, perhaps by permitting no additional driveway openings onto feeder roads within a certain distance of the interchange. Controlling the number of driveways on feeder roads is obviously a modest approach to the land use problem near interchanges. Local authorities could misplan or ignore development near interchanges until the land uses nearby generated enough traffic to overwhelm the interchange. This approach, therefore, is not worthwhile as a substitute for more adequate controls already in existence or planned. This approach has been suggested

for use only where control is lacking—a situation existing at present for many rural interchanges.

Restraining development only at those rural interchanges where traffic congestion is imminent would be advantageous because land planning effort could be concentrated on interchanges where attention is needed. No appreciable development may occur near many rural interchanges, and it is unrealistic to expect that a land use plan will be developed for each interchange. Although a land use plan in sparsely populated rural areas might be very simple, any effort to be expended for controlling roadside development probably needs to be channeled to locations where problems of interchange land use are most urgent.

A serious disadvantage in a hands-off type of approach to land use controls at interchanges is the possible development of junkyards or other eyesores near rural interchanges. Hence, more effective land use planning should be encouraged wherever its use is

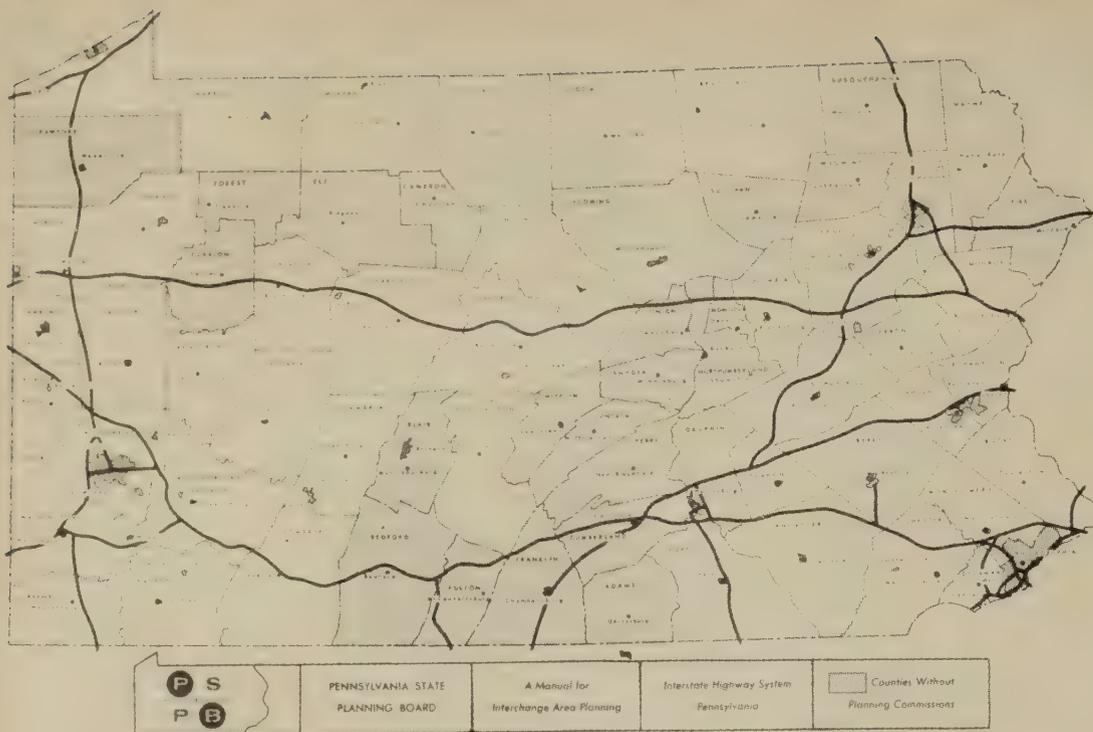


Figure 4.—Interstate highways in Pennsylvania and counties not having planning commissions.

realistic. But, if past experience is any guide, land use planning can be expected to continue to lag behind highway construction.

For urban and suburban areas, nearly any combination of control devices described heretofore can provide a satisfactory solution to the problems of land use near interchanges, if they can be enforced. To guide the development near interchanges effectively in either urban, suburban, or rural areas, more specific information is needed. Local authorities have a right to expect highway builders to furnish much of this information, such as traffic generating characteristics of certain land uses, design capacities of highway facilities, and compatible and incompatible land uses in interchange areas. Several States, through their interchange pamphlets or manuals, movies, speakers, and other media, have provided communities with at least some of the vital information, such as driveway spacing and service roads, as shown in figure 5.

Existing land use controls apparently would be more effective if better cooperation could be achieved between interested agencies.

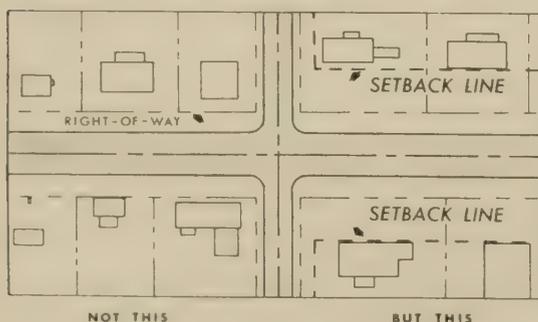


Figure 5.—Desirable type of setback (from *A Manual for Interchange Area Planning*, Pennsylvania State Planning Board).

For example, at a recent rezoning hearing on an application for a permit to construct a 16-acre amusement park and swimming pool on a busy approach road to a major highway facility, only local residents and the amusement park builders appeared. Perhaps highway builders could assume more responsibility for assuring that generators of large volumes of traffic do not encroach on highway facilities. Another possibility for cooperative action could be among the Federal Housing Authority, the Bureau of Public Roads, and the States.

Possible Solutions

The interchange research completed so far obviously has not provided all the answers needed to solve the problem of land use near interchanges. Some of the solutions recommended in the studies have been different. For example, in the report on the Georgia study land use planning was recommended primarily at the local level, but in most studies it is recommended that such an important responsibility be lodged with a State agency. One conclusion was made in all the reports: that more needs to be learned before the problem can be solved. The absence of criteria and guidelines for applying the different legal techniques available, in order to reach the overall goal of control of land usage near interchanges, is one of the obvious gaps.

General agreement seems to have been reached as to the ultimate goal: interchanges on which traffic can be expected to move in an orderly and efficient manner. A fairly satisfactory understanding also exists as to the different land use control measures presently available, such as zoning and redevelopment rights. But the principles of desirable land

use arrangements near interchanges are not completely settled. It is almost as if the *how* to plan (the legal techniques) has been learned but *what* to plan (the desirable arrangement of land use) is still unknown. The urgent need now is specific information about land uses that are suitable for interchange locations and that also are good neighbors in an interchange setting, trip generating characteristics of land uses near interchanges, space needs for highway services, and ways of implementing uses that research has demonstrated suitable.

Trip Generation Characteristics

Most studies of interchange development have involved some attempt to determine whether traffic using the interchange can be accommodated. Such an analysis requires fairly specific information about trip generating characteristics of land uses served by the interchange, the type of area served by the interchange, and traffic capacity of the interchange. In the past, problems have been encountered in getting specific information on any of these three items, including traffic assignment data (7, 18). Information now available is still far from satisfactory. For example, general agreement has been reached that the interchange area should be the area of origin and destination for trips using the interchange. Although this concept is popular, it is unwieldy in use, and some zone boundaries on experience for typical interchanges probably will have to be used in defining the interchange area.

Information about trip generation characteristics of different land uses near interchanges is becoming available, at least on a fragmentary basis. Although little specific information is available concerning highway user services such as service stations, motels, and eating places, these uses rarely have a traffic generating pattern that conflicts with the urban work trip. In at least one study, the report showed that less interference traffic was caused by fewer vehicles turning into service stations than those turning into restaurants, motels, residential, and commercial areas. Fifteen percent of the turns made for service stations caused interference compared with 24 percent of those made for other uses (19). Some of the reasons for this difference in interference are obvious, such as open spaces around service stations and a sufficient number of service stations so that left turns and waiting to enter can ordinarily be avoided.

Shopping centers

Some trip generation information pertinent to interchange planning is also available on shopping centers. Regional shopping centers that stay open in the evenings apparently have their peak traffic at about 8 p.m. Urban and neighborhood shopping centers seem to have their peak traffic loads earlier in the evening (21). Shopping centers need to be ". . . a substantial distance from residential ends . . ." and they should be placed where left turns can be avoided on the trip home from work (14). A shopping center located



Figure 6.—Example of inadequate access control on a crossroad beyond the end of a ramp. Photo shows clustering of church, residential, and shopping center developments at Stevens Creek Road interchange near San Jose, Calif. Hazardous entrance to Valley Fair shopping center (arrow 1) where vehicles make right turns into parking lot in front of traffic coming from the freeway ramp. Hazards (arrow 2) would be substantially reduced if access had been prohibited for 500 feet beyond the end of the ramp; the distance to the entrance is only 240 feet.

too close to a ramp exit is shown in figure 6. Potential congestion is, of course, more dangerous on exit ramps than on entrance ramps.

Traffic generation

The urban transportation studies now underway are expected to be a useful source of information about traffic generation characteristics. For interchanges at different distances from large urban centers, it seems important to have trip generation information by density as well as by land use. Such information from urban studies made in Chicago, Ill.; Pittsburgh, Pa.; Detroit, Mich., and Minneapolis and St. Paul, Minn., is summarized in figures 7 through 11. Density, or distance from downtown, as shown, seems to have had a noticeable effect on most of the uses classified. In addition to being a valuable source for trip generation data, the information being developed in urban transportation studies on comprehensive planning also should be helpful in the attempts being made to solve interchange area development problems generally, including those related to interchange areas outside urban areas. Also, experience being gained through the Urban Renewal Administration's Workable Programs for Community Improvement may prove to be appropriate and helpful in solving interchange area development problems (22).

For analyzing and anticipating land development problems at an interchange, information on traffic generation characteristics for nearby land uses obviously must be supplemented with information about the amount of traffic that actually uses the specific interchange and the percentage of crossroad traffic on the feeder road into the interchange. This percentage can vary; for example, up to 100 percent if the feeder road deadends at the interchange (10, p. 47).

To spread the traffic burden among nearby interchanges, a variety of land uses might be desirable. However, a variety of land uses at one interchange area might create another problem—make shoppers travel further. This problem also requires more research.

Compatible and Incompatible Uses

Many of the land use problems at interchanges, it is hoped, can be solved by excluding incompatible uses from the area. The general principle of compatible and incompatible uses has been applied previously, that is, prior to the time of the problem of land usage at interchanges. The application of this principle presents some problems and emphasizes the need for more research. At present, information available on compatible uses seems to be somewhat contradictory, no doubt because it is incomplete.

An axiom in city planning theory is that like things belong together. For example, food wholesalers located together permit careful buyers to keep their travel at a minimum while they visit several establishments. Such highway-oriented establishments as service stations, restaurants, and motels are considered to be compatible because they have common customers. Having such compatible uses near one another, preferably in the same quadrant of the interchange, seems to be reasonable as a goal and has been achieved in many locations.

The principle of grouping like or compatible uses together should probably be applied to interchange areas with some restraint, because it is obvious that "... a land use arrangement which has a variety of uses is superior to one which has segregation of uses; variety spreads the traffic burden while segregation concentrates it." (23). For example, a factory and a machine shop may be compatible but their proximity to one another and to an interchange may aggravate traffic problems during the morning and evening peak traffic periods. From research findings already available, some determinations have been made on ways to reconcile these two principles: that like uses are compatible, but that a variety of uses spreads the traffic burden. If different quadrants of an interchange are

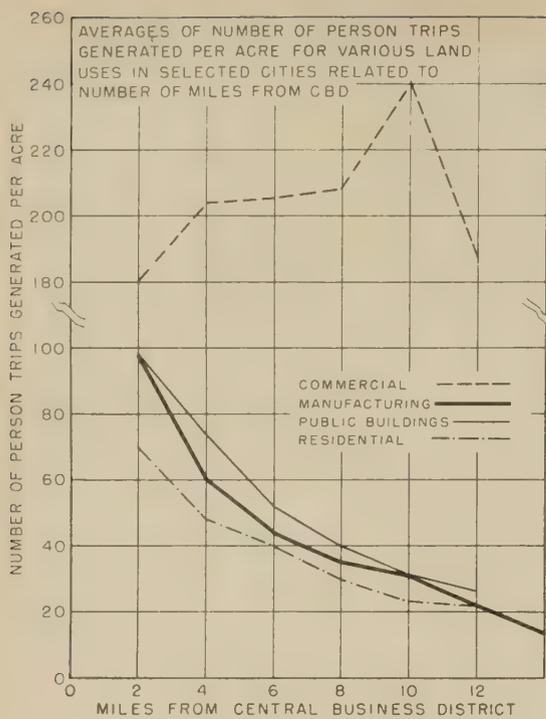


Figure 7.—Traffic generation by combined land uses.

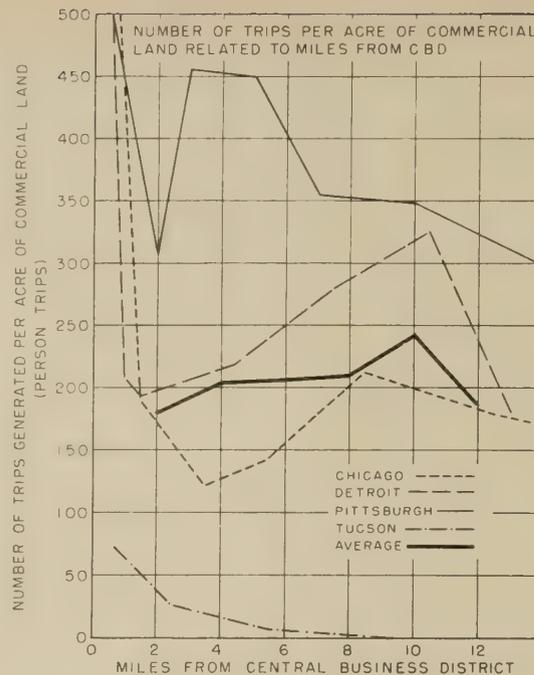


Figure 9.—Traffic generation by commercial land uses.

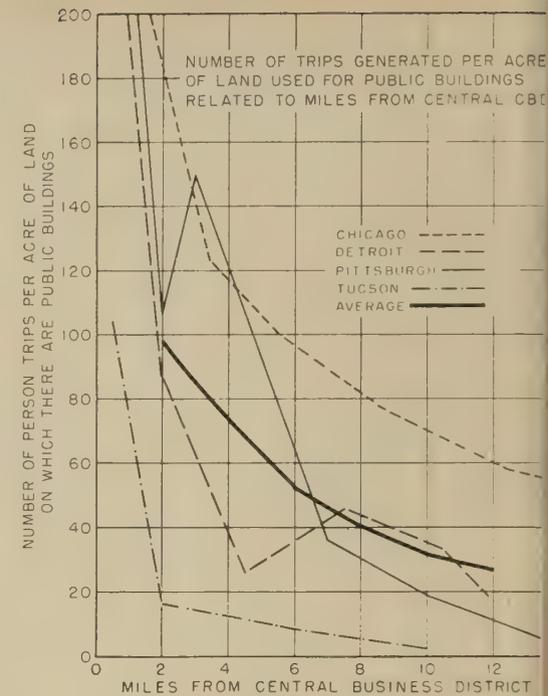


Figure 11.—Traffic generation by public buildings land uses.

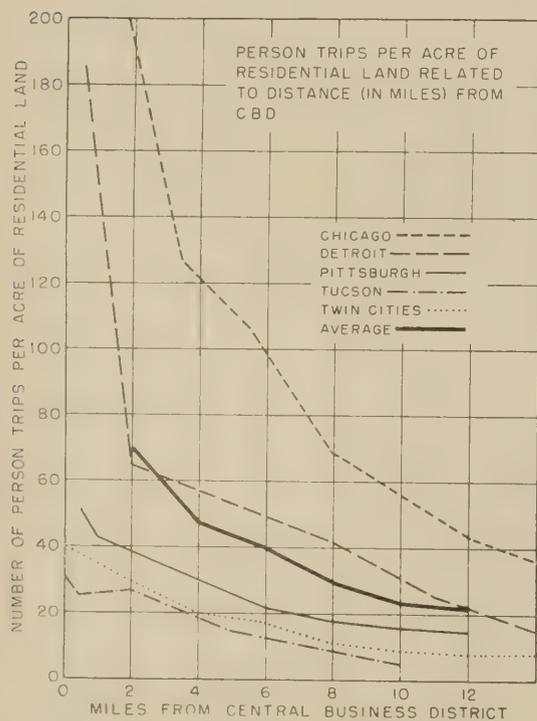
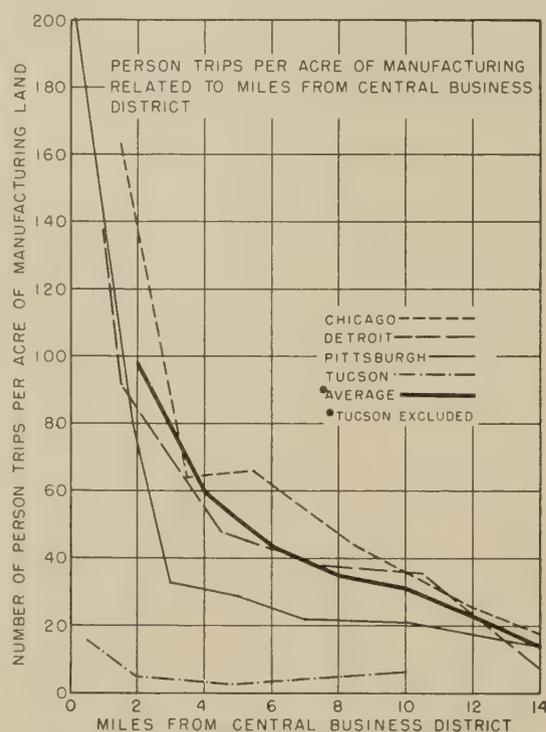


Figure 8.—Traffic generation by residential land uses.



SOURCE: AVERAGES DERIVED FROM DATA IN THE CHICAGO, DETROIT, PITTSBURGH, TUCSON AND TWIN CITIES TRANSPORTATION STUDIES.

Figure 10.—Traffic generation by manufacturing land uses.

put to different uses, both principles apparently can be served. Thus, perhaps such low traffic generators as motels can be located in one quadrant, and a factory, which generates heavy peak traffic loads, can be located in another. Such an arrangement would be in accord with the concept presently receiving some attention, that land use for some interchanges should be limited to highway services and for others, to community services.

More research is needed to obtain additional information about the conditions under which certain uses are compatible or incompatible. The general belief that highway user service facilities are compatible may need to be revised. At one interchange, an overnight facility has been established for horses being transported by trailer or truck. Although such land use is apparently a highway-oriented business, it is probably incompatible with

businesses such as motels and restaurants. Another development complicating the concept that highway-oriented businesses are compatible is the use being made of motels, community and convention centers, as well as tourist stops. The traffic generating characteristics of motels providing these services undoubtedly differ from those of motels catering only to highway travelers.

The concept of compatibility can also be applied to compatibility between the interchange and certain types of use. Some businesses established at interchange locations do not need to be there and, in fact, may be detrimental to the use of the interchange or the business may be affected adversely by such a location. Although auto junkyards are generators of low volumes of traffic, they obviously should not be permitted near interchanges. Also, locating schools and churches near interchanges may be less desirable than selecting locations along a controlled-access highway between interchanges, where access can be gained away from the highway or from a frontage road. Such a location would permit the institution to realize the benefits of being on display along a modern highway, of having an easily remembered address—near a certain interchange or exit number—and of being easily accessible to people walking in the neighborhood.

Space Needs Near Interchanges

Additional research is also needed to determine whether user services or other vital needs are being satisfactorily anticipated. There is general agreement that space for user services should have priority and that other uses, such as residential, should not preempt it. Because of the aggressiveness of oil companies in acquiring building sites, the danger of a shortage of space for service



Figure 12.—Cars parked near an interchange by members of carpools.



Figure 13.—Parking on feeder road by members of carpools.

stations is apparent. But space requirements for other highway services are not being cared for so well. For example, space for off-street parking at strategic locations near interchanges is needed for people assembling for carpools, a practice that is becoming fairly common in outer suburban areas near large cities. This land use need should be recognized and met. The current practice of parking haphazardly along the sides of feeder roads, as illustrated in figures 12 and 13, has had several bad effects. For example: Snow removal and maintenance have been impeded; landscaping has been damaged; capacity has been reduced on the crossroad; and the accident potential has been increased because the drivers' sight distances have been reduced. Little specific information is available on this problem. Information from one study indicates that space is needed for 5 to 10 cars near an interchange where such parking is done. Those parking near an interchange typically travel 30 miles to work, one-fourth of it before the interchange is reached. The average membership of carpools assembling at an interchange is 3.5 members (24). Encouragement of suburban parking near an interchange and the resultant use of carpools should alleviate downtown traffic problems.

Research needed

Additional research effort is needed to determine generally the future space requirements for such highway user services as motels and service stations. Information about apparently workable solutions to the problem of parking near interchanges should also be gathered and analyzed. For example, a few shopping centers now welcome all-day parkers. This solution, though not applicable to land uses near interchanges in outer suburban areas, seems promising as commuter parking normally ends between 5 and 6 p.m., before peak shopping center parking requirements occur between 6 and 8 p.m.

Techniques to Implement Interchange Planning

Local governments sometimes are criticized for their failure to provide adequately for orderly development in interchange areas. But local officials may be busy on other problems and cannot always act to establish controls on development suddenly caused by highway construction. Furthermore, the facts needed by a local government before it can deal effectively with some of the land use problems in interchange areas often must first be provided by a sophisticated regional planning operation, from urban transportation studies, or from a State highway agency.

Sometimes, however, available information establishes the fact that local land use control would be desirable. A few of the incentives used to encourage a local government to act have included: (1) State grants to localities to cover costs of administering land use controls; (2) State highway improvements that are conditioned on the existence of an acceptable local land use plan; and (3) tax relief for developers who use good design, when good design can be agreed upon (25).

As suggested previously, one of the best ways to encourage local land use planning is to provide the information and technical assistance necessary. Undoubtedly, provision of information as it becomes available to illustrate general truths about transportation and land use relationships would be worthwhile. Some examples of this type of information are: (1) highways sustain land values only so long as there is a reasonable balance between the capacity of the highway and the uses to which the land is being put or (2) good esthetics are good economics. In studies in Pennsylvania and Texas, the close relationship existing between good esthetics and good economics has been especially emphasized, as has the fact that unsightly interchange areas may not attract the same tourist trade as the well-planned land use near

other interchanges. The close relationship between high development standards and sound economic development was demonstrated convincingly in a Dallas study that includes information about Richardson, Tex.; this relationship is apparent when the economic development of comparable towns is considered along with their lower development standards (26).

Quantification of Data

Some of the information from interchange area research has been presented in numerical form. Such quantification, though it may have limitations, permits comparison between study findings in different locations and ultimately should facilitate certain administrative decisions. The start that has been made, for example, in comparing redevelopment costs with the cost of acquisition in fee simple obviously could be useful in making a decision as to the approach to use in guiding development (12, p. 37).

In another analysis, the cost of not having some control device, such as roadside zoning, was reduced to a numerical value by applying the 5 cents of each highway dollar spent to remove structures from highway right-of-way to the \$500,000 being spent to modernize the system over a 20-year period. The resultant \$25,000 could be regarded as the cost of not having some type of land use control to prevent structures from being erected on land eventually to be used for a highway right-of-way. Other useful types of quantification of aspects of the interchange problem include the information on rezonings that was presented by Professor Horwood and his colleagues, data that Professors Adkins, Pendleton, and others have presented on annual percentage changes of land use in interchange areas (27), and information associating development trends with the number of new driveways for certain areas (2, p. 70).

Study Approach Needed

One of the useful findings from completed interchange studies is a fuller realization of the complexity of the problem of land usage near an interchange. That problems tend to arise in interchange areas not subject to public control of land planning is a general hypothesis not proved in at least one study (18, p. 20). Some interchange areas, where no land use controls were in effect, have been developed without causing any significant traffic congestion; but other interchange areas, where land use controls were in effect, caused land development and traffic problems. Apparently a case study approach—a study in depth—is needed. Then the area of origin and destination for the traffic using an interchange could be delineated. Also helpful would be an explanation of the extent to which land uses a considerable distance from an interchange, such as a hospital, may generate traffic that uses the interchange.

Studies in the detail necessary for an understanding of all aspects of the development of interchange areas apparently will require considerable research effort. Areas having more than one interchange should be selected for study. They could be chosen from broad, overall studies of wide areas, such as aerial surveys, mailed questionnaire surveys, and/or land use inventories, which can be made while a researcher drives through the interchanges. Broad survey studies can also be used for gathering information on secondary but important aspects of the interchange land use problem as to: (1) the optimum distances required for access control along the feeder road; (2) whether orderly development and a sound tax base are associated with adequate land use controls; (3) whether land use of interchange areas becomes specialized—for example, primarily tourist services or community services; (4) how well needs, such as for commuter parking and highway services, are being met; and (5) which interchange areas are developing rapidly, where special land use planning may be required.

REFERENCES

(1) *Land Use Policy and Problems in the United States*, edited by Howard W. Ottoson, 1963, p. 293; and *Land Use Controls in the United States*, by John Delafons.

(2) *Roadside Protection Through Access Control*, by Frank M. Covey, Jr. (A Thesis for the Degree of Doctor of Juridical Science, published by Automotive Safety Foundation), March 1960, p. 64.

(3) *A Scorecard for Interchanges*, by James P. Neve, Jr., *Traffic Engineering*, vol. 32, No. 12, September 1962, pp. 22-23, 35.

(4) *X Marks the Spot, Interchange Area Development*, by the Highways Oil Planning Committee of Ohio, 1962, p. 8.

(5) *The New Four Corners*, by the Office of Planning, Michigan State Highway Department.

(6) *A New Front Door for Your Community*, by the Pennsylvania State Planning Board, 1964.

(7) *Land Development Policy at Highway Interchanges*, by Edgar M. Horwood, *Highway Economic Series, Research Report No. 25* of the University of Washington Transportation Research Group, December 1961, p. 44.

(8) *Highway Access Areas in Tennessee, a Study of Problems and a Suggested Program for Orderly Land Use Development*, by the Tennessee State Planning Commission, 1962.

(9) *The Municipal Yearbook, 1963*, by The International City Managers Association, edited by Orin F. Nolting, David S. Arnold, and Stanley P. Powers.

(10) *Freeway Interchanges: A Case Study and an Overview*, by Frank M. Covey, Jr., *Marquette Law Review*, vol. 45, No. 1, 1961, pp. 21-58.

(11) *Regulation of Access vs. Control of Access in Oklahoma*, by LeRoy Powers, *Right-of-Way*, 1956, HRB Bulletin 140, pp. 55-69.

(12) *An Evaluation of Land Use Controls at Freeway Approaches*, by Charles H. Graves, Edgar M. Horwood, and Clark D. Rogers, *Highway Economic Series, Research Report No. 23* of the University of Washington Transportation Research Group, December 1961, p. 37.

(13) *Highway Interchanges and Land-Use Controls*, by William H. Stanhagen, *Land Use and Development at Highway Interchanges*, a symposium, HRB Bulletin 288, 1961, pp. 32-60.

(14) *Land-Use Planning and Control Along the Interstate Highway System in Georgia*, by Harry W. Atkinson and Howard K. Menhinick July 1963, pp. 83-86.

(15) *Highways—Opportunities and Land Use Controls*, by Mark C. Flaherty, Minnesota Highway Research Project, Duluth, 1964, pp. 66-69.

(16) *Supply and Demand for Land at Highway Interchanges*, by William L. Garrison, *Land Use and Development at Highway Interchanges*, a Symposium, HRB Bulletin 288, 1961, pp. 61-66.

(17) *Capacities and Characteristics of Ramp Freeway Connections*, by Joseph W. Heslop, *Highway and Interchange Capacity*, HRB Record No. 27, 1963, pp. 69-115.

(18) *Studies of Land Development at Interchanges*, by William G. Adkins, *Texas Transportation Institute*, June 1962.

(19) *Effects of Ribbon Development on Traffic Flow*, by R. I. Wolfe, *Traffic Quarterly*, vol. XVIII, No. 1, January 1964, pp. 105-117.

(20) *Characteristics of Travel to a Regional Shopping Center*, by Walter G. Hansen and Jacob Silver, *PUBLIC ROADS*, vol. 31, No. 12, December 1960, pp. 101-108; and *Traffic Characteristics at Regional Shopping Centers*, by Donald E. Cleveland and Edward J. Mueller, 1961.

(21) *Socio-Economic Impact of the Capital Beltway in Virginia, Before Study*, by Robert C. Burton, David G. Edens, and Frederick J. Knapp, Jr., *Bureau of Population and Economic Research, University of Virginia*, February 1963, pp. 111-132.

(22) *Current Trends in Urban Renewal*, by Robert C. Weaver, *Land Economics*, vol. XXXIX, No. 4, November 1963, pp. 325-344.

(23) *Urban Traffic, A Function of Land Use*, by R. B. Mitchell and C. Rapkin, 1954, pp. 175-177.

(24) *Parking Conditions and Habits Near Expressway Interchanges*, by Michael J. Gruenbaum and Peter P. Hale, *Traffic Engineering*, vol. 30, No. 9, June 1960, p. 18.

(25) *Face of the Metropolis*, by Marvin Meyerson, 1963, p. 236.

(26) *Some Economic Effects of the Suburban Portion of North Central Expressway, Dallas, Texas*, by Russell H. Thompson and William G. Adkins, *Bulletin No. 15*, Texas Transportation Institute, 1961.

(27) *Economic and Legal Aspects of Land Use at Freeway Interchanges*, by William J. Pendleton and Robert R. Wagner, August 1960, p. 20 (processed report by Farm Economics Research Division, U.S. Department of Agriculture).

Interchange and Land Use Control Studies Completed April 1965

Georgia

The Georgia Institute of Technology, in cooperation with the State Highway Department of Georgia and the Bureau of Public Roads, has completed a study entitled *Land Use Planning and Control on the Interstate System in Georgia*. A priority system has been established for counties according to their need for land use planning. Priority 1 includes counties not having a planning commission and in which the Interstate highway has been completed or will be completed soon.

Illinois

Barton-Aschman Associates, in cooperation with the Illinois Department of Public Works and Buildings, Division of Highways, has prepared a study *Highways and Land Use Relationships in Interchange Areas* and supplementary reports. Recommendations are made concerning land use control, design, and location. For land use control, State action is recommended only when the community has not provided control of development in the interchange area. The study report showed that only 15 of 51 counties in which Interstate highways are located had zoning controls and that either existing or potential traffic problems affect 25 percent of the 200 interchanges in Illinois.

Kansas

The League of Kansas Municipalities, in cooperation with the State Highway Commission of Kansas and the Bureau of Public Roads, has completed a study of land use and planning controls entitled *Planning Tools—Theory, Law, and Practice*. This is a study of the theory and application of land use and planning controls available to local governing units for developing safe and efficient streets and highways in the State of Kansas.

Michigan

The Michigan State Highway Department has prepared a report, *Interchange Development Along 180 Miles of I-94*, in which the development near 66 interchanges is analyzed as of 3½ years after the opening of the freeway. The information in the report suggests that the high prices paid by motels and service stations for sites near interchanges had been justified.

Minnesota

Highways—Opportunities and Land Use Controls, a Case Study in Duluth, is a study prepared by the Duluth Department of Research and Planning in cooperation with the Minnesota Department of Highways and the Bureau of Public Roads. The possibilities of coordinating highway planning and local use planning were investigated and recommendations are made in the report for locations for interchanges, frontage roads,

and service facilities such as service stations and motels. Guidelines are also given for use in determining space needed for highway services, and the types of land use controls that might be appropriate for interchange areas are described.

Mississippi

The University of Mississippi, in cooperation with the Mississippi State Highway Department and the Bureau of Public Roads, has completed a report, *A Planned Interchange in a Residential Area—Some Interim Influences*. The influence that a planned but uncompleted freeway and a full cloverleaf interchange have on residential property values are considered in this report.

Pennsylvania

Pennsylvania State University, in cooperation with the Pennsylvania Department of Highways and the Bureau of Public Roads, has completed a study, *Planned versus Unregulated Development in a Suburban Community—a Case Study*. In this report, the problems are reviewed that arise in the absence of effective planning in a community where rapid growth is taking place. The policies and programs that local government can utilize to solve growth problems related to highway development are also described.

Tennessee

The Tennessee State Planning Commission, in cooperation with the Housing and Home Finance Agency, has completed a report, *Highway Access Areas in Tennessee*. Suggestions are made on how to plan and guide land development at interchanges by: (1) new legislation to aid local governments within existing planning jurisdictions; and (2) the State initiating a cooperative program in which local government would assume responsibility for areas not in existing planning jurisdictions.

Texas

The Texas A. & M. College, Texas Transportation Institute, in cooperation with the Bureau of Public Roads, has completed a report, *Studies of Land Development at Interchanges*. Recommendations are made that case studies in depth be conducted for interchange areas where the land use problem has definitely been demonstrated.

Virginia

The University of Virginia, Virginia Council of Highway Investigation and Research, in cooperation with the Virginia Department of Highways and the Bureau of Public Roads, has completed Progress Report No. 4 of *A Study of the Economic Effects of the Emporia Interchange, Bypass and Business Loop*. In this report the economic effects on business, land value, and land use in the area of the facilities studied have been analyzed.

The University of Virginia, Virginia Council of Highway Investigation and Research, in cooperation with the Virginia Department of Highways and the Bureau of Public Roads, has also completed a report on *Economic Problems Emerging as a Result of Interchange Patterns on the Interstate Highway System of Virginia*. This report describes the need for considering nonuser effects in justifying highway improvements such as an interchange. The report also presents a model and a problem solution intended to show the relationship between interchange capacity, land use development, land use control devices, and construction and maintenance costs. For purposes of the problem solution by the model, values have been assigned and were not based on experience.

Washington

The University of Washington, Transportation Research Group of the Graduate School in cooperation with the Bureau of Public Roads, has completed Research Reports 21 through 25, *A Study of Land Development Problems at Freeway Interchanges*. The purpose of this study is to identify the land uses competing for sites in approach areas and areas adjacent to highway interchanges, the congestion and traffic-generating characteristics of different land uses, the adequacy of existing controls, and future land needs at freeway approaches and highway interchange areas.

Wisconsin

The University of Wisconsin, in cooperation with the State Highway Commission of Wisconsin and the Bureau of Public Roads, has completed a report, *A Study and Evaluation of Local Highway Planning in Wisconsin*. The report recommends changes in administrative practices and in the scope, detail, and technical content of State and local long-range highway plans. A key is provided in this report to the integration of land use and transportation planning in Wisconsin's rapidly expanding urban areas.

The Department of Resource Development, State of Wisconsin, has completed a study on *The Protection and Development of Interchanges on Wisconsin's State Highway System*. The findings from this study indicate that the Interstate problem should be dealt with in the context of a comprehensive plan based upon economic, population, land use, and other data; the principal elements are land, transportation, and public facilities and services plans.

Other reports

Some State highway departments and planning agencies have issued pamphlets or manuals presenting information intended to facilitate land use planning at interchange areas. These include:

Pennsylvania, *A Manual for Interchange Area Development Planning* and, a pamphlet, *A New Front Door for Your Community*.

Indiana, a pamphlet, *The Traffic Interchange and Community Growth*.

Michigan, a pamphlet, *The New Four Corners—Interchange Areas*.

Ohio, a pamphlet, *Interchange Area Development*.

Subject matter covers such information as: desirable driveway spacing, recommended set-

backs, the close relationship between good esthetics and good economics. This information, and a movie on land use at interchange produced by Michigan, suggests ways in which interchanges can be used for economic betterment.

Interchange and Land Use Control Studies in Progress April 1965

Maryland

A *Freeway Interchange Control Study* has been started in Maryland that is expected to provide information for determining an action program that can be recommended for implementation by the Maryland State Roads Commission in cooperation with the local governments. The aims for this program are: (1) to preserve and improve the capacity and safety of the major highways interchanging with the Baltimore Beltway and other existing freeways, (2) to establish design and land use standards and policies for development of adjoining access highways for other freeways in Maryland, and (3) to evaluate the combined needs for coordinated highway and land development design standards in the interest of highway safety and efficiency, as well as of optimum land development in the vicinity of major highway routes.

Mississippi

Mississippi is conducting a study, *Control of Development of Interchanges*. During the study the best methods will be investigated for controlling development at interchanges in Mississippi's urban and rural areas so that these interchanges can be planned to minimize the effect of business and residential interference on efficient traffic flow.

Nebraska

The Nebraska Department of Roads is in the process of collecting data on land use changes along Interstate 80 between Lincoln and Omaha and is preparing a study on land use near interchanges.

Oklahoma

The University of Oklahoma, Oklahoma Center of Urban and Regional Studies, in cooperation with the Oklahoma Department of Highways is conducting a study of land use patterns near highway and expressway interchanges at selected locations in urban and rural areas in Oklahoma. The purpose of Oklahoma's *Highway Interchange and Land Use Study* is the determination of how interchange location affects land use and how different land use patterns influence the capacity of the interchange.

Pennsylvania

Pennsylvania State University, in cooperation with the Pennsylvania Department of Highways, is conducting a study on *The Impact of Highway Improvement on Land Use, Business Enterprise, and Community Development in Selected Areas of Pennsylvania*. Matters being considered during the study include: procedures for planning and predicting growth at interchange locations, procedures for estimating quantitative meas-

ures of the extent to which growth can be explained, and procedures for determining how social deterrents to planning and zoning activities can be overcome. A research model is now being assembled, processed and analyzed for use in determining the best development plan. An analysis of community receptivity to planning and zoning in 20 or 25 interchange communities along major expressways also will be made.

Utah and Vermont

Utah is conducting a highway interchange and land use control study on *Land Use Adjacent to Interchanges*. Vermont is conducting a study on *Interchange and Land Use* which includes interchanges on Interstate Highways 89 and 91.

Washington

The Washington Department of Highways is making an inventory of certain highway-oriented businesses at interchanges. Businesses located within 1 mile of the interchanges are to be included in the study.

West Virginia

The University of West Virginia, in cooperation with The State Road Commission of West Virginia, is conducting a study on *Land Use and Planning Controls in West Virginia*.

Aerial Color Photography and Its Use in Materials Surveys

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Recent developments in the technology of aerial color photography and the advantages and disadvantages of using color film for aerial materials surveys are discussed in this article. The research for this study was undertaken because of the increasing interest in the use of color aerial photography for highway materials surveys—the full potential has not been realized—and the many misconceptions that exist concerning this use of color photography.

The new developments and improvements in the photographic industry are being made so rapidly that even persons currently using aerial color photography have difficulty in keeping abreast of all the technological developments. Therefore, the authors are hopeful that the information presented here will be helpful to those now using this medium and those who may be contemplating the use of color aerial photography for materials surveys.

Introduction

SIGNIFICANT findings in the use of aerial color transparencies in construction materials surveys conducted by the Federal Highway Projects Office, Region 9,² U.S. Bureau of Public Roads, are summarized in this article. Selected data and costs of aerial films and processing thereof, as well as trends in use and development of aerial color films, are presented, and suggestions are made as to areas in which more research is needed.

The evaluation of aerial color photographs, reported in this article and a previous one (1),³ was a secondary objective of a comprehensive survey of construction materials. The total project was not designed as a controlled research experiment, and the results are representative of fairly restrictive climatic conditions, geographic area, and different geologic materials.

Photographs were taken along the major road system and in other selected locations in Yellowstone National Park, Wyoming. Aerial color transparencies (Kodak Ektachrome Aero Film, replaced in 1962 by an improved product called Ektachrome Aero Film, Process E-3) were made at a scale of 1:6,000 (500 feet to 1 inch) in single flight

strips. The photographs were taken with a 6-inch focal length Pleogon lens from an average flight height of 3,000 feet. More than 400 flight-strip-miles were photographed on color film during the summers of 1961 and 1962. Photographs of selected segments, totaling about 100 linear miles, were taken with conventional panchromatic film at the same scale.

The color transparencies were examined in three dimensions by using a mirror stereoscope and portable light source. Potential construction material sources thus located were annotated on transparent plastic envelopes containing the aerial photographs; then, each source was verified by ground inspection. Potential sources that appeared to have the best construction material were further investigated in the field with a backhoe, after administrative approval to examine each potential site had been obtained. Representative samples were taken from each source investigated and laboratory soil tests were performed for engineering evaluation.

Findings

As a primary result of the Yellowstone Park study and other materials surveys in which aerial color photography was used in Region 9, it is believed color photography has many advantages over black-and-white photography for use in materials surveys. Some of these advantages have been previously reported (1).

The use of panchromatic aerial photographs for interpretation of specific ground conditions, soils, or geologic materials involves the interpretation of different photographic tones. The number of such tones or shades of gray that can be differentiated is extremely limited, and many different types of soils or geologic materials may have about the same tonal expression. As the human eye can perceive about 20,000 shades and hues of color, interpretation of color photographs is considerably easier than that of black-and-white photographs. Identification of materials deposits can be based partially on the color of the deposits rather than having to rely on photographic tones of the panchromatic photographs. The authors realize, of course, that neither color nor photographic tone alone can be used in identifying materials, but they do represent one of the more important elements used in photographic interpretation.

An extreme example illustrating the shortcomings of black-and-white photographic tones for use in photographic interpretation was noted in the Yellowstone Park study. Occasionally it was extremely difficult to differentiate between certain low-growing types of vegetation and soil or rock on black-and-white photographs because they produced identical gray photographic tones. Differentiation was, of course, very simple on the color transparencies. This is an extreme example of the difficulty that can arise in use of panchromatic film, but it was paralleled by the difficulty encountered in attempts to differentiate between types of materials.

Minard and Owens (2) in mapping soils and geology of the Atlantic Coastal Plain in New Jersey noted that certain rock and mineral types can be identified much more readily from aerial color photographs than from panchromatic photographs. This was also true in the Yellowstone Park study where aerial color photography was used. Color differences of sands and gravels that contained large percentages of obsidian or siliceous sinter could be differentiated from sands and gravels composed of the more common rock assemblages. The distinction between these different sands

¹ Presented at the 43d annual meeting of the Highway Research Board, Washington, D.C., Jan. 1964.

² Includes Colorado, New Mexico, Utah, and Wyoming.

³ References indicated by italic numbers in parentheses are listed on p. 179.

and gravels was not nearly so obvious on panchromatic photographs of the same areas.

Color differentiation also has proved to be superior to black-and-white photographic tones for identification of engineering materials and geologic features on other projects undertaken in Region 9. For example, in Dinosaur National Monument, Colorado and Utah, where geologic formations are well exposed and of variegated coloring, a comparison of color positive transparencies with black-and-white prints at a scale of 1:6,000 showed that: (1) differentiating between strata of sandstone and shale is easier on color than on panchromatic photographs, (2) flat erosional remnants of granular mountain outwash that overlay dipping sedimentary formations are more easily and more positively identified on color than on panchromatic photographs, (3) highly fractured light-colored limestone strata can be identified and differentiated about equally well on either type of photographs, and (4) river terrace remnants can be more reliably identified on color photographs.

Organic soils, wet soils, boggy ground, and seepage zones also can be more readily identified on color photographs than on panchromatic because of their distinctive greens and browns. Minor drainageways, poorly drained depressions and swales, and seepage areas in landslides show up very clearly on color photographs. On panchromatic photographs such areas are displayed in generally darker photographic tones, but identification or delineation of these areas cannot be as positive; sometimes the conditions are not apparent even to an experienced interpreter.

Different vegetative types can also be recognized more readily on color than on panchromatic photographs; correlation can be made between type of vegetation and specific types of materials or ground conditions. Thus for areas covered by vegetation, the color photography is superior to panchromatic. Image identification is easier on color aerial transparencies than on black-and-white prints because of the color contrasts provided by the transparencies. Color transparencies are especially helpful in making identification of cultural features such as trails and aerial targets.

Although aerial color photography generally is superior to aerial panchromatic photography in terms of ease of interpretation and quality of results obtained, it does have disadvantages. The most obvious of these disadvantages is cost. Generally, aerial color photography costs approximately three to four times as much as the conventional panchromatic photography. This cost comparison reflects only the actual cost of the film material and its processing. The cost factor is discussed in greater detail later in this article.

Another disadvantage of using color photography is the difficulty encountered in obtaining proper film exposure, especially in areas where extreme lighting contrasts occur within the area covered in a single photograph. For example, in the Yellowstone Park study, hot springs deposits that were light in color and devoid of vegetation provided such sharp contrast to the surrounding dark vegetation that their color often exceeded

the exposure latitude of the color film. For such light-colored areas, any colors present were often washed out in the photograph, and images generally were not well defined.

In the Yellowstone Park study considerable differences in quality of color reproduction were sometimes noted between flight strips of the same areas photographed at different times. For example, some overlapping flight strips of aerial color photographs taken during the summer of 1962 had generally better color reproduction than those taken in 1961. This improvement was particularly noticeable for areas of dense vegetation where green hues were predominant; the 1962 photography generally reproduced the other areas and different colors of the features in a more natural way than the 1961 photography. The more natural color reproduction was particularly helpful in mapping old, gray, sandy beach deposits in heavily forested areas. In the 1961 photography, the gray colors were mostly obscured by an overall greenish cast of the photographs; this made the detection of the beach deposits difficult. The improvement in the films made in 1962 was attributed to more accurate film exposure.

Another fault of color transparencies as compared to panchromatic photographs is the relatively expensive production of duplicate transparencies and the difficulty of obtaining color reproduction of the originals: considerable experience is required for this process. Therefore reproduction of color transparencies is rather impracticable; if a color transparency is lost or damaged, it cannot be replaced as can a black-and-white print. When one is working with color transparencies, considerable care in handling must be exercised.

Because color transparencies must be viewed by transmitted light, a suitable illuminating source is necessary if they are to be used successfully for materials surveys. This has not generally handicapped office use of the transparencies, but it can prove to be somewhat of a problem when the transparencies are used in the field. In the Yellowstone Park study, special portable light boxes were used. They were provided with a vibrator power supply that could be connected to an automobile electrical system. The use of these portable light boxes was fairly successful, but it was awkward to work with them in the field vehicle and, of course, they could not be used away from the vehicle.

The necessity for transmitted light when color transparencies are viewed also means that a mirror stereoscope must be used; individual transparencies cannot be easily overlapped, as can black-and-white prints. In the field, a mirror stereoscope is relatively more awkward than the smaller lens stereoscope commonly used for viewing black-and-white prints.

As noted previously, in the Yellowstone Park study, primarily aerial color transparencies were used, and the comparisons made here have been between black-and-white photographs and these aerial transparencies. If color prints were to be compared with black-and-white prints, it is obvious that some of the findings and con-

clusions from the Yellowstone Park study would no longer be valid. For example, transmitted light would not be needed for viewing the color prints; and adequate duplicates of color originals would be available, thus eliminating the danger of loss or damage to the originals during interpretive work.

In one area of Yellowstone Park some short flight strips were photographed with Agfacolor Negative Film CN 17. Because these photographs were taken in conjunction with another project, only cursory examination was made. Contact color prints tended to have an excess of green, but they had good resolution. It was later determined that these photographs had been printed with a light source that did not provide a full spectrum. Contact prints subsequently were made with an appropriate printing light source and the color balance was greatly improved. Black-and-white prints made from the same color film negative were of excellent quality.

Procurement of Aerial Color Photographs

Several of the more important aspects in the procurement of aerial color photographs are discussed in the following paragraphs.

The distance between the project to be photographed and the airfield at which the photographic aircraft is based is extremely important in either a black-and-white or color photographic mission. Some delay in procuring color photography for the Yellowstone Park study was experienced because the photographic aircraft and crew were based several hundred miles from the project and could not take advantage of short periods of excellent photographic weather during prolonged cloudy and rainy periods.

Because the exposure latitude of most color film is narrower than for conventional black-and-white film, exposure difficulties are encountered where there is extreme contrast in the light reflectance within an area photographed. The light-colored areas tend to be overexposed. Consequently, colors wash out and images are not always registered distinctly. In flying over areas that are either light or dark, the photographer can properly adjust the exposure for the given scene. In this connection it is well to note that the ability of the photographer to think and use good judgment in making photographs under varying conditions of light, haze, clouds, and changing subject matter is important in procuring quality color photographs.

As flight heights increase, particularly in certain geographic areas and at certain times of the year, haze tends to cause color photographs to have an overall bluish cast and thus subdues original ground colors recorded on film. The effects of haze are less noticeable for relatively large-scale photographs taken at fairly low flight heights. Different color films also have greater or lesser sensitivities to haze. Haze filters and compensation in the printing process can be used to minimize the effects

aze. To overcome some of the haze difficulty, those making aerial color photographs are tending to use high quality, shorter-focal-length lenses, which permit lower flight heights or a given photographic scale. In addition to reducing the haze problem, such high quality, short-focal-length lenses sharply reduce the amount of darkening of corners of photographs, a common problem related to color aerial photographs taken with inferior lenses. Antivignetting filters on the aerial cameras and automatic-dodging printers also can minimize corner darkening.

Filters used with an aerial camera reduce the amount of light reaching the film and sometimes are a source of difficulty. For example, in some of the flight strips made in the Yellowstone Park study, the images in the corners of the aerial photographs were blurred. It was later determined that this blurring was caused by a faulty color-balancing filter that had inadvertently been exposed to excessive heat. Fortunately, the blurring was not sufficiently serious to affect the use of the photographs.

Color balance of an aerial photograph depends upon the geographic latitude, season of the year, time of day, amount of haze and cloud cover, film exposure, type and variation of emulsion, type of filters used, and film processing and printing. One need not wonder why the attainment of true color reproduction in an aerial photograph is a very difficult task. However, the excellent results that can be obtained despite all these deleterious factors are remarkable.

Trends in Aerial Color Films

Through continued research by film manufacturers, improvements in aerial color films have steadily been made. Many former objections and criticisms of color films are no longer valid. Significant trends, particularly within the last 5 years or so, have been: (1) a large increase in emulsion speed or light sensitivity, (2) reduction in granularity and consequent increase in resolution, (3) improvements in dye formulas that provide a stronger degree of color fidelity, (4) wider latitude of exposure, and (5) decreasing costs.

Standards of sensitivities and resolution have been reached today that were hardly thought attainable by many only 10 years ago. Costs of color film have been decreasing, and this trend is expected to continue as aerial color film comes into more general use. One Government agency has reported that the cost of color photographic paper has been reduced by more than 50 percent in the last 3 years, mostly because of the increase in demand.

Aerial color negative films of both domestic and foreign manufacture have recently been introduced in the United States. The advantages of aerial color negative film over color positive transparencies make it appear that negative film will come into greater use, particularly as improvements are made in emulsion speed and exposure latitude, and as costs decrease. Use of color negatives provides a greater flexibility as both black-and-white prints and color prints can be made

from the same negatives. The negatives can be saved and additional prints made as required. Compensation for incorrect exposure, haze, vignetting, and color balance can all be made in the photographic laboratory. Color-balancing filters are not required on the aerial camera as they are when reversal-type film is used.

Generally the paper base material on which color photographs are printed has many of the same characteristics as the base material used to print black-and-white photographs. At least one film company produces color print material that is tough, waterproof, and dimensionally stable (3). The office and field problems associated with use and storage of paper-base prints are well known.

Summary of Some Aerial Color Film Data and Characteristics

The following listed aerial color films are now commercially available. Only selected characteristics are included. Further information regarding these films can be obtained from the respective manufacturers.

Kodak Ektachrome Aero Film, Process E-3, is a color reversal film from which positive transparencies are obtained. This film replaces Kodak Ektachrome Aero Film, High Contrast. This film has an Aerial Exposure Index of 25 that is about three times as fast as the previous film that had a speed index of ASA 40 daylight. Haze filters are recommended and color-balance filters are used when necessary for particular emulsions. The Aerial Exposure Index is a number assigned by the Eastman Kodak Co. to indicate the speed of film. It is used in calculating film exposure with Kodak Aerial Exposure Computer and should not be confused with ASA Exposure Index (4).

Kodak Ektachrome Infrared Aero Film, Process E-3, replaces Kodak Ektachrome Aero Film (Camouflage Detection). The new film is a false-color, reversal film that has three layers sensitive to green, red, and infrared radiation, rather than blue, green, and red as in conventional color film. A yellow Kodak Wratten Filter No. 12 is used to absorb blue radiation to which all three layers are sensitive. Color compensation filters may be used for color improvement of transparencies. This film has an Aerial Exposure Index of 10, which takes into account the use of the yellow filter.

Kodak Ektacolor Professional Film, Type S, is color negative film that has recently become available; it has a speed index of ASA 80 daylight. Use of a haze filter is recommended. Color balancing is accomplished in the printing process. (A recent experimental trial by the authors showed that good-quality aerial color prints can be produced from this negative film. This film appears to have reasonably wide exposure latitude without objectionable shifts in color balance. Although not designed for aerial photography, it has fairly high contrast and good haze penetration without the use of a haze filter.)

Ultra-Speed Anscochrome is a color-reversal film from which positive transparencies are

obtained. The speed index for this film is ASA 200 daylight. By forced processing, the speed can be pushed to ASA 400-800. This film has a temperature-color balance of 6,000° K. and has high resolution when exposed under normal conditions. The latitude of exposure is about plus or minus one-half lens stop for accurate reproduction and good color saturation. Color positive prints (Printon) can be made from this film.

Super Anscochrome is a color-reversal film having a speed index of ASA 100 daylight. Exposure latitude and color balance are similar to Ultra-Speed Anscochrome. It has slightly higher resolution and provides somewhat less contrast than the latter.

Agfacolor Negative Film CN17 is a negative color film having a speed index of ASA 40 daylight. Typical exposures are 1/250 to 1/450 second at f4 to f5.6 under average conditions of brightness. Satisfactory results can be obtained at one to two lens stops lower than for optimum exposure. Ultraviolet and light yellow filters can be used. Color balancing is accomplished in the printing process.

Since this article was originally written, several new films have become commercially available. They are: Ektachrome Infrared Aero, Type 8443; Ektachrome Aero, Type 8442; Special Ektacolor Aerial, Type SO-282; and Anscochrome FPC-132 and Anscochrome FPC-289. Information regarding these films may be obtained from the manufacturers: Eastman Kodak Co., Rochester, N.Y., and Ansco, Binghamton, N.Y.

Cost of Aerial Color Photography

One of the foremost considerations to most persons, and a question frequently asked is, "How much does aerial color photography cost?" Perhaps a followup to this question should be, "Is aerial color photography worth the cost?" To answer the latter question first, the authors are of the opinion that the answer in most instances is an unqualified yes. Perhaps one could apply the saying, "You get what you pay for," with respect to aerial color photography.

No attempt has been made to make a cost analysis here, because no matter how completely one analyzes the economics of aerial film, the question remains unanswered as to whether color aerial film is worth its cost. As previously mentioned, raw aerial color film and processing costs are about three to four times the cost of conventional black-and-white photography. This is not surprising, as color films have three emulsions and panchromatic films have only one. The price of chemical kits used for processing both types of film is about the same.

In terms of the entire operation, including the photographic mission itself, the cost of procuring and processing aerial color transparencies is only about twice that for panchromatic film. Sometimes both types of photographs may be procured during the same mission. Other factors influencing cost are the total number of photographs required, length and number of changes in direction of

flight strips, and distance of the project from the base of operations.

However, one government agency, which takes its own photographs and does its own photographic laboratory work, reports that the cost of producing color prints is about four times that for black-and-white prints.

One commercial aerial color processing photographic firm quotes a price of \$90 for processing negative color film (a roll 9½ inches by 100 feet) and \$115 for color-reversal film of the same dimensions. Color paper prints that are not color balanced can be obtained for about \$0.90 a print. Prints that have been color corrected and dodged for lens vignetting cost \$3 each.

A price quotation obtained for 1:6,000-scale photography from a commercial photogrammetric firm was \$55 per flight-strip-mile. This price included one set of contact color prints, one set of black-and-white prints, and one photographic index. Additional color prints could be obtained for \$15 per flight-strip-mile, and additional black-and-white prints could be obtained for \$1 each.

Aspects of Color Film Processing and Printing

Only a few of the most important aspects of aerial color film processing and printing are presented here. No attempt is made to discuss all the ramifications of this complex subject.

One of the more important phases, and one that is often neglected, is the extreme care necessary in the photographic laboratory in regard to general cleanliness and prevention of contamination of chemical solutions. Good housekeeping is a must in a color photography laboratory. In addition, processing procedures must be rigidly controlled. The general attitudes, habits, and procedures followed in most black-and-white photographic laboratories are not good enough.

One phase of color processing most misunderstood is the time required in the photographic laboratory. Usually, the total time required to process a roll of exposed aerial color film is only slightly longer than that required for panchromatic photographs, if the proper equipment is available. Processing of color-reversal film takes slightly longer than for color negative film. Although color processing time does not differ significantly from the time for panchromatic, the complete attention of the laboratory technician is required throughout the color-processing operation. This full-time attention is not required for processing panchromatic photographs.

Two government agencies report that their production capacity for panchromatic prints is from 2 to 2½ times greater than that for color prints. This comparison illustrates the additional time required to make color prints with the equipment used in these particular photographic laboratories. Most laboratories use the so-called wind-and-rewind type of aerial color film processing equipment. Continuous processing such as is used in the

motion-picture industry is not made to accommodate aerial color film. Continuous processing equipment is very expensive, and at the present time cannot be justified by the quantity of aerial color film processed.

Contact printers, either conventional or automatic-dodging type, equipped with full spectrum tubes, can be used to make color prints from either positive transparencies or color-film negatives. The color balance of each photograph, if required, can be regulated by using special filters or adjusting the printing light source. Compensation for haze can also be made in the printing process by removing some of the blue color with filters. Differences in film exposure and light quality (time of day) can also be compensated for in printing. By using automatic-dodging printers, a more uniform density can be obtained throughout a given photograph, and the photographs in a flight strip will tend to be more nearly uniform. Some objection has been voiced regarding the use of automatic-dodging printers because serious color-balance shifts occur on some films; this shift is due to reciprocity failure (longer exposure time required in printing). Attainment of perfect color balance in each print remains a costly and time-consuming process.

Figure 1 shows the possible products (contact size) that may be obtained from color negative and reversal-type films. Enlargements can also be made from both types of film.

Viewing Aerial Color Photographs

A few special requirements must be met for optimum stereoscopic viewing of aerial color photographs. For optimum color perception, a light source that radiates energy over the entire color spectrum is necessary. Some modern fluorescent lights and combinations of fluorescent and incandescent lights meet this requirement. Most of the light sources used for photographic interpretation of aerial color photography in the past have been improvised. Recently, special fluorescent tubes that are coated with selected phosphorus and provide energy in the entire color spectrum have become available. This light source is color balanced at 3,900° K. and has intensities of 400 and 600 footlamberts. The higher intensity is used for viewing dense transparencies. Diffusers provide an even distribution of light. This special light source has the added advantage of maintaining its color balance and intensity of output for long periods of time, something ordinary fluorescent light cannot do. As is true for other fluorescent light sources, providing for heat dissipation is not the problem it is when incandescent bulbs are used.

Double projection photogrammetric instruments currently in use have not been designed for use on aerial color photographs. Use of color aerial photography in these instruments, both qualitatively and quantitatively, has been experimental in nature up to this time. In the Kelsh stereoscopic plotter, color positive transparencies sandwiched between glass plates have been used by means of polarized light and a

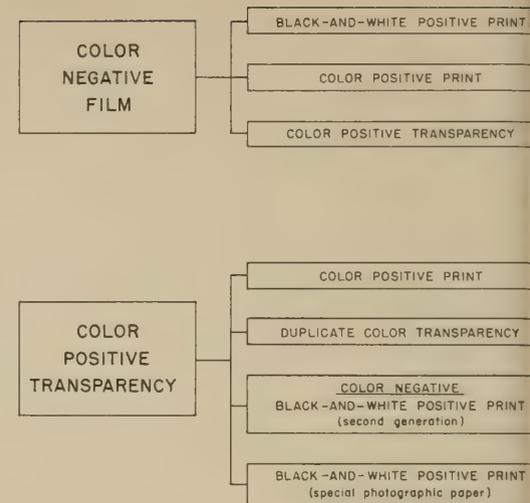


Figure 1.—Possible products from color negative and reversal-type film.

special platen that has a surface of anodized aluminum. Despite its limitations, this approach appears to have considerable merit, particularly for interpretation purposes (4). Color transparencies have also been experimentally employed in optical-train photogrammetric instruments. As these instruments do not depend on the anaglyph principle for their operation, polarized light is not required for stereoscopic viewing. This approach has proved successful for qualitative use.

Color diapositive plates for use in photogrammetric plotting instruments are not commercially available (Kodak Special Plate, Type 032-01). Diapositive plates eliminate the dimensional instability problem associated with positive film transparencies. The color diapositive consists of duplicate film laminated on a 0.250-inch glass plate. As a result of this recent development, more extensive use of color photographs will be possible in photogrammetric instruments, both quantitatively and qualitatively.

Although not specifically designed for the 9- by 9-inch size format used extensively in highway work, a stereoscopic viewing instrument of interest to the military service and others has recently been developed. This instrument permits the viewing of projected 70-mm. strip color and conventional photographs in three dimensions without the aid of polarized light or color lenses. This is accomplished by a special projection system and viewing lens. Magnification is also provided.

Quality of Color Reproduction and Photographic Interpretation

Establishment of a set of specific rigid criteria as a basis for evaluating the acceptability or nonacceptability of aerial color photographs for use in materials surveys is nearly impossible and at best not practical. General requirements applying to panchromatic photographs procured for interpretation

purposes are applicable to color photographs. The judgment of the particular user must be the prime basis for governing decisions regarding acceptability of color photographs for any given project.

To the layman, as well as to the trained interpreter, natural colors accurately reproduced in an aerial photograph are more pleasing than poorly reproduced colors. The value of true color reproduction, however, in interpretation of soils, locating sources of construction materials, and mapping geologic formations is questionable when considered in terms of the effort and cost of attaining this objective.

Although true color reproduction would probably be esthetically desirable to obtain, the effort and cost are at present too great to warrant it. Actually, color distinctions and differences are of paramount importance, and it may sometimes be necessary to disturb good color balance to obtain certain color contrasts.

Proper film exposure enhances color differences and is particularly important when color-reversal film is used, as there is little leeway in the photographic laboratory to compensate for errors. Overexposure generally tends to wash out colors. Latitude of exposure varies considerably with different color films and for some films it may be desirable to underexpose rather than overexpose. The reverse may also be true for other films. For critical work, test exposures should be made with the same film (same emulsion number) that is to be used on the project. Laboratory procedures should be standardized.

Resolution in an aerial photograph is an important consideration. It may, however, be less important on a color than on a panchromatic photograph because color rendition and contrasts are probably more important in differentiating images. Aerial color films generally have much greater contrast than color films produced for ground photography. Aerial color photographs having high image resolution are certainly desirable, but other considerations may be more important for photographic interpretation. When photographs are to be viewed under magnification or when enlargements are to be made, resolution becomes more important.

Research Needs

The body of available knowledge related to use of aerial color photographs for interpretive purposes is still relatively small. As most State highway departments do not have the time, trained specialists, facilities, or funds to undertake comprehensive research projects of a basic nature, most research in this area has been conducted by the universities and

by agencies of the Federal Government. Though considerable research in this field has been conducted by the military services, the results of this work generally have not been made available to civilian engineers and scientists because of security restrictions.

The need for research in the use of aerial color films for materials surveys and for interpretation in general cannot be denied. The authors have suggested some avenues of possible research activity.

The selection of the proper film and/or filter for use on specific projects having unique color combinations needs to be investigated. Some research of this type has been done more or less on a trial-and-error basis in which different film-filter combinations and film exposures have been used. A limited amount of work has been done through an approach that eliminates most of the guesswork, by using spectral reflectance measurements (spectrophotometric studies) of the soils and rocks to be photographed. The results of these measurements show the dominant wavelengths of reflected light and enable photographers to select the appropriate filter so that optimum color contrasts will be shown (6, 7).

Aerial photographic interpretation has in the past been largely qualitative and subjective in nature. Although the amount of information that can thus be obtained is very large, the quantitative approach to interpretation may possibly be the approach that will really be effective. This approach has long been neglected and is in need of further study. By use of a densitometer or microdensitometer, color transparencies or prints can be scanned and the intensity of specific wavelengths of light, either transmitted (transparencies) or reflected (prints), can be measured and recorded. Normally, measurements of the amounts of red, blue, and green light are made. Particular rock types, soils, and landforms can then be identified and differentiated. Distinctions among geologic formations and soils often can be made in this manner that cannot be made visually (7, 8, 9).

Experimentation is needed with all types of aerial color film to determine the latitude of film exposure in relation to the value of the resultant photographs for interpretive purposes (10). Research is needed involving the use of different combinations of light sources, reflectors, filters, and light intensities in color-viewing systems for interpretation. This phase of enhancing color differences for interpretation has been neglected. The emphasis has been placed on the taking and processing phases of color photography.

The potential of false-color films for interpretive purposes needs to be evaluated. False-color films differ from ordinary color films in that one of the three emulsion layers

is sensitive to infrared. Colors produced by this film after processing are not those of the photographed objects such as soil or rock. Color contrasts and differences depend to a large extent on the differences in infrared reflectivities of the scene photographed. Therefore, use of false-color film is more advantageous than use of conventional infrared film, in which the record is in shades of gray (4, 11).

To ascertain the degree of stability of dyes under ideal storage conditions and under routine office and field use, controlled experiments in aerial color film deterioration are needed. The effect of certain chemicals used to retard the bleaching of colors on color prints should be ascertained. Normally, color prints are soaked in these solutions. When dried, the then invisible coating reduces the penetration of ultraviolet rays, which bleach dyes. Particular types of vegetation have been correlated with specific soils and ground conditions and can be used by trained interpreters to identify these conditions on aerial photographs. Recognition of vegetative types is unquestionably greatly facilitated by use of aerial color photographs. Research is needed to correlate identifiable vegetation on aerial photographs with specific conditions and materials on the ground. False-color films may have some application and potential use. This approach to interpretation probably will have its greatest success in semiarid and subarctic regions.

More test flights and use of aerial color photographs are needed over a broader area of climate, topography, and geologic materials. Perhaps a designed experiment in which the test areas would represent many conditions would be appropriate. Worthwhile results probably could come from experiments involving special photographic laboratory procedures to generally improve color photography for interpretation.

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Effectiveness of Sign Background Reflectorization

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RESEARCH AND DEVELOPMENT
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This article describes a study conducted to compare the brightnesses of signs having different degrees of background reflectorization and to analyze their effect on the ability of drivers to follow a test route to a given destination on controlled-access highways in a suburban area. The results of previous studies by the Bureau of Public Roads have indicated little practical difference in legibility of signs having different degrees of background reflectorization, including no reflectorization. But it was thought possible that the degree of background brightness might affect other sign-effectiveness factors such as detectability or reading time. Data have been compiled on the performance of a total of 150 volunteers, who attempted to follow TEST ROAD signs leading to 18 exit turns. Fifty of these volunteers were tested on each of three successive nights. One-third of the turns were marked with signs having each of three different background materials. The frequency of errors by materials was not statistically significant. The methodology used in this study may have applicability in related work.

Introduction

TO DETERMINE whether reflectorized backgrounds contribute to the overall effectiveness of highway signing, the Bureau of Public Roads conducted a study in which signs having backgrounds of different degrees of reflectorization were compared. This comparison was accomplished by analyzing whether the degree of background reflectorization seemed to affect the ability of test drivers to follow signs at night and to negotiate a test route to a given destination on controlled-access highways in a suburban area.

Present standards for directional signs on the National System of Interstate and Defense Highways require white legends on a green background. If the sign is not self-illuminated, the legend must be reflectorized; however, for roadside signs and illuminated overhead signs, reflectorization of the background is optional. There has been some question as to the degree of background brightness that is necessary and, consequently, the degree of reflectorization. The results of previous studies by the Bureau of Public Roads have indicated little practical difference in legibility of signs having different degrees of background reflectorization, including no reflectorization.¹ It is possible,

however, that the degree of background brightness affects the effectiveness of other sign factors such as detectability or reading time.

Description of Study

Test subjects drove over a route that included highways and parkways of the Pentagon network and other controlled-access highways in suburban Virginia near Washington, D.C. Changes in the direction of the route were marked by test signs placed in advance of the exits. An observer riding in the car with the test subject noted missed turns and directed the test drivers back onto the route when a turn was missed. To conceal the true nature of the experiment, the test subjects were told that they were participating in a study of "... night driving characteristics . . ." and that all of them were being asked to use the same route so that the same base could be used for comparison of results.

The test route illustrated in figure 1 was approximately 25 miles long; its controlled-access design, in which the alignment was somewhat curvilinear, dated back to the World War II period. All 18 of the test turns required right exits. Each was marked by a single test sign (fig. 2) placed 400 or more feet before the exit. All parts of the route on approaches to and in the vicinity of test signs and turn exits were on controlled-access, divided highways having 2 or 3

lanes in each direction. Some exit ramps led to streets or highways of lesser design but the route always led back to an access-controlled, divided highway, usually one-half mile or more before another test sign. Posted speed limits on the route ranged from 35 to 55 m.p.h., but were mostly 35 or 40 m.p.h. Prevailing speeds on the same highway ranged, in most places, from 35 to 45 m.p.h. All test turns on the route were marked with test signs having reflectorized white legends and green backgrounds.

Sign backgrounds

Three degrees of reflectorization were used for the test sign backgrounds: (I) nonreflectorized green background; (II) moderately bright reflectorized green background; and (III) a relatively high-brightness reflectorized green background (standard reflectorized sheeting). Specific luminance curves for divergence angles up to 1 degree at an incidence angle of 1/2 degree for these materials and for the material used for the white legend are shown in figure 3. For comparison, the specific luminance of unity of a theoretical, perfectly white diffusing surface is included. The nighttime appearance of the different materials at our location is illustrated in figure 4. Because of the limited range of brightness that can be depicted by photographic process, the views are only approximate representations.

The type of background at each turn was assigned at random each night. The only limitations on the assignment were that each night the sign marking each turn had to have a different background and one-third of the turns each night had to have each of the three background treatments. Therefore, six turns each night were indicated by signs having each of the background treatments. On successive nights, the sign background was changed at each test turn. Each of the 18 turns was therefore marked on successive nights by a sign having each of the background types. Three nights of testing (or multiples of three) were needed to balance the experimental design of background treatments and turns. A schedule of background by nights and turns is shown in table 1.

¹ Information was gathered as part of the Interstate sign tests conducted by the Bureau of Public Roads at Riverdale, Md., Nov. 1957.



Figure 1.—Map of area in Washington, D.C., and suburban Virginia showing test route.

To facilitate changing the test sign backgrounds on successive nights, three signs were fabricated for each test turn; they were identical in legend and legend spacing and differed only in background treatment. Legends and borders were white reflectorized sheeting. Eight-inch series D letters were used. The sign carried two lines of copy and appropriate arrows: The first line was a legitimate destination on the route, for example *PENTAGON*; the second line was always *TEST ROAD*. All of the test signs measured 96 by 32 inches. They slid into horizontal metal channels mounted on posts, at a height measuring 5 feet from the bottom of the sign to the pavement. The posts were a minimum distance of 2 feet beyond an unmountable curb or edge of a shoulder. The signs were mounted

at approximately right angles to the roadway, but the angle always exceeded 90 degrees in order to minimize specular reflections.

Precautions

The test signs were not conspicuously different in size and legend style (letters and arrows) from the permanent directional signs along the route, most of which had either black legends on a white reflectorized background or white reflectorized legends on a nonreflectorized background. None of the test signs gave directions that conflicted with or appeared to duplicate the permanent signing. In a few places, a test sign temporarily replaced a permanent sign.

Even with these precautions, the subjects could have learned to associate, either consciously or subconsciously, the test message with signs having green backgrounds. This would have biased the results in favor of reflectorized backgrounds. Furthermore, subjects could also have learned to associate the test message with the low, wide, rectangular shape or the two-line legend and arrow design of the test signs. So, to further camouflage the differences between the test signs and the permanent signs, two dummy signs that more nearly resembled the permanent signs were placed along the route. Dimensions and color combinations—black legend on a white reflectorized background—of the dummy signs were similar to the permanent signs. In addition, two decoy signs were placed. The dummy signs are illustrated in figure 5 and

Table 1.—Schedule of sign backgrounds, by nights and turns

Turn number	Sign background material ¹		
	1st night	2d night	3d night
1.....	I	II	III
2.....	I	III	II
3.....	III	I	II
4.....	III	II	I
5.....	I	II	III
6.....	II	I	III
7.....	III	I	II
8.....	I	III	II
9.....	I	II	III
10.....	II	III	I
11.....	II	III	I
12.....	II	I	III
13.....	III	II	I
14.....	III	I	II
15.....	I	II	III
16.....	II	III	I
17.....	II	III	I
18.....	III	I	II

¹ Roman numerals refer to degree of reflectorization as follows: I, nonreflectorized green background; II, moderately bright reflectorized green background; and III, relatively high-brightness reflectorized green background (standard reflectorized sheeting).



Figure 2.—Day view of test sign.

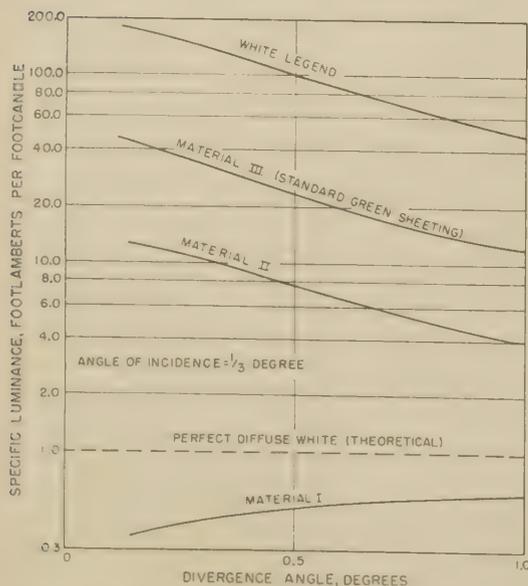


Figure 3.—Specific luminances of materials used on test signs for an incidence angle of 1/3 degree and divergence angles up to 1 degree.

Table 2.—Characteristics of test subjects

Characteristic	Number of test drivers—		
	1st night	2d night	3d night
Organization: ¹			
Bureau of Public Roads.....	20	20	20
Sports Car Club.....	23	19	31
Jaycees.....	9	9	7
Others.....	12	15	6
Sex of driver: ²			
Male.....	47	45	43
Female.....	3	5	7
Age of driver (years): ²			
Under 20.....	2	1	0
20-29.....	18	13	20
30-39.....	14	10	15
40-49.....	7	16	6
50-59.....	8	7	6
60 and older.....	1	3	3
Visual acuity:			
Below 20/40.....	50	49	49
Above 20/40.....	0	1	1
Familiarity with area: ³			
Very familiar.....	10	11	8
Moderately familiar.....	24	28	25
Unfamiliar.....	16	11	17
Average age of driver.....	35.1	39.3	35.9
Median age of driver.....	33	40	33

¹ Estimated from mail return and schedule of volunteers. Since subjects were identified by code number at site, there is no way of identifying the 50 subjects who participated each night by organization.

² Taken from 1st questionnaire.

³ Taken from 2d questionnaire. Subjects queried after completing course.

the decoy signs in figure 6. The decoy signs resembled the test signs in shape, design, and color combination, but the test message was omitted. Supplemented by the few permanent signs having green backgrounds, the decoy signs were intended to prevent the subjects from associating green backgrounds with only the test signs. Small 24- by 30-inch auxiliary signs used for directions on ramps and other connections on the route also had black legends on white reflectorized backgrounds (fig. 7).

Procedures

Test subjects were volunteers from organizations such as a local Junior Chamber of Commerce, a local Sports Car Club, the Bureau of Public Roads (other than the Traffic Systems Division), and other agencies of the Department of Commerce. Subjects were scheduled in advance for specific nights and times of arrival at the staging area.

The test procedure was essentially the same as that used in a previous study of route-turn markers.² On arrival at the staging area, subjects received a printed sheet that contained explanations and instructions. They were asked to complete a questionnaire on driving experience and to undergo a vision test on a Keystone Visual Safety Tester for acuity, stereopsis, and far-point fusion. They were also tested for color vision. The questionnaire and vision test were part of the general study of night driving characteristics.

² Advance Route-Turn Markers on City Streets, Lawrence D. Powers, PUBLIC ROADS, vol. 32, No. 1, April 1962, pp. 12-16.



Figure 4.—Night views of signs at same location having different background materials. Brightnesses are approximate. Background materials I, II, III were test signs from top to bottom, respectively.

In addition, tests served in screening subjects for visual defects. The questionnaire and visual acuity data are summarized in table 2 for the different groups of subjects taking part in the study each night.

To retain anonymity, subjects were identified by code numbers. It was explained that the observer would usually be too busy to give directions, and that the drivers were expected to follow the course that was marked by signs having the message TEST ROAD. Drivers were not specifically informed that the observer would guide them if they missed a turn or was a missed turn called to their attention.



Figure 5.—Dummy sign, black legend on reflectorized white background.



Figure 6.—Decoy sign, similar in design and color to test signs, no test message.



Figure 7.—Auxiliary sign, for ramps and other changes in route.

that dealt with such items as the subject's familiarity with the area of the route and his problems in following the route.

Reflective Properties of the Test Sign Materials

The specific luminance curves shown in figure 3 were derived from outdoor measurements on 24-inch-square plaques identical to the materials used for the test sign. Similar measurements made on a sample basis of the actual test signs were compared with those on the plaques and were essentially the same. The curves plotted were derived from the measurements on the plaques. Because of the limited number of measurements on these materials and the accuracy of the available instrumentation, the curves shown are representative of the relative specific luminances of the materials rather than the absolute specific luminances.

The luminance values for material I, the nonreflectorized background material, appears somewhat high, probably because the material was a smooth sheeting and produced some specular reflection. However, when used on the test signs, the same characteristics were exhibited.

Data on figure 8 show how the brightness of the sign materials varied with distance from the sign for each turn indicated. These data represent actual field measurements of the 24-inch-square plaques mounted on the sign supports and illuminated by the low beams of a single vehicle. While the vehicle was stationary at a measured distance from the sign, brightness measurements were made by a Pritchard photometer mounted at the driver's head position. The plotted numbers represent the turn at which the brightnesses were obtained for material III, the standard sheeting sign background, at the indicated distances from the signs. The solid curve has been drawn through the median brightness for all turns at each distance for this material (the median value for the 700-foot distance is based only on those signs that were not obscured at that distance). The median

curves for material II, the intermediate sheeting, and the white legend material, respectively, are shown by broken lines below and above the curve for the standard sheeting.

The large differences in brightness for a given material at a specified distance were caused by the variations in horizontal and vertical curvature on the approaches to the signs at the individual sign locations. This variation in curvature caused differences in incidence angles and in the amount of headlamp illumination incident on the signs. To a lesser extent, variations in the approaches also caused differences in divergence angles. For each sign location and distance, the incident illumination and incidence and divergence angles were the same for each material, and thus the brightnesses were in the same ratio as the specific luminances. Although there is considerable overlap in the brightness for the three materials at different locations, the brightnesses of individual materials at the same location were in the same ratio. The median curves are therefore parallel, and the individual measured points for the other two materials, if shown, would be as far from the corresponding turn points indicated for the standard sheeting as the distances between the median curves for the other two materials. The brightness values of the three materials at each location were obtained under low-beam illumination by a single vehicle and are therefore minimum values. The brightnesses of the signs during the tests could have been higher as a result of illumination contributed by other vehicles on the highway.

Volunteers

The number of test subjects was limited by the need to run the study in multiples of 3 nights so that all three background treatments could be used an equal number of times at each turn. It was not feasible to extend the test to 6 or more nights because of increased field crew requirements and possible publicity of the test project. The 5-minute intervals between the start of each test run permitted

Table 3.—Number of errors, by turns, nights, and background

Turn number	All errors							All errors, less doubtfuls						
	1st night	2d night	3d night	Back-ground I	Back-ground II	Back-ground III	Errors by turns	1st night	2d night	3d night	Back-ground I	Back-ground II	Back-ground III	Errors by turns
1	16	19	19	16	19	19	54	13	15	18	13	15	18	46
2	11	7	13	11	13	7	31	10	5	11	10	11	5	26
3	16	8	13	8	13	16	37	14	3	11	3	11	14	28
4	3	4	4	4	4	3	11	2	4	4	4	4	2	10
5	4	8	4	4	8	4	16	4	6	4	4	6	4	14
6	1	2	3	2	1	3	6	1	2	2	2	1	2	5
7	1	2	2	2	2	1	5	1	2	2	2	2	1	5
8	1	1	2	1	2	1	4	1	1	2	1	2	1	4
9	5	1	0	5	1	0	6	4	1	0	4	1	0	5
10	2	2	2	2	2	2	6	2	2	2	2	2	2	6
11	1	4	5	5	1	4	10	1	3	4	4	1	3	8
12	10	7	9	7	10	9	26	5	6	4	6	5	4	15
13	1	1	0	0	1	1	2	1	1	0	0	1	1	2
14	1	0	0	0	0	1	1	1	0	0	0	0	1	1
15	1	0	0	1	0	0	1	1	0	0	1	0	0	1
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1	4	2	2	1	4	7	1	2	1	1	1	2	4
18	0	1	1	1	1	0	2	0	1	1	1	1	0	2
SUMMARY:														
Turns 1-18	75	71	79	71	79	75	225	62	54	66	58	64	60	182
Turns 1-3	43	34	45	35	45	42	122	37	23	40	26	37	37	100
Turns 4-18	32	37	34	36	34	33	103	25	31	26	32	27	23	82

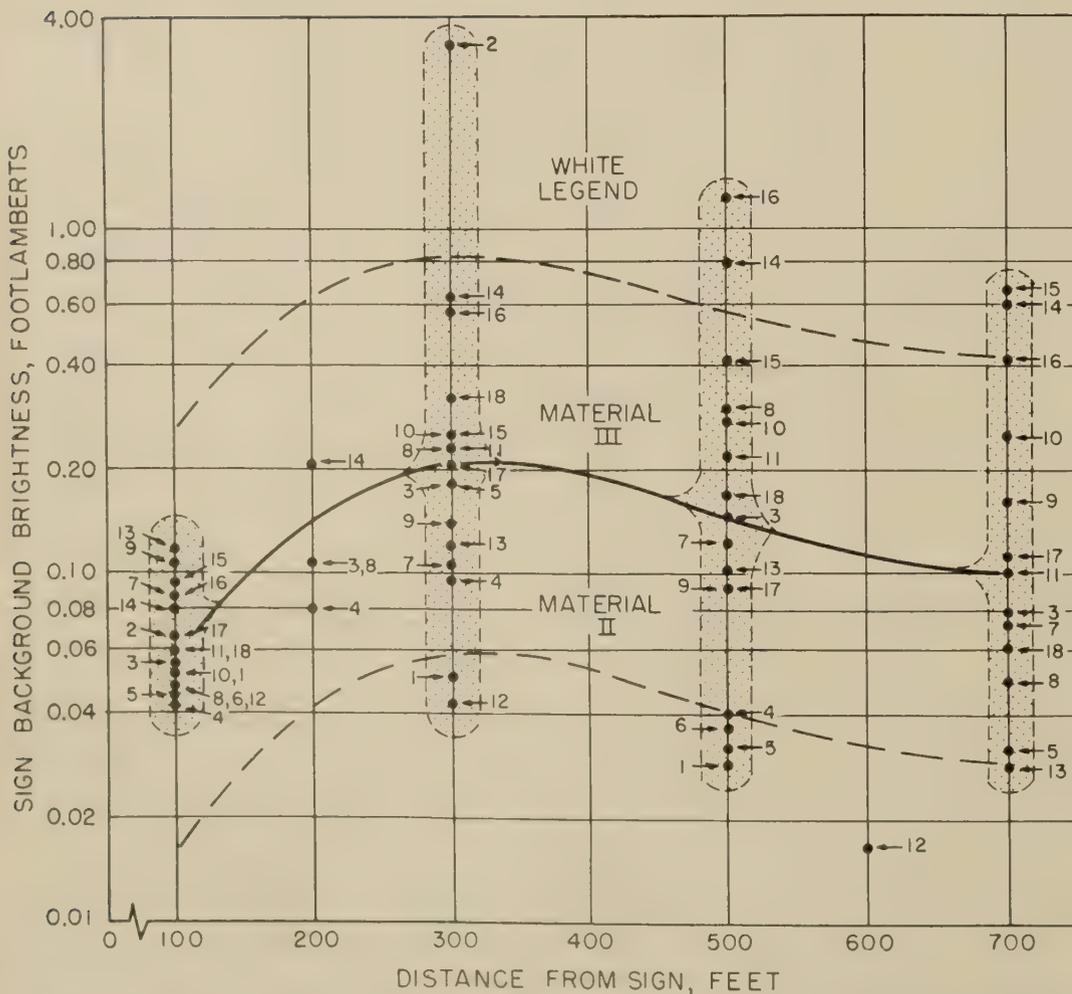


Figure 8.—Brightness of sign materials in place, by distance from signs for two-lamp, low-beam illumination. All plotted points are for material III, shown here as solid curve. Numbers next to points refer to turns where measurements were made. Dashed curves represent median brightnesses for material II and white legend.

about 60 subjects to be scheduled each night. Test runs began after 6:30 p.m., when the evening traffic peak had ended, and terminated shortly after midnight, which was as late as volunteers would remain on week nights.

Actually, more than 60 volunteers were tested on each of the 3 nights. However, because the last test sign was inadvertently removed on the first night while some test subjects were still on the route, all 60 test subjects were not completely exposed to the balanced experimental test design. In addition, a few erratic drivers missed almost all the turns and were hopelessly lost, and the data were not used. Complete data were collected for only 50 test subjects on the first night. To maintain a balanced experimental design, data for only the first 50 subjects of each of the other 2 nights were used.

Confounding factors

Several factors that may have confounded the results became apparent during the field operations or on inspection of the data sheet. Toward the middle of the runs in the second night and, to a lesser extent, later in the evening of the third night, temperature and humidity changes caused moisture condensation on many of the signs. This caused a lowering of the brightnesses of the reflective material.

It became apparent, also, that some of the test subjects had not fully grasped the intent of the written instruction, which had emphasized the *TEST ROAD* message rather than the type of sign. Because the first sign having this message was the small auxiliary sign encountered at the exit from the stage

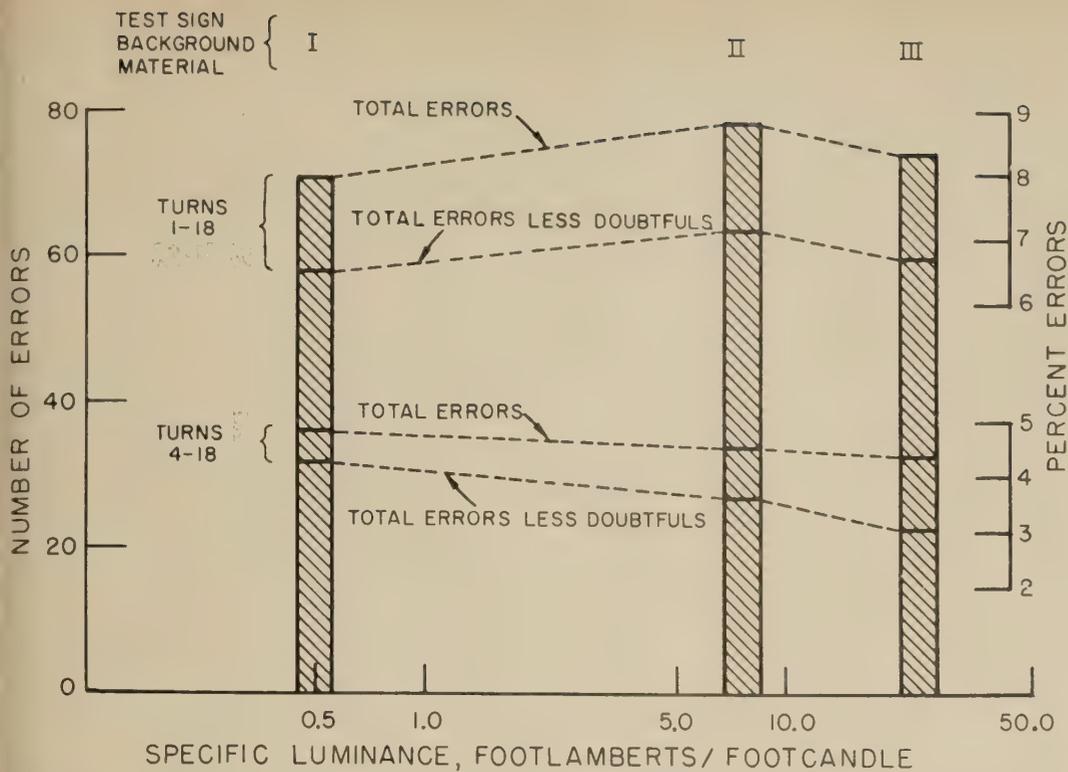


Figure 9.—Frequency and percentage of errors, by specific luminance of test sign background materials for different items of comparison. (Percent errors is based on 900 possible correct turns, for each material, for turns 1-18; and on 750 possible correct turns for each material, for turns 4-18.)

area, many subjects apparently formed a psychological set and, for the first few turns, looked only for the small white signs and ignored all others. This was substantiated by the fact that more than half of the total errors were made at the first three turns. Furthermore, an analysis of the data for consecutive turns missed showed that several subjects missed the first two or three turns

before they realized that the test message appeared on other types of signs than the small auxiliary signs.

Finally, it became apparent that some of the exit gores and throats were poorly defined. Because the study was conducted in the middle of winter, the pavement markings were somewhat obliterated and the melting of previous snowfalls had left debris and dust at

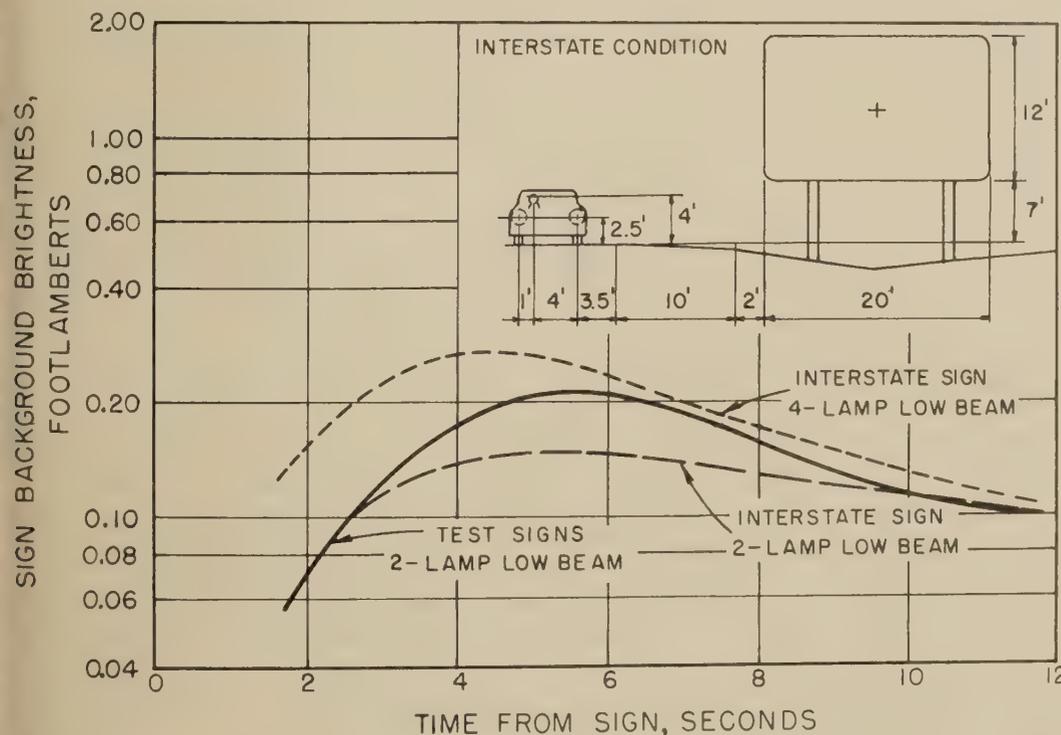


Figure 10.—Comparison of brightness of standard sheeting background material measured for test signs and calculated for typical Interstate highway signs. Assumed Interstate highway geometry used in calculations shown in inset.

Table 4.—Summary of chi-square tests

Item of comparison	X ²	Probability ¹
By nights:		
All errors—		
Turns 1-18	0.46	0.79
Turns 4-18	0.37	0.83
Doubtful errors omitted—		
Turns 1-18	1.34	0.51
Turns 4-18	0.78	0.69
By background material:		
All errors—		
Turns 1-18	0.46	0.79
Turns 4-18	0.14	0.93
Doubtful errors omitted—		
Turns 1-18	0.31	0.86
Turns 4-18	1.54	0.47

¹ Probability shown is that of obtaining by chance alone a chi-square value as large as or larger than that observed; for example, a chi-square value as large as or larger than 0.46 would be expected to occur almost 8 times out of 10 merely from chance.

the curbs and road edges. (At the time of the tests, however, no snow was on the ground and the pavements were dry.) The observers recorded on the data sheets that the subject often called out when he saw the sign or reduced speed and operated his turn signal but failed to make the turn. From these comments, it was concluded that many of the errors were caused by the subject missing the exit rather than the sign. On the basis of the observer's comments, an attempt was made to cull out those errors that should not have been attributed to the signs. In the statistical analyses, these errors were termed *doubtfuls*.

Two analyses of errors were made by nights and by backgrounds for several categories: (1) data for turns 1 through 18, and (2) data for turns 4 through 18. Total errors and total errors from which doubtfuls were excluded were analyzed in each.

Data Analysis

The number of errors, by nights and by backgrounds, for each turn on the route and for selected groups of turns are shown in table 3. The results of chi-square tests³ performed on these frequencies of errors are shown in table 4. The probability shown is that of obtaining by chance alone a chi-square result as large as or larger than that observed; for example, a chi-square statistic as large as or larger than 0.46 would be expected to occur almost 8 times out of 10 merely from chance.

The chi-square tests produced no evidence of any significant differences between the numbers of errors for any of the items of comparison, either by nights or by background treatments, as summarized in table 4. Chi-square tests on the relative frequencies of errors, by turns, were generally significant at the 1-percent level or less, indicating that there were significant differences in frequencies

³ *Introduction to Statistical Analysis*, Wilfrid J. Dixon and Frank J. Massey, Jr., McGraw-Hill Book Co., Inc., New York, 1957, ch. 13.

of errors among the turns. These differences had been anticipated and the experiment designed accordingly.

The number of errors for the different items of comparison, as shown in figure 9, has been plotted by relative specific luminance of the background materials at a $\frac{1}{2}$ -degree divergence angle. The scales on the right side of the figure are the percentages of errors based on the number of sign encounters for each of the comparisons. Consideration of the errors for all turns shows the occurrence of errors to have been approximately $8\frac{1}{2}$ percent of total possible errors. Omission of the doubtful errors brings the percentage down to 7. When the data for the first three turns are eliminated, total errors drop to approximately $4\frac{1}{2}$ percent; and when the doubtfuls are omitted, total errors drop to $3\frac{3}{4}$ percent. Differences in the percentages of errors among the three background materials do not exceed 1 percentage point, and they are not statistically significant.

Discussion

This study was designed to test one aspect of the relative effectiveness of different degrees of sign background reflectorization: the ability of drivers to react correctly to information displayed on signs. Therefore, the analysis is directed primarily to a comparison of the relative frequency of errors made for signs in relation to different background materials. Differences that occurred in brightness for each of the sign locations were not part of the experimental design of the study. But, the same material will vary in brightness because of differences in highway alignment of the approach to the sign. Alignment affects the incidence angles and the intensity of headlight illumination on the signs. In fact, because of differences between locations, moderately reflective material II was brighter at some locations than material III (the standard sheeting) was at other locations.

Although the experimental design ensured that turns were balanced by background material, there was no balance between turns and brightnesses of the backgrounds. This was further confounded by the reduction in the brightness of some signs because of moisture condensation. However, because relative frequencies of errors by nights were not statistically significant, it is concluded that reductions in sign brightness did not cause an increase in errors. A plot of errors by sign background brightness (measured at 300 feet from the signs, the distance of maximum median brightness) showed such scatter that no definite trend could be determined. A possible trend toward fewer errors at higher background brightness was indicated by the plot of errors, but the small number of locations at which high background brightness occurred and the lack of balance between turns and brightness made an analysis of errors by brightness almost meaningless.

The measured brightness of the sign materials on signs in place are shown in figure 8. Although analysis of the study data showed no evidence of any difference in relative frequency of errors between materials for the brightnesses covered, it is possible that fewer errors would have been made if the brightness level had been higher. Before considering this possibility, it might be well to compare the sign brightnesses recorded in the study with those that would exist in actual practice on an Interstate highway. To compare the relative brightness of the same material under test conditions and under Interstate conditions, the standard sheeting median brightness curve for the test signs from figure 8 and brightness curves of standard sheeting for Interstate signs, calculated for four-lamp and two-lamp low beams, have been plotted in figure 10. To allow for differences between speeds of 40 m.p.h. on the test route and 60 m.p.h. on Interstate highways, the abscissa is in units of time elapsed before the sign is reached. This illustrates that, for the same material, the brightnesses of the test signs and those of Interstate signs were comparable. Comparison of the curves for two-lamp illumination shows that the test signs were, on the average, slightly brighter than the Interstate signs. Therefore, sign backgrounds brighter than those tested would have had to have more brightness than ordinarily is available from standard sheeting on Interstate signs.

As previously stated, the highways on which the tests were conducted were designed to lower standards than those for current Interstate highways, and prevailing speeds were also lower. Compared to Interstate conditions, speeds on the test route were approximately two-thirds of those on Interstate highways; sign legends were about one-half the size; and the signs themselves were about one-fourth the size of Interstate signs. The size ratio between the test signs and Interstate signs was smaller than the ratio between the speeds on the respective facilities. Therefore, except for the closely spaced exits, study conditions may have constituted a more difficult test of signing than current Interstate conditions impose.

The methodology employed for the study discussed here may have applicability to other studies in related subject areas. A relatively large number of test subjects would be needed, however, because of the small proportion of typical errors observed. As in all studies involving test subjects as drivers, precise and concise instructions are essential to minimize confusion. Temperature, humidity, and precipitation are additional factors that must be considered, although they are usually outside the realm of control.

Findings

The findings obtained from this study are limited because of the relatively few errors made and the presence of confounding factors in the tests. Errors made by test subjects in following the route were not statistically

significant by type of sign background. Therefore, the study findings do not substantiate the existence of any difference in the effectiveness of different degrees of sign background reflectorization. Because all data omitted turns are enumeration data and therefore insensitive to small differences, more data—more subjects or more turns—would be required to establish statistical significance.

The occurrence of errors, in absolute terms was relatively small: errors made, from whatever source, averaged $8\frac{1}{2}$ percent of total possible errors; and errors attributable to the signs and not to the conditions of the study amounted to less than 4 percent. If the probability of missing a single sign, regardless of the degree of background reflectorization is 4 percent, the probability of missing two advance signs would be in the order of 0.1 percent.

Based on the observers' comments, one of the major problems in providing guidance to drivers is to enable them to relate the information on the sign and the placement of the sign to a decision to change direction. Another problem facing drivers is that of locating the geometric features to which the sign relates, particularly the exit gore.

ACKNOWLEDGMENTS

This study could not have been made without the assistance and cooperation of many individuals and organizations. Particular appreciation is extended to Richard N. Schwab of the Traffic Systems Division for his assistance during the organization and execution of the study and for his direction of the visual and photometric tests. Appreciation is also extended to Region 15 of the Bureau of Public Roads for the fabrication and erection of the sign supports and for the placement and removal of signs during the study; to the Arlington County Highway Division, the Virginia Department of Highways, and the National Park Service of the Department of the Interior for permission to erect signs on highways under their jurisdictions; to Government Services, Inc., for the use of the Columbia Island Marina Parking Lot and Boathouse for a staging area; to the District of Columbia Department of Highways and Traffic for the fabrication of the auxiliary signs used in the study; to the Junior Chambers of Commerce of the District of Columbia and Maryland suburban local chapters of the Lions Club, and the local chapter of the Sports Car Club of America for their cooperation in communicating to their members the need for test subjects; to the individuals who volunteered to be test subjects; to the group of men who, during their period of training as Junior Engineers in the Washington office of the Bureau of Public Roads, took part in the study; and to Sterling Seagrave, reporter for the Washington Post & Times Herald newspaper, for withholding his article on the study until after completion of the field test.

Shear Loads on Pavements

by EDWARD S. BARBER, Highway Research Engineer,¹
Structures and Applied Mechanics Division

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RESEARCH AND DEVELOPMENT
BUREAU OF PUBLIC ROADS

INFLUENCE charts are presented here for determining the horizontal normal stresses from a uniform shear load over any area. These data are presented as a supplement to *Shear Loads on Pavements*, by E. S. Barber, in *PUBLIC ROADS, A Journal of Highway Research*, vol. 32, No. 6, February 1963, pp. 41-144, in which information on the vertical normal and horizontal shear stresses from a shear load is given (p. 143 and fig. 9).

The charts are similar to those developed by Newmark² for a vertical applied load. To calculate horizontal normal stress in a direction parallel to the direction of the load, use figure 1 for Poisson's ratio of 0.5 and figure 2 for Poisson's ratio of 0. Values for other Poisson's ratios are determined by linear interpolation, which is theoretically exact for this load.

To determine the stress below point A at a depth of A-Z, plot the loaded area on the chart by using the distance A-Z=depth, as the plotting scale. Two scales A-Z are shown so that unequal shrinkage of paper will not affect calculations. Count the number of blocks covered by the loaded area. The transmitted stress is $0.001 \times$ number of blocks \times applied shear stress. The influence

is symmetrical about the lower edge of the chart; any loaded area below the edge is folded about the lower edge onto the region above the edge. There is similar symmetry about the left edge, except that the influence to the left of the left edge is negative (tension). The small area in figure 2 between point A and the dotted curve has a very small negative influence.

Use figures 3 and 4 to determine the horizontal normal stress in a direction perpendicular to the direction of the applied load for Poisson's ratio equal, respectively, to 0.5 and 0. There is symmetry about the lower and left edges as in figures 1 and 2. In figure 4, the influence of the blocks covered with pattern is tension.

¹Mr. Barber is also Associate Professor of Civil Engineering at the University of Maryland, College Park, Md.

²Influence Charts for Computation of Stresses in Elastic Foundations, by N. M. Newmark, University of Illinois Eng. Expt. Sta. Bul. No. 338, 1942.

Aerial Color Photography and Its Use in Materials Surveys

(continued from page 171)

REFERENCES

(1) *A Preliminary Evaluation of Color Aerial Photography for Use in Materials Surveys*, by J. R. Chaves, *PUBLIC ROADS*, vol. 32, No. 1, April 1962, pp. 17-20.

(2) *Application of Color Aerial Photography to Geologic and Engineering Soil Mapping*, by J. R. Minard and J. P. Owens, *Soil Foundation and Materials Exploration Methods, Application and Evaluation*, HRB Bulletin 116, 1962, pp. 12-22.

(3) *Aerial Color Film*, by W. J. Nagel, presented at the annual meeting of the American Society of Photogrammetry—American Congress on Surveying and Mapping, Washington, D.C., 1962.

(4) *Kodak Data for Aerial Photography*,

Kodak Publication No. M-125, Eastman Kodak Co., Rochester, N.Y., 1961.

(5) *Use of Polaroid Filters on Kelsh Plotters*, by H. D. Petterson, *Photogrammetric Engineering*, vol. 29, No. 5, September 1963, pp. 882-887.

(6) *Color Aerial Photography in Geologic Investigations*, by W. A. Fischer, *Photogrammetric Engineering*, vol. 28, No. 1, March 1962, pp. 133-139.

(7) *Spectral Reflectance Measurements as a Basis for Film-Filter Selection for Photographic Differentiation of Rock Units*, by W. A. Fischer, U.S. Geological Survey, Professional Paper No. 400-B, 1960, pp. 136-138.

(8) *Quantitative Photography—A Geologic*

Research Tool, by R. C. Ray and W. A. Fischer, *Photogrammetric Engineering*, vol. 26, No. 1, March 1960, pp. 143-50.

(9) *Application of a Microdensitometer to Photo Data Assessment*, by A. J. Derr, presented at the Fifth Annual Symposium of the Society of Photographic Instrumentation Engineers, August 1960.

(10) *Experimental Studies of Aerial Photographs in Japan*, by T. Maruyasu and M. Nishio, *Institute of Industrial Science, University of Tokyo*, vol. 8, No. 6, March 1960.

(11) *Color and False-Color Films for Aerial Photography*, by R. G. Tarkington and A. L. Sorem, *Photogrammetric Engineering*, vol. 29, No. 1, January 1963, pp. 88-95.

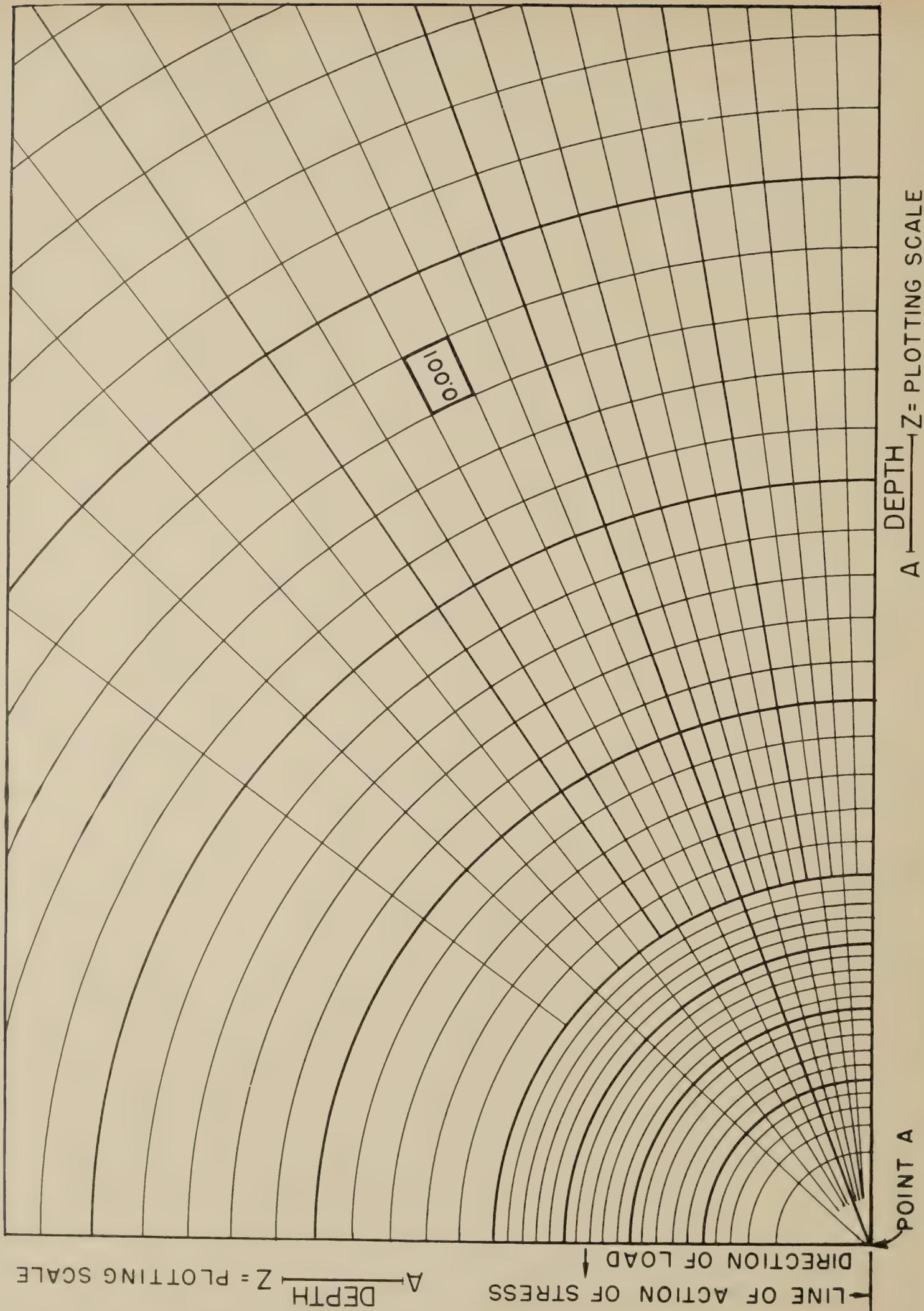


Figure 1.—Influence Chart for horizontal normal stress from applied shear load, stress parallel to load—Poisson's ratio, 0.5.

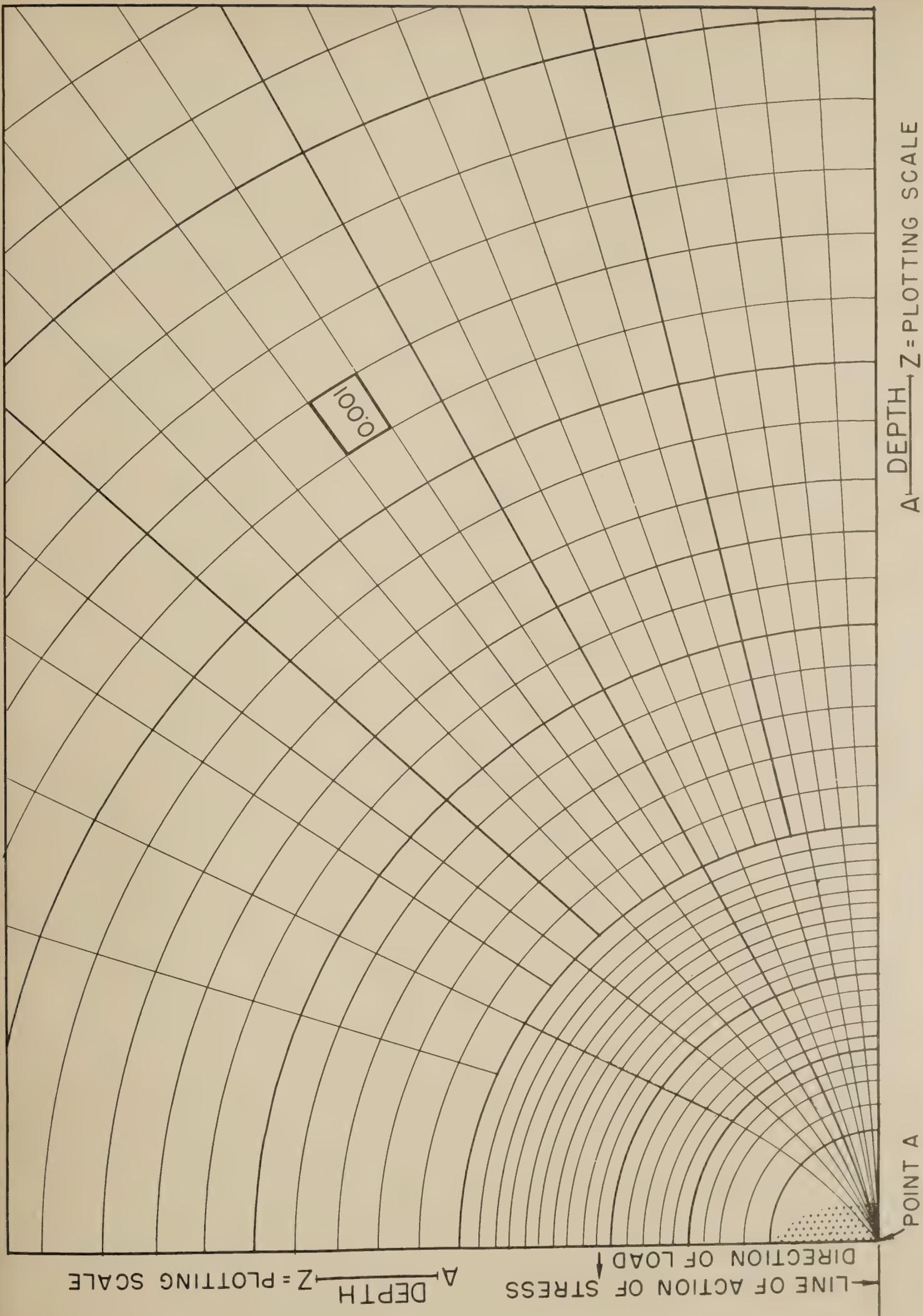


Figure 2.—Influence Chart for horizontal normal stress from applied shear load, stress parallel to load—Poisson's ratio, 0.

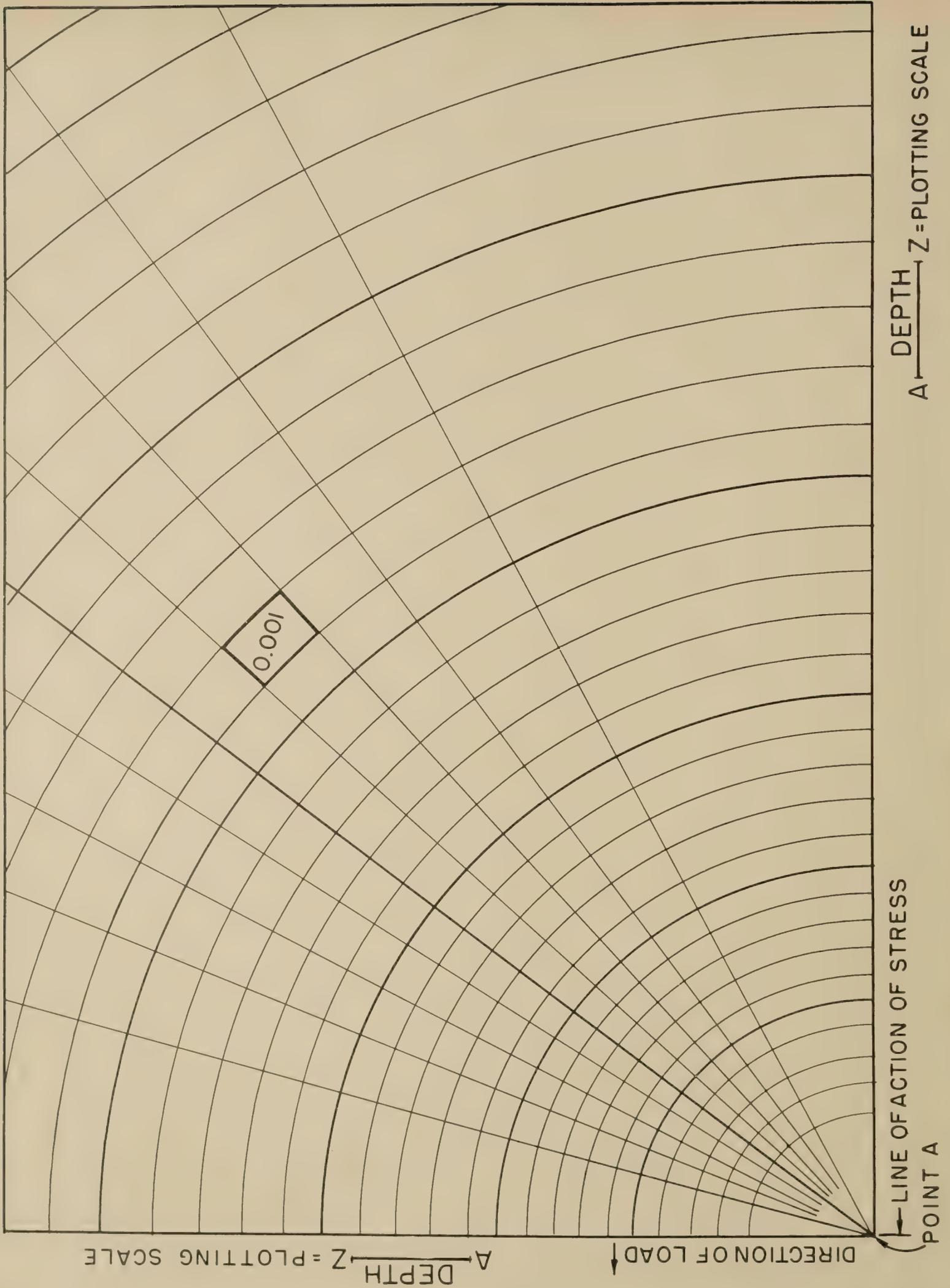


Figure 3.—Influence Chart for horizontal normal stress from applied shear load, stress perpendicular to load—Poisson's ratio, 0.5.

Figure 3.—Influence Chart for horizontal normal stress from applied shear load. Stress perpendicular to load, $\nu = 0$.

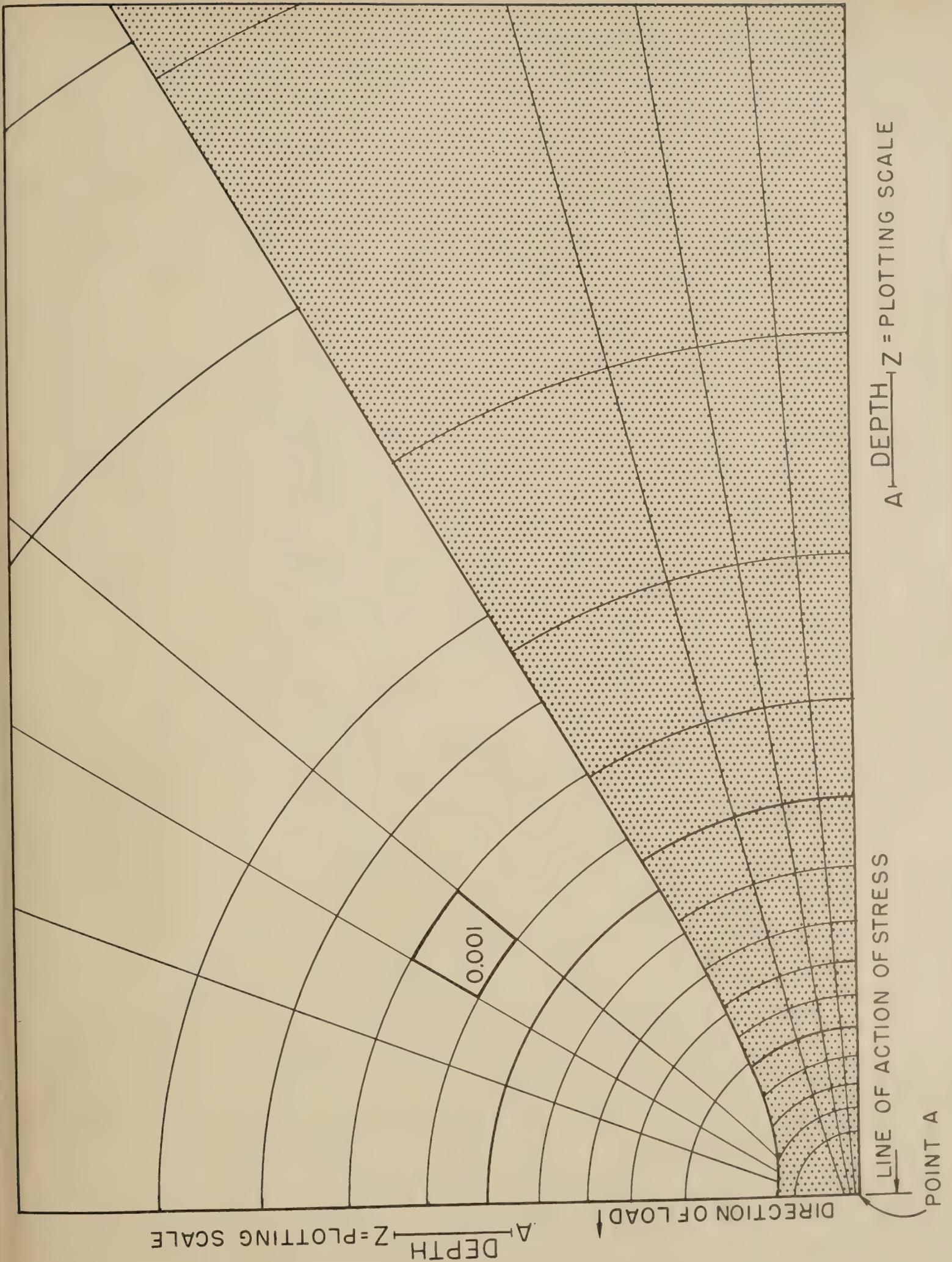
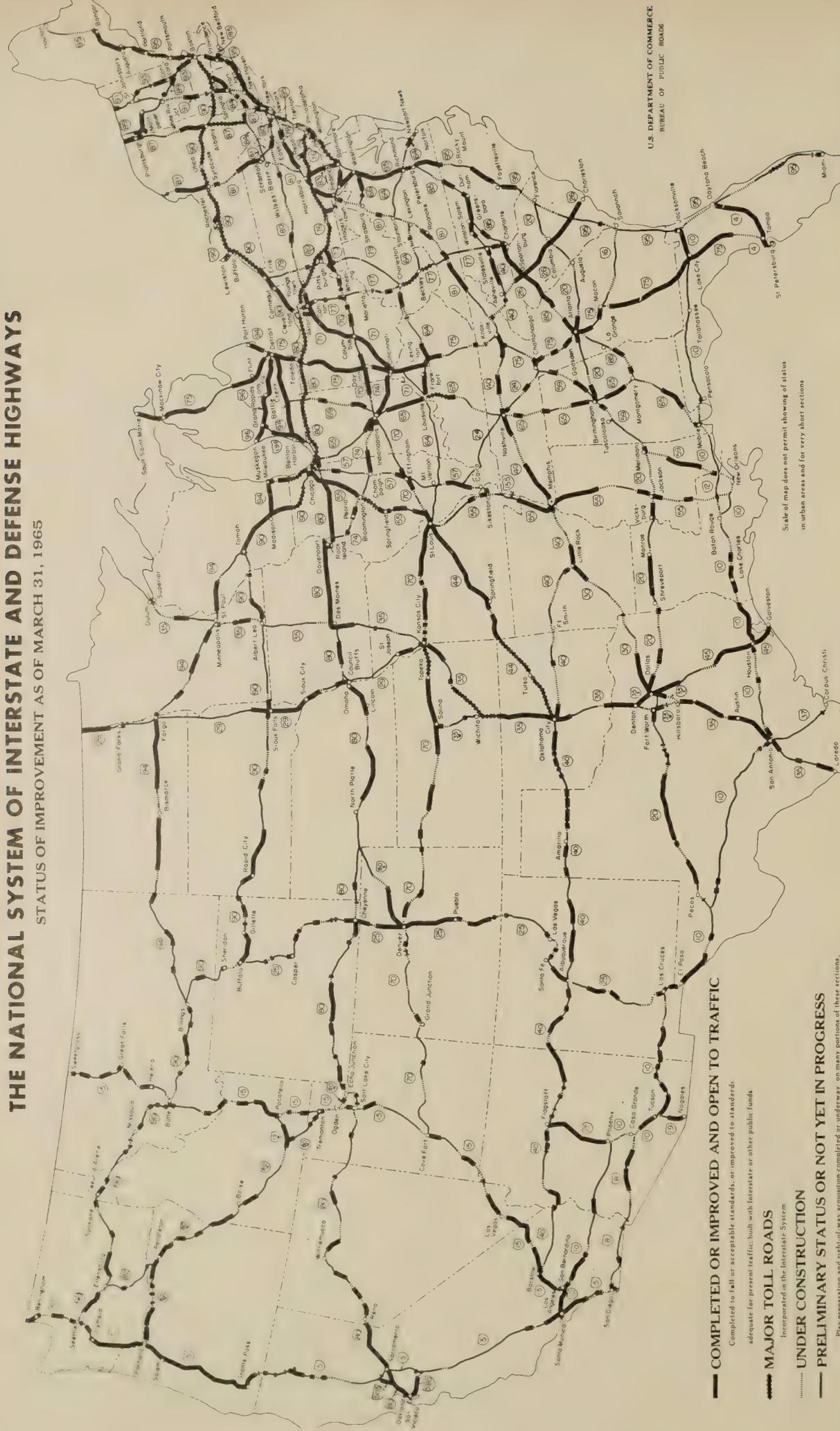


Figure 4.—Influence Chart for horizontal normal stress from applied shear load, stress perpendicular to load—Poisson's ratio, 0.

THE NATIONAL SYSTEM OF INTERSTATE AND DEFENSE HIGHWAYS

STATUS OF IMPROVEMENT AS OF MARCH 31, 1965



U.S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS

Scale of map does not permit showing of status in urban areas and for very short sections

- COMPLETED OR IMPROVED AND OPEN TO TRAFFIC**
Completed for present traffic; built with Interstate or other public funds adequate for present traffic; built with Interstate or other public funds Completed to full or acceptable standards, or improved to standards
- MAJOR TOLL ROADS**
Incorporated in the Interstate System
- UNDER CONSTRUCTION**
- PRELIMINARY STATUS OR NOT YET IN PROGRESS**

Plan preparation and right-of-way acquisition completed or underway on many portions of these sections.

INTERSTATE
TOTAL
41,000
MILES

<p>Preliminary Status or Not Yet in Progress 4,316 Miles</p>	<p>Engineering and Right-of-Way in Progress 11,920 Miles</p>	<p>Under Construction 5,591 Miles</p>	<p>Open to Traffic 19,173 Miles</p>
<p>24,764 Miles</p>			

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