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HIGHWAY RESEARCH BOARD
Special Report 12

Research Needed in Geometric Highway Design

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HIGHWAY RESEARCH BOARD

Special Report 12

Research Needed in Geometric Highway Design

Includes Research Problem Statements Outlining Areas for Large and Small Unit Research on Different Phases of 26 Selected Subjects for Which Data Are Needed in Highway Design.

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A Report on

RESEARCH NEEDED in the FIELD of GEOMETRIC HIGHWAY DESIGN

D. W. Loutzenheiser, Chairman
Committee on Geometric Highway Design

SINCE 1948 when the Committee on Geometric Highway Design was formed, it has had under consideration various methods whereby the research needed in that field could be made evident to those interested and thereby expedite the accumulation of needed data. It was concluded to undertake the listing of a group of separate subjects on which research in this field was needed and the preparation for each of these subjects of an outline of the type of observations and data needed. Twenty-six subjects were selected as a reasonably complete slate of items of current importance.

After trial of several forms of statement preparation, it was deemed most important to draft these statements so as to demonstrate the separate and related items or phases of research needed rather than to outline the general highway design problem. Some of the subjects are very broad in scope and it seemed essential to outline the separate component fields of search that an individual or small group might undertake. A rather concise research problem statement of this type has been prepared for each subject. These now are offered by the Committee for general distribution by the Highway Research Board to any and all agencies or individuals that may be in a position to aid in the needed research.

In order to make clear the general field within which these research problem statements are applicable, the Committee has agreed on the following definition:

> "Geometric highway design is a phase of highway design dealing with the visible dimensions of a roadway.
> "It is dictated, within economic limitations, by the requirements of traffic and includes the design elements of horizontal and vertical alinement, sight distances, cross section components, lateral and vertical clearances, intersection treatment, control of access, etc."

For any one subject the basic problem, or end product is that of the "how" and "what" in design--how best to arrange dimensions and design elements within a given section of highway. However, the basic research needed invariably is data on traffic operation, vehicle characteristics, driver behavior and accident data, as related to the different geometric elements and highway conditions. In actual use, conclusions from these research data must be applied with knowledge of materials, construction, maintenance, drainage, roadside, economic, and administrative controls before a safe and economical highway design can be made. The research needed includes inquiries that enter into work of several of the Board's committees all of whom are always willing to cooperate with the individual or agency desiring to undertake research in the respective committees field of activity. The application into current design practices or standards of data secured through research on these problems is recognized as a function of committees of other organizations.

For some of the subjects research already has been started to some degree and it remains to broaden and complete the collection of data. The problem statements include selected references in order to indicate known inquiries of this type. These are major references, largely publications available in most engineering libraries. Whenever applicable, the terms in the AASHO adopted definitions have been used.

Each of the following research problem statements has been prepared in as concise a form as possible to clearly point out the conditions for which observations and data are needed. It is the intent to make evident to those in universities, highway departments, and other agencies that might be in a position to undertake any form or any part of the needed research, the limited field of data needed for each subject. It is recognized that to undertake a research project on the whole, or a part of any subject, an expanded problem statement would be necessary. The Committees of the Highway Research Board stand ready to assist any group in the formulation of more detailed statements and outline of procedure as might be applicable to any contemplated research study. Additional references such as unpublished reports, college theses, etc., probably can be offered in many cases; and it may be possible to assist individuals or groups in finding sponsors or means whereby an item of research can be completed and reported.

Following is a list of the 26 subjects for which problem statements have been prepared. In a general way, those considered to be of greatest importance are first in the group, but the specific numbering of the statements primarily is for identification, rather than a priority rating of the subject material.

List of Subjects

Highway Research Board
Committee on Geometric Highway Design

Research Problem Statement Number 1

WIDTH AND CROSS SECTION OF A MEDIAN

I. General Problem

To evaluate each of the design elements of medians as determined by their effect on traffic operation.

II. Specific Statement

Observations on the volume, type, speeds, and placement of traffic, together with analyses of accident statistics and costs of construction and maintenance are needed in relation to the design elements, widths, and treatment of medians.

III. Factors Involved

A. Volume, type and character of traffic.

B. Type of median
   1. Narrow vs. wide
   2. Curbed, flush or depressed

C. Type of area
   1. Downtown
   2. Suburban
   3. Rural

D. Headlight glare re median width and roadway elevations.

E. Design of auxiliary lanes within median.

F. Design for protection of crossing vehicles.

G. Emergency storage of vehicles.

H. Placement of signs, traffic signals and structural appurtenances (center piers, drainage facilities, light standards, etc.)

I. Storage of snow and drainage of median area

J. Future widening of traveled way.

K. Economic factors.

IV. Research and Data Needed

A. Observations and analyses (see II) on medians of different widths in relation to:
   1. Type of highway
      a. Freeway; full control of access
      b. Expressway with partial control of access
      c. Major street or highway without control of access
   2. Separation of opposing traffic
      a. Driver strain and concentration
      b. Type of area traversed and speeds
      c. Headlight glare
   3. Protection of turning and crossing vehicles
      a. Size and type of vehicles
   4. Provision of auxiliary lane within median space
      a. One side
      b. Both sides
   5. Protection as a pedestrian refuge
   6. Clearances for center piers, signs, traffic signals, and light standards.

B. Observations and analyses (see II) on medians of different cross section design in regard to:
   1. Effect of type of median edge treatment
      a. Barrier curbs
      b. Mountable curbs
      c. No curbs--flush sections
      d. No curbs--depressed sections
   2. Drainage facilities required

C. Economic considerations
   1. Cost of construction and ROW
   2. Effect upon business frontage

D. Provision of and frequency of median openings to provide service to adjacent property.

V. Selected References

Research Problem Statements Number 16 and 24.

A Policy on Intersections at Grade - AASHO, 1940.

A Policy on Highway Types - AASHO, 1940.

A Preliminary Discussion on Arterial Highways in Urban Areas - Part I, February 1950, AASHO.

Highways With a Narrow Median - HRB Bulletin 35, 1951.

Highway Median Study in 1952 - E. T. Telford and R. J. Israel, HRB Proceedings, 1953.

Highway Research Board
Committee on Geometric Highway Design

Research Problem Statement Number 2

WARRANTS FOR HIGHWAY INTERCHANGES

I. General Problem

To obtain or collect the information from which warrants may be determined for interchanges, i.e., highway grade separations with ramps.

II. Specific Statement

Since interchanges are expensive it is desirable to set up a method for determining and evaluating the factors to be considered in establishing warrants for the separation of grades at an intersection of two streets or highways. Such warrants often are based on a comparison of the at-grade condition with the separation improvement.

III. Factors Involved

A. For at-grade condition
   1. Value of investment on annual basis
   2. Site conditions and topography
      a. Effect on intersection type
      b. Effect on traffic control
   3. Traffic information
      a. Volume and type of traffic
      b. Turning movements
      c. Speeds
      d. Type of traffic control
      e. Capacity analyses
   4. Costs of operation
      a. Highway maintenance and operation of traffic control devices
      b. Operating costs of vehicles
      c. Costs of time losses
      d. Monetary value of accidents
      e. Comfort, convenience, etc.

B. With highway grade separation
   1. Annual cost for ROW and construction
   2. Traffic service during construction
   3. Salvage value of existing facilities
   4. Site conditions and topography
      a. Effect on intersection type
      b. Effect on traffic control

5. Traffic information
    a. Volume and type of traffic
    b. Turning movements
    c. Speeds
    d. Type of traffic control
    e. Capacity analyses
6. Cost of operation
    a. Highway maintenance and operation of traffic control devices
    b. Operating costs of vehicles
    c. Costs of time losses
    d. Monetary value of accidents
    e. Comfort, convenience, etc.

C. Future considerations
    1. Traffic growth and travel adjustments
    2. Developments in vicinity of site

IV. <u>Research and Data Needed</u>

A. Operating costs of vehicles involved
    1. On through highways
    2. On curves and grades of ramps
    3. Deceleration, stopping, and acceleration

B. Observation of time loss at an at-grade intersection in stopping, accelerating, and decelerating as related to type and volume of traffic.

C. Observation of time loss by and due to left turning traffic

D. Rating of accident probabilities due to:
    1. Cross traffic - angle collision
    2. Turning traffic - angle collision
    3. Turning traffic - pinching collision
    4. Stopping traffic - rear-end collision
    5. Pedestrians

E. Monetary value of potential accidents

F. Value of time (convenience and economic)

V. <u>Selected References</u>

Highway Capacity Manual - U.S. Government Printing Office, 1950.

Traffic Performance at Intersections - Bruce D. Greenshields.

The Economics of Highway Planning - Technical Bulletin No. 7, Oregon State Highway Department, 1937.

Highway Economics - Tucker and Leager

Highway Intersection Designs Analyzed - Connecticut State Highway Department, Engineering News-Record, January 20, 1949.

Road User Benefit Analyses for Highway Improvements - AASHO, 1952.

A Policy on Grade Separations for Intersecting Highways - AASHO, 1944.

Research Problem Statement Number 3

TRAFFIC BEHAVIOR ON A CLOVERLEAF INNER LOOP

I. General Problem

To evaluate each of the design elements of a cloverleaf inner loop as determined by the effect on traffic operation.

II. Specific Statement

To make observations and formulate conclusions on the volume, speeds and lateral placement of traffic operating on cloverleaf inner loops of different shapes, radii, superelevation, widths, grades, and curb sections.

III. Factors Involved

A. Effect of radii, roadway cross section, type of traffic, etc., on operating speed and practical capacity.

B. Effect of loop size.

C. Effect of curb types on utilization of pavement and shoulder widths.

D. Rate of superelevation for various radii, grades, and operating speeds.

E. Effect of commercial traffic on gradient, width, and radii.

F. Coordination of ramp terminals with speed change lanes.

G. Method of traffic control at the exit of a ramp and its effect upon gradient, width, radii, and shape of ramp. No control vs. stop sign vs. traffic signals.

IV. Research and Data Needed

A. Observations of traffic volumes, speeds, paths, and other behavior indications in relation to inner loop:
   1. Shapes and grades

2. Radii, widths and superelevation
   a. One-lane vs. two-lane operation
3. Curb sections or shoulder areas, both at right and at left
4. Combinations of 1 to 3 as arranged for deceleration facility at loop entrance terminal
   a. Offset distance for curb nose
5. Combinations of 1 to 3 as arranged for acceleration facility at loop exist terminal
   a. Transitions to single lane widths

B. Analyses of data from IV-A to indicate practical capacities for various designs of inner loops.

V. Selected References

A Policy on Grade Separations for Intersecting Highways - AASHO, 1944.

Highway Capacity Manual - U.S. Government Printing Office, 1950.

Progress in Grade Separations - H. W. Giffin, Roads and Bridges, April 1946.

Research Problem Statement Number 4

EFFECT OF PROPORTION AND CHARACTER OF COMMERCIAL VEHICLES ON GEOMETRIC DESIGN ELEMENTS

I. General Problem

To determine the traffic behavior patterns for different proportions and character of commercial vehicles in relation to the highway geometric design elements.

II. Specific Statement

Observations are needed to establish traffic behavior patterns that will correlate two general sets of factors, (a) the proportion and character of commercial vehicles in the traffic stream and (b) the geometric design elements such as horizontal curves, grades, widths, lateral clearances, etc. Obtainment of data over a range in these factors should permit conclusions as to the geometric design dimensions needed for traffic streams with designated proportions and character of commercial vehicles to result in a desired freedom of operation of all vehicles.

III. Factors Involved

A. Characteristics of commercial vehicles
   1. Types and sizes

2. Turning radius and overhang
3. Speeds and speed-change
4. Grade ability

B. Traffic data, by vehicle types
1. ADT, peak hour, 30th highest hour, etc.

C. Highway Design
1. Open highway conditions
a. Alinement
b. Profile; added climbing lanes
c. Cross section: pavement, shoulders, curbs, guardrail, etc.
d. Sight distance
e. Roadside development
2. Intersection conditions
a. Radii of all-paved areas
b. Radii and width of turning lanes
c. Parking, bus stops, etc.
3. Railroad grade crossings
a. Stop requirements

D. Segregation of vehicles by types

E. Economic limitations

IV. <u>Research and Data Needed</u>

A. Traffic data
1. Volumes: segregation by vehicle types
a. ADT
b. 30th highest hour, etc.
c. Directional proportion

B. Character of commercial vehicles
1. Size and type
2. Weight
3. Weight-power factors

C. Highway design elements on sections where traffic observations made.
1. Horizontal curves
2. Grades and profile
3. Width
a. Pavement
b. Shoulders
c. Lateral clearances
4. Sight distances
5. Roadside development
6. Other conditions affecting
a. Intersections
b. Railroad grade crossings

D. Traffic behavior observations correlated with traffic data and highway design
   1. Speeds: types of vehicles
   2. Placement
   3. Other behavior patterns

E. Analyses of data obtained to determine need for increase in design elements above that considered suitable for passenger cars only.

V. Selected References

Highway Capacity Manual - U. S. Government Printing Office, 1950.

Highway Practice in the USA - Bureau of Public Roads, 1949.

A Policy on Highway Types - AASHO, 1940.

A Policy on Highway Classification - AASHO, 1940.

Effect of Roadway Width on Vehicle Operation - A. Taragin, Public Roads, Oct.-Dec. 1945.

Hill Climbing Ability of Motor Trucks - C. C. Saal, Public Roads, May 1952.

Effect of Length of Grade on Speed of Motor Vehicles - A. Taragin, HRB Proceedings, 1945.

Research Problem Statement Number 5

PERCEPTION TIME AS RELATED TO STOPPING SIGHT DISTANCE

I. General Problem

The effect of perception time on the required safe stopping sight distance varies with individual drivers, operating conditions, type of object, and vehicle speeds. Due to the dearth of information from scientifically controlled perception time tests, the assumptions made and perception times used in determining safe stopping sight distances should be verified or changed.

II. Specific Statement

To determine from scientifically controlled tests, perception times which would take into account the mental and physical conditions of drivers, condition of roadway and roadsides, complexity of the traffic situation, the characteristics of the object sighted, and degree of visibility.

III. Factors Involved

A. Driver characteristics
   1. Visual acuity
   2. Mental alertness
   3. Physical condition-reflexes
   4. Habits vs. elements of surprise

B. Characteristics of object
   1. Type
   2. Size and shape
   3. Color and contrast

C. Roadway
   1. Lane widths
   2. Shoulders
   3. Curbs
   4. Condition of sight limitation

D. Roadside development

E. Atmospheric conditions and visibility

F. Braking distance: see Research Problem Statement 6

IV. Research and Data Needed

A. Observations to determine values of perception time under various conditions for:
   1. Drivers
      a. Age groups
      b. Physical condition
      c. Minimum physical requirements of licensing laws
   2. Type of object and situation
      a. Simple situation (single stationary object)
      b. Intermediate situation (moving object)
      c. Complex situation (moving or stationary objects with distractions)
   3. Roadways
      a. Lane widths
      b. Shoulder widths
      c. Pavement: color and texture
      d. Horizontal vs. vertical sight limitation
   4. Roadside
      a. Effect of types of landscaping
      b. Effect of ribbon development
   5. Visibility
      a. Fair, rain, fog, snow
      b. Day and night

V. Selected References

A Policy on Sight Distance for Highways - AASHO, 1940.

Effect of Varying the Visibility of the Lead Vehicle on Perception of Relative Motion and Distance Between Vehicles at Night - D. Hoppe, HRB Bulletin 43, 1951.

Research Problem Statement Number 6.

Research Problem Statement Number 6

BRAKING DISTANCES FOR REPRESENTATIVE VEHICLES

I. General Problem

To determine required braking distances for vehicles, over the likely range in speeds.

II. Specific Statement

To determine from controlled tests on selected vehicles of different types the required distance for braking under conditions ranging from those of emergency stops (maximum deceleration) to those of an anticipated stop (comfortable deceleration). Information is needed for speeds from 20 to 80 mph., especially for the higher half of the range.

III. Factors Involved

A. Perception time (time for driver to perceive object and determine its status). See Research Problem Statement Number 5.

B. Brake reaction time (time required to apply brakes after perception).

C. Braking distance (distance required to bring vehicle to full stop after brakes are applied).

D. Pavement surface
   1. Types
   2. Condition
   3. Wet and dry

E. Vehicle braking characteristics
   1. Passenger cars
   2. Single-unit trucks
   3. Truck combinations
   4. Test vehicles vs. on-the-road vehicles

F. Tires
   1. Variation in tread and size
   2. Variation in composition
   3. Determination of samples representative of typical traffic

G. Driver variation
   1. Range in reaction time
   2. Range in habitual deceleration rates for other than emergency stops

IV. Research and Data Needed

A. Measurement of brake reaction time to determine encompassing range for representative individual drivers, recognizing
   1. Driver characteristics
      a. Age
      b. Sex
      c. Experience
      d. Habitat
   2. Motion involved, foot feed to brake, in different makes and types of vehicles

B. Measurement by controlled tests of actual braking distances at different speeds from 20 to 80 mph. for different conditions of:
   1. Type of pavement
      a. Wet and dry
   2. Type of vehicle
      a. Passenger cars
      b. Single unit trucks
      c. Truck combinations
   3. Type and condition of tires
      a. Composition
      b. Tread
      c. New vs. worn
   4. Driver control of deceleration rate
      a. Maximum rate
      b. Habitual or comfortable rate
      c. Intermediate rates

C. Observations of deceleration rates of unadvised drivers operating under normal highway conditions
   1. Highway situation
      a. Stop sign or traffic signal
      b. Deceleration lane
      c. Toll gate, etc.
   2. Type of vehicle
      a. Passenger cars
      b. Single-unit trucks
      c. Truck combinations
   3. Other variables
      a. Night and day
      b. Wet and dry

V. Selected References

A Policy on Sight Distance for Highways - AASHO, 1940, defines non-passing sight distance as follows: The nonpassing sight distance is the sum of two distances; one the distance traversed by a vehicle from the instant the stationary object is visible to the instant the brakes are applied, and the other, the distance required to stop the vehicle after the brakes are applied. The first of these two distances depends upon the speed of the vehicle and the sum of the perception time and the brake reaction time of the operator. The second distance depends upon the speed of the vehicle, the characteristics and condition of the brakes, tires, and pavement surface, and the alinement and grade of the highway.

Reaction Time - H. E. Neal, Highway Research Board Abstracts, October 1946.

Study of Visibility on Convex Vertical Curves - Mennier: Ann Ponts Chaus., 1946, 116 (4) 418-62.

Skidding Characteristics of Automobile Tires on Roadway Surfaces - R. A. Moyer, Bulletin 120, Iowa Engineering Experiment Station.

Deceleration Distances for High Speed Vehicles - E. E. Wilson, HRB Proceedings, 1940.

Research Problem Statement Number 5.

Skid Resistance Measurements of Virginia Pavements - HRB Research Report No. 5-B, 1948.

Acceleration and Deceleration Characteristics of Private Passenger Vehicles - John Beakey, HRB Proceedings, 1938.

Braking Distances of Vehicles from High Speeds - O. K. Normann, HRB Proceedings, 1953.

Age and Complex Reaction Time - Research Report No. 41, American Automobile Association, 1952.

Research Problem Statement Number 7

EFFECT OF OPERATION OF BUSES ON URBAN ARTERIAL HIGHWAYS

I. General Problem

To observe the over-all effect of operation of buses, including accidents and delays, upon other traffic operating on urban arterial highways.

II. Specific Statement

Traffic conflicts caused by buses on urban arterials are subject to improvement or possibly elimination through design and regulation. Study of the effect of bus operation on traffic flow should suggest appropriate remedial measures.

III. <u>Factors Involved</u>

A. Type of Arterial
   1. Full control of access
   2. Partial control of access
   3. Access not controlled

B. Pertinent Locations
   1. Loading points
      a. Loading on through lanes of arterials
      b. Loading on widened arterial pavement (bays or turnouts)
      c. Off-arterial loading
   2. Between loading points

C. Effects upon capacity

D. Accidents

E. Bus service demand
   1. O and D for bus patrons

F. Bus regulations
   1. Private vs. Public operation

G. Economics

IV. <u>Research and Data Needed</u>

A. Obtainment and analyses of accident data
   1. With and without bus operation
      a. By location (stops and between stops)
      b. Security

B. Observations of traffic movements on different types of urban highways to determine
   1. Traffic volumes and speeds
   2. Headway between buses and other vehicles
   3. Opportunity to pass buses
   4. Gap required in traffic for bus to enter
   5. Acceleration and deceleration practices of buses
   6. Interference and blockage caused by buses at stops

C. Observations of bus operation to determine for selected routes:
   1. Number of persons carried by bus vs. number in private vehicles
      a. Trends in number of riders with arterial bus service and influence upon number of private vehicles
   2. Loading practices (time required to load and unload, etc.)
   3. Required frequency of stops
   4. Bus sizes and dimensions
      a. Type of equipment for least interference with traffic flow and most efficient bus service

5. Driver practices in use of stop facilities
6. Observance of traffic regulations
7. Type of bus operation
    a. Express
    b. Turn back
    c. Skip stop

D. Observations of operations made at different bus stop facilities involving:
    1. Special operating lanes
    2. Roadside bays or turnouts
        a. Location of bays
        b. Length of bay (storage requirement)
        c. Provision of and length of acceleration and deceleration lanes
        d. Length and sharpness of curve to effect widened bay
        e. Separated vs. nonseparated bays
            (1) Flush separators
            (2) Raised separators
    3. Loading platforms
    4. Pedestrian facilities
        a. Stairs vs. ramps

E. Observations of operations made at bus stop facilities with different regulation such as:
    1. Parking restrictions in bus loading zones
    2. Near-side vs. far-side bus stops
    3. One-way street operation
    4. Location and timing of traffic signals

F. Analyses of conclusions from above data regarding
    1. Provision of special bus facilities to consider:
        a. Time savings to bus patron
        b. Savings in cost of operation to transit company
        c. Delay to other vehicles
        d. Additional cost of operation to other traffic
        e. Initial and maintenance costs

V. <u>Selected References</u>

National Safety Council Accident Facts, yearly.

Highway Capacity Manual, U. S. Government Printing Office, 1950.

A Preliminary Discussion on Arterial Highways in Urban Areas - Part I, February 1950, AASHO Committee on Planning and Design Policies.

Report of Project Committee on Near-Side and Far-Side Bus Stops - H. S. Simpson, HRB Department of Traffic, 1939.

Manual of Transit and Traffic Studies, 1947 - American Transit Association.

Research Problem Statement Number 8

SPACING OF SAFE PASSING SECTIONS ON 2-LANE HIGHWAYS

I. General Problem

Preferably 2-lane highways should be designed with continuous safe passing sight distance throughout. In other than flat terrain this seldom is feasible because of extensive cut and fill construction. The minimum number of passing opportunities consistent with reasonable freedom of operation should be determined.

II. Specific Statement

To make traffic behavior studies for different conditions of sight distance restriction and to correlate these data with possible criteria for measurement of passing sight distance restrictions.

III. Factors Involved

A. Highway conditions
   1. Alinement and profile as determined by topography
   2. Character and uniformity as related to design speed
   3. Cross section

B. Traffic conditions
   1. Volumes and fluctuations
   2. Type of vehicles
   3. Nominal vs. actual speeds

C. Resultant need for passing maneuvers

D. Distance required for safe passing
   1. Perception and reaction time
   2. Clearance at beginning and end of passing
   3. Differences in speeds
   4. Actual passing distance
   5. Clearance to oncoming vehicle

E. Conditions resulting in hazardous passing maneuvers

F. Differences between 2-lane and 3-lane conditions

IV. Research and Data Needed

A. Observations to obtain data on passing frequencies in normal highway operations as related to length of passing section for different:
   1. Traffic volumes
   2. Sizes and proportions of trucks
   3. Highway design conditions

B. Traffic behavior and operation studies on selected lengths of highways having different spacings of passing sections to determine:
   1. Type of highway and design speed
   2. Traffic volume
   3. Percentage of trucks
   4. Average running or over-all speeds
   5. Distribution of speeds
   6. Proportion of over-all trailing time
   7. Passings accomplished per unit of volume and distance
   8. Over-all retardation or delay to traffic by comparison with highways having continuous passing sight distance
   9. Accidents

C. Correlation of above data to several possible criteria for measurement of passing sight distance restriction with
   1. Individual passing sections, based on
      a. AASHO values, 4.5-foot height of eye to 4.5 foot object, for different design speeds
      b. Sight from 4.5-foot height of eye to actual physical limitation, as pavement surface, of selected sight distances as 500, 1000, 1500, 2000 feet, etc.
   2. Over-all passing sight distance condition on continuous length of highway, based on
      a. Percentage of total length of highway on which sight distance is restricted to less than that in items 1-a and 1-b above.
      b. Proportion of various lengths per mile
      c. Other

V. Selected References

Highway Capacity Manual - U. S. Government Printing Office, 1950.

A Policy on Sight Distance for Highways - AASHO, 1940.

Highway Practice in the U S A - Bureau of Public Roads, 1949.

Methods of Measuring Judgment and Perception Time in Passing on the Highway - T. W. Forbes, HRB Proceedings, 1939

Hill-Climbing Ability of Motor Trucks - C. C. Saal, HRB Proceedings, 1941.

Effect of Length of Grade on Speed of Motor Vehicles - A. Taragin, HRB Proceedings, 1945.

Passing Practices on Rural Highways - C. W. Prisk, HRB Proceedings, 1941.

Time and Gasoline Consumption in Motor Truck Operation - HRB Research Report No. 9-A, 1950.

Research Problem Statement Number 9

CORRELATION OF DESIGN SPEED, RUNNING SPEED, OVER-ALL SPEED AND CHARACTER AND VOLUME OF TRAFFIC

I. General Problem

On a given highway for different traffic volumes the relation of the running, over-all and design speeds appears to vary. As an essential tool for highway design and to avoid undesirable operating conditions, the actual relations should be known. The following definitions (AASHO) apply:

Design Speed - A speed determined for design and correlation of the physical features of a highway that influence vehicle operation. It is the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern.

Running Speed - The speed over a specified section of highway, being the distance divided by running time (the time the vehicle is in motion). The average for all traffic, or component thereof, is the summation of distances divided by the summation of running times.

Over-all Speed - The speed over a specified section of highway, being the distance divided by over-all travel time (the time of travel, including stops and delays except those off the traveled way.) The average for all traffic, or component thereof, is the summation of distances divided by the summation of over-all travel times.

II. Specific Statement

To determine the actual over-all and running speeds obtained on different type highways under different terrain conditions and with different design speeds for a range in traffic volumes and types of vehicles.

III. Factors Involved

A. Design features of highway
   1. Design speed
   2. Topography
   3. Number of lanes
   4. Rural vs. urban

B. Control of access
   1. Frequency of access connections
   2. Roadside business and resultant interference

C. Legal speed limits
   1. Extent of enforcement

D. Driver behavior under particular conditions

E. Volume and composition of traffic

IV. Research and Data Needed

A. Traffic observations on selected highway sections to determine
   1. Volume data, hourly, daily, and annual
   2. Traffic classification
   3. Running and over-all speeds over total section lengths

B. Compilation and analyses of accident data for sections studied

C. Coordination and correlation of data collected with design speed, expressed in terms of general types for factors involved.

V. Selected References

Highway Practice in the U S A, (Part 2) - Bureau of Public Roads, 1949.

Highway Capacity Manual - U. S. Government Printing Office, 1950.

A Preliminary Discussion on Arterial Highways in Urban Areas - Part I, February 1950; AASHO Committee on Planning and Design Policies.

Report on Road User Benefit Analyses for Highway Improvements - AASHO, 1952.

A Study of Vehicle, Roadway, and Traffic Relations by Means of Statistical Instruments - T. J. Carmichael and C. E. Haley, HRB Proceedings, 1950.

Evaluation of Techniques for Determining Over-all Travel Time, HRB Highway Research Abstracts, December, 1951.

Driver Behavior Study: Speed Characteristics on Vertical Curves - B. A. Lefeve, HRB Proceedings, 1953.

Relationship of Fuel - Horsepower - Performance and Safety of the Motor Vehicle - T. J. Carmichael, HRB Proceedings, 1953.

The Effect of Speed and Volume on Motor-Vehicle Accidents on Two-Lane Tangents - D. M. Belmont, HRB Proceedings, 1953.

Research Problem Statement Number 10

SPEED-CHANGE LANES FOR RIGHT TURNS

I. General Problem

To determine the effect on traffic behavior of shape, width, length, surface contrast and other design elements of speed-change lanes for right turns.

II. Specific Statement

Observations are needed on the speeds, paths, speed-change and other traffic behavior characteristics at different types and dimensional treatments of speed-change lanes for right turns.

III. Factors Involved

A. Coordination of ramp terminals, crossroads, and T intersections with speed-change lanes for right turns.

B. Type of highway

C. Effect of speed and traffic volume on length of speed-change lanes.

D. Effect of volume and type of traffic on width of speed-change lanes.

E. Influence of various transition designs on traffic operation.

F. Use of different pavement color or texture to differentiate between through lane and speed-change lane.

G. Effect of signing.

H. Driver choice: early pullover or delayed continuous curve path.

IV. Research and Data Needed

A. Observations on selected different speed-change lanes to obtain data on the vehicle speeds at different points along the length, the vehicle paths, and other behavior indications in relation to:
   1. Shape of transition or taper
   2. Length of lane and radius of terminal curve
      a. Contiguous lanes
      b. Separated lanes
   3. Width of lane
   4. Lane contrast in texture and color of surface
   5. Type and location of curbs at deceleration lane terminal curve
   6. Signing and marking or other traffic control devices

B. Above data for different highway conditions of:
   1. Type of highway
      a. 2-lane and multilane
      b. Control of access
      c. Rural vs. urban

2. Type of intersection
   a. All paved
   b. Channelized
   c. Interchange ramp
   d. Acceleration vs. deceleration facilities
3. Range in traffic data; total and adjacent lane
   a. Volumes: ADT and peak hours
   b. Type of vehicles: Passenger car vs. trucks and buses

V. Selected References

Design of Acceleration and Deceleration Lanes - ASCE Transactions 1942.

A Policy on Intersections at Grade - AASHO, 1940.

A Policy on Grade Separations for Intersecting Highways - AASHO, 1944.

Traffic Performance on Acceleration and Deceleration Lanes - HRB Highway Research Abstracts, April 1948.

Traffic Performances at Urban Street Intersections - Yale Bureau of Highway Traffic, Tech. Report No. 1, 1947.

Research Problem Statement Number 11

PARALLEL PARKING LANES ALONG A MAJOR STREET

I. General Problem

Street parking is an important contributing factor to traffic interference and congestion. Its detrimental effect upon capacity and safety extends beyond the contiguous lane. Geometric design is desired which will develop maximum capacity and safety on a major street with parallel parking.

II. Specific Statement

To determine effects on traffic operation of various widths for parallel parking lanes in combination with adjacent lane widths as related to interference with through traffic and increased safety.

III. Factors Involved

A. Street conditions
   1. Lane widths
   2. Type of area and development along street
   3. Enforcement of traffic regulations

B. Traffic Control Devices
   1. Lane striping
   2. Traffic signal control
   3. Regulation of turning movements

C. Traffic Operation
   1. Volumes and fluctuations
   2. Speeds
   3. Types of vehicles
   4. Pedestrian movements
   5. Turning movements
   6. Lateral placement

D. Parking
   1. Length of stalls and marking
   2. Time limit and turnover
   3. Maneuvers to park
   4. Position with respect to curb

E. Other
   1. Bus stops
   2. Influence of weather
   3. Future use of parking lane for through traffic

F. Costs of ROW and construction vs. economic benefits to users

IV. Research and Data Needed

A. Observations of traffic behavior on major streets for various combinations of parking and through lane widths (parking lane 8 to 20 feet wide)
   1. Traffic and operation
      a. Volumes: hourly, daily and annual
      b. Speeds
      c. Types of vehicles involved
   2. Lateral clearance
      a. Between moving vehicles
      b. From parked vehicles
   3. Parking maneuvers
      a. Usual steps involved
      b. Space and time occupied, maneuvers and parked
      c. Effect of single parking maneuver on through movements
      d. Effect of multiple parking maneuvers

B. Collection and analyses of accident data, related to pertinent items under IV-A.

C. Analyses of economic data related to IV-A and B
   1. Extent and cost of delays to through traffic
   2. Cost of wider parking lanes

V. Selected References

Highway Capacity Manual - U. S. Government Printing Office, 1950.

Parking Manual - American Automobile Association, 1946.

A Factual Guide on Automobile Parking for the Smaller Cities - Bureau of Public Roads, 1947.

A Preliminary Discussion on Arterial Highways in Urban Areas Part I, February 1950, AASHO Committee on Planning and Design Policies.

Research Problem Statement Number 12

WIDTH OF TRAFFIC LANES ON DIVIDED HIGHWAYS

I. General Problem

As a result of recent traffic observation studies lane widths of 11 and 12 feet now are widely accepted for 2-lane highways carrying mixed traffic. Divided highways differ in that there are at least 2 lanes for traffic in each direction and lane widths do not involve clearances in meeting opposing traffic in the adjacent lane. Accordingly, there is question if lane widths as determined for 2-lane highways are applicable directly on divided highways.

II. Specific Statement

To observe effects of various lane widths for divided highways as related to speeds, volumes, types of vehicles, and highway geometric design.

III. Factors Involved

A. Traffic volumes and speeds

B. Type of traffic and vehicle dimensions

C. Type of highway
   1. Street
   2. Major Street or Highway
   3. Expressway or Freeway

D. Cross section
   1. Pavement type
   2. Shoulder type, width and amount of use
   3. Lateral clearance to curbs, poles, walls, rails, etc.
   4. Median width and type

E. Traffic stripes and other control devices

IV. Research and Data Needed

A. Traffic studies on different type and width of highways to determine:
   1. Volumes; hourly, daily, and annual
   2. Types of vehicles included

B. Simultaneous traffic operation studies to obtain:
   1. Speeds of vehicles by types
   2. Use of different lanes in same direction
   3. Lateral clearance with respect to different cross section elements
      a. Between curbs and vehicles
      b. Between vehicles
   4. Distances and clearances in passing maneuvers
      a. Distances used in passing
      b. Lateral clearances, vehicles and curbs

C. Analyses of related accident data

V. Selected References

A Policy on Highway Types - AASHO, 1940.

Highways with a Narrow Median - HRB Bulletin No. 35, 1951.

Research Problem Statement Number 13

GEOMETRIC DESIGN OF HIGHWAY SHOULDERS

I. General Problem

Shoulders are essential parts of modern highways. However, there are wide variations in the dimensions, type, and extent of shoulders provided. Continuous wide shoulders obviously are not feasible on all highways, but can be justified for certain conditions.

II. Specific Statement

Data are needed on the actual use of shoulders and related traffic behavior observed on different types of highways, over a range in traffic volume, for different terrain and development conditions, and for different designs of shoulders. Also needed are data on accident experience and cost records for correlation with operational and usage patterns.

III. Factors Involved

A. Type of highways
   1. Two lane
      a. Primary
      b. Secondary

2. Multilane
3. Control of access

B. Traffic
1. Volumes: annual, daily and hourly
2. Speeds
3. Types of vehicles

C. Roadside development
1. Topography
2. Rural vs urban
3. Frequency of crossroads and connections
4. Roadside businesses and driveways
5. Aesthetics related to landscape

D. Design details
1. Width and rounding to side slope
2. Cross slope
3. Type of surface
4. Continuous shoulders vs turnouts
5. Curbs: inside or outside edge of shoulder

E. Structural design of shoulder
1. Local materials
2. Climatic conditions
3. Subgrade and pavement structural design
4. Maintenance practices and costs

F. Accident experience

IV. <u>Research and Data Needed</u>

A. Traffic behavior studies to show speeds and clearances of through traffic when a vehicle is parked
1. Off the pavement, entirely on the shoulder
2. One wheel on pavement, partially on the shoulder
3. Both wheels on pavement

B. Observations of actual use of shoulders for different conditions of
1. Traffic volumes and type of highway
2. Shoulder width and type
3. Continuous vs. turnouts
4. Type of traffic, scenic aspects, and roadside businesses
5. Alinement, profile, and topography
6. Emergency stops vs. rest stops

C. Accident studies comparing experience on highways with different traffic and shoulder conditions

D. Maintenance records to show costs as related to
1. Shoulder type
2. Pavement width and type
3. Traffic types and volumes

E. Studies to show difference in cost of alternate designs with
   1. Narrow vs. wide shoulders
      a. On cuts, fills and structures
   2. Stabilized vs. unstabilized shoulders

V. Selected References

Reports of Highway Research Board Roadside Development Project Committees on Shoulders, 1946-1953.

Transverse Placement of Vehicles as Related to Cross Section Design - A. Taragin, HRB Proceedings, 1943.

A Policy on Highway Types - AASHO, 1940.

Highway Capacity Manual - U. S. Government Printing Office, 1950.

Shoulders on Primary Highways in California - E. T. Telford, AASHO Convention Group Meetings, 1950.

Effect of Shoulders on Speed and Lateral Placement of Motor Vehicles - A. Taragin and H. G. Eckhardt, HRB Proceedings, 1953.

Research Problem Statement Number 14

REVERSE FLOW OPERATION ON MULTILANE STREETS

I. General Problem

To summarize characteristics of reverse flow operation on portions of multilane highways. In this pattern of operation, the center two lanes of (say) a six-lane radial street would be used for inbound flow during the morning peak hours and the same two lanes would be used for outbound flow during the afternoon peak hours. Throughout the day flow on the outside pairs of lanes would remain fixed in the usual "keep right" manner. During off-peak hours the flow would be three lanes in each direction. With this type of operation the six-lane street serves as an equivalent eight-lane section during peak hours.

II. Specific Statement

Observation data are needed on the volumes, speeds, placement, other operating characteristics and accident experience on different multilane streets operated with reverse flow upon the inner lane or lanes.

III. Factors Involved

A. Methods of traffic control for reverse flow operation
   1. Signs and markings
   2. Traffic signals

3. Movable stanchions
4. Separators or curbs, movable or fixed
5. Manual control

B. Traffic volumes vs. street capacity
1. Unbalance of directional traffic during peak hours
2. Length of street with width suitable for reverse flow

C. Operation problems during peak hour unbalanced lane flow
1. Separation of traffic moving in opposite directions
2. Control of movements at terminals of unbalanced lane section
3. Effect of turning movements on reverse flow area
4. Cross street movements
5. Arrangements for pedestrian crossings
6. Loading areas for mass transportation vehicles

D. Accident experience

IV. <u>Research and Data Needed</u>

A. Observations of volumes, speeds, vehicle placement and other traffic behavior indications on streets under different methods of control for reverse flow upon the inner lane or lanes.
1. Signs and markings
2. Traffic signals
3. Movable stanchions
4. Separators or curbs, movable or fixed
5. Combinations of above, including manual control

B. Supplementary studies for specific conditions relating to:
1. Friction between streams of traffic
   a. Infringement upon lanes for opposing traffic
2. Effect of left turn movements
   a. Upon major flow of traffic
   b. Upon minor flow of traffic
   c. Adjustments in cross street traffic when left turns prohibited
3. Terminal problems
   a. Capacity of transition section compared with through pavement
4. Bus loading zones
5. Mid-street refuge for pedestrian crossings

C. Analyses of accident data
1. Comparison of reverse flow experience with that for normal operation.

V. <u>Selected References</u>

Effects of Reversible Lane Movement Signalization of 3-lane Highways - M. M. Todd, HRB Proceedings, 1950.

The Use of the Off-Center Lane Movement in Los Angeles - Traffic Quarterly, July 1948.

Detroit Without Mass Transportation for 59 Days - Traffic Engineering, December 1951.

Research Problem Statement Number 15

VEHICLE DIMENSIONS AND DRIVER'S POSITION IN VEHICLE

I. General Problem

The recent trend in vehicle design is toward larger units and changed shapes. Data are needed on vehicle dimensions that are significant in the safety and efficiency of vehicle operation and geometric design of highways and streets.

II. Specific Statement

Studies are needed to determine the driver's position in vehicles and the corresponding dimensions of those portions of the vehicle that limit his view ahead, to the sides and to the rear. Also dimensional data are needed on the vehicle clearances, etc. that must be considered in geometric design. Information is needed for the different types of vehicles and for different years models to establish trends as related to the logical and safe position of drivers.

III. Factors Involved

A. Types of vehicles
   1. Passenger cars
      a. Large and intermediate
      b. Economy size
   2. Conventional cab trucks
   3. Cab over engine trucks

B. Variation in vehicles of same type with regard to
   1. Makes
   2. Body types
   3. Yearly models

C. Variation in driver position
   1. Difference in physique
   2. Habitual position while driving

D. Determination of dimensions for use in design
   1. Extremes of ranges
   2. Typical or average values
   3. Percentile values

IV. Research and Data Needed

A. Measurement studies to determine range and distribution of height of driver's eye above pavement level for all types of vehicles and representative drivers:
   1. Vehicle dimensions, pavement to seat level
      a. Passenger cars, all makes and sizes
      b. Conventional cab trucks
      c. Cab over engine trucks
      d. Trends in yearly models, for the last 10 years
   2. Driver; dimension from seat level to eye
      a. Normal position
      b. Likely adjustments in position while driving
   3. Analyses to determine representative values for drivers seated in each major type of vehicle

B. Measurement studies to determine dimensions for different type and model vehicles as related to the view ahead from the point of a representative driver's eye:
   1. Windshield limitations
      a. Left side post
      b. Center support, if any
      c. Right side post
      d. Top or visor
   2. Hood and fender limitations
      a. Profile or silhouette limiting view of pavement ahead
   3. Trends in yearly models for the last 10 years
   4. Analyses in conjunction with several likely possibilities for convenient expression of relative visibility (or blind areas)

C. Measurement studies to determine dimensions for different type and model vehicles as related to the view to the sides and to the rear from the point of a representative driver's eye:
   1. Location of side blind areas due to
      a. Door and side posts
      b. Top and bottom of windows
   2. Location of rear blind areas due to
      a. Rear corner posts and body sections
      b. Top and bottom of rear window
   3. Trends in yearly models for the last 10 years
   4. Analyses in conjunction with several likely possibilities for convenient expression of relative visibility (or blind areas)

D. Measurement studies to determine representative dimensions on different type and models of vehicle elements related to geometric highway design
   1. Underclearances
   2. Front overhang and underclearance
   3. Rear overhang and underclearance
   4. Height of taillights

5. Fender extremities
6. Doors, opened
   a. Underclearance
   b. Width beyond body
7. Trends of above dimensions in yearly models

V. Selected References

Architectural Graphic Standards, Page 481, Ramsey and Sleeper, 1951

Traffic Engineering Handbook, Page 89 - Institute of Traffic Engineers, 1950.

Determination of Windshield Levels Requisite for Driving Visibility - W. Heath, HRB Bulletin No. 56, 1952.

Traffic Engineer's Technical Notebook, pages G-9 to G-19 - Institute of Traffic Engineers, 1952.

Research Problem Statement Number 16

SPEED-CHANGE LANES FOR LEFT TURNS (MEDIAN LANES)

I. General Problem

To determine the effect on traffic behavior of shape, width, length, surface contrast and other design elements of median lanes
AASHO definition: Median lane - a speed-change lane within the median to accommodate left-turning vehicles.

II. Specific Statement

Observations are needed on the speeds, paths, speed-change and other traffic behavior characteristics at different types and dimensional treatments of median lanes.

III. Factors Involved

A. Type of Highway
   1. Major street or highway
   2. Expressway
   3. Urban vs. rural areas

B. Intersection conditions
   1. Traffic control
      a. Stop signs
      b. Traffic signals
   2. Width of median for median lanes
      a. Without curbs
      b. Curbs at left only
      c. Curbs on both sides

3. Type and width of cross street

C. Traffic factors
   1. Volumes: through, turning and cross
   2. Speeds
   3. Types of vehicles involved

D. Median lane design elements
   1. Shape of transition or taper
   2. Median lane area
      a. Length as related to volumes, speeds and storage
      b. Width: contiguous or separated
      c. Contrast in texture and color of surface
      d. Shape of narrowed median end

E. Traffic behavior
   1. Speed-change
   2. Vehicle paths
   3. Storage and headway on turning

IV. <u>Research and Data Needed</u>

A. Observations on selected different median lanes to obtain data on the vehicle speeds at different points along the length, the vehicle paths and other behavior indications in relation to:
   1. Shape of transition or taper
   2. Length of lane
      a. Contiguous lanes
      b. With separating island on right
   3. Width of lane when delimited by
      a. Pavement stripes
      b. Mushroom buttons
      c. Mountable curbs
      d. Barrier curbs
      e. Combination of a to d
   4. Lane contrast in texture and color of surface
   5. Traffic control devices

B. Above data for different highway conditions of:
   1. Range in traffic data
      a. Volumes: ADT and peak hours, through traffic, both directions
      b. Type of vehicles: passenger cars, trucks, buses
   2. Type of highway
      a. Without control of access
      b. With control of access
      c. Rural vs. urban
   3. Type of intersection
      a. All paved, minor crossroad
      b. Channelized, major crossroad
      c. Stop control vs. traffic signals
      d. Acceleration vs. deceleration facilities

V. Selected References

A Preliminary Discussion on Arterial Highways in Urban Areas - Part I, February 1950, AASHO Committee on Planning and Design Policies.

A Policy on Highway Types - AASHO, 1940.

Channelization; The Design of Highway Intersections at Grade - HRB Special Report 5, 1952.

Research Problem Statement Number 10.

Research Problem Statement Number 17

TRUCK SPEEDS WHEN ASCENDING LONG GRADES

I. General Problem

It is a common experience for a passenger car driver to get caught behind a loaded truck slowly climbing a hill. Data are needed on the decelerating speeds of trucks as they ascend grades of various lengths and gradients. Use of such data with known or assumed values for entry speed at the bottom and minimum speed on the grade will permit determination of the critical length for a given gradient, as needed for purposes of design.

II. Specific Statement

Traffic observation data are needed on trucks of different types, ages, sizes and power groups operating up grades of various lengths and gradients. Available data of this character should be supplemented to reflect the recent trends toward larger and heavier truck units, and the regional differences in predominant truck types and sizes.

III. Factors Involved

A. Type of trucks
  1. Single unit
  2. Truck tractor and semitrailer combinations
  3. Truck tractor and full trailer combinations

B. Truck power characteristics
  1. Weight-power ratios
  2. Transmission arrangements

C. Variation in truck loads

D. Highway conditions
  1. Different gradients
  2. Different lengths of grade

3. Traffic volume: daily and hourly
4. Effect of intersections along the grade

E. Speeds
   1. At bottom of grade
   2. Running speeds for a several mile section

IV. Research and Data Needed

A. Traffic observations to obtain speed-gradient-length data for different trucks ascending known grades
   1. Type of truck
      a. Single unit
      b. Truck tractor and semitrailer
      c. Truck tractor with one or more full trailers

   2. Weight-power groups
      a. Older type vehicle
      b. New vehicles
      c. Future possibilities
   3. Different loads
      a. Partial
      b. Full

B. Analyses of data from A with types, sizes and weights of trucks as found today in different regional areas
   1. Determination of ranges in and representative values for regional truck characteristics

C. Analyses of data to determine trends in deceleration rates of trucks ascending grades

V. Selected References

Uphill Speeds of Trucks on Mountain Grades - W. E. Willey, HRB Proceedings, 1949.

Time and Gasoline Consumption in Motor Truck Operation as Affected by the Weight and Power of Vehicles and the Rise and Fall of Highways - HRB Research Report No. 9-A, 1950.

Hill-climbing Ability of Motor Trucks - C. C. Saal, Public Roads, May 1942.

Effect of Length of Grade on Speed of Motor Vehicles - A. Taragin, HRB Proceedings, 1945.

Amount and Characteristics of Trucking on Rural Roads - Public Roads, July-September 1943.

Traffic Trends on Rural Roads in 1950 - Public Roads, December 1951.

Research Problem Statement Number 26.

Research Problem Statement Number 18

OPERATIONAL CHARACTERISTICS OF UNCHANNELIZED INTERSECTIONS

I. General Problem

Most intersections in use today are the unchannelized (all-paved) type, i.e., they do not have islands or other lane separating devices. Data are needed to indicate the conditions for which this design is suitable.

II. Specific Statement

To determine operational characteristics of unchannelized at-grade intersections for various site, geometric, and traffic conditions.

III. Factors Involved

A. Type of intersection (3-Leg, 4-Leg and Multileg.)

B. Geometric features of intersection and its approaches
   1. Pavement and traffic-lane widths
   2. Grades
   3. Sight distance
   4. Corner radii
   5. Marginal treatment, curbs or shoulders

C. Traffic characteristics on both preference and nonpreference road
   1. Approach speeds
   2. Traffic volumes, through and turning
   3. Proportion of trucks
   4. Pedestrians, if any

D. Control Devices, stop signs or signals

E. Topography and land use.
   1. Flat, rolling or rough
   2. Urban vs. rural
   3. Roadside businesses

IV. Research and Data Needed

A. Traffic studies on different all-paved intersections of a given type to obtain data on:
   1. Volumes: daily and hourly
      a. Through movements
      b. Turning movements
      c. Trucks

2. Speeds and delays
    a. Through traffic on preference road
    b. Cross road through traffic
    c. Turning movements
3. Placement and vehicle paths
    a. Through movements
    b. Turning movements

B. Observations correlated with data from A to furnish values and factors for
1. Economic aspects of operation
    a. Time losses in speed-change
    b. Time losses in vehicle stops
    c. Accident experience
2. Different intersection types
    a. Cross road - nearly right angle
    b. Cross road - acute angle
    c. "T" - nearly right angles
    d. "Y" - or 3-road acute angle
3. Different traffic control methods
    a. Preference road signs
    b. Stop signs
    c. Traffic signals
4. Different types of highways
    a. Two-lane
    b. Multilane, undivided
    c. Multilane, divided
    d. Rural vs. urban
    e. High speed vs. low speed

V. <u>Selected References</u>

Manual on Uniform Traffic Control Devices - U. S. Government Printing Office, 1948.

A Policy on Intersections at Grade - AASHO, 1940.

The Relation of Traffic Signals to Intersection Accidents - J. C. McMonagle, HRB Proceedings, 1953.

Research Problem Statement Number 19

AERIAL PHOTOGRAPHS AND MODELS AS AIDS TO PLANNING AND DESIGN

I. <u>General Problem</u>

Proposed highway projects can be visualized and demonstrated by the use of aerial photographs and models. Oblique photographs, on which the contemplated improvements are superimposed, have been utilized effectively. Various types of models, too, have been employed to depict important and complex designs. Information is needed to determine the value and applicable use of aerial photographs and models in planning and design.

II. Specific Statement

To determine costs, feasibility, effectiveness, and methods of preparation of "daubed-in" aerial photographs and various types of models and their over-all value as aids to planning and design.

III. Factors Involved

A. Major
1. Complexity and scope of highway project
2. Features to be shown on photograph or model
3. Accuracy required of exhibit
4. Cost of photo exhibits or models

B. Minor
1. Availability of aerial photographs and model materials
2. Training or talent required for preparation of photo exhibits or models
3. Sizes, scales, and materials used in making models
4. Time element involved in preparation of photo exhibits or models.

IV. Research and Data Needed

A. Aerial photo exhibits
1. Study of existing exhibits to determine:
   a. Cost and time of preparation
   b. Size or scale
   c. Special techniques in preparation
   d. Degree of refinement in detail
   e. Purposes for which used and benefits derived

B. Models
1. Study of existing models to determine:
   a. Cost and time of construction
   b. Size and scale
   c. Basic materials and techniques used
   d. Degree of refinement in detail
   e. Benefits derived

V. Selected References

The Making of a Model- Virginia Highway Bulletin, Nov.-Dec. 1951.

The Use of Scale Models - L. N. Abrams, Traffic Quarterly, April, 1952.

The Use of Artists' Sketches and Scale Models in Urban Planning - R. H. Baldock, American Highways, October 1950.

Adoption of Aerial Surveying for Highways - W. T. Pryor, HRB Proceedings, 1953.

Research Problem Statement Number 20

OPERATIONAL CHARACTERISTICS OF DIAMOND INTERCHANGES

I. General Problem

The diamond (or H-type) interchange is receiving increasing attention in conjunction with expressway design. It is an interchange with a single one-way ramp in each quadrant, elongated along the major highway; all left turns are made directly on the minor highway. Information is needed to indicate the specific conditions for which the diamond interchange is best suited.

II. Specific Statement

To determine operational characteristics of diamond interchanges for various conditions of site, geometrics, and traffic.

III. Factors Involved

A. Geometric features of interchange and approaches
   1. Alinement, grade, and sight distance
   2. Pavement and lane widths
   3. Other cross section elements
   4. Ramp terminal design

B. Traffic characteristics
   1. Approach speeds
   2. Traffic volumes, through and turning
   3. Left turning movements and delays
   4. Proportion of trucks
   5. Pedestrians, if any

C. Control devices: stop signs or signals

D. Topography and land use.
   1. Flat, rolling or rough
   2. Urban vs. rural
   3. Roadside businesses

E. Safety

IV. Research and Data Needed

A. Traffic studies on different diamond interchanges to obtain data on:
   1. Volumes - daily and simultaneous hourly movements of through and turning traffic, including proportions of trucks.

2. Speeds - through and turning traffic for various volume conditions
3. Time losses - due to speed change and vehicle stops for various volume conditions
4. Vehicle storage - for all movements required to stop, measured in number of vehicles and space occupied per interval of time, as one minute or one cycle, for various volume conditions
5. Accident experience

B. Correlation of above observations to furnish values and factors for
   1. Economic aspects of operation
   2. Various ramp shapes, widths, location of terminals with respect to structure, and degree of channelization
   3. Different types of crossroad
      a. Two-lane
      b. Multilane, undivided
      c. Multilane, divided
      d. Rural vs. urban
      e. High speed vs. low speed
   4. Different traffic control methods
      a. Preference road signs
      b. Stop signs
      c. Traffic signals

V. Selected References

A Policy on Grade Separations for Intersecting Highways - AASHO, 1944.

Highway Capacity Manual - U. S. Government Printing Office, 1950.

Research Problem Statement Number 21

SUITABILITY OF LEFT-HAND ON AND OFF RAMPS FOR AN EXPRESSWAY OR FREEWAY

I. General Problem

The large majority of entrances and exits to expressways and freeways are on and off at the right of the through traffic lanes and widespread acceptance has been accorded the right-hand ramp. It is desired to determine if the left-hand exit and entrance are functionally acceptable and, if so, to show a comparison, under various conditions, of left-hand exits and entrances with right-hand exits and entrances.

II. Specific Statement

To obtain data on operational characteristics and safety of on and off at the left ramps as compared with those on the right.

III. Factors Involved

A. Driver familiarity with and acceptance of left-hand on and off ramps

B. Education of drivers to left-hand exits and entrances

C. Signing to provide adequate advance warning and directional information

D. Entrance and exit connections for minor movements as compared with major movements

E. Geometric features

F. Type of area, relative traffic volumes, and speeds

G. Safety

IV. Research and Data Needed

A. Controlled observations of traffic behavior at left-hand ramps as compared with those on the right
   1. Hourly volumes - combinations merging or diverging, passenger cars and trucks
   2. Speeds - on different lanes of approaches and speed changes involved in merging or diverging at various hourly volumes
   3. Vehicle placement or paths followed
   4. Accident experience

B. Correlation of above data with respect to
   1. Geometric characteristics of junction and approaches with regard to pavement widths, alinement, gradeline, sight distance, and especially the length and shape of auxiliary pavement for merging or diverging
   2. Signing
   3. Character of junction
      a. Representative or normal ramp
      b. Major fork

V. Selected References

Research Problem Statement Number 16.

Highway Capacity Manual - U. S. Government Printing Office, 1950.

Research Problem Statement Number 22

SAFETY ON LONG TANGENT SECTIONS VERSUS EASY CURVED ALINEMENT

I. General Problem

In some instances extended mileages of pavements ten miles and over in length have been constructed on tangent alinement. One result is monotonous vehicle operation, usually at fairly high speed. It is believed that this contributes to the occurrence of accidents.

II. Specific Statement

Under similar traffic and roadway conditions to compare the traffic behavior and the accident experience on extended mileages on tangent alinement with corresponding mileages on easy curved alinement.

III. Factors Involved

A. Vehicle Operation
   1. Speeds and volumes
   2. Lateral placement on pavement
   3. Alertness of drivers vs. time at constant speed

B. Accident experience
   1. Number
   2. Severity
   3. Types

C. Geometric design
   1. Alinement, profile, and cross section
   2. Impaired sight on flat curves
   3. Roadside treatment within ROW
   4. Number of through traffic lanes

D. Topography
   1. Variation offered in horizon view
   2. Type of landscape, extent of adjacent development

IV. Research and Data Needed

A. Observation of traffic behavior on extended mileages on tangent alinement as compared with corresponding mileages on easy curved alinement
   1. Speeds and volumes; speed variations along length of study section
   2. Lateral placement of vehicles
   3. Measure of driver alertness or fatigue as related to monotony
   4. Complete accident reports for sufficient period of time to be significant

B. Correlation of above data with
   1. Geometric characteristics
      a. Tangent alinement with flat profile vs. easy curved alinement with flat profile
      b. Tangent alinement with flat profile vs. easy curved alinement with rolling profile
      c. Tangent alinement with rolling profile vs. easy curved alinement with flat profile
      d. Tangent alinement with rolling profile vs. easy curved alinement with rolling profile
   2. Type of highway
      a. Type, smoothness, and condition of pavement
      b. Two-lane, constricted and desirable cross section
      c. Multilane, undivided
      d. Multilane, divided
   3. Type of topography, area, and landscape

V. Selected References

The Influence of Alinement on Operating Characteristics - O. K. Normann, HRB Proceedings, 1943.

The Relation of Highway Design to Traffic Accident Experience - D. M. Baldwin, AASHO Convention Group Meetings, 1946.

Driver Behavior Study: Speed Characteristics on Vertical Curves - B. A. Lefeve, HRB Proceedings, 1953.

The Interstate Highway Accident Study - M. S. Raff, HRB Proceedings, 1953.

Research Problem Statement Number 23

LATERAL CLEARANCE TO A WALL SECTION

I. General Problem

Walls or rock cut faces parallel to the edge of pavement are necessary on many highways. Large variations occur in the lengths of wall sections. Driver behavior with regard to lateral placement of vehicles seems to be a function of wall dimensions, offset, vehicle speed, and traffic volume.

II. Specific Statement

To observe the effect of lateral clearances to wall sections, both short and continuous, on traffic operation.

III. Factors Involved

A. Wall conditions

1. Height and length
2. Lateral clearance to wall
3. Type of material or construction, color, finish

B. Roadway conditions
1. Number of lanes and width
2. Lane stripes
3. Contrast at lane edge
4. Shoulder on approach, width and type

C. Operation
1. Speeds and volumes
2. Lateral placement of vehicles
3. Accidents

IV. Research and Data Needed

A. Observations of traffic behavior at walled sections or similar lateral obstructions
1. Speeds and hourly volumes (passenger cars and trucks); speed variations along study section
2. Lateral placement of vehicles and resulting paths along study section
3. Driver opinion of restrictive effect
4. Accident experience

B. Correlation of above data with
1. Type of wall section
    a. Short, long, continuous
    b. Low, high
    c. Terminal treatment at approach end of wall
    d. Construction - color, finish, batter or slope
2. Offset - normal edge pavement to wall face
    a. Right side
    b. Left side
3. Highway geometrics
    a. Lane width
    b. Curbs, if any
    c. Curved or tangent alinement
    d. Profile and gradient
    e. Sight distance, horizontal and vertical
    f. Shoulder on approach, width and type
4. Type of Highway
    a. Two-lane
    b. Multilane, undivided
    c. Multilane, divided
    d. Rural or urban

V. Selected References

Effect of a Roadside Structure on Lateral Placement - H. W. Case, S. Hulbert and G. E. Mount, HRB Proceedings, 1953.

Influence of Bridge Widths on Transverse Positions of Vehicles - W. P. Walker, HRB Proceedings, 1941.

Research Problem Statement Number 24

LATERAL OFFSET FOR VARIOUS TYPES OF CURBS

I. General Problem

Many drivers move toward the center of the road when there is a restriction, such as a curb, close to the edge of their lane. This change in lateral position reduces the capacity of the highway by decreasing the effective width of pavement and by creating additional traffic friction. To minimize the effect of curbs on the lateral placement of traffic it is common practice to place curbs outside the edges of the normal traffic lanes.

II. Specific Statement

To observe the effect on traffic operation of the lateral clearances to curb sections (offset, normal edge of pavement to face of curb.)

III. Factors Involved

A. Curb design
   1. High, low, and lip
   2. Intermittent and continuous

B. Marginal conditions
   1. Shoulder restrictions, if any
   2. Speed-change or auxiliary lane
   3. Guardrail
   4. Sidewalk

C. Width and number of lanes, lane stripes

D. Operation
   1. Speeds and volumes
   2. Lateral placement of vehicles
   3. Accidents

IV. Research and Data Needed

A. Observations of traffic behavior on various curbed highway sections
   1. Speeds and hourly volumes (passenger cars and trucks). Speed variations along study section where curbs are intermittent and where continuous
   2. Lateral placement of vehicles
   3. Accident experience

B. Correlation of above data with

1. Type of curb section
   a. Intermittent (short, long), continuous
   b. Nonmountable
   c. Mountable
   d. Curb and gutter
   e. Terminal treatment where intermittent
2. Offset - normal edge pavement to curb face
   a. Right side
   b. Left side
3. Through or auxiliary lane
4. Highway geometrics
   a. Lane width
   b. Alinement, profile, sight distance
5. Marginal conditions
   a. Shoulder restrictions
   b. Useable shoulder beyond curb
   c. Guardrail
   d. Sidewalk
6. Type of highway
   a. Two-lane
   b. Multilane, undivided
   c. Multilane, divided
   d. Rural or urban

V. Selected References

A Policy on Highway Types - AASHO, 1940

Highways with a Narrow Median - HRB Bulletin No. 35, 1951.

Influence of Bridge Widths on Transverse Positions of Vehicles - W. P. Walker, HRB Proceedings, 1941.

Research Problem Statement Number 25

LENGTH OF SAG VERTICAL CURVES

I. General Problem

Charts and tables are available for the design of crest vertical curves but there is little comparable information for the design of sag vertical curves. Lengths of crest vertical curves are based on values of minimum sight distances and design speeds. Probable controls for lengths of sag vertical curves are (1) general appearance, (2) smooth traffic operation at designated speeds, and (3) sight distances at night with light from headlamps only.

II. Specific Statement

To study existing sag vertical curves and operation thereon, to establish a criterion from which guide values for lengths may be established.

III. Factors Involved

A. Type of highway and number of lanes

B. Design and running speed

C. Smoothness of traffic operation, comfort

D. Appearance

E. Grade differences

F. Drainage longitudinally on highway where pavements are curbed

G. Minimum sight distances using headlamps only

H. Springing and riding characteristics of vehicles

IV. Research and Data Needed

A. Observations on existing highways of all factors involved (listed above) as related to length of sag vertical curve

B. Experience of State highway departments in which criteria have been established

V. Selected References

Design Practices in State Highway Departments of: Illinois, New Jersey, New Mexico, Ohio, Oregon, South Carolina, and Washington.

Policy on Sight Distance for Highways - AASHO, 1940.

Research Problem Statement Number 26

CLIMBING LANES FOR SLOW-MOVING VEHICLES ON LONG GRADES

I. General Problem

In many cases construction of an additional traffic lane or passing strips along parts of a long grade may be more economical than reducing the gradient to an acceptable value, and such treatment might relieve congestion, as much as or possibly more than reduction of the gradient.

II. Specific Statement

To obtain data on operational characteristics and safety of sections of highway with a climbing lane (an added uphill lane to the right of traffic for slow-moving vehicles) and to compare these data with that for sections of highway without a climbing lane having similar traffic and roadway conditions. These observations may serve as a guide in developing the criteria and warrants for the design of climbing lanes.

III. Factors Involved

A. Geometric features
   1. Design speed
   2. Pavement and traffic lane widths
   3. Alinement, profile, sight distance
   4. Gradient, rate and length
   5. Shoulders, type and width

B. Traffic characteristics
   1. Speeds - approach and variations over study section
   2. Traffic volumes, daily and hourly, and distribution by direction
   3. Lateral placement of vehicles
   4. Type, size, and proportion of trucks
   5. Density variations and delay

C. Pavement markings, contrasting pavements, and signing

D. Driver tolerance of reduced speeds and delays

E. Acceleration, deceleration, and hill-climbing ability of trucks

F. Accidents

G. Road user costs and costs of adding climbing lanes

IV. Research and Data Needed

A. Observations on existing highways with climbing lanes, and on those without climbing lanes having similar traffic and roadway conditions, of all factors involved (listed above) as related to length and rate of upgrade

B. Additional controlled observations to show the effect of
   1. Width of climbing lane
   2. Relative position of beginning and ending of climbing lane (full width)
   3. Length of taper at beginning and ending of climbing lane
   4. Pavement marking, contrasting pavement, and signing

V. Selected References

Uphill Speeds of Trucks on Mountain Grades, W. E. Willey, HRB Proceedings, 1949.

Time and Gasoline Consumption in Motor Truck Operation as Affected by the Weight and Power of Vehicles and the Rise and Fall of Highways, HRB Research Report No. 9-A, 1950.

Hill-Climbing Ability of Motor Trucks - C. C. Saal, Public Roads, May 1942.

Effect of Length of Grade on Speed of Motor Vehicles - A. Taragin, HRB Proceedings, 1945.

Research Problem Statement Number 17.

Climbing Lanes for 2-Lane Highways - AASHO Convention Group Meetings, 1951.

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