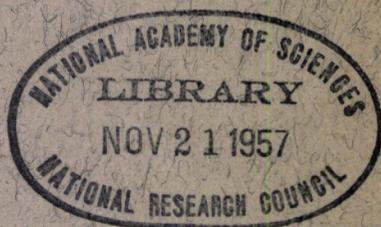# HIGHWAY RESEARCH BOARD

Bulletin No. 16

Expressways

COMMITTEE REPORT AND THREE PAPERS

PRESENTED AT THE
TWENTY-SEVENTH ANNUAL MEETING

1948

HIGHWAY RESEARCH BOARD

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⌊EXPRESSWAYS⧸

COMMITTEE REPORT AND THREE PAPERS
PRESENTED AT THE TWENTY-SEVENTH ANNUAL MEETING

1947

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PROGRESS REPORT OF COMMITTEE ON EFFECT OF CONTROLLED ACCESS EXPRESSWAYS ON URBAN AREAS

CHARLES M. NOBLE, *Chairman*
State Highway Engineer, New Jersey State Highway Department

The Committee had its first meeting immediately preceeding the 1946 meeting of the Highway Research Board for the purpose of formulating a program and to decide upon the procedures for carrying this program forward. It was agreed to break down the over-all subject into topics and that these topics would be assigned to the various members of the Committee for the purpose of developing them into a formal report. In the development of the papers on the various topics, investigation and research will be carried on by the topic leaders in order that the completed report will represent as nearly as possible the latest thinking and advanced techniques.

The general subject has been subdivided into topics as follows:

(A) Location in Relation to Street Systems

(B) Effect of Width on Street Systems

(C) Spacing of Traffic Interchanges

(D) Design of Interchanges

(E) Criteria for Bridging Existing Streets

(G) Effect of Public Utilities

(H) Effect on Mass Transportation

(I) Economics of Expressway

(J) Effect on Tax Ratables

(K) Economics of Design

(L) Traffic Data

(M) Economic Effect on Fronting Street Properties

(N) Effect of Stage Construction

(O) Parking and Terminal Facilities

(P) Effect on Street Systems

The Topic Leaders assigned are as follows:

Norman M. Wilke, Engineer of Design, Cleveland Planning Office	Topics (A) (B)
Lawrence S. Waterbury, Assoc. Engineer, Parsons, Brinckerhoff, Hogan & Macdonald	Topics (C) (J) (M)
Hugo H. Winter, Eng. of Street & Parkway Design, Office of the City Engineer, Los Angeles	Topics (D) (G)
Donald McNeil, Traffic Engineer, Bureau of Traffic Planning, Pittsburgh, Penna.	Topics (E) (F)
A. F. Malo, Safety Engineer, Department of Street Railways, Detroit, Michigan	Topic (H)
Sigvald Johannesson, Director Division of Planning and Economics, New Jersey State Highway Department	Topics (I) (K) (L)
Fred J. Hughes, Secretary, Programming and Planning Engineer, Public Roads Administration	Topic (N)
Nathan Cherniack, Economist The Port of New York Authority	Topic (O)
Roy E. Jorgensen, Deputy Highway Commissioner State Highway Department of Connecticut	Topic (P)
W. T. Brooks, State Highway Engineer State Highway Department of Tennessee	Reviewing Authority

Prior to the 1946 meeting of the Committee some progress had been made by the topic leaders in developing their sub-

jects and papers were submitted by Hugo H. Winter, covering the two topics assigned him, namely, (D) Design of Interchanges, and (G) Effect of Public Utilities, and by Norman M. Wilke, on his topics (A) Location in Relation to Street Systems, and (B) Effect of Width on Street Systems. Papers were also submitted by Sigvald Johannesson on his topics (I) Economics of Expressway, (K) Economics of Design, and (L) Traffic Data, and by Lawrence S. Waterbury on his assigned topics of (C) Spacing of Traffic Interchanges, (J) Effect on Tax Ratables, and (M) Economic Effect on Fronting Street Properties.

These papers were discussed by the Committee in session and suggestions offered by the members.

Insofar as the procedures were concerned, it was decided that during the year topic leaders would submit papers to the Secretary for preliminary review by the Chairman and then be circulated among the entire Committee membership for comments and suggestions. Such comments to be sent to the Secretary for coordination and transmission to the Reviewing Authority.

The Reviewing Authority will peruse the original paper together with the comments of Committee members and summarize the various suggestions and recommend revisions in the original manuscript. These recommendations will be transmitted to the Secretary for distribution to the various authors. The original author will then revise his manuscript as appears justified in the light of the comments of the Committee members and the recommendation of the Reviewing Authority.

In this manner it is hoped that a great deal of ground can be covered in progressing the work of the Committee during the year and that a considerable amount of coordination and threshing out of controversial issues may be accomplished, reserving to the Committee meetings such issues as can not well be resolved by correspondence. It is the ultimate aim of the Committee to submit a report on all of the above listed topics as a coordinated whole for publication and dissemination to the membership of the Highway Research Board.

It is recognized by the Committee that many of the topics will necessarily overlap into other Departments and Committees of the Highway Research Board and it is the intention of the Committee to contact appropriate Department and Committee Chairman where such subjects over-lap in order to avoid offering information in the report which would conflict with the findings of other Committees, and so as to take full advantage of research conducted by such Committees. It is earnestly requested that other Committees cooperate in this coordination in order that the entire effort may merge in with the activities of the entire Highway Research Board.

As an aid to uniformity and understanding the Committee will use the definitions of highway and traffic terms adopted by the American Association of State Highway Officials, Manual on Uniform Traffic Control Devices and the Highway Research Board Committee on Highway Capacity.

During the past year the Librarian of the Headquarters Staff of the Highway Research Board has prepared an extensive bibliography covering the various topics being investigated by the Committee and this bibliography is appended hereto.

To date papers have been prepared on the following topics:

(A) Location in Relation to Street Systems	Norman M. Wilke
(B) Effect of Width on Street Systems	
(C) Spacing of Traffic Interchanges	Lawrence S. Waterbury
(J) Effect of Tax Ratables	
(M) Economic Effect on Fronting Street Properties	
(D) Design of Interchanges	Hugo H.
(G) Effect of Public Utilities	Winter
(I) Economics of Expressway	Sigvald Johannesson
(K) Economics of Design	

(L) Traffic Data

(N) Effect of Stage   Fred J. Hughes
     Construction

(O) Parking and Ter-   Nathan Cherni-
     minal Facilities   ack

(P) Effect on Street   Roy E. Jorgen-
     Systems   sen

As an indication of the progress of the work of the Committee, two of the above reports are being presented at this meeting, namely, "Parking and Terminal Facilities" by Nathan Cherniack, Economist, The Port of New York Authority (Topic (O)) and "Effect of Stage Construction" (Topic (N)) by Fred J. Hughes, Programming and Planning Engineer, Public Roads Administration.

PARKING AND TERMINAL FACILITIES

NATHAN CHERNIACK

Economist, The Port of New York Authority

Parking and terminal facilities in urban areas include: (a) curb spaces along the existing street system; (b) offstreet facilities such as public and private parking lots and garages; (c) parking facilities within commercial buildings for autos and trucks, ranging from recessed street level truck tailboard spaces within building lines, to large areas below or above street floors, connected by ramps or elevators; and (d) such specialized terminals as union bus and truck terminals.

Vehicles that now utilize offstreet parking and terminal facilities arrive there for the most part via existing street systems. Even where urban limited access expressways are available, only portions of vehicles that use offstreet parking and terminal facilities arrive via expressways.

As more urban expressways are constructed and areas tributary to expressways expand, increasing proportions of vehicles parking at individual parking and terminal facilities will arrive or depart via expressways. New parking and terminal facilities will then tend to be located as close to expressways as possible in order to reduce vehicle travel on existing street systems to a minimum. This growing intimacy between expressways and large individual parking and terminal facilities is bound to create serious traffic problems, particularly in the vicinity of traffic interchanges. Engineers must consequently provide flexible designs for expressway interchanges that will relieve inevitable traffic pressures as they arise, since some types of expansions cannot be completely envisaged when the expressways are being planned.

It is a commonly accepted fact that a limited access expressway lane can handle 3 to 5 times the traffic of a city street lane. Or, in other words, one expressway lane can deliver enough traffic to keep 3 to 5 street lanes busy absorbing the traffic, if the traffic can be absorbed. Query: What happens if the rate of diffusion on the street system in the vicinity of the expressway is slowed down by the rate at which cars can be parked at large concentrated off-street parking and terminal facilities? Answer: Chronic traffic backups on the expressway, when rush hour traffic is arriving in town.

Conversely several large individual offstreet parking and terminal facilities located in a local area in the vicinity of an expressway entrance ramp may in a peak period deliver to the expressway entrance ramp a flood of traffic far in excess of its ability to absorb it. In this case, too, there would be chronic traffic congestion on the city street system, in peak periods, when traffic was leaving town.

Approximate locations and spacing of entrance and exit ramps are usually determined by the vehicular volumes that originate in or are destined for one or more interchanges. More precise locations of interchanges can be determined by giving special consideration to individual existing and potential offstreet parking and terminal facilities that would contribute substantial portions of traffic to specific interchanges. Such offstreet parking facilities would also indicate the design types of entrance and exit ramps required. A number of these types are described in Mr. Winter's paper on expressway interchanges. For example, concentrations of parking facilities in a local area would require that some interchanges be provided with more than merely

an accelerating or decelerating lane. Some might require adjoining service streets that could function as reservoirs, like the plazas of vehicular bridges and tunnels. It must also be borne in mind that while any given interchange proper may have the capacity to deliver to the expressway all the peak period traffic of the surrounding offstreet parking facilities, the expressway itself at this point would have only the margin of its available unabsorbed traf-

expressway traffic delivered by the local interchanges.

In the selection of locations, determination of the number of interchanges, and the provision of extra widths of expressways proper, in given local areas, the essential desideratum is to maintain a proper balance in the capacities of (a) the expressway proper, (b) its local interchanges, (c) the local traffic light controlled street system in the vicinity of interchanges and (d) the rate of ab-
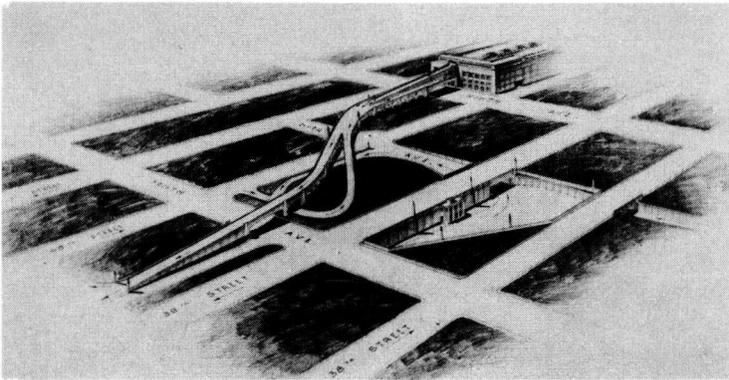
Figure 1. Sketch of Proposed Ramp Connections Between the Port of New York Authority's Lincoln Tunnel and the Mid-Manhattan Union Bus Terminal to be Constructed by the Port Authority.

fic capacity to absorb the traffic delivered to it by this individual entrance ramp. If the available unabsorbed margin of traffic capacity of the expressway is less than the traffic contributed by the interchange, congestion is bound to occur.

Consequently, in the design of expressways in the vicinity of interchanges, particularly where there are or are likely to be concentrations of offstreet parking and terminal facilities, short stretches of expressways may have to be widened to provide extra lanes in the vicinity of interchanges. These short stretches of widened expressways would permit of properly absorbing peak traffic. They would also permit the storage of moving vehicles while the street systems in the vicinities were diffusing and the offstreet parking and terminal facilities were absorbing peak

sorption or delivery of vehicles by local offstreet parking and terminal facilities.

Auto Parking Terminals - It may generally be said, that today, existing lots and garages in urban areas are very largely located without much relationship to where they are actually needed. Many garages are former stables. A few have been built at locations where land is cheap but at much greater than convenient walking distances from major urban destinations. Existing lots have been located wherever land is available, usually in blighted areas at the fringes of business districts, pending redevelopment of the areas. Consequently most existing garages and lots are no criteria for the future locations of offstreet parking and terminal facilities.

There are, however, certain existing

EFFECT OF PORT AUTHORITY BUS TERMINAL ON INTERSTATE BUS TRAFFIC THROUGH MID-MANHATTAN STREETS

Figure 2

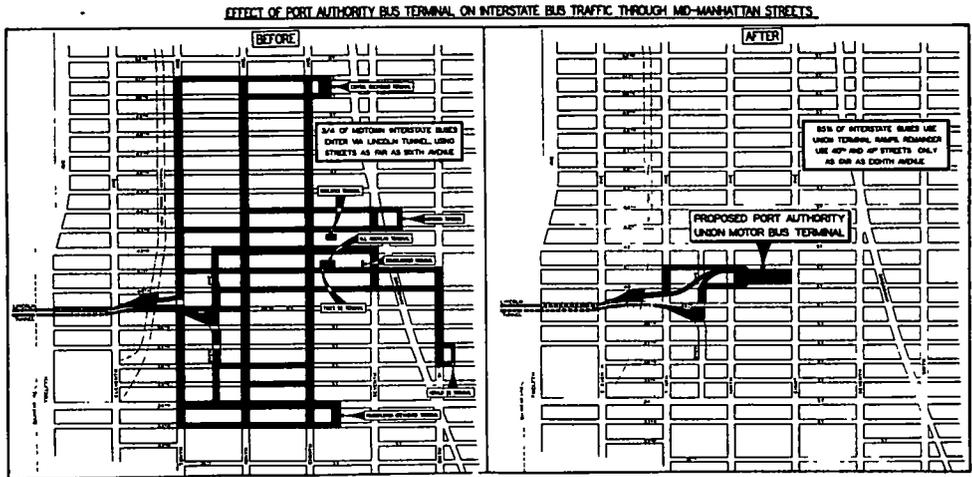parking facilities which would require particular attention in connection with the design of proposed urban expressways. They are the concentrations of parking in connection with places of public assembly, such as, large ballparks and stadia. Designs of expressway interchanges in their vicinities require special study and treatment, if chronic traffic congestion is to be avoided.

With regard to future offstreet parking facilities, current thinking appears to favor municipally financed lots and garages. Where large public parks of wide boulevards are available, these are being suggested for underground municipal parking facilities. In some cities like Pittsburgh, for example, comprehensive plans have been prepared for a system of municipally financed and operated garages; those near the shopping areas for short time parkers and toward the fringes of the business district for long time parkers. It is believed that these plans for large municipal parking and terminal facilities will eventually materialize, then designs for interchanges in their vicinities should be flexible enough to be constructed or enlarged if and when, traffic to and from them develops.

It is the opinion of the author that, gradually, municipalities will adopt zon-

ing ordinances requiring new commercial buildings to provide offstreet parking and truck berths. Should this be the future trend, offstreet parking facilities would once more become less concentrated, more diffused. This gradual diffusion of offstreet parking facilities should improve traffic conditions around expressway interchanges by spreading peak traffic loads by the travel time required between nearest and farthest parking areas tributary to individual expressway interchanges.

Bus Terminals - Interurban and intercity buses usually enter cities from several directions via city streets. Large buses travelling along narrow city streets congest these streets out of all proportion to the number entering the city. Where the number of buses are substantial, municipalities out of self protection will eventually require them to use a union bus terminal. A union bus terminal would be so located as to be convenient to downtown offices, shopping areas, theatres and hotels but also as close to urban expressways as possible so as to utilize city streets to a minimum. Where municipalities are contemplating requiring one or more union bus terminals, expressway interchanges should be
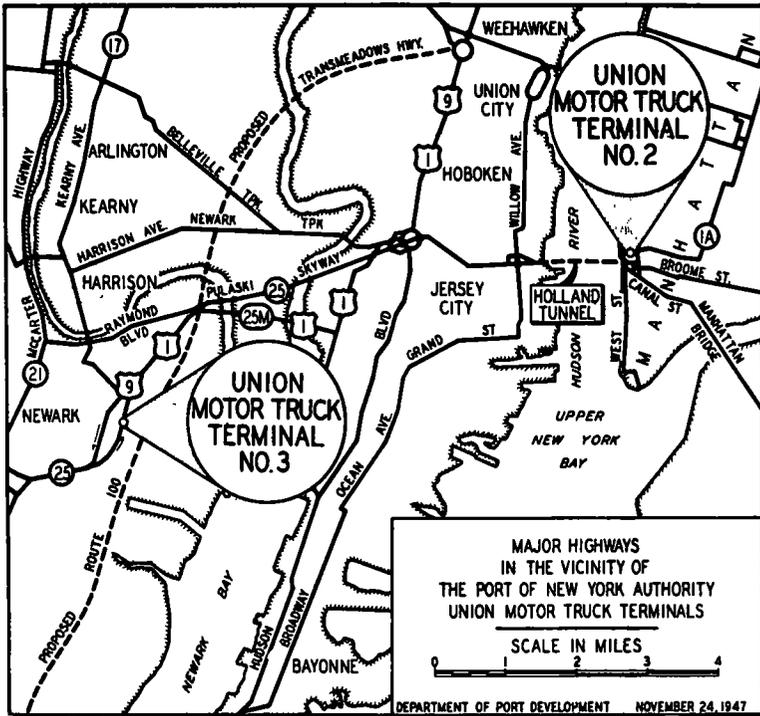
Figure 3

designed to give easy access to and from such bus terminals.

For example, the Port Authority's Union Bus Terminal in mid-Manhattan will be provided with special ramps connecting the terminal with the north and south tubes of the Lincoln Tunnel. These ramps will keep 85% of the 2,500 daily bus trips into the Union Bus Terminal entirely off city streets in the vicinity of the terminal. (A sketch of the Port Authority Union Bus Terminal and its ramp connections with the Lincoln Tunnel is attached.)

Union Truck Terminals - Into and out of most cities long haul, over-the-road tractor-trailer combinations haul freight daily. Individual operators' truck terminals are usually scattered throughout the city. Many of these trucks and trailers meander about on the narrow streets of cities picking up and delivering small lots of freight. Whether moving or parking on these narrow streets, these oversized vehicles congest these

narrow streets out of all proportion to the numbers of tractor-trailer combinations in relation to other traffic. Consequently, where this type of tractor-trailer traffic is growing, municipalities will eventually demand that over-the-road truck operators operate out of union truck terminals and that smaller trucks pick up and deliver their freight within the cities. Where union truck terminals are built, they would be located close to expressways. Large tractor-trailer combinations would thus arrive via expressways and proceed to the Union Truck Terminal using city streets to a minimum.

Where it is anticipated that a union truck terminal will be constructed close to an expressway, interchanges in the vicinity of the terminal should receive particular attention. Expressway interchanges should be so designed as to be convenient for vehicles to enter and depart from the union truck terminal with a minimum use of city streets. The streets which trucks do use, however, should have

THE PORT OF NEW YORK AUTHORITYS
UNION TERMINAL FREIGHT STATION Nº 2
(UNION MOTOR TRUCK TERMINAL)

LOCATION—
  MANHATTAN NEAR HOLLAND TUNNEL
SIZE—
  TERMINAL STRUCTURE   100' x 1000'
  FREIGHT PLATFORM   80' x 800'
  WITH AUTOMATIC CONVEYOR
CAPACITY—
  TRUCK BACK-UP SPACES   144
  VOLUME PER DAY   2000 TONS
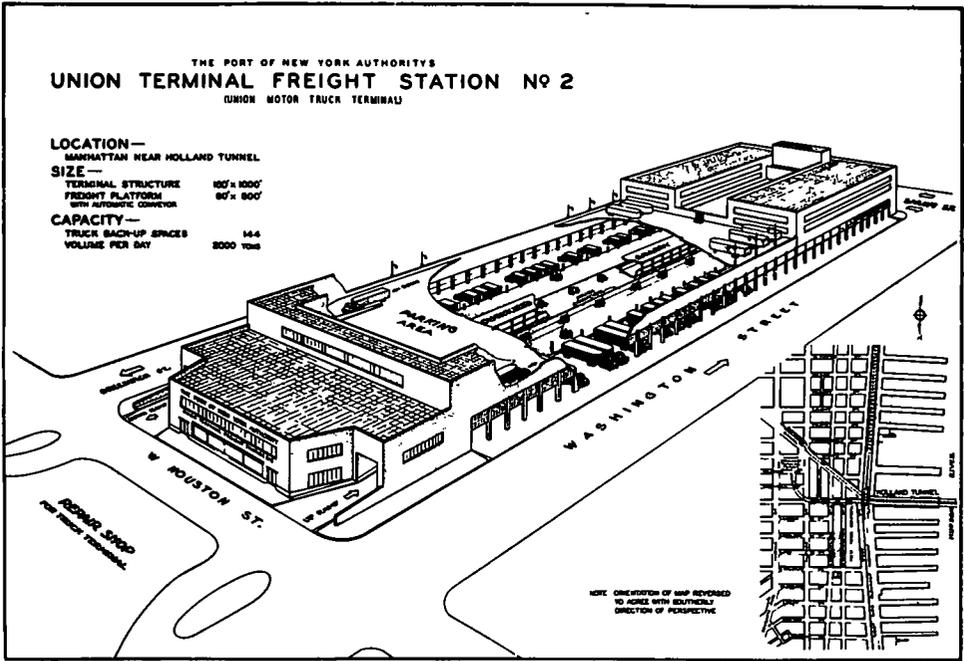
Figure 4

the capacity to absorb all trucks de-livered to them by the expressway in peak periods. Interchanges should be designed to pass peak traffic; the expressway should be able to absorb all trucks de-livered thereto by the interchanges. The Port Authority is now constructing two Union Truck Terminals, one in New York City in lower Manhattan, the other in Newark, N. J., and in selecting their locations has recognized these princi-ples.

The truck terminal on Manhattan is within 1/2 mile of the Holland Tunnel via which vehicular crossing most of the over-the-road trucks will arrive at this union terminal. The Manhattan entrance and exit of the Holland Tunnel being so convenient to the lower Manhattan Union Truck Terminal, trucks will use city streets to a minimum to reach it. (See attached sketches which show location of the Port Authority's lower Manhattan Union Truck Terminal).

The Newark Terminal is located close to the existing New Jersey Route 25 and in the vicinity of proposed Route 100, the major arterial routes via which most of the over-the-road trucks will arrive

at this union terminal. The inter-changes of the New Jersey routes will be designed to give easy access to the Newark Truck Terminal and consequently there, also, trucks will use the streets in the vicinity to a minimum. (The illustrations herein show the location of the Port Authority's Newark Truck Termi-nal).

TRUCK MOVEMENTS TO AND FROM
UNION MOTOR TRUCK TERMINAL NO 3

OUTBOUND FREIGHT
INBOUND FREIGHT

Figure 5

EFFECT ON CITY STREETS OF STAGE CONSTRUCTION
OF LIMITED ACCESS EXPRESSWAYS

FRED J. HUGHES, *Programming and Planning Engineer*
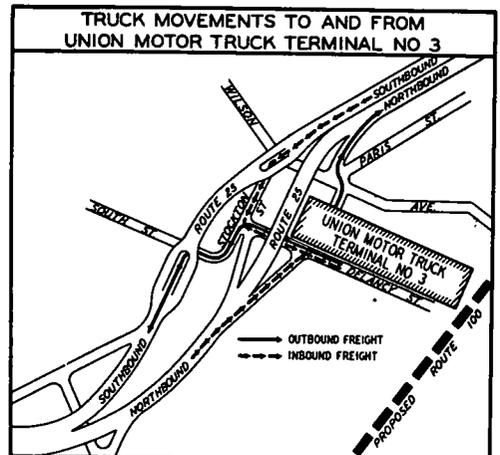*Division One, Public Roads Administration, Albany, New York*

SYNOPSIS

Stage construction proposals generally stem from a need to stretch available funds to secure early relief. This may be justified in certain cases but should be accepted only as a last resort after consideration is given to the possibilities of finding the added amounts (and, probably, sources) of funds so urgently needed to meet and keep pace with our highway requirements.

If stage construction is necessary, comparisons between the advantages of obtaining as a first-stage operation a facility usable throughout most or all of its length, as contrasted to the more generally-used method of building it section by section, might be worthwhile. Getting work underway over an entire project might do much to establish and guarantee the route, avoid rights-of-way delays, encourage and influence re-zoning and other city planning activities and result in the efficient and non-conflicting location of industries, housing and like developments in the urban area.

The primary purpose of urban expressways is, of course, to correct unsatisfactory traffic conditions on existing city streets. A good plan for stage construction may produce relief quickly where needed most and provide a preview of things to come which can help with financing and other problems. Contrariwise, a bad plan could add to the distress on city streets and endanger the entire proposal. Therefore, the effects of proposals for stage construction on those streets should carry much weight when the merits of such proposals are evaluated. No set rules for determining these effects can be made because physical, economic and social conditions and traffic problems differ in each urban area. However, to assure that a stage construction proposal is sound and workable, a complete analysis of traffic flows and travel habits seem essential. This analysis should be particularly concerned with the probable effect of the proposal on the loads on existing streets (and intersections) and the potential advantages (or disadvantages) to traffic which will remain on or be diverted to each street (temporarily or permanently) as well as to that accommodated on the expressway.

For the purposes of this discussion, the term, "stage construction", is construed as meaning the construction of an expressway to something less than the ultimate planned improvement but to a stage where the facility or a portion of it may be opened to and used by traffic. Our particular interest in the subject excludes stage construction practices such as the acquisition of rights-of-way, grading of the roadbed, or the construction of structures separately from and in advance of paving operations, since these operations do not produce a usable improvement.

Examples of stage construction of interest at this time are:

1. Placing a temporary rather than a permanent pavement.

2. Paving less than the ultimate width of roadway, or one roadway of an ultimate divided highway.

3. Deferral of construction of grade separations.

4. Deferral of construction of interchanges, or construction of less than the ultimate interchange, for example, building two ramps of a four-ramp plan.

5. Deferral of construction of service roads.

6. Deferral of landscaping, installation of lighting and other items not essential to a reasonably safe utilization of the improvement.

7. The progressive construction of an expressway by sections or units over a

period of years. In this case a constructed section might be complete within its limits but it would constitute only one stage of the construction required to make available the benefits of the ultimate improvement.

Proposals for stage construction almost always stem from a need to stretch currently available funds so that traffic conditions may be improved as quickly as possible and prior to the time when the entire expressway can be financed. Now, this reason for constructing something less than a complete improvement may be a very good one and sometimes the only way to get a project started. However, a word of caution seems in order. Too ready acceptance of the need for improvising, by stage construction or otherwise, to overcome an apparent inability to finance an improvement could well prolong beyond reason the time required to remedy the intolerable traffic conditions of our urban areas. Without a doubt, it is going to be necessary (in general) to find additional amounts (and, probably, new sources) of funds to meet and keep pace with our highway requirements. We should be extremely reluctant to employ stage construction to side-step the critical issue of inadequate finances for overwhelming highway needs.

In case immediate construction of a complete improvement is determined to be impossible, more consideration than it often receives then might well be given to the feasibility of initiating activity over the entire project as quickly as possible. This might be done by utilizing one or more of the first six stage construction techniques previously mentioned instead of the more generally-used method of progressive construction of an improvement by sections which are complete in themselves. Getting work underway throughout the length of the proposed expressway would establish and guarantee the route to be followed by the facility. It might avoid serious delays over rights-of-way. It also might do much to encourage and influence zoning or re-zoning and other city planning activities, and the efficient and non-conflicting location of industries, housing, and like developments in the urban area.

A careful study and comparison of the advantages of obtaining as a first-stage operation a facility usable throughout most or all of its length, as contrasted

to building it section by section, might be highly illuminating and possibly lead to a new concept of the value and flexibility of stage construction.

However, regardless of all other considerations, it must be kept in mind that the primary purpose of the improvement is to correct, or at least, relieve unsatisfactory traffic conditions on city streets. Therefore, it seems obligatory that the effects on those streets should be considered carefully and should carry much weight when decisions regarding the nature and extent of stage construction proposals are to be made. A good stage-construction plan might produce relief quickly where needed most and result in a substantial measure of the desired improvement in traffic conditions being realized and enjoyed several years in advance of what would otherwise be possible. Also, a good plan for stage construction could provide a preview of things to come which might help materially with financing, rights-of-way acquisition or other problems. On the other side of the ledger, however, a bad plan could add to the distress on city streets and even endanger the entire proposal by presenting an unfavorable picture of the effects of expressway construction in an urban area.

The effect on city streets of stage construction of expressways will depend on the particular physical, economic and social conditions and traffic problems existing in the urban areas to be entered or traversed as well as on the nature and extent of each stage construction proposal. For this reason, no set rules for evaluating the effects of stage construction can be determined with the idea that they may be applied to all proposals which may be advanced. Each case will require intensive study, particularly of the capacities of existing streets (and their intersections), the loads on them, the probable effect of the proposal on those capacities and loads, and the potential advantages (or disadvantages) in service to traffic which will remain on or be diverted to each street (temporarily or permanently) as well as to that accommodated on the expressway.

One of the major problems encountered in planning urban expressway construction is that of providing for the collection and distribution of traffic by means of the connecting street network. This pro-

blem may be intensified when an expressway is constructed by stages. To assure that a stage construction plan is both worthwhile and workable, a complete analysis of traffic flows and travel habits seems essential. As a minimum, it is believed that answers to the following questions should be determined:

1. Which streets will be benefited by the stage construction proposal and to what extent?

2. Which streets will be required to carry heavier loads than at present and are they capable of doing so?

3. Will interchanges to be built as part of the stage construction plan have adequate capacities?

4. If it is planned to defer grade separations, what will be the effect on the expressway and city streets? Will they function with reasonable efficiency or will barriers be created at heavy cross-traffic streets which might nullify all other advantages?

5. If a project is to be constructed by sections, will a particular section, when completed, be effective in providing traffic relief in the area in which it is

built? What will be the operational behavior at its end points and can controls be established which will permit traffic to traverse the remainder of the route with reasonable ease until the entire improvement is completed?

Once these questions and others suggested by them are answered, it will be possible to formulate a sound and efficient stage construction plan rather than be compelled to go ahead on a hit-or-miss basis set up mostly with an eye on available funds.

To summarize, it is recognized that stage construction may be necessary. If so, however, the plan to be followed should be based on comprehensive and comparative studies which will insure it is the best that can be devised, that it will better, not worsen, traffic conditions, and that no unworkable situations or traffic bottle-necks will be created by the temporarily curtailed construction program. Also, may I stress again the thought that stage construction should be a last resort rather than the first "out" when funds are scarce.

EXPRESSWAY ROUTE SELECTION AND
VEHICULAR USAGE

R. M. BROWN, *Assistant Engineer of Road Design,*
State Highway Commission of Indiana

SYNOPSIS

From experiences gained in conducting three comprehensive Origin and Destination Surveys for the State Highway Commission of Indiana and the subsequent preparation of Traffic Survey and Highway Plan Reports, this paper presents the development of effective methods for the selection of urban expressway routes and the determination of their percent of usage by vehicles.

The selection of expressway routes, because of the intricacies involved, cannot be expressed in mathematical terms, but rather must consider the major desire line graphs as the primary basis for selection coordinated with an intimate knowledge of the city applied to land use, Sanborn and city maps, aerial photographs and an intensive field reconnaisance.

The extent to which vehicles will use the expressway is shown to depend on the "expressway distance" (the length of the expressway portion of the trip), the "access distance" (the length of city streets used to enter and leave the expressway in connection with a trip), and the "adverse distance" (the increased distance required for the trip via the expressway as compared to a more direct route using the city streets). Speeds on the expressway were assumed as twice those on city streets. From these conceptions the expression

$$P = \frac{\left[P_1 + P_2\right] \times P_3}{100}$$

where
P = Percent of expressway usage,
P_1 = Factor based on "expressway distance,"
P_2 = Factor based on "access distance," and
P_3 = Factor based on "adverse distance",

provides a rational method for computing the actual percent usage of expressway. Laborious calculations involved in the application of the formula are eliminated by the use of a graph or mechanical device developed in connection with the study.

The methods reported in this paper follow from personal experience gained in conducting three comprehensive origin and destination surveys for the State Highway Commission of Indiana in cities with populations between 120,000 and 400,000 and the subsequent preparation of a basic traffic Survey Report and a Highway Plan Report for each city. In connection with all of this work, it has been our practice to review all available similar reports for other cities and seek the counsel of other engineers engaged in this field.

The completion of the comprehensive origin and destination survey and the Traffic Survey Report containing all the basic data, tables, desire line graphs, and kindred items brings the planner face to face immediately with two all important questions: Where should the routes be located? How many vehicles will use them? For the purposes of this discourse, we will assume the city in question has a population exceeding 100,000 and the an-

ticipated volumes of traffic over a future 20 year period will require the expressway type of facility.

EXPRESSWAY ROUTE SELECTION

The selection of routes that will carry the traffic most efficiently and afford the greatest amount of relief at the lowest comparable costs, presents a complex challenge to the planner. Patterns developed for other cities, if available, will aid immeasurably in visualizing certain possibilities for the city in question. Our studies to the present time indicate scant opportunity for isolating the several involved complex phases into mathematical expressions which will establish even approximate locations. Rather, we have been compelled to bring into the picture every conceivable tool that would aid in the coordination of the city street system as it exists with daring alterations and additions as dictated by survey traffic patterns. The elements absolutely essential to the determination of the final routes include an intimate knowledge of the city applied to the major desire line graphs, land use, Sanborn and city maps and aerial photographs.

A mental picture of the city gained during the field survey and subsequent analytical studies will provide the most desirable background for the preliminary selection of feasible lines. A large city map suspended from the wall will refresh the memory as, in connection with the major desire line graph, we observe the varied patterns and prepare to choose the dominant center lines. The expressway type of facility becomes desirable for movements exceeding 20,000 vehicles per 24-hr. period and we therefore examine the graph and delineate the theoretical center lines of the traffic bands which will equal or exceed this minimum for the design period of 20 years. Narrow strips of draftsman's tape offer an excellent mode of showing these center lines. The selection of center lines which combine two or more bands should be given every consideration. Lines which can be easily recognized as infeasible because of certain known physical barriers should be discard-

ed and efforts concentrated on substitute combinations. The basic survey data in this graphic form depicts the theoretical patterns and therefore demands a maximum of consideration. Throughout the location studies it will be necessary to refer continually to these traffic band patterns, in order to guard against extreme deviations as successive obstacles arise.

The transfer of these basic lines to the land use map involves very careful attention to the characteristics of each section of the city to be traversed. The planner attempts to locate these routes in such a manner as to insure maximum use of vacant, low value and decadent property, so that the right of way cost and disruption of the city may be held to a minimum. In order to make use of existing streets as service roads, center lines should be located preferably at the center of the block or, in the case of wide blocks, between one street and the alley or property line in such a manner as to provide a minimum right of way width of 300 ft. Since the survey traffic statistics in some cases show that approximately 50 percent of all vehicular trips traverse some part of the central business area, the planner will be required to locate the routes essentially approaching its center. We recognize the vital need for an ample system of collection and distribution streets and the utter impossibility from an economic standpoint of acquiring costly business establishments and consequently the attempt is made to traverse within 5 to 6 blocks of the central point. This distance will usually avoid the absorption of main thoroughfares as service roads, and thus permit the main arteries as well as the new facility to serve the city more effectively.

The selection of both potential and final routes should be based on reliable survey data and sound engineering principles rather than preconceived opinions or personal prejudices. The planner should in no way be influenced by knowledge of actual names of property ownership along the several routes. Cemeteries, substantial churches, and schools must be avoided in selecting the routes.

A veritable labyrinth of lines will thus be developed from which the final system must be evolved.

An intensive examination of these lines will reveal certain patterns which have possibilities of definite consideration for the ultimate routes. For the normal city of this class, the system will usually require two major routes approximately at right angles with each other and, in general, paralleling the existing streets. Enlarged oblique aerial photographs taken as an essential part of the survey will prove an invaluable aid to the study and selection of the most desirable lines. Sanborn maps provide detailed information for each block in the city. City plat maps supply necessary street, alley, and block widths. A comprehensive coordination of the aerial photographs and maps by the planner serves to eliminate possible lines and establish several groups of potential routes worthy of exhaustive examination.

In preparation for field investigation these lines are reproduced on combined sections of photostatic reproductions of Sanborn maps (scale 1 in. = 100 ft.). Field maps prepared in this way help the investigator to identify an area quickly and serve as a constant reminder of the nature of the area. Alterations in the lines as dictated by the field studies can be shown in red on these maps for future use in the office. Liberal time should be alloted to this reconnaisance in order that the number of potential lines can be reduced to the absolute minimum for final consideration and comparative studies. By field observations in connection with our route studies in South Bend-Mishawake, Indiana with a combined population of 140,000, we finally ruled out all parallel lines with the exception of a 2-mile section which involved the alternate of acquiring either a restricted railroad right-of-way with a minimum of residential property or adequate right-of-way in a parallel location with a greater amount of residential property. The comparative study revealed a saving in cost of $100,000, and a larger percent of vehicular usage for the latter route. The

selection of the final routes in preference to alternate parallel lines can, in many cases, be determined by office and field observations of the relative property values, the advantages of more adequate access points, the adaptability of existing streets for service roads, the greater potential vehicular usage, and the lesser construction costs. For cases where uncertainty exists, exhaustive comparative studies should be performed in which the relation of benefits to costs should be given full consideration. In our studies up to the present time we have had no major case in which an actual benefit-cost ratio study was applied to the preliminary selection of lines. However, for the final routes, we have evaluated anticipated benefits in monetary terms for time saved and reduction in accidents.

In general the direct representatives of the several affected governmental units will have collaborated in the final stages of the line selection to give informal approval to the final routes. Formal approval should be gained in a subsequent conference with the responsible officials. It is our latest practice to arrange conferences with the editors of the newspapers for a preview of our proposed routes so that, if possible, we gain their tentative approval. In all these conferences we request that plans exhibited and discussed be held in strict confidence pending approval of the final report at some later date. The acceptance of this phase of the project by responsible officials paves the way for the next vital step in the evaluation of the system, that of determining the expected vehicular usage of the facility.

VEHICULAR USAGE OF THE EXPRESSWAY

In developing the proper location of the expressway to serve the largest volume of vehicular traffic, we are faced with a number of factors which influence its percent of usage. The city streets will continue to carry all short trips and others which could utilize the expressway for only a short distance (less than one half mile) as well as those trips for which ad-

verse distance would be a prohibitive factor. The expressway will carry varying percentages of all other types of trip dependent on their course with respect to the facility and the serviceability of the existing street system. On our initial project, traffic flows were developed by an experienced recorder choosing a percent of usage by personal judgment. He was guided by an intimate knowledge of the city, the assumption of a 2:1 speed ratio on the expressway as compared with city streets and, from visual inspection of the map, by the relative distance via the expressway and normal street routing. The recorder interpreted the 2:1 ratio to mean that where the time via the expressway equalled the time via a more direct route, 50 percent of the trips would use the expressway; and only in the case where the time via the expressway was one half that by any other route would 100 percent of the trips be considered to use it. Between these limits proportionate percentages of expressway usage were determined dependent on the relative time ratios.

We soon recognized that this method failed to include all factors affecting the movements but rather that it depended almost entirely on the good judgment of the engineer performing the tabulation. In the preparation of subsequent reports, it was therefore decided to explore the possibilities of an empirical formula which, regardless of the recorder, would produce the same results. This research led us to the conclusion that percent of usage is governed by three principal factors which we designated as F_1, F_2 and F_3.

F_1 involves the distance for which a given trip can use the expressway. F_2 considers the relationship between that distance and the total length of trip. F_3 is concerned with the extra or adverse distance necessary to reach and use the expressway.

After considerable discussion, trial and experiment it was determined that F_3 rated equal in importance to the combination of F_1 and F_2 and, further, that F_1 was more important than F_2 by a ratio of 7:3. Optimum values of 70, 30, and 100 respectively were therefore assigned and the composite factor, F, for the ultimate percent of usage set up as:

$$F = \frac{(F_1 + F_2) \times F_3}{100}$$

The essential distances pertinent to potential expressway trips and necessary to develop formulae for the several factors were:

a = Expressway distance, the length in miles of the expressway portion of the trip.

b = Access distance, the length in miles of the city street portion of the trip.

c = Street distance, the total length of trip in miles by the most advantageous route using only city streets.

From these distances:

$a + b$ = total length of trip via the expressway and

$a + b - c$ = Adverse distance - v

Factor F_1 reflects only the influence which expressway distance exerts on the percent of usage. We recognized that there will be a certain amount of inconvenience in entering and leaving an expressway, relatively important for short but of minor consequence for long expressway distances. Drivers would tend to weight the benefits against the inconveniences involved and would, in varying degrees, choose to use the expressway. In light of this conception it was our consensus that percent of usage would be zero for trips with expressway distances of less than one half mile (when a = 5.4) as a sufficient distance by which the saving in time would be ample to nullify the inconveniences. For values of F_1 between those points, a parabolic variation with vertex at the upper limit (70 at 5.4 miles) was selected because it provides a sharp rise in values for the expressway distances near the lower limit where it is apparent the rate of increase would be greatest. The detailed derivation of Factor F_1 based on these assumptions is recorded in Appendix A and develops the formula:

$$F_1 = -2.8a^2 + 30.24a - 11.65$$

for values of a, expressway distance, between 0.4 and 5.4 miles. For lesser and greater values of a, F_1 retains its respective minimum (0) and maximum (70) values.

Factor F_2 shows the extent to which the access distance influences expressway usage. It can best be visualized by observing the relation of the access distance to the expressway distance when the origin and destination of the trip are located on opposite sides of the expressway route. When these points are immediately adjacent to the expressway, it is the obvious and possibly only direct route for the trip. As origin, destination or both move away from the expressway, an increasing number of parallel streets will present to the driver numerous alternate ways to negotiate the trip without resort to the expressway. The greater the access distance becomes, the greater the probability will be that some of these streets, because of their distance from the expressway, will be relatively free from congestion and will therefore minimize the expressway advantages. A relation was therefore evaluated on the basis of the ratio of the expressway distance to the total trip length via the expressway. When this ratio is 1:1, that is when the access distance (b) is zero, Factor F_2 has its optimum value (30). Zero usage was assumed when this ratio reached 1:10 on the premise that percent of usage would be negligible when the total length of trip was ten times the length of expressway which could be used. This zero point could logically have been taken where the ratio was zero (one to infinity) without materially affecting the net result but we preferred to restrict our calculations to a finite limit.

For values of F_2 between the stated limits a straight line variation was used on the premise that usage will vary almost directly with this ratio. The detailed derivation of Factor F_2 based on these assumptions is shown in Appendix B and develops the formula:

$$F_2 = 33.3 \frac{a}{a+b} - 3.3$$

Factor F_3 reflects the effect of adverse distance on the percent of expressway usage. Adverse distance v is the additional distance of travel required via the expressway as compared to that by the existing streets. The speed on the expressway is, in every case, assumed to be twice that on the existing streets. It is our opinion that the variable speeds during the day resulting from traffic volume changes will automatically maintain this average ratio of 2:1. For example we know that increased volumes on the expressway imply the same on the city street with a corresponding reduction of speeds on both facilities and under light traffic, speeds increase but logically in approximately the same ratio.

On the basis of the 2:1 speed ratio, then, from a theoretical standpoint, when the ratio of the adverse distance to expressway distance $(v:a)$ is 1:2 (0.5), the time required via either route would be the same, since, by definition:

$$(1)$$

$$v = a + b - c$$

(via expressway route) $\quad f_1 = \frac{a}{2} + \frac{b}{1}$ and $f_2 = \frac{c}{1}$ (via city street route)

$$\text{when } f_1 = f_2; \quad c = \frac{a}{2} + b \quad (2)$$

by substituting in equation (1) the value of c from equation (2)

$$v = a + b - \frac{a}{2} - b \quad \text{or}$$

$$\frac{v}{a} = \tfrac{1}{2}$$

Conditions resulting in equality of time requirement for the two routes would seem to justify an assumption of 50 percent but from a practical standpoint we considered the expressway route somewhat less favorable because of more involved turning movements and therefore arbitrarily set the usage at 40 percent for this condition. Optimum usage is attained when the adverse distance is zero, i.e. when the length of trip is the same via either route. The parabolic function was selected to express the full range of F_3 values with its vertex at a value of 100 when $\frac{v}{a} = 0$ and with a value of 40

when $\frac{v}{a} = 0.5$. This choice followed from the conviction that the rate of change should be at a maximum below the controlling value of 40 and should decrease gradually as F_3 approached its optimum value. Mathematical projection gave a zero value for F_3 when $\frac{v}{a} = .645$. The detailed derivation of Factor F_3 based on these assumptions is recorded in Appendix C and develops the equation:

$$F_3 = 100 - 240 \ (\tfrac{v}{a})^2$$

The application of the method to the determination of expressway usage by vehicles is very simple and, for any desired movement, requires the measurement of the primary distances involved in the formula as previously defined: (1) expressway distance a, (2) access distance b; and (3) street distance c. For each potential expressway movement the recorder, by means of a flexible tape, scales the b and c distances on a city map upon which has been depicted the expressway system including all service roads, entrances and exit ramps. Important city thoroughfares were given a distinctive color to aid the recorder in selecting the most favorable routes. Distances a between all access points of the expressway were measured previously and shown in a table to eliminate repeated measurements.

For example: Between two specific tracts we have a movement of 130 trips which, by observation, would involve potential expressway usage. Selecting the access points, consulting the table for a and measuring b and c, we find:

$a = 6.0$
$b = 3.0$
$c = 8.0$
$v = a + b - c = 6 + 3 - 8 = 1.0$

Application in the basic formula produces:

$$F = \frac{\left[70 \ (a \text{ exceeds } 5.4) + 33.3 \ \tfrac{6}{6+3} - 3 \ 3\right]}{100} \times$$
$$\frac{\left[100 - 240 \ (\tfrac{1}{6})^2\right]}{}$$

$$= \frac{[70 + 19] \times 94}{100}$$

$$= 84$$

Trips on the expressway therefore would be 84 percent of 130 = 109 trips they would apply between the selected access points. The remaining 21 trips would use the available city streets.

These final formulae were rigidly tested by applying them to a comprehensive selection of actual trip movements from the South Bend project. The percentages of expressway use thus computed were observed in each case to be so completely satisfactory, that we have adopted this method for all projects. It has facilitated greatly the mechanics of this phase of the work and assured us of consistent accurate results.

The cumbersome work entailed in applying these formulae to the calculation of these factors was eliminated by preparing a graphic calculator from which the three factors could be selected by using the pertinent distances involved in the formulae. Figures 1 and 2 show the use of this device in the determination respectively of Factors F_1, F_2 and F_3. (Note: Figures 1, 2 and 3 are in the back of this book.) Factor F_1 is read directly as a stub item on the left side of the chart. For value $a = 6$, $F_1 = 70$ ($F_1 = 70$ for all values of a above 5.4).

For F_2, the value of $a + b$ on the pivoted arm scale (Fig. 4) is brought to an intersection with the vertical line through the a value on the top scale. The reading where the arm intersects the upper arc is the value for F_2. For our example $a + b = 9$ intersects $a = 6$ showing a value in the upper arc for $F_2 = 19$. For F_3, the value a on the pivoted arm scale (Fig. 5) is brought to an intersection with the vertical line through the v value on the top scale. The reading where the arm intersects the lower arc is the value for F_3. For our example, $a = 6$ intersects $v = 1$ to produce $F_3 = 94$. The recorder completes the combination of the factors on a calculating machine.

Since the development of the described tool for determination of factors, Mr. P. M. Cassidy of the Indiana District Office of the Public Roads Administration, who had consulted with us on this

study, further interested himself in the project by developing a mechanical device from a series of nomographs designed and arranged to perform completely the solution of all equations including the additions, subtractions and multiplications involved. Figure 3 is a photograph of the device depicted to show how it would solve the stated example.

The operation of the device is as follows: The left sliding pointer is moved to a equal 6.0, the right sliding pointer is moved to b equal 3.0, the slider on the tape near the center is moved so that c points to 8.0 on the c scale. String 1 (revolving about the left pointer) is moved around to position 1 so as to touch the right pointer in which position F_2 is determined (19) from where the string crosses the diagonal F_2 scale. Nineteen is then added mentally to the value of $F_1(70)$ which is given opposite the a reading (this addition which is always very simple is the only mental calculation required in this method) and this sum (89) is set on the extreme left hand scale of $F_1 + F_2$ scale. String 1 is then moved around to position 2 so that it passes through the value of 1.0 on the v scale (4th from left) and the extension of this line through the intersection with the diagonal F_3 scale gives the value of F_3 equal to 94. It will be noted that v was obtained directly by reading in the little opening of the slider on the tape. (It is just coincidence that string 1 crossed the value of v equal 1.0 at this point.). String 2 is then revolved (to position 1) so that it intersects the vertical F_3

scale, at the right, at reading of 94 and the percent usage (84) is read where this string intersects the "percent usage" scale near the center; then placing one's thumb on the string at the "percent usage" reading and revolving string 2 around to position 2 so that it intersects the "number of vehicles involved" scale, for the given value of 130 and which had been set to start with, the vehicle usage is then determined from the "vehicle usage" scale which reads 109 vehicles.

A series of examples run by the use of graph and by the mechanical device revealed a saving of approximately 20 seconds for each operation by the latter method. The recorded time by the graph as 1 min. 20 sec., by the mechanical device 1 min. After a period of actual use of the mechanical device, we anticipate the time per operation can be reduced even below the 1 minute figure. The advantages in addition to saving in time include a greater accuracy and elimination of a certain amount of drudgery connected with the former method. The device requires only one operator to determine and record the flows in lieu of two for the other method.

The selection of expressway routes and the determination of traffic flows thereon constitute a most important part of the development of a highway plan for the city. The methods we have described are presented for the constructive use and criticism of all interested engineers engaged in this field to the end that through the mutually sharing of accomplishments, the greatest progress will follow.

APPENDIX A

DERIVATION OF FORMULA FOR
FACTOR F_1

It was the general consensus of those associated with expressway "use" determinations that a factor that would reflect only the expressway trip length should have a value of 0 when the length was 0.4 mile and a value of 100 when the length was 5.4 miles, and for lengths in between the variation should be parabolic.
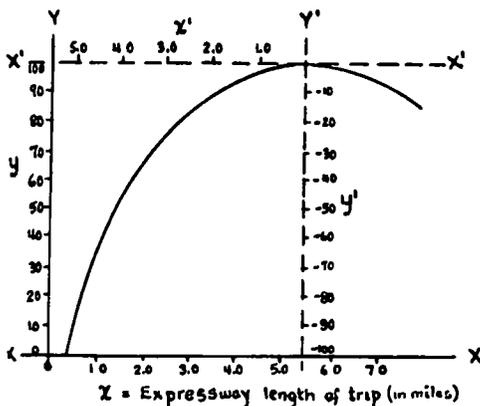
X = Expressway length of trip (in miles)

The curve indicated in the diagram is the desired curve based on the above conditions, and the equation of this curve related to the X and Y axes is the equation desired. The basic mathematical expression for this particular parabola referred to the X' and Y' axes is

$$y' = k (x')^2$$

solving this equation for k when $y' = -100$ and $x' = -5$ gives a value for $k = -4$

therefore $y' = -4 (x')^2$

to change this equation so as to refer to the X and Y axes instead of the X' and Y' axes substitute $y - 100$ for y', and $x - 5.4$ for x', and the equation becomes

$$y = -4x^2 + 43.2x - 16.64$$

This is the basic equation which expresses in percent the "use" of the expressway insofar as the length alone is concerned.

As indicated elsewhere the length factor carries a weight of only 70 in relation to a weight of 30 for Factor F_2 in the final determination of expressway usage, therefore values in the above equation are multiplied by 0.7 to give the proper values to Factor F_1. The equation then becomes

$$F_1 = -2.8x^2 + 30.24x = 11.65$$

or since designation "a" instead of "X" is used to indicate the length of expressway the equation becomes

$$F_1 = -2.8a^2 + 30.24a - 11.65$$

Where a is the expressway length of trip in miles.

APPENDIX B

DERIVATION OF FORMULA FOR
FACTOR F_2

It was the general consensus of those associated with expressway "use" determinations, that a factor that would reflect the effect of the distance the origin or destination was from the expressway could be expressed by the ratio that the expressway distance was to the total length of the trip and that the values corresponding to various ratios should be as follows: 100% when the ratio was one, zero % when the ratio was 0.1 and in between values to vary as a straight line. The line indicated in the diagram at the right is the desired line, based on the above conditions.

The general equation is $y = mx + d$ where m is the slope of the line and d the Y axis intercept

but $m = \dfrac{100}{.9}$ and $d = \dfrac{-(.1)}{} \dfrac{100}{.9} = \dfrac{-10}{.9} = \dfrac{-100}{9}$

substituting, the equation becomes

$$y = \frac{(100x)}{(.9)} - \frac{(100)}{(9)}$$

further substitution of the value of

$$\frac{a}{a+b} = x$$

the equation becomes

$$y = \frac{100}{.9} \frac{(a)}{(a+b)} - \frac{100}{9}$$

X = ratio of expressway length of trip to total length of trip.
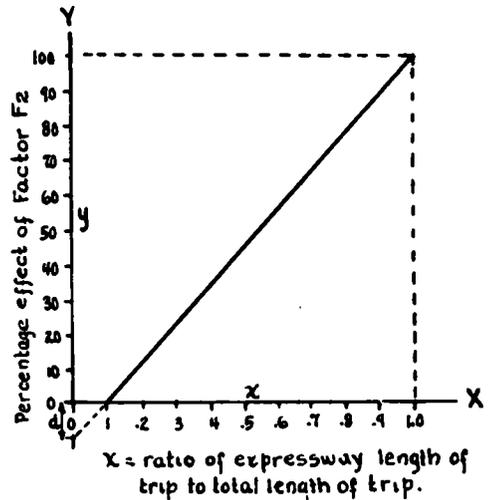
As indicated elsewhere the F_2 factor in the final usage percentage determination should carry a weight of only 30 in relation to a weight of 70 for the F_1 factor, therefore the above equation should be multiplied by 0.3 to give the proper values to factor F_2.

the equation for factor F_2 then is

$$F_2 = \frac{30}{.9} \frac{(a)}{(a+b)} - \frac{30}{9}$$

or $\qquad F_2 = 33.3 \dfrac{a}{a+b} - 3.3$

where a is the expressway length of trip in miles and b is the access distance in miles.

APPENDIX C

DERIVATION OF FORMULA FOR
FACTOR F_3

It was the general consensus of those associated with expressway "use" determinations that a factor that would reflect usage relating the time via the expressway to the time via the more direct route could be expressed by the ratio that obtained between the adverse distance, and the length of trip actually on the expressway, and that the values that these ratios should indicate would be as follows: 100% when the ratio was 0, 40% when the ratio was ½, and 0% when the ratio was .645.

The curve indicated in the diagram is the desired curve based on the above conditions, and the equation for this curve related to the X and Y axes is the desired equation.

The basic mathematical expression for this parabola which has its vertex at the intersection of the X' and Y' axes is

$$y' = k(x')^2$$

when $y' = -60$, $x' = .5$ and substituting and solving for k, $k = -240$ and the equation becomes

$$y' = -240 (x')^2$$

To change this equation so as to refer to the X and Y axes substitute $Y - 100$ for
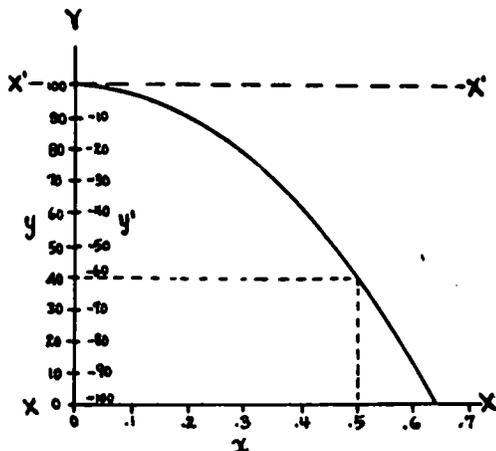
x = ratio of adverse distance to distance of trip on expressway

y', and x for x', and the equation becomes

$$y = 100 - 240x^2$$

Further substitution of the value of $\frac{v}{a}$ for x and the equation becomes that for Factor F_3 which is

$$F_3 = 100 - 240 \left(\frac{v}{a}\right)^2$$

where a is the expressway length of trip in miles and v is the adverse distance in miles.

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