

section of the tunnel is sufficiently large. For longer tunnels, ventilation may be provided by properly spaced ventilating shafts, or longitudinal ventilation. Suitable fan equipment is required for both.

The principal purpose of an expressway in a city is to improve travel conditions. A common obstruction to travel is a vehicle which has become disabled on the road. If it remains on the regular travel lanes it becomes an accident menace and may seriously delay the traffic. Therefore, whatever the type of structure may be, the expressway should, throughout its length, be provided with a shoulder strip outside of the land area, preferably as wide as a lane, but at least wide enough to permit continuous traffic when a disabled vehicle is using the shoulder strip for refuge.

LOCATION OF TRAFFIC INTERCHANGES

The primary function of controlled-access urban expressways is the provision of an adequate artery to serve the vehicular traffic needs within the urban area. In the designation, "controlled-access" is the connotation of the restriction of immediate entrance and exit between the expressway and properties fronting on the expressway. Access is provided only at designated points. Thus, spacing of the accesses becomes one of the most vital aspects in the planning and design of urban expressways.

The term, "traffic interchange", as used in this discussion, means literally any point where there is an interchange of traffic between the expressway and other highway or street, even though the interchange may not be necessary or possible for all direction flow of traffic. The term, "interchange" is used to designate the turning facilities at the intersection or junction of two or more main highways in conjunction with grade separation.

An expressway is a highway which provides express service for vehicular traffic. As in railroads, a highway which "makes all the stops" is not an expressway. However, a "non-stop"

highway through a city in similar manner to a by-pass, would serve only through traffic and benefit the city only by removing the through traffic from the city streets. The urban expressway is usually planned to serve various types of traffic. For through traffic it should provide a relatively uninterrupted flow. However, its greatest service is in facilitating the flow of traffic between the business district, or districts, and outlying residential areas or other points outside the city. The pattern of spacing of interchanges must conform to this principal function.

It follows, therefore, that access should generally be more frequent in these terminal areas, that is, in the outlying residential districts and in the central business district with access somewhat less frequent in the intervening areas. Access at a distance from the business district would not conform to this function. Ordinarily such traffic can be best served by the existing streets.

No exact or fixed criteria for the spacing of interchanges have been developed. For instance, no rule has been, nor can be, developed which states that access should be provided at regular intervals such as one thousand feet or one mile. In this discussion, which is restricted to urban expressways, the subject or problem is one of proper location rather than of spacing of interchanges. The question, rather than being primarily of how far apart should they be, is one of where they should be. The criterion for location of an interchange is usually one of economic justification balanced against its effect on the efficiency and function of the expressway.

1. Volume of Traffic Justifying a Traffic Interchange.

First in the consideration of the location or spacing of interchanges is the question of traffic volumes. No expressway can be planned or designed wisely without adequate counts of traffic volumes within the area affected by the expressway. These counts must be carefully compiled, analyzed, and plotted to present a clear picture of the existing traffic pattern.

But a count of the over-all traffic volumes alone is not sufficient. Careful planning of the location of interchanges requires more detailed traffic data, data which will segregate and show the pattern of that part of the total traffic with which the design of the expressway should be concerned. Such traffic is that which the expressway would handle when properly designed to serve its principal function. In order to obtain this segregation of traffic volumes an origin and destination study must be made. This study should be as complete as possible and should be planned with the purpose of obtaining the picture of the pattern of traffic concerned with the expressway. Intracity traffic, sometimes neglected in cordon-type origin and destination surveys of cities, merits careful consideration.

The data from traffic studies should, of course, be adjusted, expanded or projected to fit the time of completed construction and for a reasonable period in the future as well.

On the basis of a general examination of the traffic data with an on-the-spot knowledge of local traffic behavior, tentative locations for interchanges can be determined. A flow diagram of anticipated traffic then may be made. This diagram should include an interchange turning movement, that is, an estimate of the traffic volume on each access drive or ramp as well as on the main roadways. Consideration should be given to long-time average counts and to peak conditions. The resultant pattern of traffic on existing streets is given principal consideration.

This analysis may readily give an indication of whether or not the access is needed and, if so, what its design capacity should be. However, the scope of the problem extends beyond that of need for access. There is the added consideration: "Is the access economically justified?" It has been mentioned that a numerical criterion for justification is not possible. The nearest approach to a numerical criterion is a benefit-cost ratio derived from a study of economic justification. The tools for this type of investigation in highway planning have not been fully developed but they are sufficiently accurate, when

judiciously employed, to demonstrate whether or not a proposal is justified. Methods of economic analysis for the justification of entire highway projects have been used in a few cases, and the system is becoming more widespread. These same methods may be used to justify the construction of an interchange.

On the basis of the estimated traffic volumes, the benefits from the proposed interchange may be evaluated. These benefits may be direct benefits to the users as calculated from the difference in cost between using the proposed facility and an alternate or existing route, or they may be indirect or community benefits to the area served. The cost includes the original and maintenance costs for the period specified. The ratio of this benefit to the cost will serve as a guide to justification.

2. Factors of Convenience and Service Regardless of Traffic Volumes.

In the above method of analysis, the factors of convenience and service may be evaluated along with other factors or benefits. They may not necessarily be a direct function of traffic volumes, but nevertheless they should be evaluated as benefits. It is impossible to evaluate convenience and service precisely, but as factors in the economic justification of an interchange a reasonable monetary value can be assigned to them with sufficient accuracy to become a part of a sound analysis.

3. Factor of Desire to Develop a Backward Area.

It is sometimes said that an interchange may be built in order to develop a backward area even though it is not "economically justified". However, in the light of the interpretation of economic justification as herein discussed, the interchange so planned would be economically justified since the decision involved some monetary evaluation of future benefits in relation to its estimated cost. An exact dollar value of future benefits may not have been stated in the analysis, but some rough conception of its magnitude must necessarily be involved in any reasonable consideration of the problem.

The decision may later be proved to be unsound, or for some causes not anticipated, the location of the interchange may not have proved justified, but at the time of the analysis it may have been justified.

In order to arrive at the justification of an interchange for the purpose of developing of an area, the period of years used as a basis of analysis is very important. It is obvious that in twenty years an interchange may have been proved justified when in one year it could not be considered justifiable. Practical limitations are put on the length of time involved by physical life of construction components, capital costs, etc.

4. Effect on Efficiency of Expressway.

It was stated previously that a highway with too frequent access could not be an expressway. The frequency of access to an expressway does affect its efficiency. At any point of interchange of traffic the smooth flow and safety of traffic is somewhat hampered even though the connection is well designed. Safe speed of travel is thus affected, but the efficiency of the expressway is not rendered completely ineffective unless too frequent access reduces this speed to a point at which the new facility offers no advantage over the existing streets. An expressway without intermediate access to the areas intended to be served would be efficient for through traffic, but it could not be considered efficient in an over-all sense.

Certain physical considerations such as required length of acceleration and deceleration lanes, the number of lanes, weaving distance and design speed would determine a minimum distance between interchanges provided normal design standards are maintained. This problem is particularly evident at a point of intersection of expressways when local access at that point must be provided.

Again no numerical criteria exist for the determination that access is too frequent. It may be stated as a general principle that, when frequent access is required, it is desirable to construct a reasonable number of high-capacity interchanges with adequate feeder con-

nections rather than many minor access facilities.

Ordinarily the justification of an access or interchange may be made on an economic basis. There are, however, other factors which figure in the decision; factors which are characterized by force or pressure and not of free choice on the part of the planner. These factors include the legal, political, or military necessity of providing access where the economic necessity is not sufficient. Sometimes, too, physical barriers or adverse topographical conditions dictate the location of an access at a given location instead, for instance, of continuing parallel service roads.

It sometimes happens that an access may be demonstrated to be entirely justified economically but that available funds are not sufficient to include it. Thus the "ability to pay" is an important factor in the location of interchanges.

DESIGN OF TRAFFIC INTERCHANGES

1. General Considerations.

It is considered that the scope of this report concerns only traffic interchanges between expressways and surface street systems in urban areas. "Traffic interchange" as used herein refers to the interchange between expressways and the surface street system unless otherwise stated. This report is not primarily concerned with the detailed geometric design of traffic interchanges. Rather its purpose is to discuss those elements of design of traffic interchanges which concern their relationship to the existing street system and the effect of the interchanges upon, and the service which they render to the urban area in general and the district traversed in particular.

While some general rules and governing considerations may be laid down to guide the designer, it will normally be found that each traffic interchange is a special problem which can best be solved only after analysis of all related factors. When the location, general type and required capacity of the interchange has been determined, actual detailed design and planning may be carried on in ac-