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 connections 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-

cordance with recognized design standards.

The judicious spacing and design of traffic interchanges is of vital importance to the greatest efficiency and use of the expressway and surface street system. Spacing was discussed more fully in the previous section. As noted too many interchanges will hamper the smooth flow of traffic along the expressway. Conversely, too few interchanges will reduce the value of the expressway in providing, the communities or districts through which it passes, the maximum traffic relief or transportation service. It is necessary therefore to balance these two factors to assure a facility which will provide the greatest efficiency and safety of movement and the maximum of traffic service to the urban area. The adopted spacing and design of interchanges should be determined only after an exhaustive study has been made of all factors relating to the expressway design.

Normally, connection will be made to the surface street system either directly to or in close proximity to a major surface artery which is to be kept open across the expressway. Such an artery is usually already carrying a heavy traffic flow. It is therefore undesirable, if it can be avoided, to introduce additional intersections into these busy arteries, or to create intersections which are difficult to control by traffic regulatory devices. These intersections will create additional turning movements, interferences to traffic flow and traffic hazards which may tend to reduce the efficiency of the surface artery, thus reducing the overall benefit which the urban area will derive from construction of the expressway.

Where it is necessary to create new intersections in or directly connected to a major surface artery, the design should preferably be one which does not involve left-turning across traffic at grade. However, it is found in developed urban areas that the expense of grade separating all left turns on surface arteries is so great, and the taking of land so serious in its effect on the district, that it is not feasible to design this type of traffic interchange except in unusually favorable cases. Left-turning in the direction of the heaviest traffic flow or flows may at times be grade separated by special construction, but where this is done, considerable thought must be given to the possibility that future development in the vicinity may alter the pattern of traffic movements, and thus reduce the value of the partial treatment. Locations in a park, public land or in marginal undeveloped areas may permit a design which grade separates all left turns.

The pattern of the surface street system and the angle of the crossing of the expressway, together with a determination of the necessary directions of movement and the volumes of such movements to and from the expressway, are controlling elements which affect the design of the traffic interchange.

Ramps should be designed to provide sufficient moving and storage capacity so that the continuous flow of traffic along the expressway is not hindered. They should be of sufficient length to permit transition between expressway speeds and surface traffic speeds and to provide sufficient storage space so that cars will not overflow onto the expressway or beyond the entrance at the surface artery while making the transition to surface artery or expressway. Properly designed acceleration and deceleration areas should be provided along the expressway in connection with ramps. Except for short ramps having minor use, two lane width or a traversable shoulder should be provided so that disabled cars will not block the ramp. Where off-ramps enter the surface artery and where on-ramps enter the expressway it is desirable to reduce the width to one ample lane (usually 14 feet wide) to (1) discourage illegal entrance of traffic from the surface artery and (2) encourage the use of the accelerating area in entering the expressway.

2. Types of Expressway Interchanges:

a. Interchanges Eliminating Left Turns (Types a)

a-1. Cloverleaf Interchanges - (Types a_1). The type of interchange which eliminates all left turns across

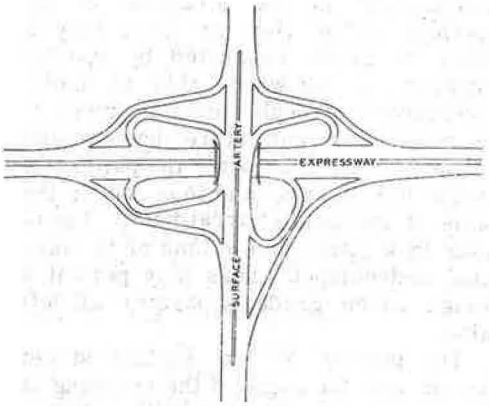

Figure 1. Typical Cloverleaf at Intersection - Surface Artery with Expressway - Type a_1.

traffic with the least additional construction cost is the cloverleaf. A typical cloverleaf is shown in the illustrations as "Type a_1". A cloverleaf interchange, while not usually suitable at the intersection of two expressways because of the low volume traffic which may be handled through it, may be satisfactory in some cases as an interchange between expressway and surface artery. The cloverleaf type involves additional travel distances for the left-turning movements. Its capacity for left-turning traffic is limited by the relatively small radii of the cloverleaf turns, which govern the possible speed of interchange and the length of storage space available before cars back into the expressway.. A serious disadvantage of the cloverleaf, especially from the standpoint of traffic along the expressway, is the short weaving distance available for traffic entering and leav- the expressway. This acute angular crossing of traffic is hazardous to traffic along the expressway and to a lesser degree is also hazardous to traffic along the surface artery. Furthermore, it is difficult to regulate traffic along the surface artery at a cloverleaf because of the large radius turns by which traffic enters and leaves the surface artery. Protection of pedestrians walking through the intersection along the surface artery is also difficult. A cloverleaf interchange requires the acquisition of a large amount of right-of-way. For the above reasons its use as an interchange in developed urban areas is limited.

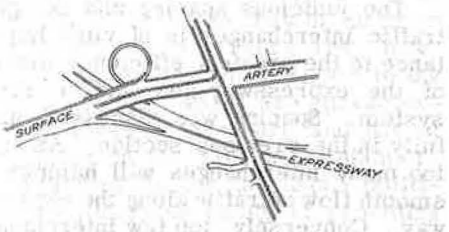

Figure 2. Typical On and Off Ramps - Type a_2.

While it is rarely practical from an economic standpoint to eliminate or separate the grades of all left turns at an intersection of expressway and surface artery, it may be practical and desirable to grade separate the heaviest left-turning movement or movements. Where the intersection varies considerably from a right angle it is not always necessary to provide for turning movements in all directions and a partial treatment may therefore be more readily accomplished. Sketch "Type a_1" (partial) shows a partial cloverleaf which eliminates only one left-turning movement at grade into the surface artery.

Many geometric variations of these designs are possible.

a-2. Direct-Connection Interchanges (Types a_2). This type of interchange includes all those in which left turns are eliminated or grade separated by special construction and wherein turning movements are accomplished with little if any additional travel distance. The interchange of traffic from expressway to surface artery is accomplished with no grade crossings of traffic and with a minimum of merging friction or weaving of traffic.

While theoretically very desirable, direct-connection interchanges become very costly for these usually require several levels of construction with considerable structural expense or large areas of land with consequently high right-of-way costs. A complete interchange of this type could seldom be

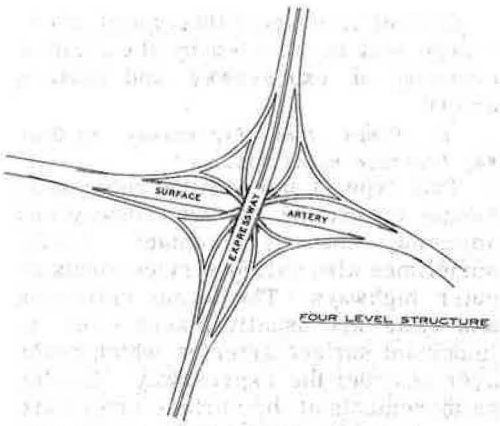

Figure 3. Direct Connection Interchange - Type a_2.

economically justified between an expressway and surface artery in a developed urban area. Again, however, as in the case of the cloverleaf intersection, it may be possible to use the direct interchange principle to provide grade separation for the heaviest or heavier turning movements.

The direct types of interchange may require less right-of-way than the cloverleaf type but are usually more costly in construction expense. A "4-level" intersection providing grade separation for all left turns is shown in the illustrations as "Type a_2" and a "3-level" and a "2-level" intersection at an acute angle which provide for grade separation of certain left turns are shown as "Type a_2" (partial). The above types are very attractive for expressway interchanges and their additional costs can usually be justified for such intersections. Many other geometric variations of this type are possible.

b. Direct Ramps from Expressway to Surface Artery (Type b).

This type of interchange consists of ramps leading directly from the expressway to a surface artery passing over or under the expressway. It is commonly used where no service or frontage roads are provided adjoining the expressway and requires little additional right-of-way at the intersection of the two thoroughfares. If the expressway occupies the location of a

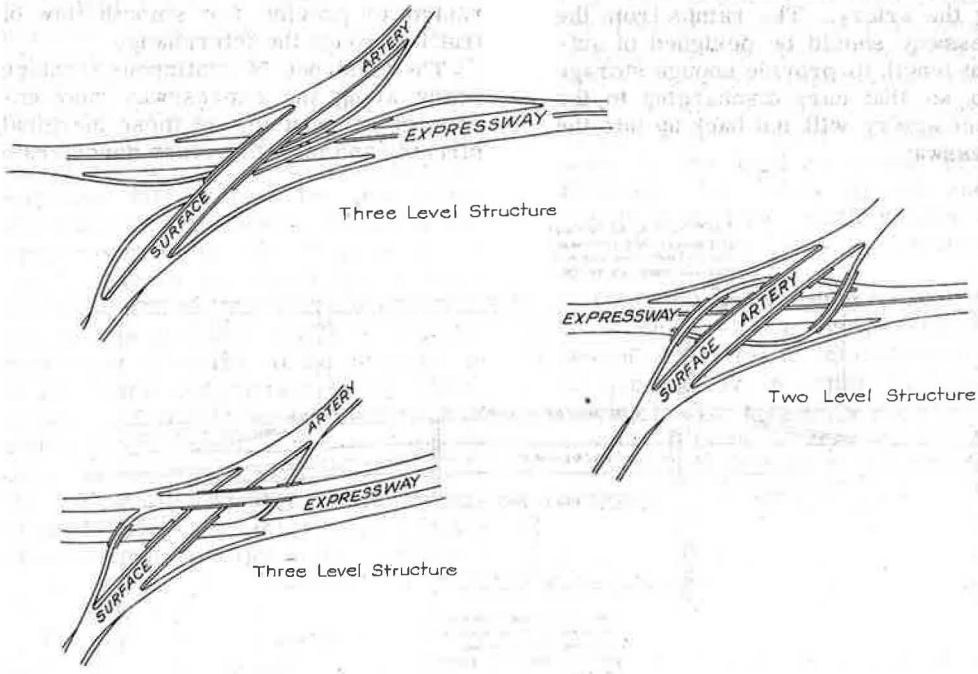

Figure 4. Typical Direct Connection Partial Interchange Type a_2 (Partial).

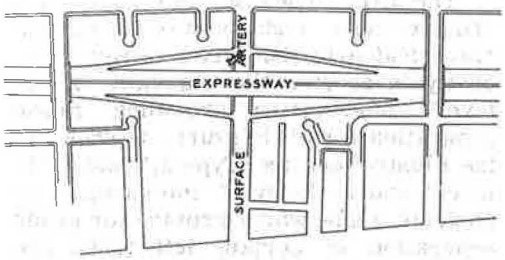

Figure 5. Typical On and Off Ramps - Type b.

former existing street crossing the surface artery, no new intersection is created or turning movements added along the surface artery. If the expressway is along a new right-of-way, an additional intersection is created at the surface artery, involving 4-way left turns across the traffic along this street. If the turning movements are large, or the flow of traffic along the artery is heavy, regulation of the intersection by traffic signal may be required. Such signals should be timed with other signals along the surface artery in order not to delay the flow of traffic along the artery. The ramps from the expressway should be designed of sufficient length to provide enough storage space so that cars discharging to the surface artery will not back up into the expressway.

Geometric design of this type of interchange will be affected by the angle of crossing of expressway and surface artery.

c. Ramps from Expressway to One-Way Frontage Roads (Type c).

This type of interchange consists of ramps connecting the expressway and adjoining one-way frontage roads, sometimes also called service roads or outer highways. The ramp entrances and exits are usually placed close to important surface arteries which cross over or under the expressway. Insofar as movements at the surface artery are concerned, this type involves all turns which occur at a surface artery with a "Type b" interchange. However, it is possible by traffic control to prohibit left turns across the surface artery traffic either entirely or during peak hours and require the accomplishment of this movement by circling the block to the right via existing surface streets if the street pattern permits. The suggested movement is shown on the illustration of "Type c". While this may introduce considerable additional travel for left-turning traffic it may be warranted to provide for smooth flow of traffic through the interchange.

The existence of continuous frontage roads along the expressway may encourage an undue use of these marginal streets, and may therefore concentrate

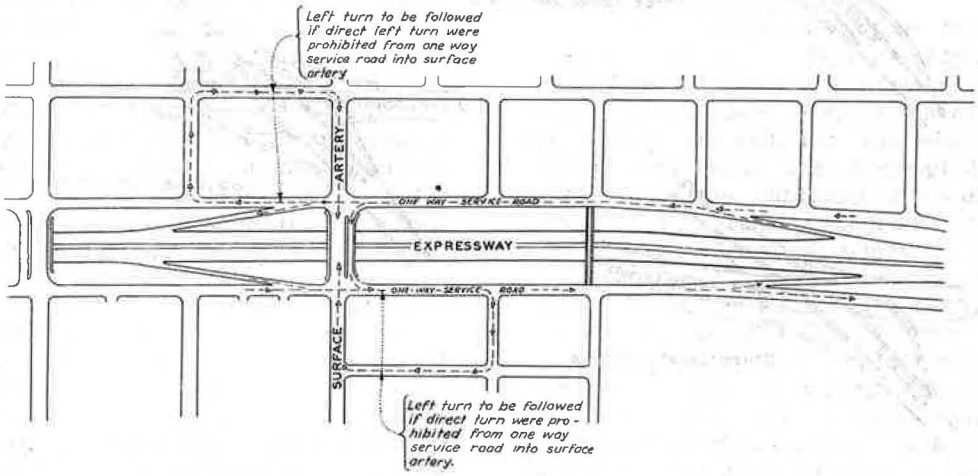

Figure 6. Typical On and Off Ramps at One-Way Service Roads - Type c.

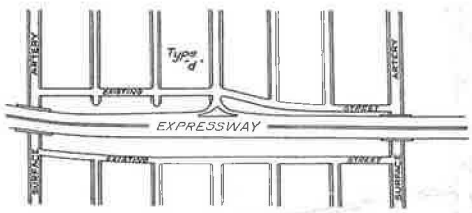

Figure 7. Typical On and Off Ramps - Type d.

large volumes of cross traffic alongside the expressway at the major arteries. This condition tends to partially offset the value of the grade separation of traffic effected by construction of the expressway. Where existing surface streets parallel the expressway, not too far removed therefrom, it is therefore not desirable to create new frontage roads which are continuous over long distances.

d. Ramps to Existing Streets Paralleling the Expressway (Type d).

This type of interchange may be used between an expressway and an existing 2-way street paralleling or adjoining the expressway. On and off ramps should be provided with as generous radii as possible, a desirable minimum being 130 feet. The outlets and inlets of the ramps at the surface street should preferably be aligned (in the proper direction of travel) with an existing local street not carried across the expressway but intersecting the paralleling marginal street. Where design of expressway permits, the off ramp and on ramps may be separated one or more blocks apart at the surface street to obtain less potential conflicts or concentration of traffic at the intersection of the ramps and surface street. Distribution of traffic to and collection of traffic from major surface streets crossing the expressway may be made via the paralleling street, with no additional street intersections being created along the major surface arteries.

e. Ramps to Stub-end Existing Streets (Type e).

This type of interchange consists of inlet and outlet ramps connecting the expressway to the stub-end of a street not of sufficient importance to be continued across the expressway. No additional intersections in the surface street system are created by such interchange. Distribution of traffic to and from the major surface arteries is not as direct as in the case of some of the other interchanges.

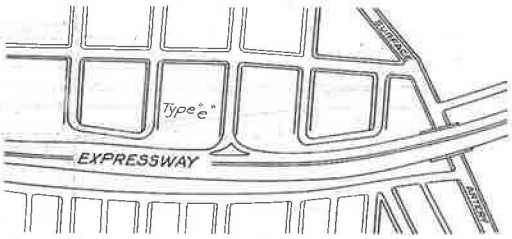

Figure 8. Typical On and Off Ramps - Type e.

f. Ramps to Pairs of One-Way Streets (Type f).

This type consists of direct ramps from an expressway to a pair of one-way surface arteries crossing the expressway with connecting frontage roads. Its use involves the crossing of one-way traffic for left turns into or out of the one-way street, but only merging movements for other turns.

In the planning of an expressway within a developed area, it will probably be found that any or all of the above described types may be applicable at different points along the expressway. The selection of the type to be used at any particular location must be made on the basis of the local conditions with due allowance for future growth and for change in the local traffic pattern which will necessarily follow the construction of the expressway.

Other things permitting, there should be as much uniformity as possible in the design of the traffic interchanges along an expressway in order that the fast moving traffic may know what to expect at each point of interchange and that no element of surprise or uncertainty is present.

3. Volume of Traffic Justifying Elimination of Left Turn on the Existing Street.

Principal objectives in the design of traffic interchanges are the following:

a. At the expressway.

To permit traffic entering the ex-

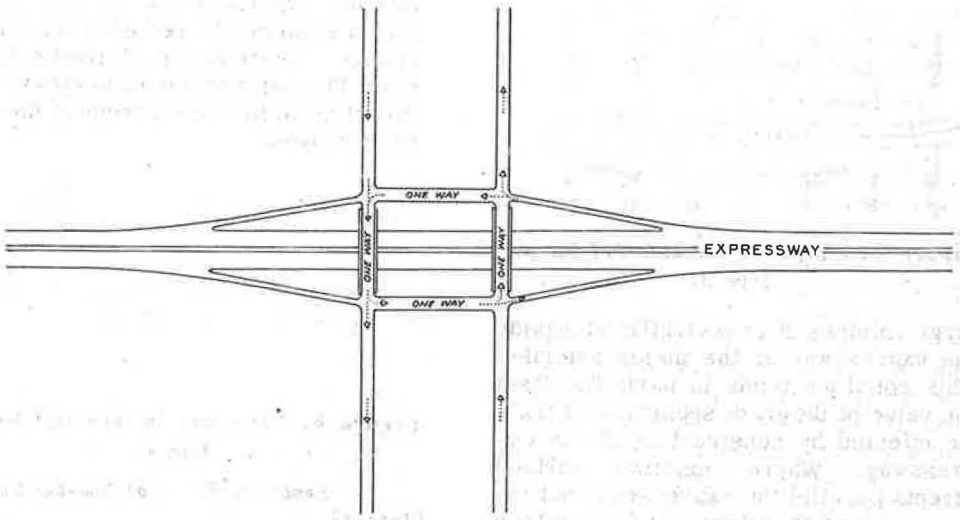

Figure 9. Typical Ramp System at Intersection with Pair of One-Way Streets - Type f.

pressway or leaving the expressway to do so without interfering with the smooth flow of traffic along the expressway.

b. At the surface artery.

To permit traffic moving from the expressway to blend smoothly with the surface street traffic without delay or hazard to either stream of traffic. To permit traffic moving from the surface artery to enter the ramp without delay or hazard to the surface artery traffic.

In connection with objective (b) above, left turns at grade across the surface artery to and from the interchange ramps will naturally affect to varying extents the smooth flow of traffic. Basically, as previously stated, it is therefore desirable to eliminate left turns at grade by design wherever possible or particularly where the number of left turns is sufficient to materially reduce the capacity of the surface artery and the expressway ramps.

Extensive studies of intersection capacities have been reported on by the Committee on Highway Capacity of the Highway Research Board. These include the effect of turning movements on the traffic capacity of an intersection. These data will permit close estimating of the traffic volumes which can be handled through any specific intersection and, therefore, an analysis of the effect of permitted turning movements on the capacity of that intersection. It then becomes the problem of the designer to determine whether this effect will be detrimental to the general traffic flow and whether it is desirable to eliminate left turns at the intersection in question.

The amount of left-turning traffic which can be or should be accommodated at an intersection will be governed by such special considerations as the location of the expressway and the characteristics of traffic flow and traffic control along the surface artery.

For example, if on either side of the expressway intersection, there are traffic signals and permitted left turns between the artery and cross streets, there would appear to be no great need for going to considerable additional expense to eliminate left turns at the intersection of the expressway ramps. Where it is possible to control the traffic along the surface artery at the interchange in such a way that there is no overall delay to traffic along the artery, and the expressway ramps effectively handle the traffic wishing to use them, certainly the elimination of left turns is not justified.

It is probable that there cannot be set up a fixed rule or numerical basis on which to conclude whether left turns should be eliminated. A few left turns might possible disrupt traffic along an

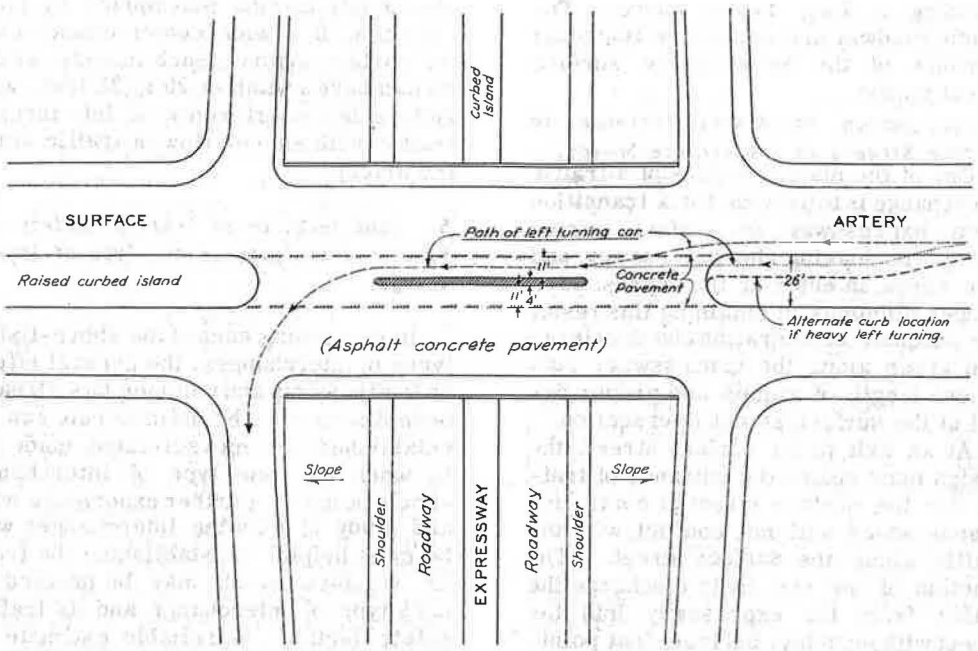

Figure 10. Protected Left Turns at Expressway Ramps.

artery carrying its maximum traffic, whereas a large percentage of traffic entering a less heavily traveled artery might make left turns without causing serious delay to other traffic.

In addition to traffic considerations, a major factor in considering the elimination of left turns at grade will be the economic consideration of the additional cost of facilities to eliminate the left turns.

4. Design at the Existing Street Connections, Left Turn: No Left Turn.

Design of ramp inlets and outlets at the surface artery, together with design of the roadway of the surface artery, should be pointed to the accomplishment of the objective in 3 (b). Following are some of the major considerations which must be carefully studied.

a. Protection Against Entry of Traffic at Off Ramps.

The danger of traffic entering the expressway at off ramps must be considered in its design. Reduction in the width of exit to one generous lane width, usually 14 feet, with appropriate signing, will usually be effective in reducing illegal entrance. If the off-traffic exceeds one lane capacity, a redesign of the surface street roadway may be required to provide against the contingency of improper entrance.

b. Islands at Exits of Off Ramps.

Islands are sometimes placed in the exit of an off-ramp in order to divide the right-turning traffic from the left-turning traffic. This may permit the right-turning traffic to move continuously while the left-turning traffic is waiting opportunity to move and thus expedite the movement of traffic through the intersection. However, some disadvantages should be mentioned.

Any island in a traffic stream is a potential hazard. To relieve public responsibility, it must be well lighted, and a flasher or reflectors should be installed to give warning of its presence. The presence of an island increases the difficulty of controlling the intersection by traffic signals where this is necessary and may encourage right-turning traffic to enter the intersection at excessive speeds unless such entrance is controlled by boulevard stops. The hazard to pedestrians is also materially increased by the width of the crossing

and the unusual direction of traffic rounding a long radius curve. The double roadway may encourage improper entrance of the off-ramp by surface street traffic.

c. Design to Assure Entrance to Surface Streets at Appropriate Speeds.

One of the main functions of a traffic interchange is to provide for a transition from expressway to surface street speeds in leaving the expressway and vice versa in entering the expressway. Proper elements in obtaining this result are adequate acceleration and deceleration areas along the expressway, sufficient length of ramps and proper detail at the surface street intersection.

At an exit to the surface street, the design must insure the entrance of traffic into the surface street at controlled speeds which will not conflict with the traffic along the surface street. The function of the exit is to discharge the traffic from the expressway into the street without delay, but from that point, traffic must of necessity conform to the limitations of traffic along the surface street. There is, therefore, usually no advantage in large radii turns or other features which would encourage rapid and uncontrolled entrance of traffic into the surface artery.

It may be necessary to control traffic entering the surface street by boulevard stop or traffic signal.

d. Positive Elimination of Left Turns.

If it is possible to provide convenient access to and from the expressway by prohibiting left turns on the surface artery, this may be accomplished by an actual barrier consisting of a raised curbed island along the center of the artery. Such barriers may also be used to discourage illegal turns into exit ramps. Auxiliary roadways on grade separation bridges may be provided across the expressway to permit "U" turns between one-way frontage roads without the necessity of traffic entering the main roadway of the surface artery. An auxiliary roadway of this type is illustrated on the drawing of Type "c" interchange.

e. Protection of Left-Turning Movements Along the Surface Artery by Center Island Construction.

In some cases it may be possible to shield left-turning movements by construction of a wide center island along the surface artery. Such islands, which should have a width of 20 to 25 feet, will reduce the interference of left-turning traffic with smooth flow of traffic along the artery.

5. Consideration of Traffic Safety and Volumes Justifying Each Type of Interchange.

In describing each of the above-listed types of interchanges, the general effect on traffic safety and volumes has already been discussed. No definite rule can be established nor measurement made as to when any one type of interchange should be used. Further experience with and study of existing interchanges will be most helpful in establishing the traffic volumes which may be handled by each type of interchange and its traffic safety factor. A reliable estimate of the traffic to be handled and the number of turning movements is essential in the selection and design of the traffic interchange. Having this information the data gathered by the Committee on Highway Capacity, Highway Research Board, will be a helpful guide in the selection and design of interchanges. Each design must be based on a careful analysis of the situation and requires close cooperation between the designer and the traffic engineer.

BRIDGING EXISTING STREETS

In the location and design of a controlled access, urban expressway, bridging existing streets poses two problems: (1), Carrying some existing streets over or under the expressway; and, (2) grade separation of feeder streets in areas tributary to the expressway, to accommodate present or anticipated local overloads.

1. Expressway Grade Separations.

A controlled access expressway presents a barrier to movements of traffic from one side to the other unless cross roadways are under- or over-