Interchange Study and Selection Process

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The ability of the public to use a highway facility to the capacity level for which the roadway was designed will depend to a great extent on the accommodations made for intersecting traffic patterns. The use of grade separations and interchanges can result in improved operations on both roadways. However, because of the investment required to provide grade separations, the selection of the highest priority locations and the design of the interchange are critical. One method of determining the priority of competing interchange locations is through a cost-benefit analysis. The Texas Transportation Institute developed a computer analysis program called Texas Ranking of Interchange Projects (TRIP) to accomplish a relative analysis of interchange cost reductions on a macroscopic level. The major economic benefits of an interchange include a reduction in delay costs, a reduction in vehicle operating costs, and the expected accident cost reductions. These benefits are summarized and matched against the expected construction and right-of-way costs of the proposed interchange. The selection of the interchange type is influenced by many external constraints. These constraints may include limited right-of-way, environmental considerations, historical structures, and handling traffic under construction. Interchange types include trumpets, diamonds, cloverleafs, and directionals. Each interchange type has specific advantages and disadvantages. The design selected must be constructible and maintainable under traffic and must be able to handle traffic movements into the ultimate design year. Experienced design, comprehensive research, and knowledgeable drivers are necessary to achieve the maximum highway user benefits from these facilities.

The ability of the public to use a highway facility to the capacity level for which the roadway was designed will depend to a great extent on the accommodations made for intersecting traffic patterns. When these intersecting traffic patterns can be grade separated, the resulting roadway will function with increased efficiency, improved operations, and a higher degree of safety. However, it is not practical or cost-effective to grade separate all intersecting traffic movements. Since interchanges represent the most costly intersection treatment in terms of initial investment, the selection of the highest priority intersection locations and the design of the interchange are critical in providing an effective and efficient highway system. An example of the order of the interchange selection and design process is shown in Figure 1.

An interchange is defined by AASHTO as a system of interconnecting roadways in conjunction with one or more grade separations, providing for the movement of traffic between two or more roadways on different levels (*1*). Interchanges may be included in new location projects or in facility upgrade projects. Reconstruction work may improve an existing grade separation or provide a new interchange at the at-grade intersection of two or more roadways.

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Requirements such as structures, embankments, and rights-of-way contribute significantly to the cost of an interchange. Whereas simple interchanges may cost a few hundred thousand dollars, it is not unrealistic for a fully directional freeway-to-freeway interchange in an urban area to cost more than $100 million. The decision to build an interchange and the type of facility to construct will have a significant impact on the financial resources of a transportation agency.

Each transportation agency is faced with limited funds to design, construct, and maintain the highway system within its jurisdiction. The agency must first make a commitment to maintain the infrastructure currently in place. The remaining resources can be used to improve, expand, or relieve congestion within the existing network. An interchange accomplishes these goals through improved highway safety, expanded traffic operations in the area of the intersection, and relief from existing roadway congestion.

Because resources are limited, the locations with the greatest potential for improvement must be given priority. In order to maximize highway user benefits, ranking methodologies are used to identify proposed interchange locations with the greatest potential for increasing user benefits and reducing user costs.

After the intersections needing improvement are ranked, the application of a particular interchange configuration begins to come into focus. Present and future traffic movements must be identified. The functional classifications of the intersecting roadways will often give preference to one of the roadways in the design. Socioeconomic constraints should be identified as early in the planning and design phase as possible to avoid future conflicts or design changes.

Methods for determining interchange need and setting priorities will be discussed in more detail in the following sections. Some of the considerations in determining interchange configurations will also be presented.

SYSTEM VERSUS SERVICE NEED

Even though interchanges are, of necessity, designed to fi individual conditions and controls, it is preferable that th pattern of interchanges, ramps, and access control along freeway follow some degree of consistency (*2*). Factors suc as the number of lanes, signing, lane balance, and route co tinuity also contribute to this consistency. To accomplish th consistency, an interchange design must take into account total highway system approach. Although this has always bee true in initial roadway construction, it is becoming increa ingly important for reconstruction projects. The sheer ma nitude of a major interchange project will affect traffic mov

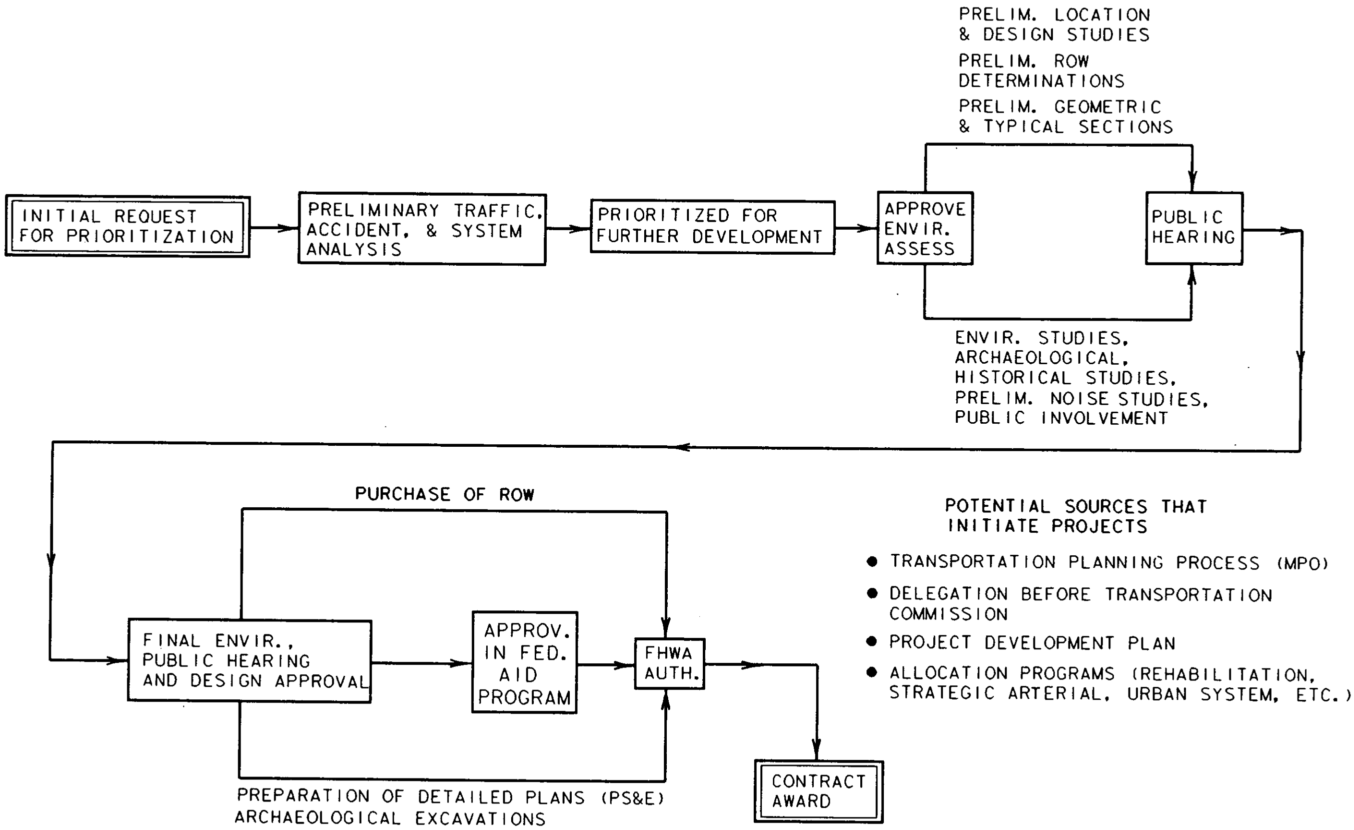

FIGURE 1 Interchange selection and development process.

nents far upstream and downstream on the through roadways nd will have a significant impact on adjacent land use.

Interchanges may contribute to a system operation or a ervice operation. Generally, system interchanges provide for reeway-to-freeway connections, whereas service interhanges connect one level of the highway system to a lowerervice-level facility. The design of service interchanges may e influenced by the functional classification of the roadways, ith priority given to the higher classification.

A system approach to interchange need will often dictate nitial interchange placement. For example, freeways usually equire grade separations at existing state system routes. If ufficient traffic demands are evident, county road crossings ay also indicate the need for a grade separation. The extent nd complexity of these separations will depend on present nd future traffic demands.

A service approach to interchange need indicates a regular attern of access to the through roadways. Where existing outes do not dictate the need for interchanges in rural areas, e need for a freeway grade separation may be related to ser delay. Urban conditions may relate interchange need to affic demand or spacing frequency.

A commonly used guide for freeway interchange spacing is mi in urban areas and 3 mi in rural areas. These spacings e often changed to meet demand and, in urban areas, may changed through the provisions of collector-distributor roads d grade-separated ramps. Urban area interchanges may so require detailed traffic projections, including turning movements and capacity analysis, before the alternatives can be narrowed to a final design.

INTERCHANGE NEED PRIORITIES

When a transportation department faces a limited pool of resources, proposed interchange locations must be analyzed to determine which sites merit the highest priorities. These needs should be outlined as early in the program planning stage as possible. These decisions suggest the use of a consistent ranking process. One method of ranking these projects is through the use of a benefit-cost analysis. Unfortunately, there is often little detailed operational data available in the early programming phase. A benefit-cost analysis is necessary to establish preliminary project priorities. This preliminary analysis can evaluate simple road user costs to allow an early planning stage analysis of design alternatives.

Several computer programs are available to analyze the more complex operational aspects of intersections and interchanges. Some examples of these programs include PASSER-II, TRANSYT-7F, and NETSIM. However, these programs generally require a significant amount of data on traffic operations to produce accurate output. At the programming stage, this level of traffic detail is rarely available. A macroscopic modeling procedure is usually necessary to compare competing interchange location alternatives.

The Texas Transportation Institute developed a computer analysis program called Texas Ranking of Interchange Projects (TRIP) to accomplish a relative analysis of interchange cost reductions on a macroscopic level (*3*). Although TRIP cannot produce a finalized ranking of priorities, the program goes beyond simple road user costs and summarizes the major cost savings associated with project development to make comparisons between similar interchange requests. The major economic benefits, or cost reductions, associated with interchange development can be grouped in three categories.

The first benefit to be analyzed is the reduction in delay cost associated with providing a grade-separated interchange or upgrading the interchange design. Figure 2 shows a comparative summation of intersection delay for various interchange configurations (*3*). Although delay can be used strictly for a relative comparison of the improvement, this savings can also be used as an actual numerical measure by placing a value on this delay time. At the programming stage, only the most significant traffic characteristics can be compared in delay reductions. The analysis makes a comparison of the movements on the at-grade intersection against the movements resulting with the grade separation and the remaining operations occurring at-grade. The difference in delay represents the savings realized through delay reductions. An example of system delay curves for a simple diamond interchange is shown in Figure 3 (*3*).

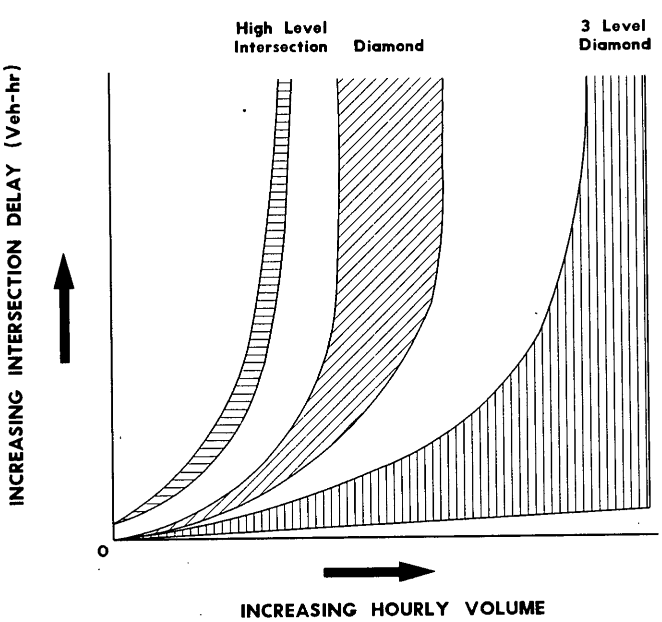

FIGURE 2 Example of delay versus capacity (*3*).

The second cost area to be analyzed is the reduction in vehicle operating cost. Estimates are made of running costs for vehicular travel, slowing and stopping at intersections, and idling while waiting to execute a particular movement. These operating costs are summarized for both before and after conditions to determine the savings in vehicle operating costs due to grade-separated movements at an interchange.

Finally, an analysis is performed to determine the expected accident cost reductions. Accident rates are estimated for both the existing intersection and proposed interchange. Coded accident data often make it difficult to distinguish between different existing intersection configurations in comparative assessments. The total accident costs will be the cost per accident multiplied by the accident rate. Significant differences exist in cost per accident figures, but application of a consistent set of figures will make a relative comparison valid.

These three major cost reductions are summed to give an early planning stage estimate of the gross benefits to be realized from interchange development. These benefits will be matched against the total construction cost of the interchange including any needed right of way. Although the complete design will not have been determined at this stage, any proposed interchange layout must adequately satisfy the present and future traffic demands. These locations with the highest benefit-cost ratios will be placed at the top of priority lists for further consideration and development.

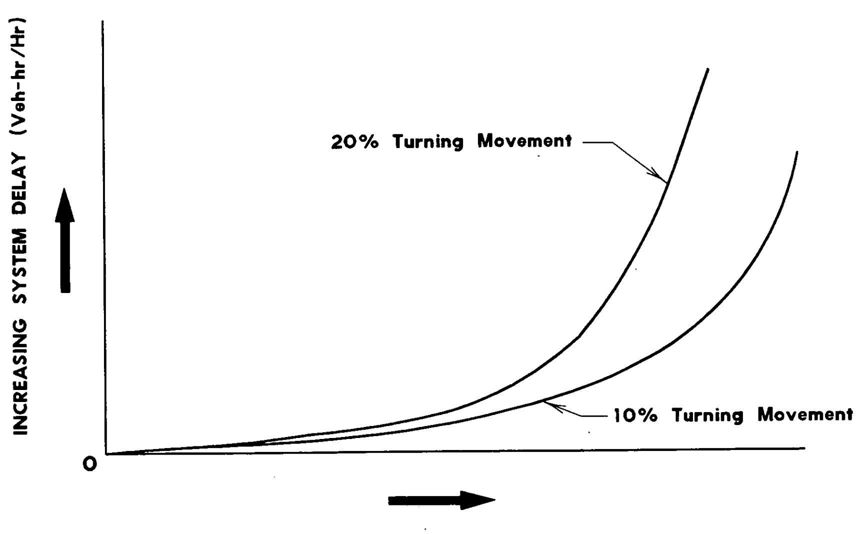

FIGURE 3 Example of system delay curves for a simple diamond interchange (*3*).

CONSIDERATIONS IN INTERCHANGE SELECTION

Traffic-handling techniques have improved considerably since the days of the intersection shown in Figure 4. However, many of the design constraints of yesterday still exist and are magnified in today's urban and rural environments. Interchanges designed to meet the best possible geometric and operational configurations with no outside limitations would represent an ideal design situation. However, interchanges are rarely designed strictly for geometric and operational considerations without external constraints. These external constraints may be numerous and vary considerably from project to project.

Right-of-way restrictions are some of the most common conditions that influence the ultimate interchange layout. Some of these restrictions in right-of-way may be manmade, such as developments or office buildings. If the development is significant enough, then it may not be economically feasible to obtain the right-of-way. In developed urban areas, right-of-way costs have exceeded $100/ft^2 in some cases. This right-of-way cost still does not include applicable damages to remaining property or damages for lost or reduced access during construction. The natural terrain of the right-of-way may limit development of a complete interchange in one or more quadrants. Existing roadway conditions may play a major part in determining the operational and design options available for the proposed interchange locations. The presence or absence of frontage roads within the right-of-way may also have a major influence on the final layout.

Environmental considerations are becoming an increasing concern to the public in all highway construction. Interchanges are environmentally scrutinized to even greater lengths because of the large land area that they occupy and the concentration of traffic in the area. Noise levels around the interchange are estimated, and mitigation factors may be necessary if neighborhoods will be disturbed. Storm water run-off from the interchange area may have to be filtered if contaminant levels exceed recommended limits. Wetlands areas can generally not be taken unless they are replaced in kind. Historical abutting property structures should be identified early in the planning phase to avoid conflicts with the proposed interchange. The public is demanding that transportation agencies be environmentally accountable and reduce the potential impacts of highway construction and traffic operations to the greatest extent possible.

The geometrics of intersecting roadways also specify some of the conditions of the design selected. The selection of the prioritized traffic movements and the roadways to be carried

IGURE 4 Circular intersection.

over on structures will dictate subsequent design decisions. Considerations such as topography, drainage, and economics will influence the choice between overpasses and underpasses.

The selection of particular interchange designs, as shown in Figure 5, will also depend on the merge and diverge opportunities that are needed to handle traffic demand. If a particular turning movement has significant traffic volumes, then the chosen design must be capable of handling the needed capacity. Also, if an individual turning movement has a high percentage of trucks, then the geometrics of the connectors or ramps must be liberally designed with respect to curvature and superelevation to allow efficient operation. In particular, the combination of a downgrade with a sharp turning maneuver against adverse superelevation is believed to increase the overturning tendency of large trucks (*4*).

Of particular concern in urban areas, where interchanges are being rehabilitated or reconstructed, is the ability to accomplish the proposed construction under traffic. Coordinated traffic handling is necessary to ensure the safety of the traveling public as well as the safety of construction personnel. Signing and pavement markings, both during construction and after completion, are critical to the expected performance and capacity of an interchange design. The old saying, "If you can't sign it, don't build it," is still a good rule. With increasing traffic volumes, more elderly drivers, and greater vehicular size differentials, safe and efficient traffic operations depend on a uniform and identifiable system of signing and markings.

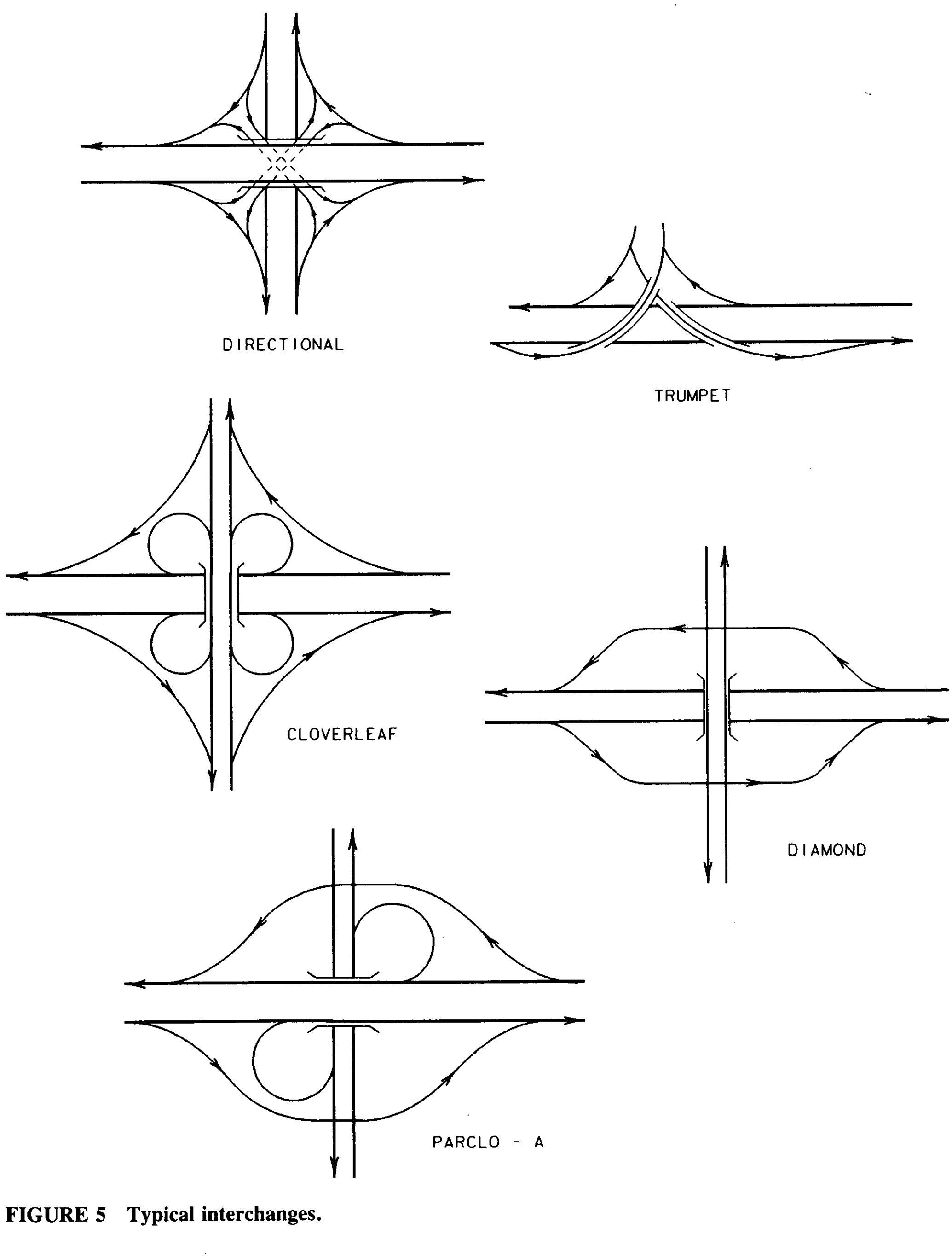

FIGURE 5 Typical interchanges.

WEIGHING ALTERNATIVE DESIGNS

The actual interchange layout will depend on the traffic movements that must be economically processed through the interchange. Carefully selected traffic objectives need to be outlined before selection or elimination. Each interchange configuration has advantages and disadvantages, which cover a wide range of conflicting areas of need. Comparisons and decisions often have to be made among issues that are not directly related.

When one roadway terminates at another through roadway, a trumpet interchange with one or more grade separations may be selected. These interchanges are referred to as T-type if the third leg intersects a through roadway at right angles. If the intersecting roadway forms an acute angle, the interchange is referred to as a Y-type. Although the difference between these types is not significant, the three-leg intersections show wide variations in interchange designs.

Loop ramps for trumpet interchanges are used to make connections between the through roadway and the terminal leg. The design should give preference to the turning movement with the greatest volume. The use of an oblong shape with appropriate superelevation for the loop ramp allows for better operations under high-volume and high-speed conditions. Depending on the level of service desired, the interchange may necessitate increased amounts of bridge structure. Also, where traffic weaving is necessary, provisions for sufficient ramp length at the merge and diverge points should be analyzed early in the design phase. Generous loop radii and merge lengths will contribute to efficient and safe traffic operations.

Four-leg interchange designs have multiple variations. One of the most common types is the conventional diamond interchange. The conventional diamond is simple and economical to construct, can provide relatively high speed entrance and exit ramps, and requires a relatively narrow strip of right-of-way (*5*). This configuration is applicable to urban and rural conditions, particularly where a major highway crosses a lower classification facility.

Conventional diamond interchanges also have several shortcomings. These configurations have double four-leg intersections; two of the approaches represent one-way operations. This may result in a potential traffic operations problem if wrong-way entry occurs at one of the intersections. The diamond is also limited by the amount of traffic that can be cycled through the two at-grade intersections. The use of a turnaround lane, to allow drivers to make u-turns without going through the at-grade intersections, can enhance the capacity of the diamond interchange.

Different versions of the diamond interchange, as shown in Figure 6, can enhance the design for selected situations. The spread diamond is one example. The spread diamond moves the ramp connections to the crossroads out far enough to allow future loop ramps inside the connections. These loop ramps will then accommodate left-turning vehicles. Unfortunately, this configuration requires considerably more right-of-way. In addition, after loop operations are added to a spread diamond configuration, the interchange features a double exit design and generally short radius loop ramps.

The split diamond interchange allows for the off-ramp connection at one crossroad while the on-ramp connection occurs beyond a succeeding crossroad. This adaptation limits access and contributes to better mainline operations. This design is particularly applicable in urban areas with narrowly spaced crossing streets. However, business owners and the traveling public may object to the chosen access points. Public involvement and careful traffic engineering analysis are necessary to provide appropriate split ramp connections.

The three-level diamond interchange allows both through roadways to cross on their own alignments with turning movements separated on their own level. Careful planning in the initial design phase can allow this configuration to be converted to a directional interchange during a subsequent construction project. Three-level diamonds are historically not recommended for ultimate design due to the limitation of turning capacities that can be handled on a single level. However, properly designed three-level diamonds operated satisfactorily for many years before the ultimate directional interchange was necessary.

Another common type of interchange configuration is the cloverleaf interchange shown in Figure 7. The full or partial cloverleaf interchange accommodates left-turning traffic through the provision of loop ramps. Although cloverleafs are more expensive than diamond interchanges, they have been used effectively in rural or lightly developed areas. Collector-distributor roads enhance the ability of a cloverleaf to handle a significant traffic volume by eliminating the double exit and removing the weaving maneuvers from the main roadway.

Cloverleaf interchanges have several disadvantages from a traffic operations standpoint. These disadvantages can be mitigated to a great extent by generous design and signing if established early in the planning stage. The use of loop ramps to accomplish a left-turn movement requires some misdirection on the part of the driver. The length of the loop and the required right-of-way will increase quickly as the design speed is increased. Larger trucks do not operate well in loop configurations, particularly if they have large off-tracking characteristics. The loop ramps in adjoining quadrants have a capacity limit of about 800 to 1,200 vehicles per hour, depending on the loop configuration and the level of service considered acceptable. Once the capacity limit of the loop ramps is reached, these inefficient ramp operations begin to affect traffic on the through roadway. Also, loops are generally limited to single lane operations (*6*).

Directional or semidirectional interchanges, as shown in Figure 8, represent the highest type of interchange and are generally reserved for freeway-to-freeway movements in urban conditions. Some interchanges will only require a direct connection for one particular left-turn movement. Directional ramps improve traffic operations by reducing travel distance and increasing speed and capacity. Directional ramps also eliminate many of the weaving maneuvers necessary in other configurations. If these connections are liberally designed, the ramps can approach the capacity of an equivalent lane on the through roadway.

Fully directional interchanges are, however, the most expensive type of single highway feature constructed. These designs also require significant amounts of high-cost right-of-way, which the public is increasingly cautious about converting to highway usage. These facilities are usually phase constructed under high traffic conditions, which significantly lengthen construction time and irritate owners of adjacent

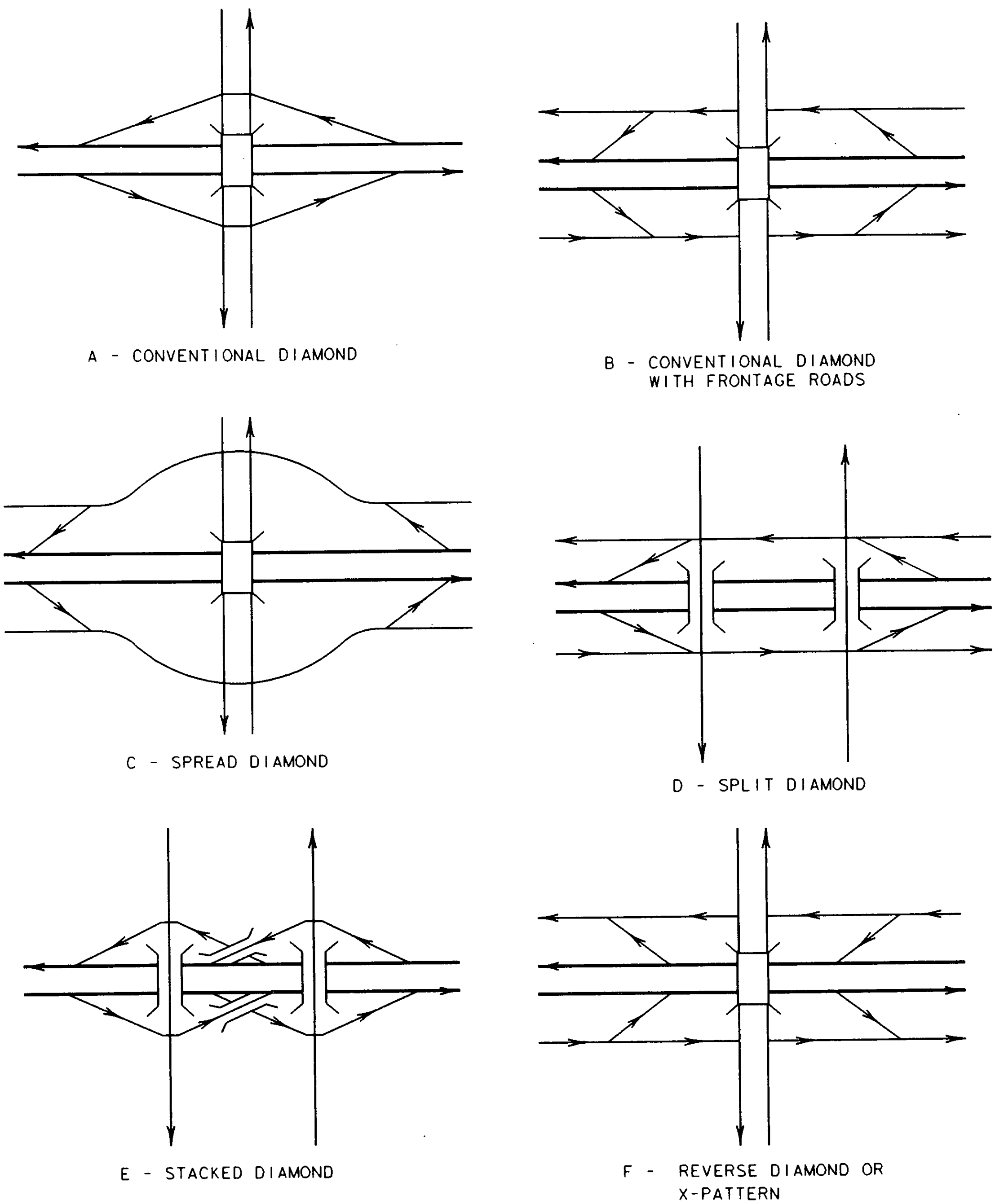

FIGURE 6 Variations of diamond interchange.

businesses and the traveling public. These interchanges are so expensive that a state district office, covering many counties and a major urban area, may find that the cost of one fully directional interchange exceeds the entire yearly construction allocation. Detailed traffic analysis and multiple design alternatives necessitate significant predesign study and public input before commitments are made to a fully directional interchange project.

Ramps and connections for all interchange designs represent a continuing source of operational difficulties and potential accident locations. This is due in part to the multiple actions and decisions required simultaneously by the driver. The driver's multiple task scenario can be further complicated if the geometrics of the ramp are restrictive, signing is not informative, advance notice of the decision point is not given, or the ramp is hidden by physical features.

Methods of overcoming these difficulties include designing ramps that satisfy driver expectancy. Single exits contribute to this expectancy and make signing much simpler to accomplish. An example of the use of single entrance and exit design is shown in Figure 9. Ramp operations may also be improved by moving the relatively sharp ramp curvature away from the ramp terminal (7). When multilane ramps or connections are necessitated by traffic volumes, the touchdown point on the

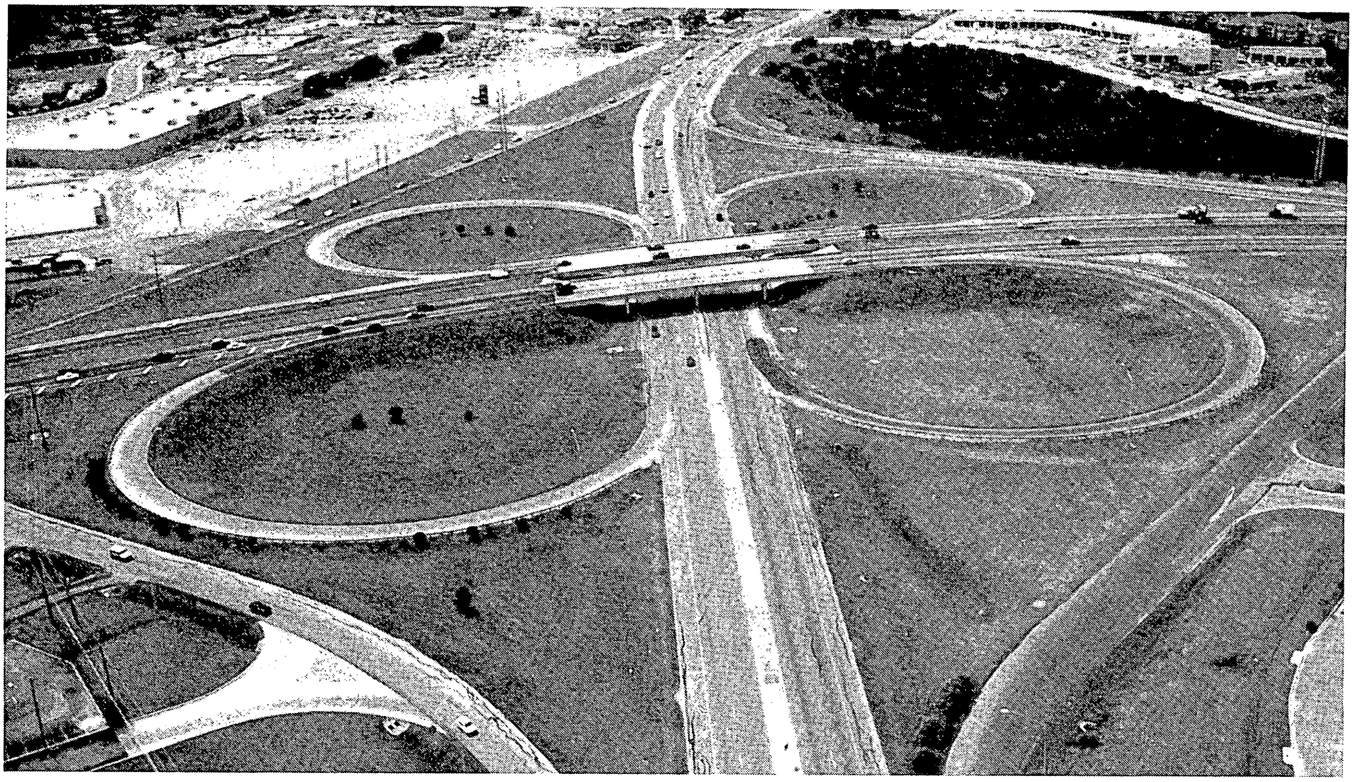

FIGURE 7 Cloverleaf interchange.

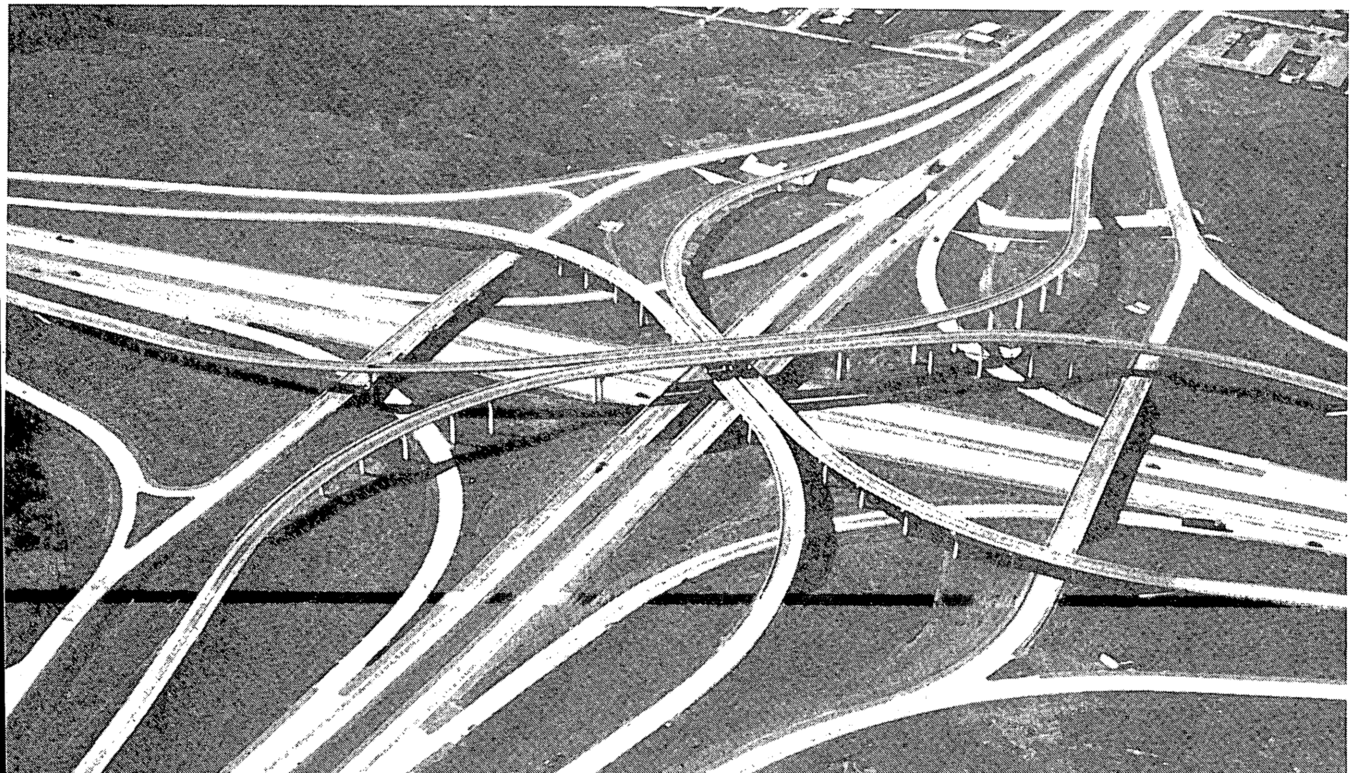

FIGURE 8 Directional interchange.

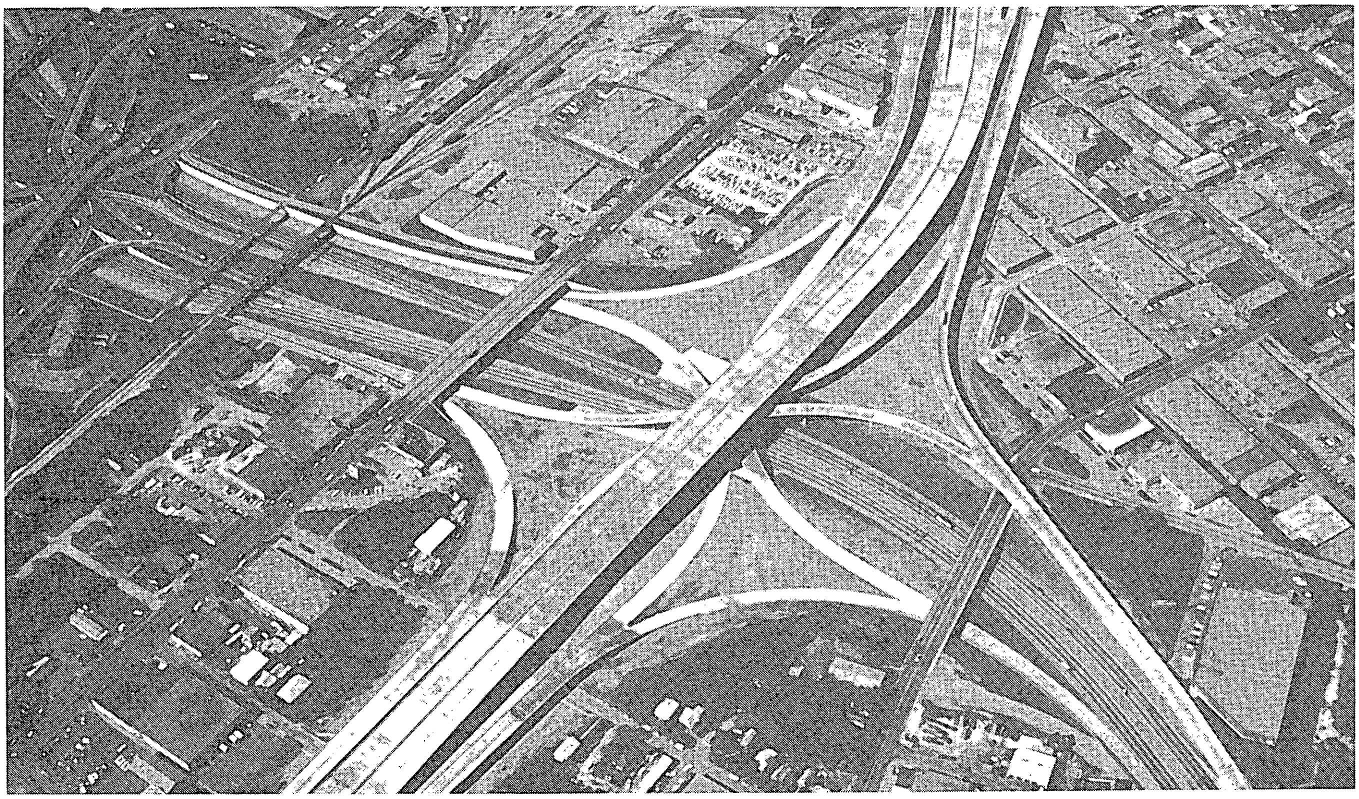

FIGURE 9 Directional interchange with single entrance and exit design.

through roadway should be able to accommodate all lanes of the roadway and the ramp for a considerable distance downstream of the terminal. If ramp lanes are forced to merge at or before the terminal, then operations will deteriorate before the design capacity of the ramp is reached, and the benefit of the multilane connector will be lost. The use of auxiliary lanes and following lane balance design can eliminate many of these deficiencies.

CONCLUSION

Because of the complex nature of the design process and the magnitude of the cost of construction, interchange development in the future must be done on the basis of specific needs. The limited resources available to transportation agencies will require a documented prioritization process for the expenditures necessary to make capacity improvements at major roadway crossings. Because highway and interchange design is rarely done without external constraints, several contributors to the process must take a more active part in the design and final implementation of a safe and cost-effective highway facility. Experienced designers, comprehensive researchers, and educated drivers all contribute to the ultimate success of the transportation system.

Design efforts need to take full advantage of the experience gained in the development of the original Interstate system (*8*). Interchange development and expansion of the future demands an economical and efficient design approach. The reconstruction process will doubtlessly be more complex than the original system construction. Designers must build on the foundation of that experience and use the best possible design techniques of the future to meet the transportation needs of a complex and changing society.

Research efforts must take on a broadened vision of interchange design. Future research efforts need to probe deeper than the simple "longer or wider is better" approach. The interaction of the individual components of an interchange design must be studied in unison. Interchange improvements must also be examined within the concept of the entire configuration, the total roadway system, and a realistic set of typical external constraints under which these facilities have to be constructed. The public will continue to be concerned about the environmental impacts and the spending of tax revenue associated with maintaining and improving the national transportation system. Suggested ideas and improvements need to give proper consideration to all these factors to be of practical value.

Efforts to educate the users of increasingly complex highway systems and interchange configurations must be continued. Some of these efforts should be passive from the driver's perspective. They include uniform signing and consistent entrance and exit terminal design at all interchanges regardless of configuration. Some efforts need to be more direct, such as the Give Them a Brake campaigns, to promote driver safety in construction zones.

Improvement in some of these areas, in conjunction with the best possible selection and design of interchanges, will ensure maximum highway user benefits from these facilities.

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