Physical Characteristics and Cost-Effectiveness of Arterial Flyovers

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One bottleneck created by a congested signalized intersection can significantly reduce the through-traffic capacity of an arterial. The flyover, a grade-separated structure that diverts arterial through traffic over the at-grade intersection, can overcome such limitation in a cost-effective manner. Usually, this result can be accomplished within the existing right-of-way of 100 ft or wider even after the at-grade cross section has been fully developed. Benefits are related to the total amount of traffic using the at-grade intersection. Costs are the result of method and type of construction, traffic delay and diversion during construction, and impacts to adjacent properties. The benefit-to-cost ratio of nine potential flyovers in Texas was estimated to range between 1.3 and 12.5.

Decision makers are frequently confronted with the problem of an arterial street in which maximum use of the surface right-of-way has been made but traffic demand exceeds capacity at one or more intersections. Such bottlenecks severely reduce the through-traffic flow and may impair functions of nearby intersections. Conventional interchanges may be built, but they are land hungry and would typically require acquisition of extra right-of-way. Acquiring additional right-of-way to increase the intersection capacity may be contrary to arterial objectives, expensive, and time-consuming. Seemingly contradictory objectives often stall measures to increase the intersection capacity, and the arterial may remain underused indefinitely.

Flyovers may provide the solution to such a dilemma. The flyover, as defined here, is a grade-separated structure that allows arterial through traffic to go over a crossing arterial or collector without slowing down or stopping for an at-grade signal. Capacity per lane is generally that of arterial through lanes, about 1,750 veh/hr. Grade separation of arterial traffic may be the only means available to increase the capacity of a critical intersection, once all surface treatments are exhausted.

However, flyovers have a narrower structure than typical diamond interchanges, and cross-street traffic may not make effective use of the internal storage allowed by a three-phase diamond signal to maximize at-grade capacity. The storage length under the structure is short and a leading or lagging green may slightly increase capacity but could easily result in blocked arterial traffic. Typically, the at-grade part of a flyover intersection should be signalized as a wide intersection rather than as a diamond interchange.

Flyovers are not a new concept. In the late 1950s and early 1960s, Chicago built three arterial flyovers to overcome capacity problems *(1)*. Figure 1 shows the Archer Avenue flyover as viewed from an at-grade approach to the intersection with Ashland Avenue, in Chicago. The all-steel structure had a total roadway width of 24 ft and provided two lanes, one each way, separated by a mountable 1-ft median. Single, at-grade lanes approached the intersection from the arterial. The Archer flyover was built within an 80-ft right-of-way. The other two Chicago flyovers provided four lanes, two each way, and were built within 100-ft rights-of-way.

The then-called "through-lane-overpass" successfully removed congestion at bottleneck intersections without impacting nearby ones. The capacity of each of the three arterials where an overpass was built increased from 114 to 300 percent, whereas the peak-hour demand at nine intersection approaches increased by an average of 33 percent. The peak-hour delay of Western Avenue traffic using the flyover crossing the Belmont Avenue decreased from 82 to 17 sec per vehicle, for savings of 80,000 vehicle-hours per year. At the Ashland-Pershing intersection, accidents decreased from 186 to 92 per year, after the flyover became operational, or about a 50 percent reduction. Collision diagrams for the latter intersection showed that serious accidents, those involving two-way traffic or arterial with cross-street traffic, decreased from 13 to 1 during the same period. A financial analysis prepared on the Ashland-Pershing flyover indicated a benefit-to-cost ratio of 2.2, using economic factors prevalent at that time.

In 1973, the Red Book *(2)* provided some general guidelines for building grade separations within the existing right-of-way of arterials. It was considered desirable to carry the entire roadway width of the approach, including parking lanes or shoulders, across the grade separation. Nevertheless, it was recognized that a restricted right-of-way could require a reduced roadway width. The full width of the through-traffic lanes plus 2 ft on each side were proposed as the minimum widths to be carried across the structure. Existing parking lanes or shoulders were to be transitioned with a long taper, preferably with a ratio of at least 20 to 1.

A good example of an arterial grade separation built within restricted right-of-way is shown in Figures K-22 and K-23 of the Red Book *(2)*. The wider of the two arterial cross sections appears to be composed of a 3-ft raised median, two 10-ft through lanes (each way), 1-ft outside shoulders on the through lanes, 1-ft retaining walls, and 1-ft inside shoulders on the at-grade approaches, single-intersection approach lanes, and sidewalks. The right-of-way from back-of-sidewalk to back-of-sidewalk appears to be less than 100 ft wide.

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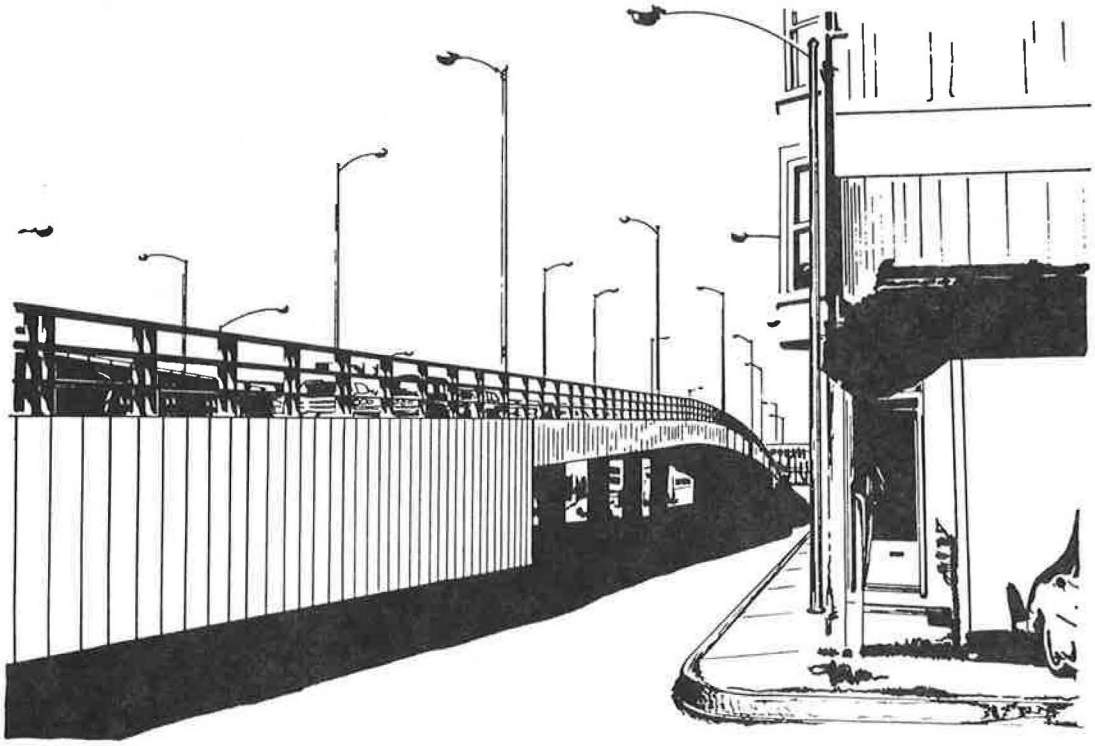

FIGURE 1 Archer-over-Ashland flyover, Chicago.

Recent publications recommend the use of prefabricated flyovers that are industrially manufactured, assembled in the field, and made operational within 5 to 6 months after the notice to proceed *(3)*. Such durations compare with the 18 to 24 months required with conventional construction methods. Impact to adjacent properties and delay and diversion of motorists during construction can be significantly reduced using prefabricated structures. Limiting impacts on the neighborhood or on motorists may make some projects publicly acceptable, provided they are economically feasible. Little information is available on the unit cost of these ingenious structures; however, capital costs of prefabricated flyovers appear to be fairly high. Most of the documented experience on prefabricated flyovers came from Europe, specially France and Germany.

During 1983, District 15 of the Texas State Department of Highways and Public Transportation (SDHPT) requested the Texas Transportation Institute (TTI) to investigate the feasibility of using flyovers to reduce congestion at some critical state-maintained intersections. In one case, the evaluation showed that a flyover would be cost-effective, whereas in another no such gain was apparent. These analyses provided useful results but they were time-consuming and costly due to the lack of a simple procedure to evaluate flyovers.

Flyover benefits are not as easy to assess as those of signal improvements. Flyover benefits accrue over 20 years or more and various assumptions need to be made on future conditions. Benefits depend on several factors regarding the value of motorists' time, vehicle occupancy, period of the day, traffic projections, discount rate of future savings, and so forth. Fortunately, most highway projects in the United States are evaluated based on similar assumptions, as outlined in the AASHTO manual on user benefit analysis *(4)*.

Flyover costs need to be estimated as closely as possible. These include primary construction costs incurred on the structure, signalization work, and so forth, and secondary impacts on adjacent properties and on motorists due to construction. Flyover costs are more stable than benefits, but the method of construction, materials used, and site-specific conditions can make them vary. During the processes of planning, programming, and appropriations, it is the capital cost that needs to be justified.

Research conducted by TTI *(5)* provides an updated perspective on the cost-effectiveness of flyovers by examining nine arterial intersections in Texas. Findings have been used to develop warrants and to propose guidelines for analysis and evaluation of potential intersections.

FLYOVER CHARACTERISTICS

With unlimited right-of-way, there would be no need for a flyover because conventional interchanges can be built and these provide more at-grade capacity than do flyovers. Within restricted right-of-way, some minimum clear width must be available. That limited cross section must allow for the required number of lanes, both on the flyover proper as well as at grade for structure appurtenances and for lateral safety clearances consistent with those along the arterial.

Right-of-Way and Cross Section

Adding a flyover on an existing arterial intersection further restricts the cross section, and enough space may not be available to provide all of the desirable lateral clearances. Trade-offs

must be made that result in an intersection with marginal, low-type, or high-type clearances. Table 1 presents recommended minimum right-of-way for these types, operating with two, four, and six grade-separated lanes.

TABLE 1 MINIMUM RIGHT-OF-WAY FOR URBAN ARTERIAL FLYOVERS

	Right-of-Way (ft) by No. of Lanes		
	Two Lanes	Four Lanes	Six Lanes
Marginal	76	98	–
Low type	100	120	140
High type	120	144	168

The marginal right-of-way widths represent flyovers built with close to the absolute minimum cross section for an urban arterial. The marginal right-of-way is not recommended except as a temporary measure or in exceptional cases for which other measures would not satisfy needs or would not be economically justified. Such dimensions have been used in the past in Chicago *(2)* and are typical of prefabricated flyovers in Europe *(3)*.

Marginal right-of-way provides enough lateral space for the use of 11-ft lanes on the structure, 1-ft separation between opposing traffic, and 1-ft separation away from the side barrier walls. These clearances, which are shown in Figure 2, do not meet recommended lateral safety standards. However, narrow shoulders are better than none at all, and a vehicle making an

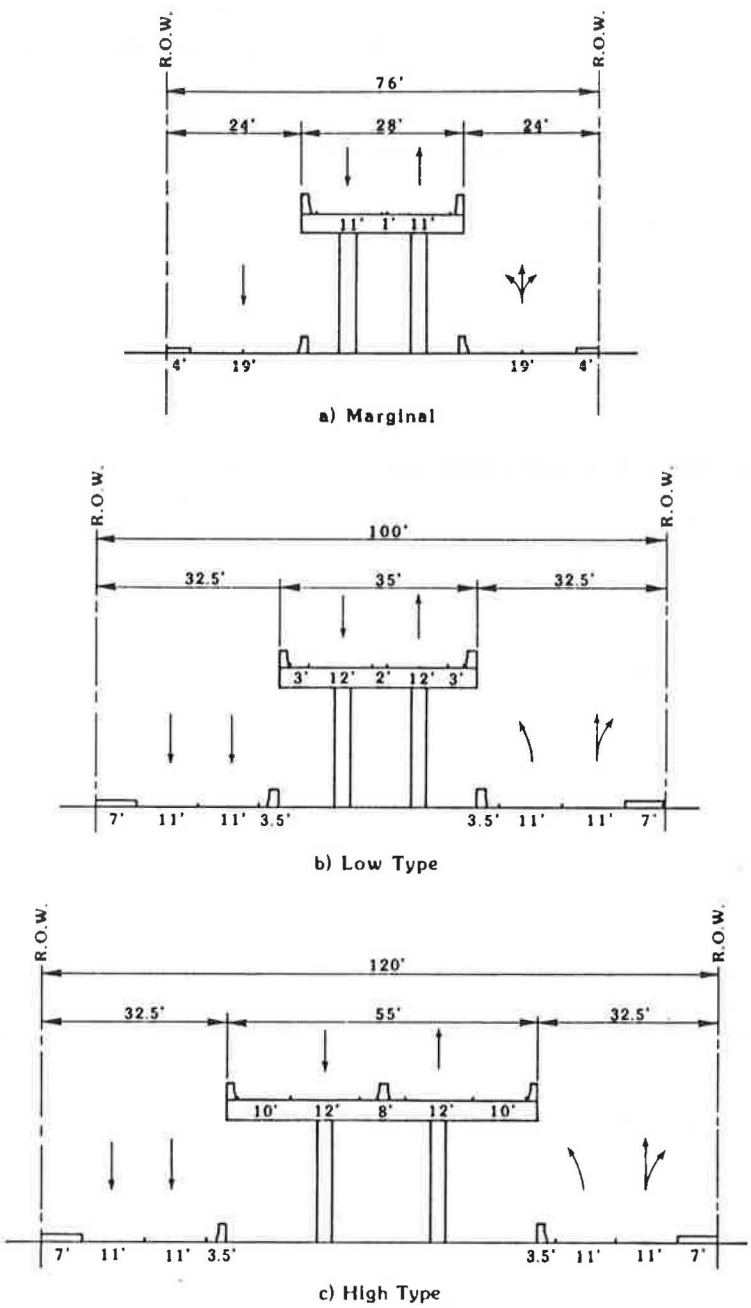

FIGURE 2 Minimum cross section and right-of-way for a two-lane flyover: (a) marginal, (b) low type, and (c) high type.

emergency stop would have some leeway for maneuvering. At-grade approaches to the intersection are single lanes requiring all turning movements to proceed from the same lane; however, they are wide enough for a vehicle to bypass a stalled one, if the latter is parked close to the curb. At-grade sidewalks at 4-ft width are minimal but adequate for occasional use. A four-lane structure would have two extra 11-ft lanes and increase the minimum required right-of-way to 98 ft. Other characteristics of the two-lane cross section would be retained. Speed would be limited to no more than 30 mph.

Low-type flyovers make use of an urban cross section, typical of most fully developed arterial right-of-way. Curbed sections allow street appurtenances as close as 2 ft from the traveled lane, but other obstructions should be at least 4 ft away. A 100-ft right-of-way allows for a two-lane flyover with 12-ft lanes, a 2-ft separation between opposing traffic, and 3-ft lateral clearance to side barrier walls. (See Figure 2 for details.) At-grade approaches have two lanes each, and thus, separate left- and right-turn movements. Sidewalks are 6 ft wide (typical of urban areas with continual pedestrian traffic) plus a 1-ft gutter. A four-lane flyover adds 20 ft in width to the structure, with through lanes reduced to 11 ft each. A six-lane flyover would take away the 2-ft separation between opposing traffic and maintain 11-ft lanes. Speed would be limited to no more than 45 mph.

High-type flyovers have the cross section more typical of freeways and rural cross section design. (Figure 2 shows the associated clearances.) A 120-ft right-of-way accommodates a two-lane flyover with full (10-ft-wide) right shoulders and a concrete median barrier to separate opposing traffic. Recommended flyover lane width is 12 ft, and widening to four or six lanes requires 24 or 48 ft, respectively, of additional right-of-way. At-grade approaches are similar to those provided for the low-type flyover. High-type flyovers would be more appropriate where the existing arterial operates with full shoulders. However, this type of construction may have limited application once the arterial right-of-way is fully developed. Design speed should be consistent with that of the arterial.

At-Grade Treatments

Safety considerations require a smooth transition from at-grade arterial lanes to the flyover. The physical split between exiting intersection-bound traffic and the through traffic must be logical, simply, and anticipated. Geometric guidelines for arterial design in the 1984 AASHTO Green Book *(6)* should be followed.

The split gore should have a tapering commensurate with the design speed along the arterial. Where a median exists, through lanes need to be redirected to match the narrow median or the lack of median of the flyover structure. A minimum taper of 10:1 may be used, but a desirable taper of 25:1 should be selected where possible. The same criteria should be used to redirect exiting lanes toward the intersection. Tapering should be maintained until full separation is attained, to accommodate the outside shoulder of the through lane, bridge wall, and inside shoulder of intersection-bound traffic. Figure 3 shows criteria for redirecting traffic lanes. These criteria are applicable

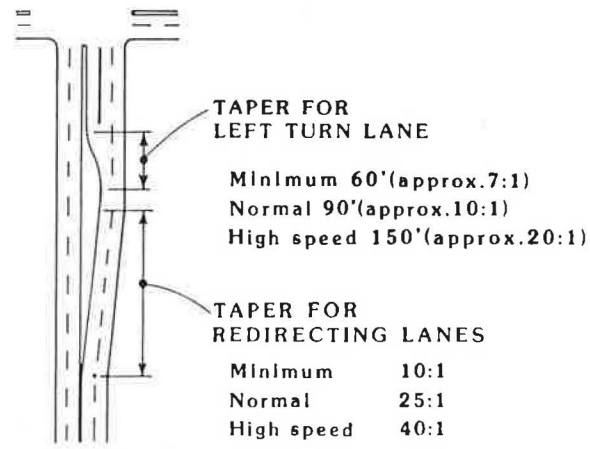

FIGURE 3 Taper design for urban streets *(7)*.

for redirecting lanes from arterial lanes towards a flyover structure as well as for redirecting lanes towards at-grade, intersection-bound exits. Merging traffic from the at-grade intersection with traffic from the flyover may require somewhat longer tapers, similar to those used for arterial lane drops. A minimum taper of 20:1 may be used, but a desirable taper of 30:1 should be used where possible.

Single at-grade lanes on the arterial, bound for or coming from the intersection should be treated as turning roadways to determine the minimum pavement width. These are essentially tangent segments, and a minimum paved lane 19 ft wide is recommended where sufficient single-unit trucks or buses use the facility to control design. Table III-20 of the 1984 AASHTO Green Book *(6)* expands on this criterion.

Barrier walls serving as flyover guardrails may also need to be protected for design speeds greater than 45 mph. Narrow crash attenuators, such as the GREAT device *(8)*, are particularly suitable for this purpose because they fit within the width of a concrete median barrier (CMB). Slow-speed arterials may forgo this treatment by quickly sloping the barrier to the ground. Guide signs in advance of this transition help drivers to place themselves in the desired lane prior to this point and reduce the risk of impact to the barrier.

CAPACITY

An important attribute of a flyover is its ability to increase the capacity of an arterial to move peak-period through traffic. In general, 2,000 vehicles per hour (vph) per lane can move on a flyover, while an arterial through lane handles only 1,750 vph per lane, multiplied by the fraction of green time allocated to the peak direction. But once the right-of-way is fully developed, fewer through lanes can be accommodated on a flyover than are available through a signalized arterial intersection. The flyover intersection must make partial use of the available right-of-way to incorporate the structural retaining walls, the lateral safety clearances, and the at-grade approaches to the intersection. The extra capacity of a flyover beyond that available to through traffic using a signalized intersection cannot be estimated until the green time available per hour is known.

The signal timings of the nine existing arterial intersections in Texas were optimized to minimize delay, as will be explained later. It was found that the through-traffic percentage of

effective green ranged from 29 to 57 percent of the corresponding cycle length. Average effective green was estimated at 43 percent, with a standard deviation of 10 percent.

Peak-direction, through-traffic saturation flow (capacity) of a hypothetical six-lane arterial on a 100-ft right-of-way can be compared with that of a two-lane flyover. It is assumed that the flyover will be used by arterial through traffic only, and to replace two inside and two middle lanes. The two outside lanes are assumed to be used by vehicles turning at the intersection, vehicles that access abutting properties, and local traffic with or without the flyover. With the flyover built, the at-grade intersection approach lanes parallel to the structure are assumed to handle all traffic to and from the intersection.

The one-way saturation flow of the inside and middle lanes of the signalized arterial can be approximated by

$$SF = (\%G)\ s_0\ N/100$$

where

SF = saturation flow (vph),
$\%G$ = effective green in percentage of cycle time,
s_0 = saturation flow rate per lane (1,750 veh per hour of green), and
N = number of lanes.

Using the percentage of green time of the optimized signal timings mentioned, the average through-traffic saturation flow is

$$SF_{avg} = 43\ (1{,}750)\ (2)/100 = 1{,}505 \text{ vph}$$

The minimum through-traffic saturation flow is

$$SF_{min} = 29\ (1{,}750)\ (2)/100 = 1{,}015 \text{ vph}$$

The maximum through-traffic saturation flow is

$$SF_{max} = 57\ (1{,}750)(2)/100 = 1{,}995 \text{ vph}$$

Based on these results, considerable variation in saturation flow can be expected with at-grade intersections that depends on local traffic characteristics.

Peak-directional capacity of the flyover now can be compared with that of the signalized intersection. Dividing 2,000 vph, the capacity of a single flyover lane, by 1,505 vph, the average signal saturation flow, a single flyover lane can be expected to provide an average of 33 percent more peak-directional capacity than two signalized through lanes. With the maximum saturation flow, the same flyover lane would provide a negligible increase in capacity over that available by two signalized through lanes. With the minimum saturation flow, a flyover would double the through-traffic capacity of two signalized through lanes.

Project Length

The profile of a flyover is principally determined by the design speed, the vertical clearance required above the cross street, and the main bridge span. Design speed may be taken as posted unless the arterial is planned for upgrading. Vertical clearance is usually 16.5 ft, but this value may be reduced.

The Red Book *(2)* was used to determine the flyover length, using K factors based on stopping sight distance for minimum length of vertical curves. [Note that the Red Book has been superseded by the 1984 AASHTO Green Book *(6)*, which provides more conservative factors that result in a longer structure. The 1984 AASHTO Green Book should be used where required or economically justifiable.] The K values so obtained indicate the horizontal distance required to realize a 1 percent change in gradient. A 100-ft span with a 16.5-ft vertical clearance was selected for all case studies. These values were used to solve simultaneous equations for the sag and crest curves that give the maximum grade on the structure as a function of the K factors. With the grade G known, the structure length is

$$L = 2G(K_s + K_c)$$

where L is the structure length (ft), G is the maximum grade (percent), and K values are expressed in feet per percent change in grade, as obtained from the Red Book.

This equation is valid for speeds of 45 mph or higher, with grades of less than 6 percent. At slower speeds where the pavement grade would exceed the desired maximum grade of 6 percent, a tangent is used to join the double-sag and single-crest curves. The length of tangents is added to the length of vertical curves to obtain the total flyover length. SDHPT standards allow a maximum grade of 8 percent on arterials where design speed is 30 mph or less and the topography is flat; yet, local traffic characteristics and arterial geometrics should be considered before deciding on grades of more than 6 percent.

A flyover alone is not the solution to intersection capacity but part of a balanced treatment to increase the volume and safety of traffic flow. The at-grade transition dividing through traffic and traffic turning at the intersection must be logical, simple, and safe. Geometric guidelines used in arterial design should be adhered to even though these transitions add to the overall project length. Traffic crossing the arterial should not be allowed closer than 200 ft from the flyover touchdowns, that is, from the points of vertical curvature (PVC). Traffic turning left after going on the flyover may require cross-street and driveway traffic to be restricted to right turns only for 500 ft or more beyond touchdowns. Such restrictions are particularly important where the arterial speed exceeds 45 mph. Driveway geometrics may remain as existing up to the intersection, because the nature of the arterial exterior lanes is not significantly altered.

Intersection Geometrics

The number of lanes entering the intersection should allow all or most of the vehicles stopping for a red signal to clear the intersection during each cycle. The 100-ft clear span recommended for the cross street allows for up to eight 12-ft lanes, but considerations on the continuity of lanes and costs usually limit the cross section under the structure to that of the cross-street through lanes plus an internal left-turn lane. The narrow right-of-way associated with a flyover generally requires a narrow structure that severely limits the length of the internal left-turn lane and its use as a storage lane. If the structure width

precludes the use of diamond-type signalization, the at-grade capacity is that of a conventional intersection.

Simultaneous left turns from the arterial may be impossible with a typical flyover because of the displaced alignment of the turning lanes. There are two ways to overcome this problem. The first and more obvious is to provide left-turn lanes under the structure, using the taper design for left-turn lanes shown in Figure 3. Yet, this is expensive because of a longer structure needed to reach the minimum vertical clearance as a left-turn lane goes under the structure. Also, impact on nearby cross streets and driveways may increase as the structure is lengthened. A second option is to modify the structure so left turns begin before the intersection, as shown in Figure 4. The modified structure is a little more expensive but the efficiency of simultaneous left turns may justify the extra cost.

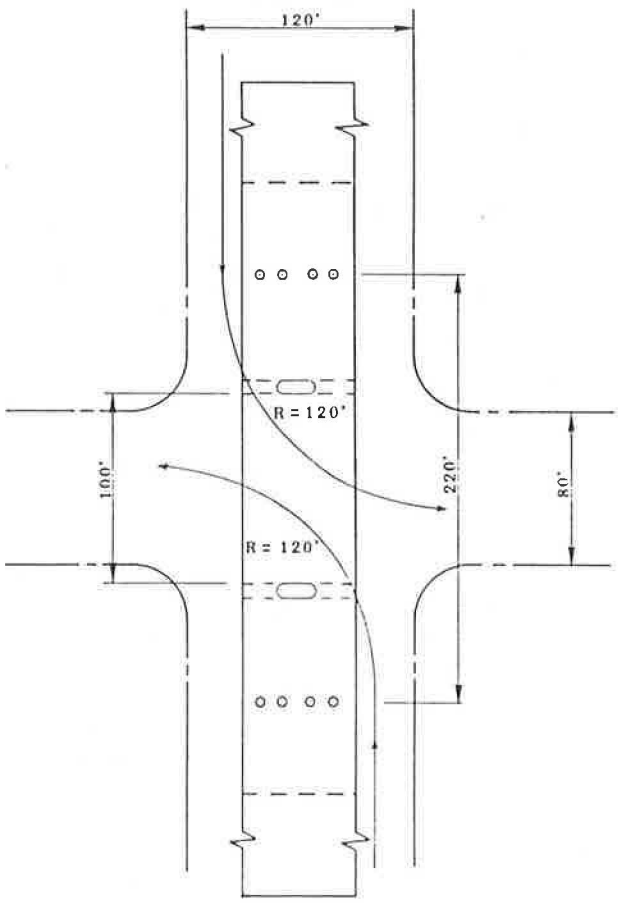

FIGURE 4 Simultaneous left turns.

Increased capacity of arterial through traffic is not the only benefit of a flyover. The improved arterial flow allows more green time to the cross-street traffic, which results in reduced travel time for all remaining at-grade traffic. Further, design that satisfies traffic demand and keeps vehicles flowing can significantly reduce delay, fuel consumption, and accidents. Such effects are a measurable benefit accrued by users and the community.

ECONOMIC ASSESSMENT

The benefits of installing flyovers at nine signalized intersections in Texas have been quantified and evaluated. Three of these intersections are located in Austin, two in Houston, three in San Antonio, and one in College Station. All of these suffer from congestion during peak periods, and traffic demand keeps growing at a fast pace. Some already have the arterial right-of-way fully developed whereas others can accommodate additional at-grade improvements. Most were selected as case studies because they are congested intersections with the potential to benefit significantly from a grade separation. However, the primary selection criterion was to provide a range of conditions from which to make flyover generalizations.

The PASSER II-84 computer model *(9)* was used to optimize signal operation and to determine delay and vehicle stops with and without the flyover. Vehicle-hours per hour, and stops per hour were calculated for peak and off-peak periods, for years 1985 and 2005. Other measures of effectiveness such as the *X* ratio (which indicates level of congestion) were used to evaluate the reasonableness of delay and stops, as well as of the flyover design and at-grade geometrics. Once the concept design was adjusted to satisfy forecast demand, and the model run to obtain delay and stops, data were entered into a brief spreadsheet program that estimated the present worth of benefits.

Several assumptions were incorporated into the spreadsheet program that allow for the adjustment of inputs to match site-specific conditions. These include the value of time, fuel cost, fuel consumption, vehicle occupancy, traffic composition, peak hours per day, discount rate of future benefits, and others. The value of time, estimated at $7.50/hr per auto occupant, may be subject to debate and makes the model fairly sensitive to its variation. Delay was assumed to grow linearly between the current year and the design year. Accident cost, which was incorporated into the spreadsheet program, was assumed to grow linearly with traffic volume. The spreadsheet program assumes an 18-hr day with 253 workdays per year in accordance with SDHPT and the *Manual on User Benefit Analysis of Highways (4)*.

The present worth of savings for the seven cases studied—the case in San Antonio representing three independent intersections—is given in Table 2. Savings were estimated to accrue over a 20-year period, using an 8 percent discount rate. Briefly, Cases 1 and 3 represent arterial intersections with very high current traffic volumes and a steep growth in future demand based on a freeway's being built. Case 4 is an extremely busy urban intersection in Houston, operating with eight through lanes and median turn lanes. The remaining cases are more typical urban intersections operating with congestion during peak hours. Cases scheduled for conversion to freeway interchanges rank first and second with $95.8 and $73.2 million in savings, respectively. The extremely busy Houston intersection ranks third with $49.2 million in savings, whereas others show somewhat lower amounts ranging from $6 to $30 million.

Some projects will be more expensive than others. They have different geometrics and operating characteristics and some are more difficult to build because of existing utilities, traffic handling requirements, and so forth. Cost estimates were prepared for the seven cases studied based on 1985 dollars. Both the conventional construction as well as the prefabricated method were considered. Estimates for the prefabricated structure were not as precise because of lack of as-built documented

TABLE 2 BENEFITS AND COST (1985 million dollars)

Case	Benefit[a] ($ millions)	Cost[b] ($ millions) Conventional	Prefabricated
1	95.85	7.7	NA
2	29.51	5.5	7.6
3	73.19	6.6	17.0
4	49.15	5.7	5.2
5	23.20	4.7	7.0
6	28.17	9.1	13.0
7	6.23	3.0	4.7

[a]Present worth, 1985 dollars.
[b]Cost in 1985 dollars—includes direct construction plus delay and diversion of motorists during construction.

experience and are based on $73/ft^2 quoted to a federal official *(3)*. A 1986 cost estimate prepared by the California Department of Transportation for flyovers on Beach Boulevard, Orange County (R. C. Blake, unpublished data), came to $73.60/ft^2, excluding mobilization and contingencies.

Cost estimates are the sum of various components including the structure, at-grade roadway improvements, signal, signs, markings, illumination, utility relocation, and traffic handling during construction. Delay and diversion costs to motorists during construction also were included, but precise figures were difficult to estimate at this level of analysis. The latter costs are very site specific as they depend on the adjacent roadway network, construction methods, and seasonal traffic variation among other factors.

Table 2 also presents the total construction cost of the seven cases studied. Not included as costs are any liabilities resulting from access impacts; however, none of the cases studied appeared to impact local traffic severely, and some properties appeared to benefit from the improved flow. Maintenance costs also were excluded because of the lack of information under similar conditions and the various construction methods considered. It was expected that the prefabricated structure would require more frequent and expensive maintenance.

The most expensive conventional flyover is Case 6 estimated at $9.1 million, but this case stands for three separate intersections. Cases 1 and 2, which would be built with high-type standards, would cost $7.7 and $6.6 million, respectively. All others would cost less than $6 million.

Prefabricated flyovers show a different ranking. Case 1 is not recommended in the prefabricated mode because it is an underpass rather than a true flyover, and the advantages of the prefabricated construction cannot be realized. Case 3 is the most expensive prefabricated flyover at $17 million more than 150 percent more costly than the conventional. This is principally the result of a long and wide bridge structure, which is the most expensive component of the prefabricated technique. On the other hand, Case 3 is one of the least expensive, and is cheaper than the conventional flyover. This may be attributed to the short and narrow structure plus a much lower delay and diversion of arterial traffic during construction.

Once benefits and costs are estimated, a ratio of these two measures can be prepared to assess the cost-effectiveness of each project. The benefit-to-cost ratios of the cases studied varied between 1.3 and 12.5, as presented in Table 3. Of the conventional cases, Case 1 exhibits the largest ratio at 12.5, followed closely by Cases 3 and 4 at 11.1 and 9.6, respectively. Those ratios appear large enough to justify each project, excluding consideration of other less important components, Ratios for other cases are smaller but still large enough to be justified, based on their economic effectiveness alone.

TABLE 3 BENEFIT-TO-COST RATIO (20-Year Life)

Case	Conventional	Prefabricated
1	12.5	NA
2	5.4	3.9
3	11.1	4.3
4	9.6	10.6
5	4.9	3.3
6	3.1	2.2
7	2.1	1.3

Prefabricated flyovers present a similar perspective in that all cases exceed a ratio of 1.0. However, only Case 4 is outstanding with a ratio of 10.6, slightly larger than the conventional flyover. All others have a ratio of less than 5.0.

WARRANTS

Warrants to justify building a flyover on an existing arterial intersection have been proposed and are summarized as follows:

- The intersection is a bottleneck and conventional traffic engineering measures cannot resolve the capacity problem.
- A minimum of four through lanes already exists and maximum use of the intersection right-of-way has been made. The sum of critical lane volumes approaches or exceeds 1,200 vph.
- It is time-consuming, expensive, or contrary to public objectives to obtain additional right-of-way. A minimum right-of-way of 100 ft is available.
- Impact to adjacent properties and minor streets limited to right turn only is not severe.
- The accident rate is significantly larger than for nearby intersections on the same arterial.

CONCLUSIONS

The preceding assessment demonstrates the economic feasibility of constructing flyovers to reduce congestion at signalized intersections that conventional at-grade improvements cannot resolve. Grade separation requires considerable capital expenditures, which can be offset by the benefits accrued through their implementation. Based on the study, some useful relationships and warrants have been developed to identify potential sites for flyover treatment.

A strong linear relationship was found between benefits, based on conditions prevailing in Texas, and the average 20-year approach volume to an intersection. A rule of thumb from

that relationship indicates that congested intersections with an approach volume averaged over 20 years of 50,000 vehicles per day or more, would justify a simple arterial flyover. Benefits add up to about $6.5 million, whereas total costs of a conventional flyover, including delay and diversion to motorists during construction, would amount to about $5.0 million.

It has been proposed that benefit-to-cost ratios exceeding 3.0 can be justified based on cost-effectiveness alone. Ratios closer to 1.0 need to be carefully examined for minor costs that may have been disregarded. In some instances, when maintenance costs are included, the ratio may drop to below 1.0. Primary benefits and costs may be readily analyzed using the methods proposed in the research study *(5)*. Delay and diversion of motorists during construction, together with indirect impacts, require additional site-specific investigations, generally conducted during the preliminary engineering phase.

Flyovers can be a cost-effective option for increasing the capacity of congested arterial intersections when less expensive at-grade solutions have been exhausted. The benefit-to-cost ratio of building flyovers at each of nine arterial intersections in Texas has been estimated to range between 1.3 and 12.5 depending on traffic conditions, site geometrics, and method of construction, among other factors. Projects with the largest benefit-to-cost ratio generally correspond to intersections with very large current traffic and projected growth.

ACKNOWLEDGMENTS

The research underlying this paper has been sponsored by the Texas SDHPT in cooperation with the U.S. Department of Transportation and the FHWA. This paper reflects the views of the author who is responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the U.S. Department of Transportation, the FHWA, or the Texas SDHPT.

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Publication of this paper sponsored by Committee on Geometric Design.