EVALUATION OF TRANSITWAY INTERCHANGES
T-INTERCHANGE DESIGN

Technical Memorandum
Work Order 3-A

Prepared for
Metropolitan Transit Authority
of Harris County

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SUMMARY

As the Houston transitway network is expanded, the need for high-speed access points becomes more critical. At the request of the Metropolitan Transit Authority of Harris County, the Texas Transportation Institute developed an "ultimate" design for a T-interchange, in particular the Kuykendahl interchange. This technical memorandum documents design guidelines which were utilized in the development of the T-interchange. Lengths of acceleration/deceleration lanes for several operating speeds were also determined. Recommended cross sections of approaches to the intersection are also provided. An estimation of costs for the interchange is given based on several structure lengths. A detailed evaluation of two alternatives for the access ramp approach to the intersection was also completed. The level-of-service for the existing and projected traffic demands were calculated for several interchanges, including the Kuykendahl design, and are presented in this technical memorandum.

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INTRODUCTION

The transitway interchanges for the Houston transitway system were initially designed for operation with buses, vanpools, and a somewhat limited number of carpools. On August 11, 1986, the occupancy requirement for carpools on the I-10 Katy Transitway was changed to allow vehicles with as few as two occupants to use the priority treatment facility. The approximate 1500 vehicles presently using the facility during the peak hour has brought the operations to near capacity conditions. Concern has been expressed by the Metropolitan Transit Authority of Harris County (METRO) operations staff, as well as the Transit Police, concerning the operation of the transitway at the various types of interchanges. This technical memorandum presents the results of an analysis by the Texas Transportation Institute (TTI) evaluating the T-interchange design.

The results presented are directly applicable to the design of the Kuykendahl interchange on the I-45 North Transitway. The guidelines presented should be considered for future development of transitway interchanges of the T-interchange design.

DESIGN GUIDELINES

The development of design guidelines for the transitway T-interchange was structured to consider several aspects of transitway operational requirements. Each geometric aspect was considered on an individual basis and then combined to determine the "ideal" or "desirable" interchange design. The items considered include: length of acceleration/deceleration lane, taper length, turning radii, and cross-section.

Acceleration/Deceleration Lane

TTI previously examined the acceleration characteristics of METRO's present bus fleet at the Lockwood (Eastwood) Interchange along the I-45 Gulf Transitway (1) and the Addicks Interchange and Gessner slip ramp of the I-10 Katy Transitway (2). To more realistically depict actual operating conditions, a combination of the results of the tests completed on the Katy Transitway were used as estimates of speeds of buses on the transitway at various distances from a stopped start. A "best" average of tests at the Addicks and Gessner interchanges were used to negate the effect of grades, and acceleration lane lengths were estimated. Figure 1 presents the results of the tests and the speed/distance relationship which was used for determination of the required length of acceleration lane.

The acceleration lane should be long enough to accelerate the vehicles entering to speeds near that existing on the transitway main lane. SDHPT freeway design criteria states that all ramps should be designed to allow vehicles to enter or exit a freeway at no less than 50% (70% usual, 85% desirable) of the freeway's design speed (Table 1) (3). These values should also be considered valid for transitways as they are essentially access controlled facilities usually designed to freeway standards. A major difference does exist in the geometrics of an entrance ramp into a freeway when compared to that of a transitway T-interchange. The T-interchange entrance exhibits more characteristics of a speed change lane with a stop condition (initial speed 0 mph) than a normal freeway entrance ramp. Figure 2 presents the SDHPT guidelines for speed change lanes.

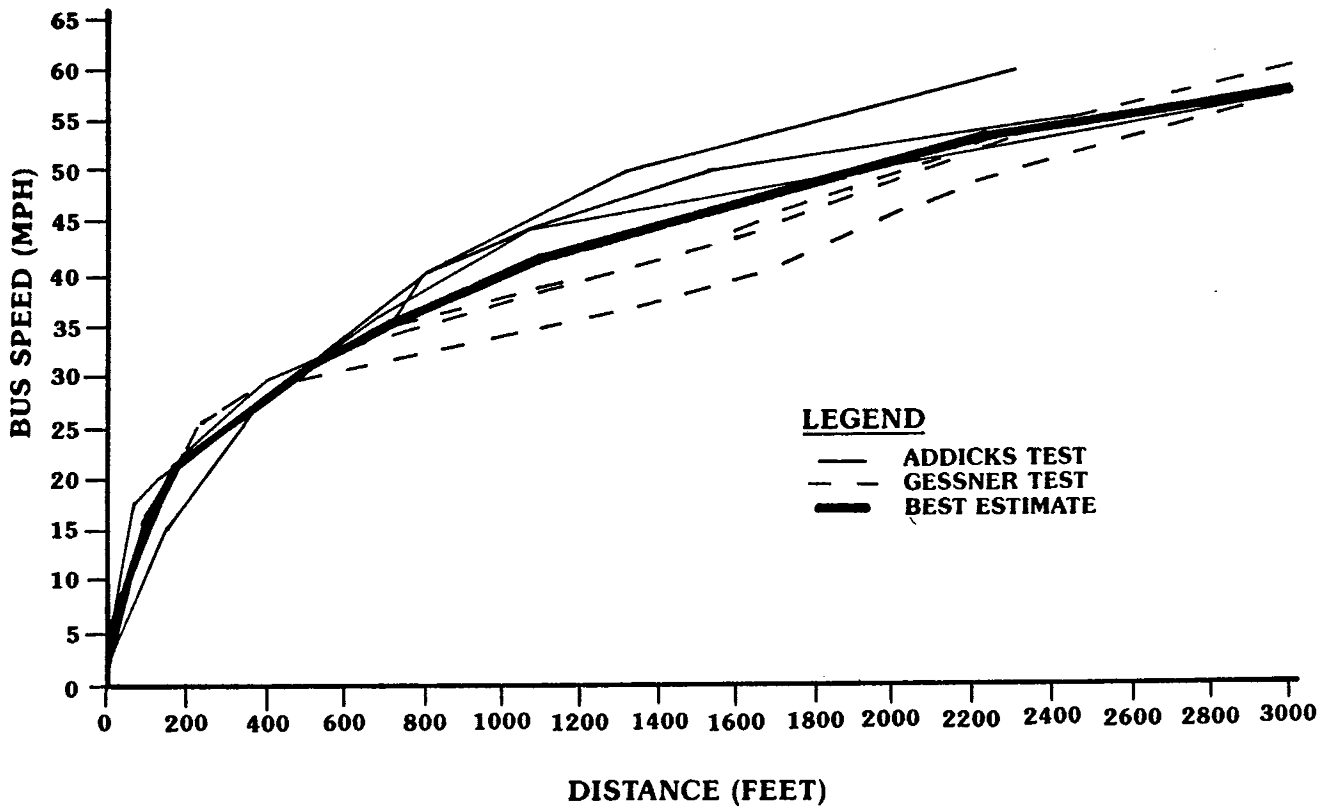
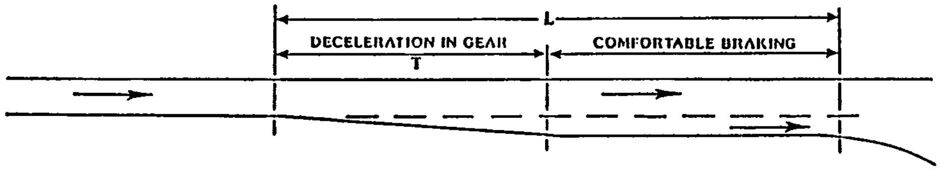
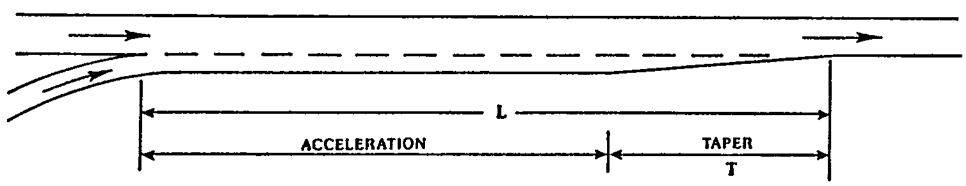


Figure 1. Transit Bus Speed Versus Distance Relationships



HIGHWAY DESIGN SPEED MPH	MINIMUM LENGTH OF TAPER (FEET) T	L-LENGTH OF DECELERATION LANE-FEET FOR DESIGN SPEED OF EXIT CURVE-MPH								
		STOP CONDITION	15	20	25	30	35	40	45	50
		FOR AVERAGE RUNNING SPEED ON EXIT CURVE-MPH								
		0	14	18	22	26	30	36	40	44
30	150	235	185	160	140	-	-	-	-	-
40	190	315	295	265	235	185	155	-	-	-
50	230	435	405	385	355	315	285	225	175	-
60	270	530	500	490	460	430	410	340	300	240
65	290	570	540	530	490	480	430	380	330	280
70	300	615	590	570	550	510	490	430	390	340
75	315	660	630	610	590	560	530	470	440	390
80	330	700	680	660	640	610	580	530	490	450



HIGHWAY		L-LENGTH OF ACCELERATION LANE-FEET FOR ENTRANCE CURVE DESIGN SPEED-MPH								
DESIGN SPEED MPH	MINIMUM LENGTH OF TAPER (FEET) T	STOP CONDITION	15	20	25	30	35	40	45	50
		FOR AVERAGE RUNNING SPEED ON EXIT CURVE-MPH								
		0	14	13	22	26	30	36	40	44
30	150	190	-	-	-	-	-	-	-	-
40	190	380	320	250	220	140	-	-	-	-
50	230	760	700	630	680	500	380	160	-	-
60	270	1170	1120	1070	1000	910	800	590	400	170
70	290	1590	1540	1500	1410	1330	1230	1010	830	580

Note: Where lengths exceed 1300 feet, or design speeds exceed 70 MPH, uniform 50:1 tapers are recommended.

Figure 2. Lengths of Right-Turn Speed Change Lanes for Non-Controlled Access Highways

Source: Ref. (3).

Table 1. Guide Values for Ramp Design Speed as Related to Highway Design Speed

Highway Design Speed, mph	50	60	70
Ramp Design Speed, mph			
Upper Range (85%)	45	50	60
Mid Range (70%)	35	45	50
Lower Range (50%)	25	30	35

Source: Ref. (3).

In various meetings and discussions with METRO staff members, it has been expressed that it is desirable for vehicles entering the transitway to achieve speeds within 10 mph of the thru vehicles. Table 2 presents recommended acceleration/deceleration lane lengths for eight thru transitway speeds and the length of taper; these lengths are sufficient to accelerate entering transit buses to within 10 mph of the thru vehicles and are based upon Figure 1. The recommended taper lengths were obtained from Figure 2. For the eight thru speeds listed, the length of acceleration lane is adequate for entering buses to reach at least 70% (SDHPT "usual" for freeway ramps and connections) of the thru vehicle speed. Figure 3 presents a conceptual layout for definitions of the recommended lane lengths.

Table 2. Recommended Acceleration/Deceleration Lane Lengths for Transitway T-Interchanges

Thru Speed (mph)	Entering Speed* (mph)	Length of Acceleration Lane (Ft)	Length of Taper (Ft)	Total (Ft)
35	25	250	170	420
40	30	400	190	590
45	35	700	210	910
50	40	975	230	1205
55	45	1400	250	1650
60	50	1900	270	2170
65	55	2400	280	2680
70	60	3000	290	3290

*Bus speed at end of taper.

The acceleration lane lengths as recommended by Table 2 either meet or exceed previously accepted transitway design standards (Table 3, 4) (4). However, the recommended lane lengths of Tables 3 and 4 include the taper lengths within the speed change distances. In the analysis presented in this report, the required taper lengths are included at the ends of the recommended acceleration lane lengths. In this manner, the speeds of transit buses entering the transitway will reach to within 10 mph of the thru traffic before being "forced" into the thru traffic lane. This criteria will provide for the most efficient operations at a non-controlled transitway T-interchange.

Table 3. Previously Recommended Lengths for Deceleration Lanes

Transitway Mainlane Design Speed (mph)	Length of Deceleration Lane (ft) for Ramp Exit Design Speed (mph)				
	0	10	20	30	40
40	320	300	240	140	--
50	500	480	420	320	180
60	720	700	620	520	180

*Desirable taper - 30:1; usual minimum taper - 20:1.

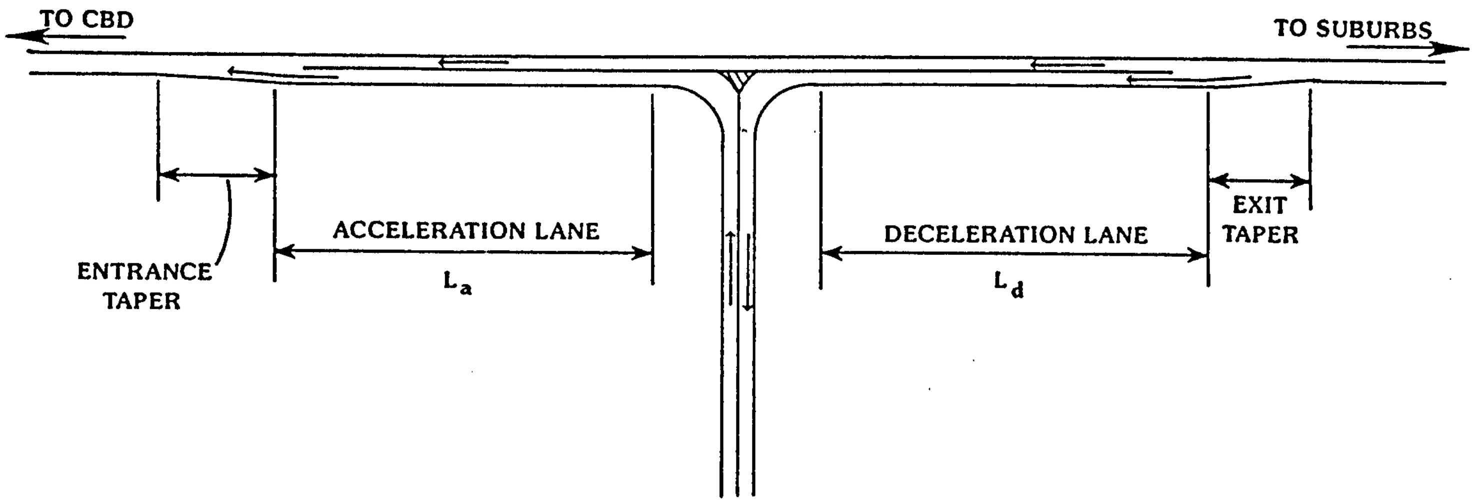
Source: Ref. (4).

Table 4. Previously Recommended Lengths for Acceleration Lane

Transitway Mainlane Design Speed (mph)	Length of Acceleration Lane (ft) for Ramp Entrance Design Speed (mph)				
	0	10	20	30	40
40	400	380	300	---	---
50	900	870	800	500	---
60	1600	1550	1500	1200	700

*Desirable taper - 50:1; usual minimum taper - 20:1.

Source: Ref. (4).



Note: This figure assumes "Reversible" style design and operation toward CBD.

Figure 3. Conceptual Layout of Transitway T-Interchange

Transitway T-Interchange Cross Section

The typical cross section of one-way one-lane reversible transitways in Houston consists of a clear distance of approximately 20 feet (Figure 4). This design is within 0.5 feet of the minimum width required for safe passage of disabled vehicles within the transitway (5). To provide for a more consistent design for approaches to the T-interchange, it is recommended that the 4 foot clearance offset (shoulder) be used for all approaches to the intersection. In cases of right-of-way or cost restrictions, a minimum offset of 2 feet may be used. The access ramp approach from the park-and-ride lot or the surface street system (usually ultimate two-way operation) should consist of the 40 foot cross section of Figure 5. The clearance offset may be reduced to 2 feet for constrained situations. The center shoulder separation should be adequately marked with pavement markings and should be easily negotiable by vehicles if necessary. If a physical separation between the opposing flows is desired, it is recommended that the separation be of a mountable curb design raised median which may be used in emergency situations. Because of the operational characteristics of the ramp, the 4 foot shoulder may be reduced to provide for a lower cost design.

Again to provide some design consistency for the transitway T-interchange design, a 32 foot cross section is recommended for the full width intersection. Figure 6 presents a typical cross section with a 12 foot thru lane, a 12 foot acceleration/deceleration lane, and a clearance offset of 4 feet for each shoulder. The clearance offset may be reduced to 2 feet for constrained situations.

Determination of Curve Radius

The T-interchange designs were developed by following several standards and specifications. In order to develop a proper ramp design, the BUS design vehicle was used as the worst case scenario. Its turning requirements are shown by Figure 7. It has a 25 foot wheelbase and an overall length of 40 feet (6). In addition to the standard bus using the transitway, the articulated bus was also considered. Longer than a conventional bus, it has a permanent hinge near the center, which allows for greater maneuverability.

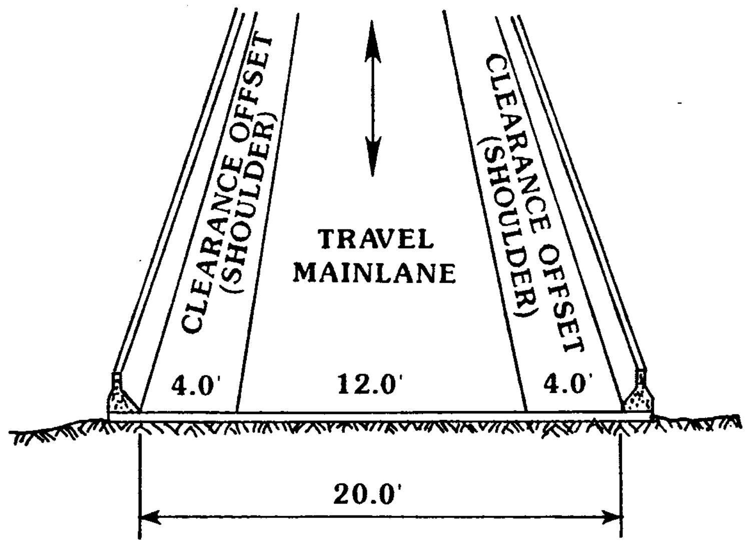


Figure 4. Typical Single Lane One-Way Reversible Transitway

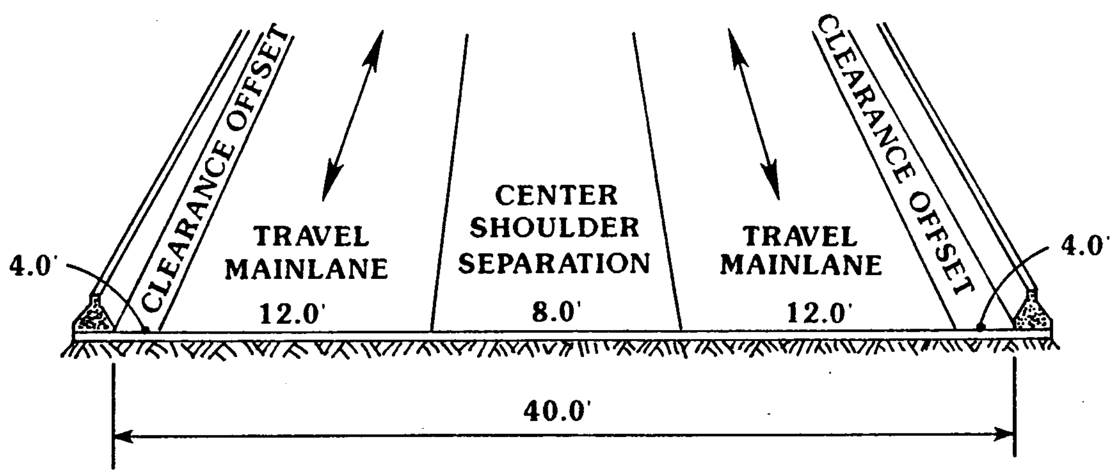


Figure 5. Recommended Access Ramp Approach to T-Interchange Intersection

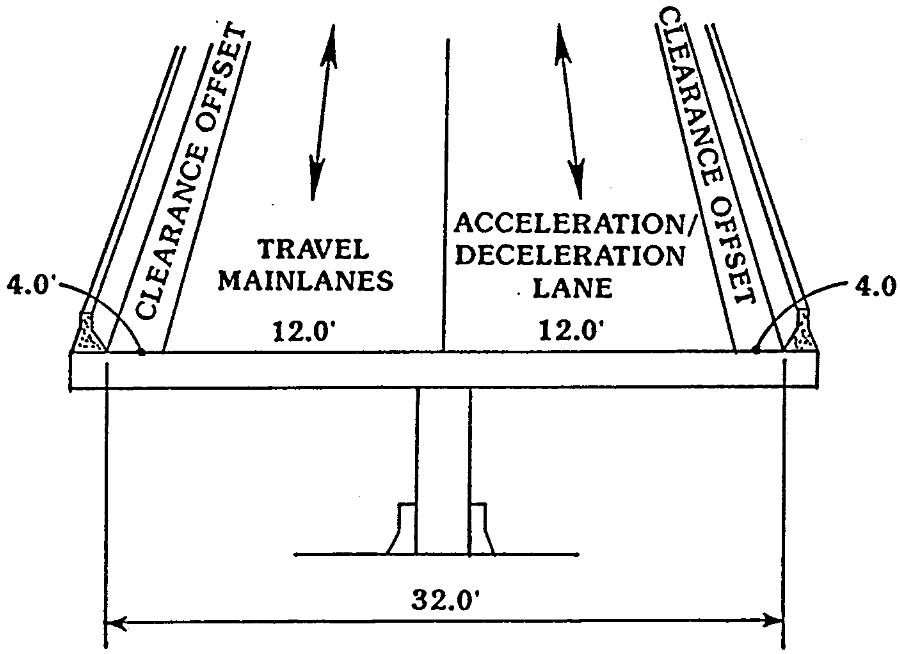


Figure 6. Recommended T-Interchange Mainlane Approach

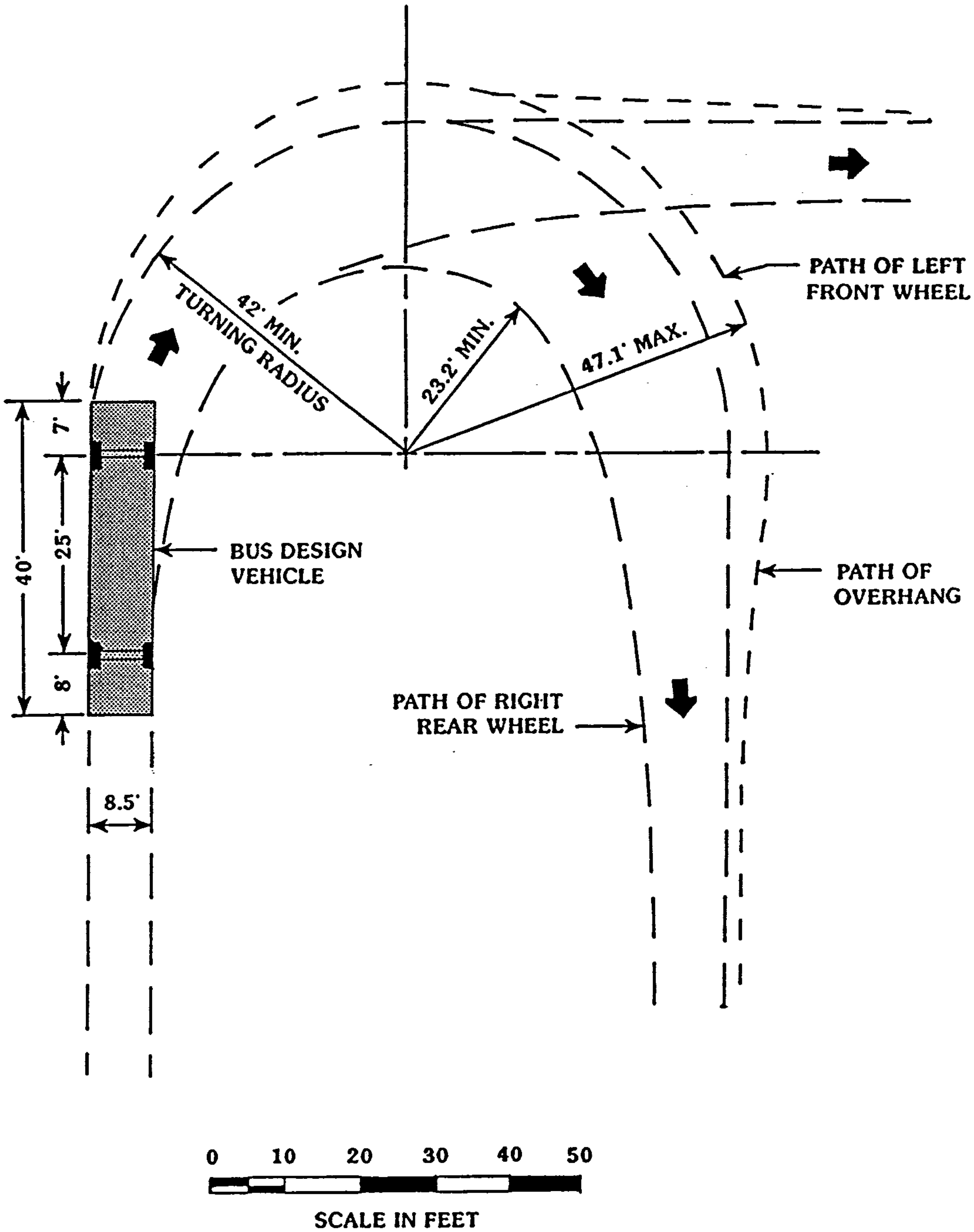


Figure 7. Minimum Turning Path for BUS Design Vehicle

Source: Ref.(6).

The A-BUS has an overall length of 60 feet and an outside wheelbase of 42 feet (6). The minimal turning radii for the A-BUS are given in Figure 8. While there is a difference when comparing the turns of design buses and actual buses, the design buses were considered as the worst case scenario and were used to determine the minimum required radius of the interchange.

The access ramp cross section follows the given standards with an 8 foot median and 12 foot lanes. However, the shoulders have been extended from a 2 foot minimum to a 4 foot desirable width. This was done in order to keep the ramp and corresponding transitway dimensions consistent, resulting in an easier transition from one to the other.

The intersection of the access ramp with the transitway main lane is the most critical part of the design. Design restrictions specify that a minimum radius of 40 feet be used (6). However, for better maneuverability of the buses, a 50 foot radius was implemented in the design. Due to the use of this radius, the design turning speed of the buses was assumed at 15 miles per hour (6).

In order for the buses to approach and complete the turn with greater ease, a taper is recommended. A taper of 10:1 is the minimum standard that should be used (6). The length of the taper was set at 100 feet, as done in standard practice. However, the exact selection of the taper length may depend upon structural requirements of the T-interchange construction. Taper lengths in excess of the 100 foot minimum are also acceptable. This design resulted in a 4 foot shoulder or offset throughout the curve. In addition to this, the median curve was set at a radius of 75 feet, based on the location of the interior 50 foot radius. Specifications require that the minimum offset, at the curve, be at least 2 feet (6). For the 2 foot offset ramp design, the taper length was held at 100 feet, as mentioned earlier, and therefore decreased the taper to 18:1. By adjusting the taper and holding the curve radius to 50 feet, the median curve radius was reduced to 71 feet.

The bus tracking dimensions were calculated from several equations and tables (6). This included a 14 foot wide tracking path of the wheels and a 3 foot front overhang as the bus is completing its turn (see Figures 9 and 10).

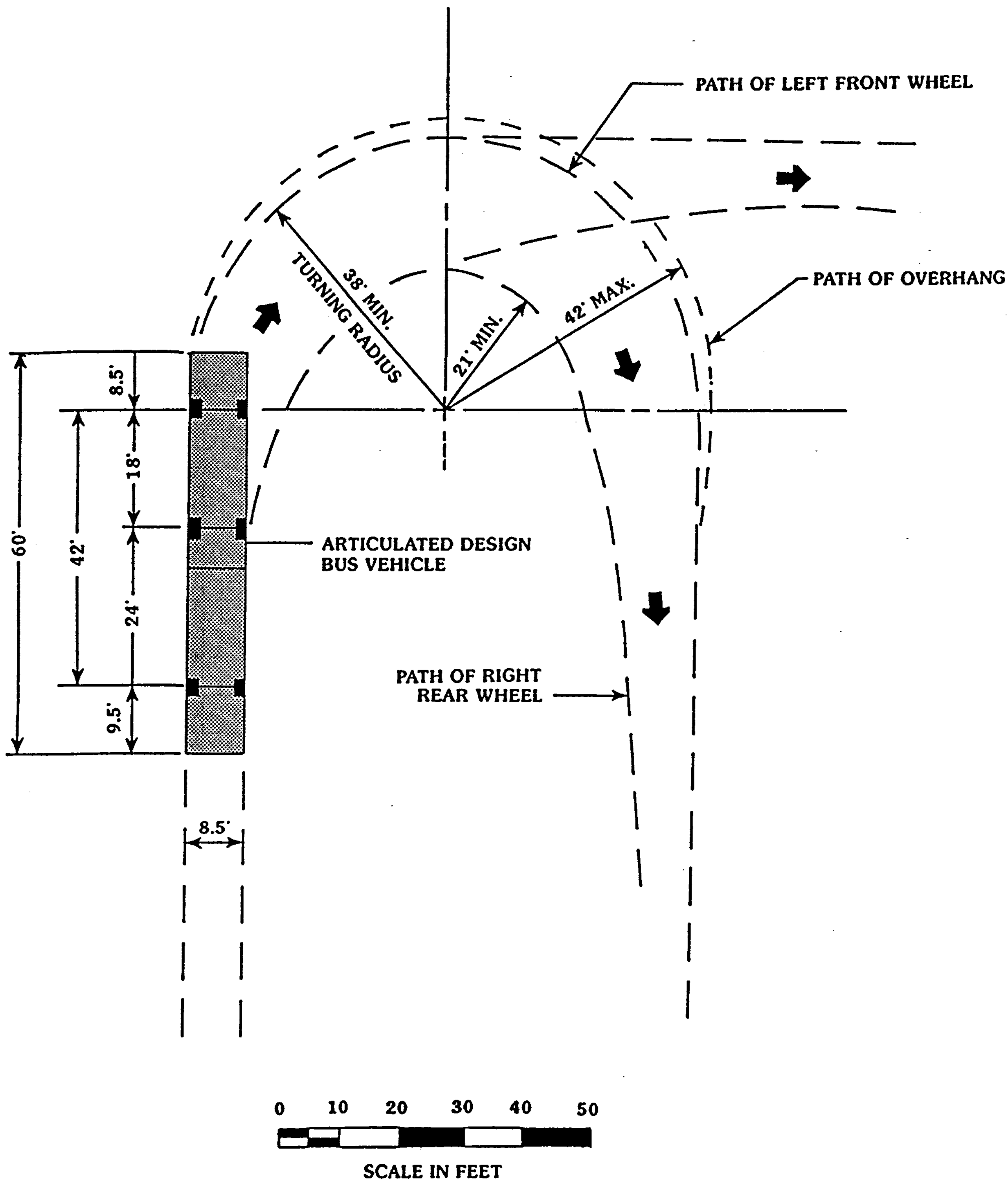


Figure 8. Minimum Turning Path for A-BUS Design Vehicle

Source: Ref. (6).

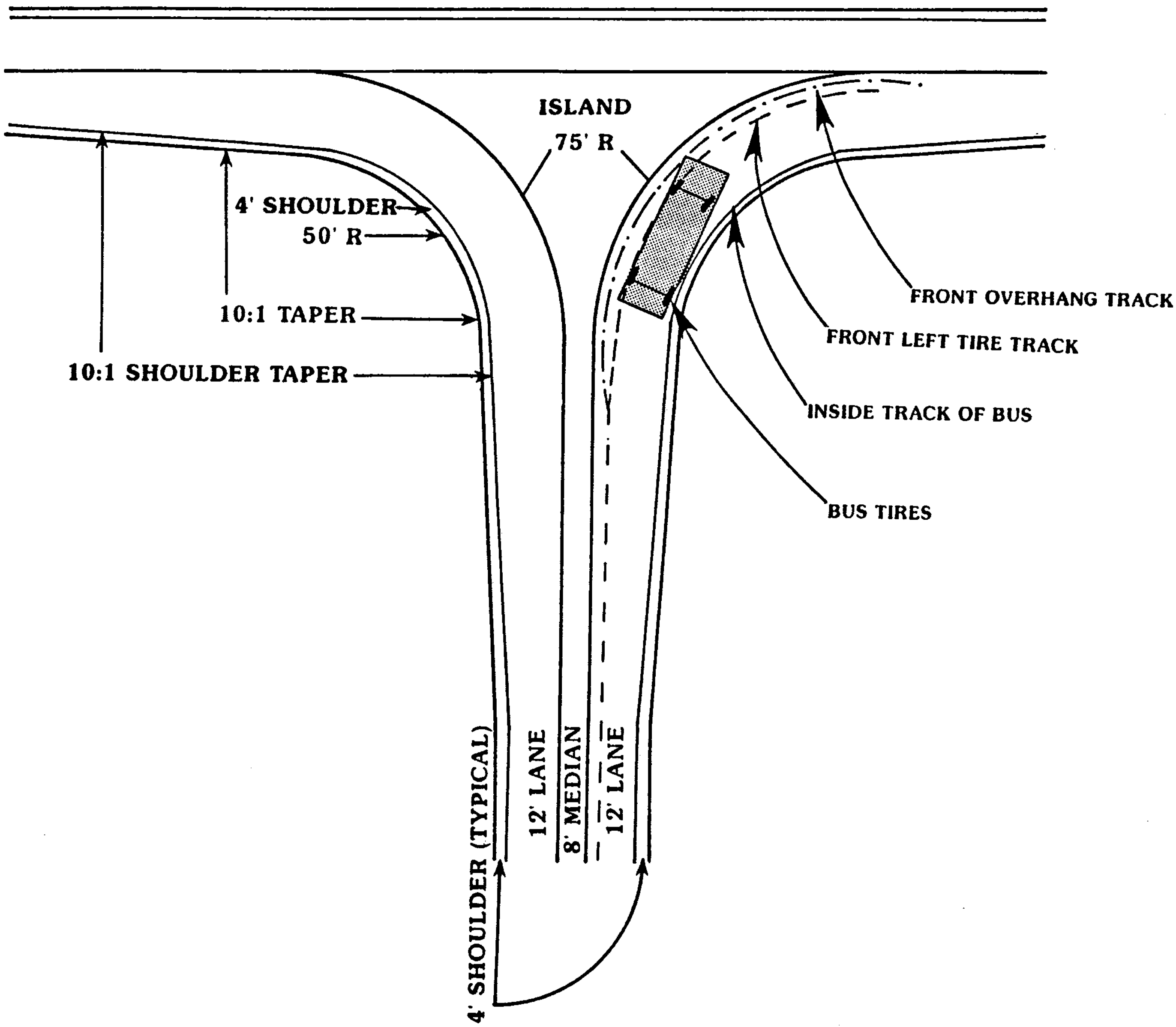


Figure 9. Bus Tracking Schematic for a 4 Foot Offset

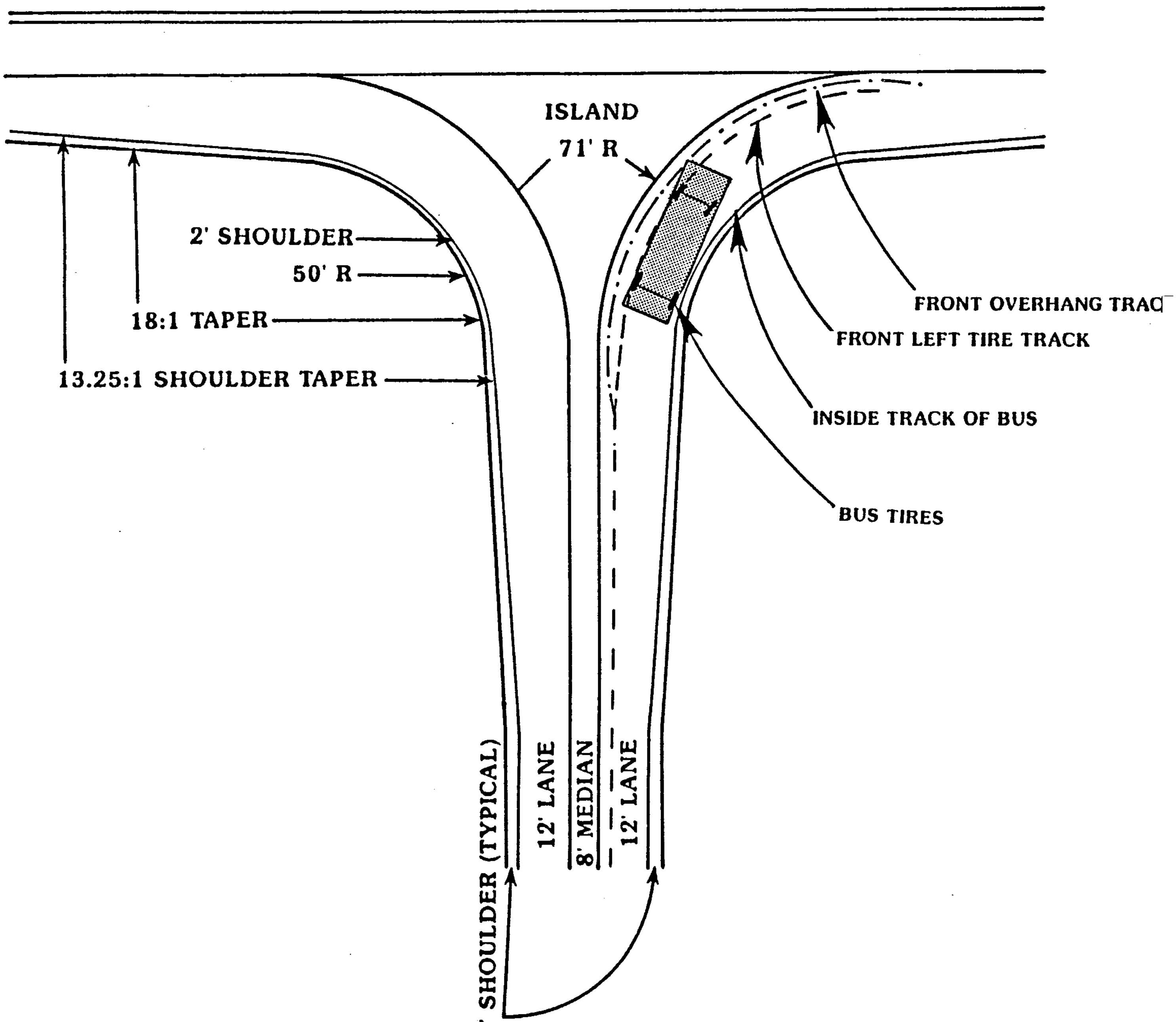


Figure 10. Bus Tracking Schematic for a 2 Foot Offset

Due to the difference in tapers, the bus maneuvering through the 10:1 taper design has 4 feet of clearance, on either side of the bus, to make its turn. Whereas the bus turning in the 18:1 taper design has only 2 feet of clearance on either side.

While both designs are acceptable, the 10:1 taper design (Figure 9) is recommended. This design provides a consistent 4 foot shoulder or offset throughout the transition from the access ramp to the transitway main lane. This results in a smoother transgression for the bus drivers and allows more leeway than the 18:1 taper design. Therefore, it is recommended that the "ideal" design of the transitway T-interchange intersection consist of that shown by Figure 9. Recommended specifications include: 4 foot shoulders and offset, 50 foot curve radius with a 10:1 taper for 100 feet, and a 75 foot radius for the center island.

Estimated Costs

The costs of T-interchanges at the Kuykendahl interchange along I-45 North Freeway were estimated and are presented in Table 5. The costs are based upon an assumed value of $40 per square foot for construction and the intersection layout of Figure 9. The length of the ramp into the Kuykendahl Park-and-Ride lot was assumed constant at 1046 feet. The estimated costs were determined based upon the required lengths of acceleration lanes as previously presented by Table 2.

Table 5. Estimated T-Interchange Costs

Thru Speed (mph)	Total Length* (feet)	Total Area (square feet)	Estimated Costs**
35	420	82,175	$ 3,287,000
40	590	92,825	3,713,000
45	910	113,050	4,522,000
50	1205	131,700	5,268,000
55	1650	159,950	6,398,000
60	2170	192,975	7,719,000
65	2680	225,500	9,020,000
70	3290	264,425	10,577,000

*Total length includes acceleration lane and taper length required to accelerate buses to within 10 mph of thru speed (Table 2).

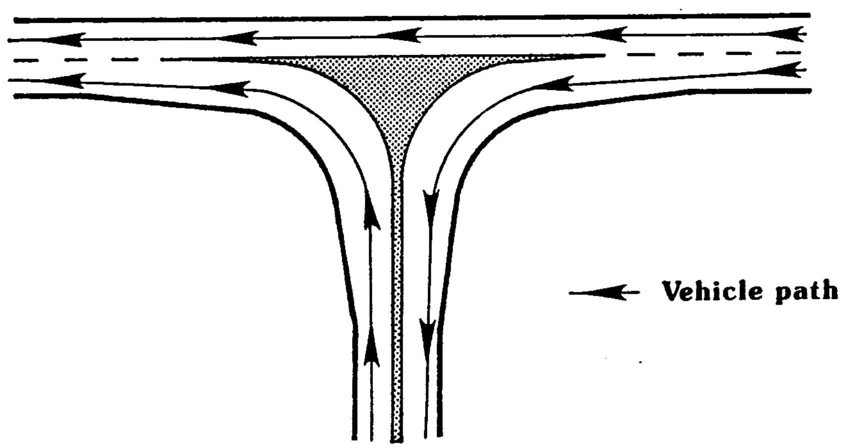
**Based upon estimated costs of $\$40/ft^2$

EVALUATION OF INTERSECTION DESIGN

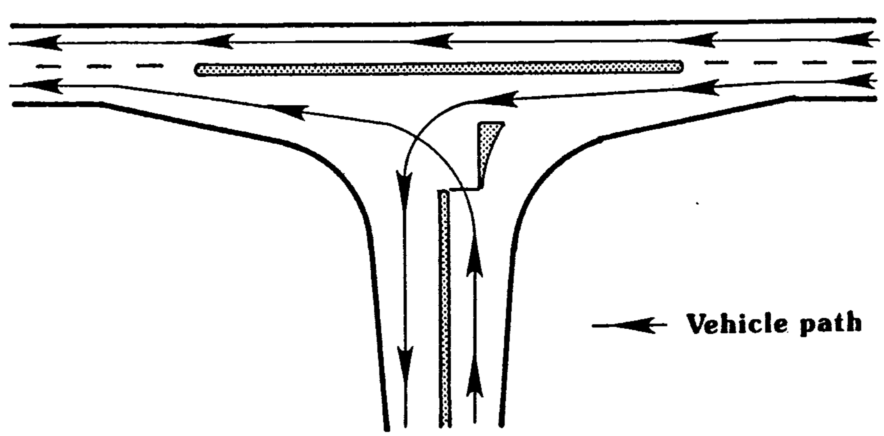
TTI completed a more detailed evaluation of two different designs of the access ramp at its intersection with the transitway main lane. The design presently implemented on the Houston transitway network ("English style" or "Reversible") is presented by Figure 11[a]. This configuration provides for operations at the intersection without requiring any additional traffic control. The concrete or asphalt island at the intersection provides for delineation at the intersection and a well defined physical separation of the thru and entering/exiting traffic. However, this design requires reversal of the traffic flow on the access ramp between the peak periods. Figure 11[b] presents a design as proposed by METRO. The geometrics are similar; however, the direction of flow on the access ramp is not reversed. The size, location, and purpose of the island is also much different. A more detailed evaluation of the operations of the two designs will be presented in this section of the report.

Previous Analysis

An analysis was previously completed by TTI which examined several intersection configurations along the proposed US 59 Southwest Freeway Transitway (7). One configuration examined included one-lane, one-way operation with separate acceleration and deceleration lanes for the two-lane access ramps. The study concluded that if the traffic projections indicated no conflicting movements at the intersection, reversal of the access ramps was not necessary and "conventional" operation was acceptable. The study also concluded that based upon the transitway configuration, the geometrics would not prevent an inbound vehicle from exiting the transitway, at three ramps which were examined. It must be noted when reviewing the results of this previous study that each ramp was examined individually with specified direction of flow and turning movements. The study also examined gap sizes and recommended acceleration/deceleration lane lengths at the interchanges.



[a] "Reversible"



[b] "Conventional"

Figure 11. T-Interchange Intersection Details

Operational Comparison

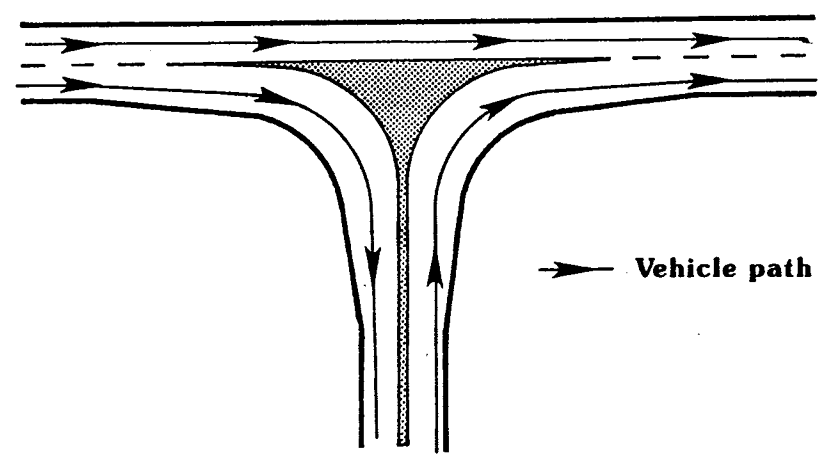
This section examines the "reversible" and "conventional" designs on an operational bases. Each intersection is considered generically; directional flows are not specifically designated as inbound or outbound and traffic demands are ignored. The differences and similarities of both designs as well as potential problems and solutions are provided.

The layout of Figure 12 has been designated as the "A-Direction" of transitway flow. Depending upon the location of the access ramp with respect to the freeway center line, the transitway "A-Direction" of flow could be either inbound or outbound. If it is assumed that all vehicles follow the paths indicated, the trade-offs between the two designs are negligible. There is no difference in the operational characteristics of the two designs and no conflict points are noted. The required length of acceleration/deceleration lanes for each design are the same. With the "Reversible" design (Figure 12[a]), wrong way movements at the intersection are not probable except in cases when vehicles negotiate the island or median. However, without some measures of traffic control, the "Conventional" design does result in three potential conflicts (Figure 13).

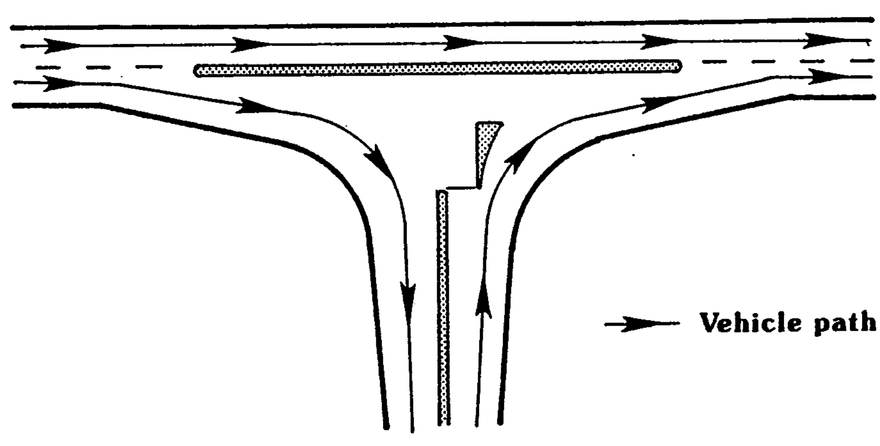
Should a vehicle (or vehicles) use the misguided paths indicated, conditions ranging from a slowdown in transitway operation to a possible collision could result. The three potential conflicts identified and the movements involved are summarized as follows:

Conflict 1 -- Caused by thru vehicle using the wrong side of the median approaching the intersection; This conflicts with a right turning vehicle entering from the access ramp (normally not impeded (Figure 12[b])).

Conflict 2 -- Caused by exiting vehicle making a right turn from the wrong side of access ramp median; This conflicts with a vehicle entering the transitway via the access ramp; Results in a wrong way vehicle on the access ramp.



[a] "Reversible"



[b] "Conventional"

Figure 12. Intersection Details for "A-Direction"

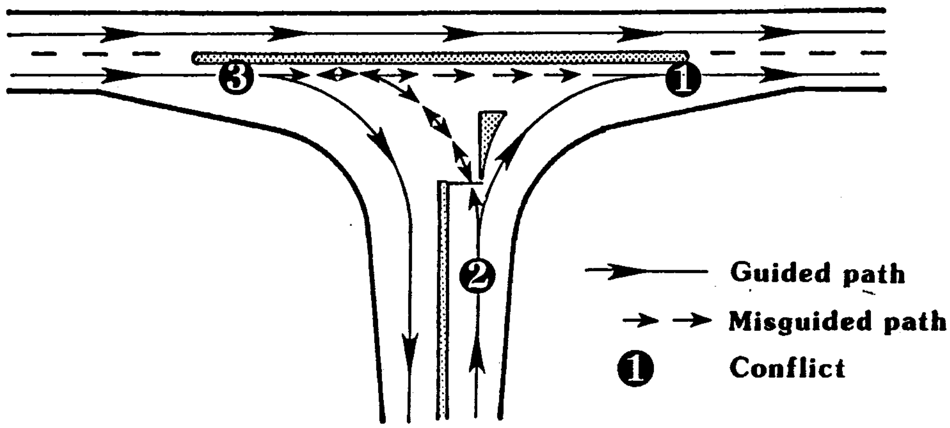


Figure 13. Potential Conflicts at Conventional Design - "A-Direction"

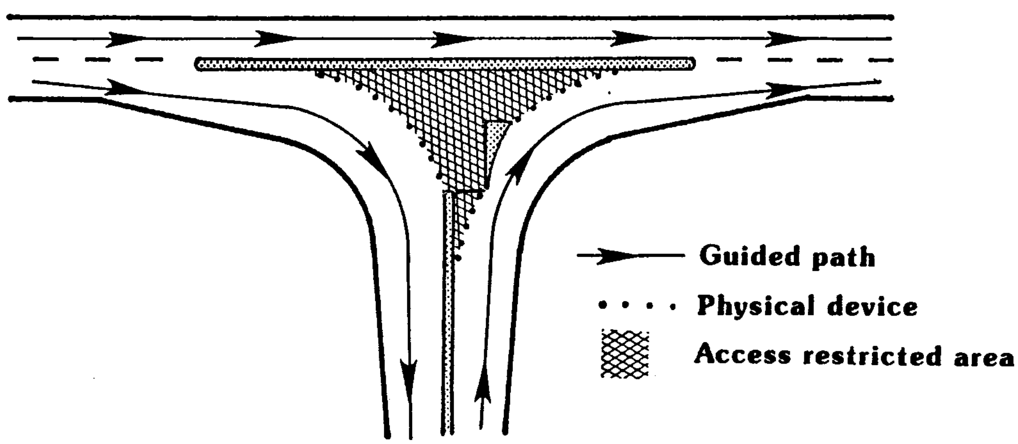


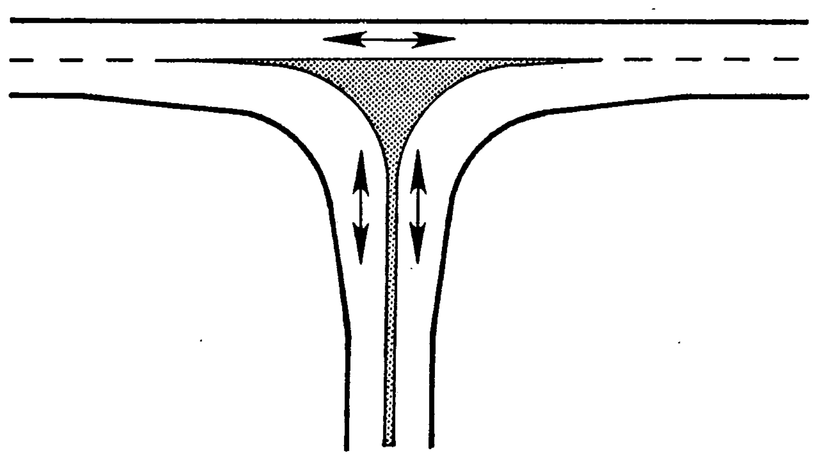
Figure 14. Recommended Traffic Control at Conventional Design - "A-Direction"

Conflict 3 -- Caused by entering vehicle making a left turn at the stop controlled movement; This will result in a wrong way vehicle on the transitway main lane during the "A-Direction" time period.

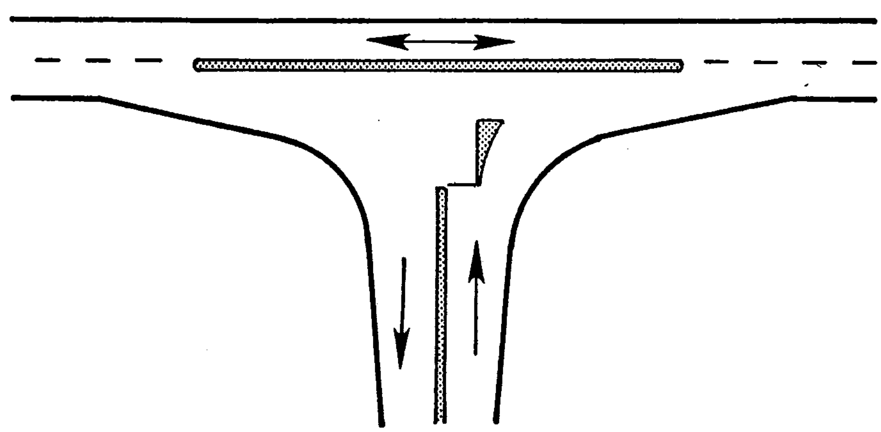
If it is desirable that the "conventional" design be implemented during the "A-Direction" time period, it is recommended that the misguided paths be restricted as indicated by Figure 14. The pavement area should be marked by cones, pylons, or some other type of physical device. However, the devices should be easily removed as the area could be used to bypass incidents which may occur in the adjacent transitway thru lane. The devices will also need to be installed/removed at the start/end of the "A-Direction" time period. It is also recommended that the area NOT be used as an enforcement area or refuge for a wrecker. The potential of conflicts at high speeds is too great for use as such.

The layout of Figure 15 indicates flows for the assumed "B-Direction" of the transitway. As indicated by Figure 15[a], the flow of traffic on the access ramp is reversed when compared to that of the "A-Direction". There are no potential conflicts at the intersection for the "Reversible" style "B-Direction". Considering the "conventional" style, a direct conflict does exist as indicated by the crossing vehicle paths of Figure 15[b]. The conflict is minimized by requiring that one of the two movements be stop controlled. For least delay at the intersection, the approach with the lowest traffic demands should be required to stop. However, if the thru transitway lane is expected to operate at high speed, placing stop control on the access ramp approach is recommended. This will also prevent delays to the thru traffic whose flow could be inhibited by stopped vehicles in the deceleration lane. In cases of excessive turning traffic at the interchange, extensive field studies may be necessary to perform a traffic signal warrant study.

In addition to the one conflict previously mentioned, the "conventional" style has the potential for three conflicts due to misguided vehicles. Figure 16 presents these potential conflicts for transitway flow in the "B-Direction". Should a vehicle (or vehicles) use the misguided paths



[a] Presently Implemented ("Reversible")



[b] Proposed Design ("Conventional")

Note: Layouts provided by METRO.

Figure 15. Intersection Details for "B-Direction"

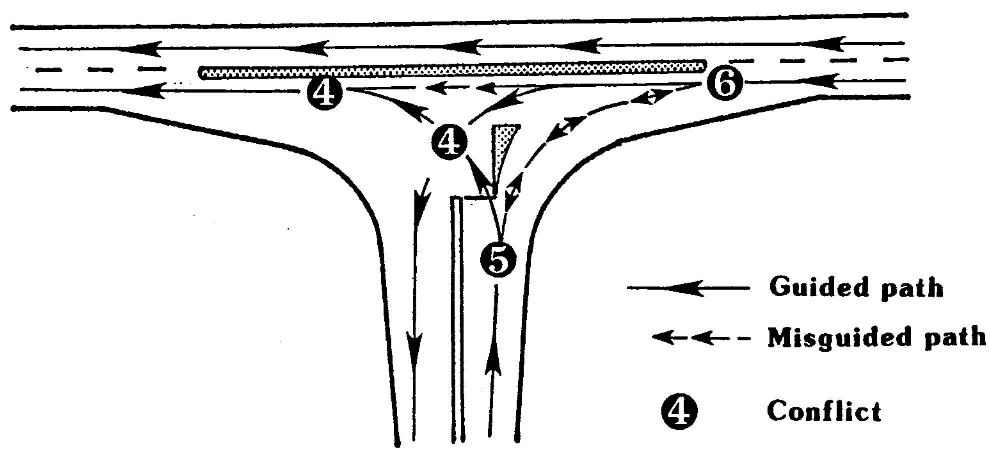


Figure 16. Potential Conflicts at Conventional Design - "B-Direction"

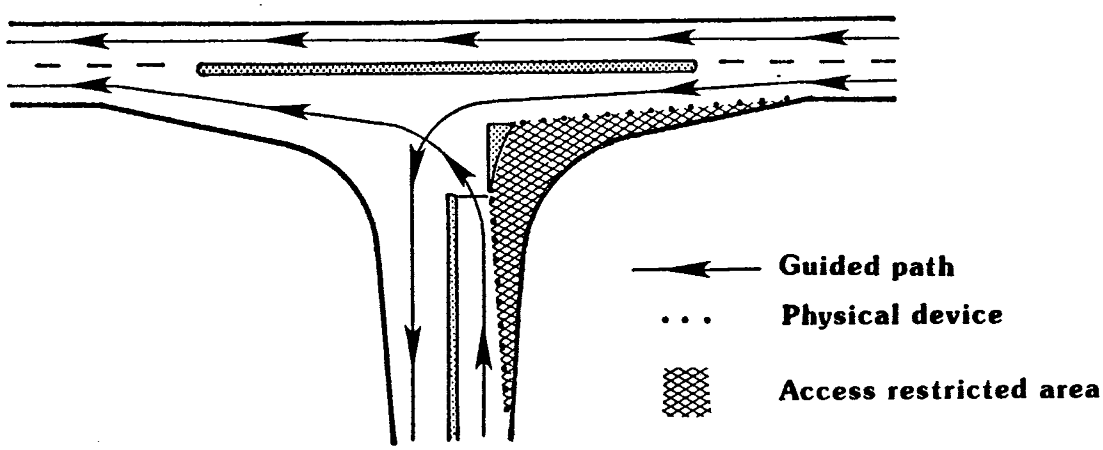


Figure 17. Recommended Traffic Control at Conventional Design - "B-Direction"

indicated, conditions ranging from a slowdown in transitway operation to a possible collision could result. The three potential conflicts identified and the movements involved are summarized as follows:

Conflict 4 -- Caused by either an exiting left-turn vehicle or a thru vehicle on the wrong side of the median approaching the intersection; The vehicle entering the transitway may have ignored the stop control on the access ramp approach or did not see the approaching vehicle.

Conflict 5 -- Caused by exiting vehicle making a left-turn into the access ramp lane approaching the intersection; Results in a wrong way vehicle on the access ramp.

Conflict 6 -- Caused by entering vehicle making a right-turn approaching the intersection. This results in a wrong way vehicle on the transitway main lane during the "B-Direction" time period.

If it is desirable that the conventional design be implemented during the "B-Direction" time period, it is recommended that the misguided vehicles path be restricted as indicated by Figure 17. All items considered for the "A-Direction" time period must also be evaluated. Although one potential conflict point does still exist, those due to misguided vehicles can be reduced.

Other Considerations

In the selection of either the "Reversible" or "Conventional" designs, adequate signage is necessary. The signing should include positive guidance and restrictive (e.g., "DO NOT ENTER") signing to reduce the possibility of wrong way operations. The "Reversible" design does require a reversal of the access ramp prior to approaching the intersection. However, this design does reduce the possibility of conflicts at the intersection, unless a vehicle negotiates the median or traffic island. The "Reversible" design does provide for operations comparable to the "conventional" design during the "A-

Direction" time period. On the other hand, implementation of the "Conventional" design increases potential conflicts at the intersection. In addition, the set-up/take-down of the recommended access restricted area may be time-consuming. It may also be easier to prevent wrong way movements at ground level (i.e., "Reversible" design) as opposed to at the elevated intersection (i.e., "conventional" design).

Existing Facilities

Consider a scenario which provides for conversion of the existing and planned T-interchanges from "Reversible" to "Conventional" design. The intersections at selected interchanges would then emulate the designs as follows:

Interchange	AM Peak-Inbound	PM Peak-Outbound
I-45 Gulf @ Eastwood	A-Direction	B-Direction
I-45 North @ Kuykendahl	A-Direction	B-Direction
US 290 Northwest		
@ Pinemont	B-Direction	A-Direction
@ Little York	A-Direction	B-Direction
@ Northwest Station	B-Direction	A-Direction
US 59 Southwest		
@ Westwood	B-Direction	A-Direction
@ Beechnut	A-Direction	B-Direction
@ Hillcroft	B-Direction	A-Direction

As indicated above, the intersection operation would not be consistent for the entire transitway system. (If I-10 Katy @ Addicks P&R is considered a T-interchange; AM Peak: B-Direction, PM Peak: A-Direction). The type of operation at each intersection is dependent upon the direction of transitway flow and the location of the access ramp with respect to the freeway centerline. **THIS INFORMATION IS PRESENTED AS A SCENARIO ONLY; CONVERSION OF THE INTERCHANGES TO "CONVENTIONAL" DESIGN WAS NOT EVALUATED IN THIS STUDY.**

LEVEL-OF-SERVICE ANALYSIS

The level-of-service (LOS) for both existing conditions and those projected for 2005 were determined for several T-interchange locations. The LOS was determined using procedures for unsignalized T-intersections in the Highway Capacity Manual (8). The criteria, for LOS analysis, given in the Manual is quite extensive. The parameters used, for the analysis, are in relation to the full directional movements of a normal T-intersection. However, due to the one-way reversible operation the transitway, the calculations were simplified. The LOS determined for the T-interchange locations were based on the "conventional" design. This was done because of the conflicting movements within the interchange and considered as the worst case scenario when compared to the "reversible" design. A more detailed LOS analysis of the T-interchanges evaluated will be presented in this section of the report.

I-45 Kuykendahl Interchange

TTI specifically analyzed the level-of-service at the proposed Kuykendahl T-interchange along the I-45 North Freeway. Figure 18 presents demand estimates for this interchange in the A.M. peak hour. The reversal of these demands were utilized for the P.M. peak hour. Due to the configuration of the Kuykendahl T-interchange, the A.M. operational flow is in the "A-Direction" (see Figure 12). This direction minimizes vehicle conflicts and results in a LOS of A for both 1986 and 2000. However, the P.M. operational flow is in the "B-Direction" (see Figure 15). This evolves into a conflicting operational configuration (Figure 16) and results in a LOS deterioration of A in 1986 to B in 2000. Note that the LOS analysis is based solely upon the demands presented in Figure 18. As compared to the "reversible" T-interchange design, the LOS results are similar. This is understandable since TTI projects **NO** P.M. demands out of the park-and-ride lot desiring to continue outbound on the transitway. This reduces the conflicts at the T-interchange and results in acceptable levels-of-service.

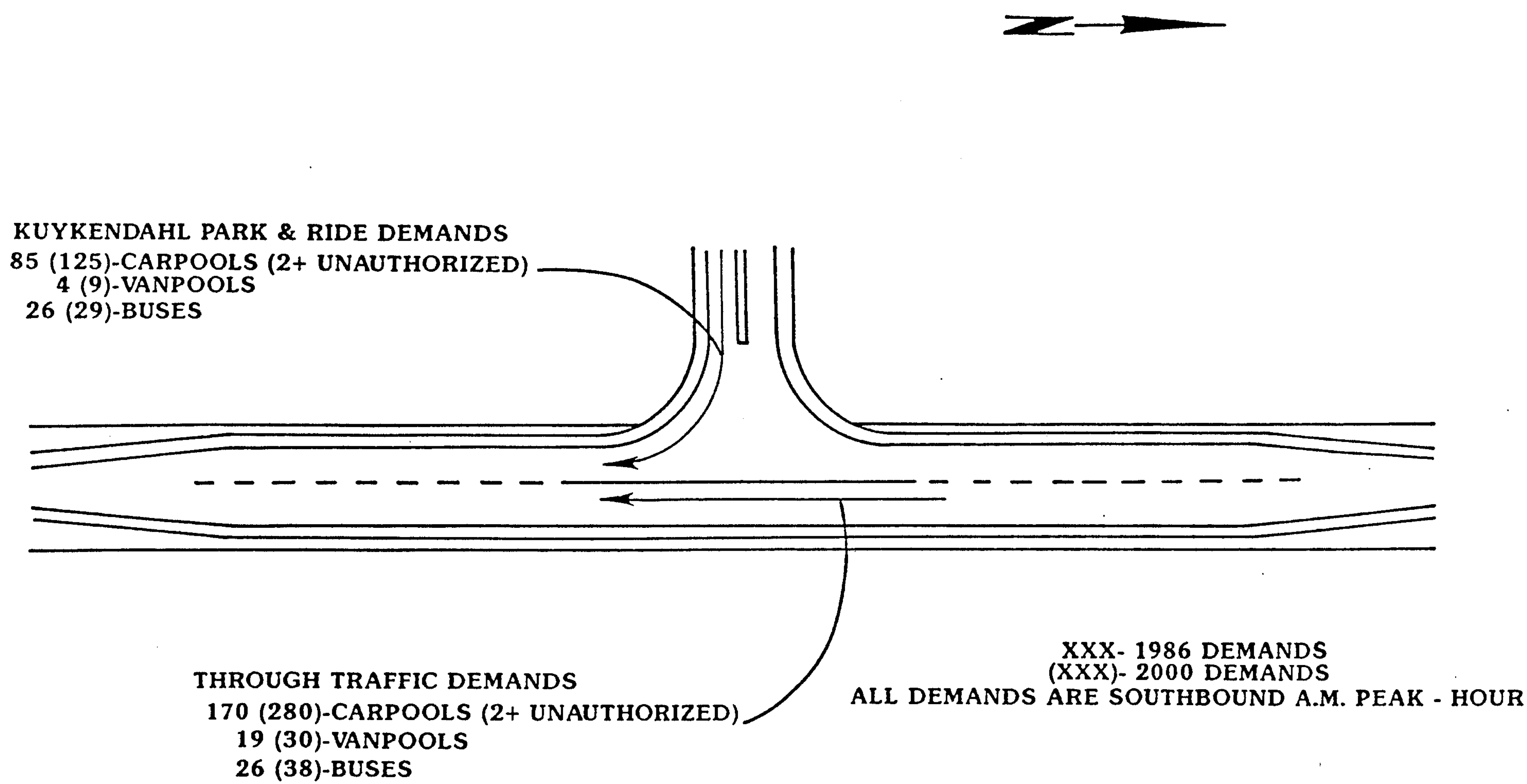


Figure 18. A.M. Peak Hour Vehicle Demands for the Kuykendahl T-Interchange

Source: Ref. (9, 10).

Other Interchanges

A similar analysis was completed for seven other transitway T-interchanges. The LOS for each T-interchange was determined using 2+ unauthorized A.M. peak hour carpool demands only (see Figure 19). As mentioned earlier, the reversal of these A.M. demands were also used for the P.M. peak hour. Table 6 shows the LOS determined for the T-interchanges that were evaluated.

Table 6. Results of T-interchange Level-of-Service Analysis

Location	A.M.		P.M.	
	1986	2005	1986	2005
I-45 North Transitway				
(Kuykendahl)	A	A*	A	B*
I-45 Gulf Transitway				
(Eastwood)	B	C	D	E
US 290 Northwest Transitway				
(Northwest Station)	A	C	A	A
(Little York)	A	A	D	E
(Pinemont)	D	E	A	C
US 59 Southwest Transitway				
(Bissonnet)	A	B	A	A
(Hillcroft)	C	D	A	C
(S. Rice)	C	D	E	E

*Projection of Demands: Year 2000

It is important to note that the LOS calculated, for the T-interchanges, was for the "conventional" design only. Again, this was done because of the conflicting movements within the T-interchange (see Figure 16). The left turn off the access ramp and onto the transitway is the most critical conflicting movement. This maneuver has a great impact on the LOS determination. The other conflicting movements can be controlled by the access restricted areas during operations. To better illustrate this, the reserve capacity for the access ramps evaluated are shown in Table 7.

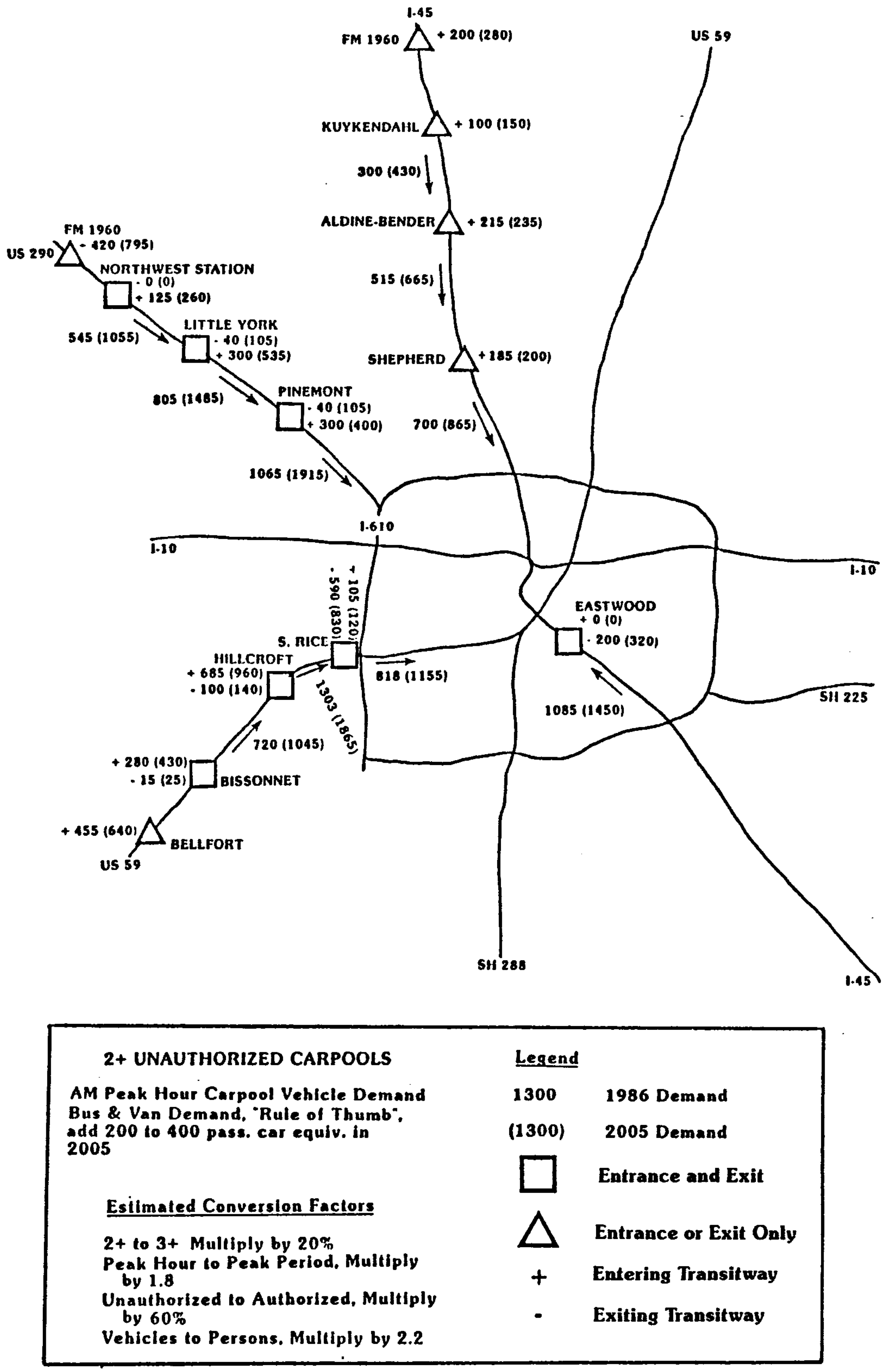


Figure 19. 2+ Unauthorized Carpool Demands for A.M. Peak Hour

Source: Ref. (11).

Table 7. Reserve Capacity of Access Ramps

Location	A.M. 1986	A.M. 2005	P.M. 1986	P.M. 2005
I-45 North Transitway				
*(Kuykendahl)	N/A	N/A	508	351
I-45 Gulf Transitway				
Eastwood	N/A	N/A	160	90
US 290 Northwest Transitway				
*(Northwest Station)	451	227	N/A	N/A
(Little York)	N/A	N/A	197	48
(Pinemont)	197	57	N/A	N/A
Us 59 Southwest Transitway				
(Bissonnet)	441	302	N/A	N/A
(Hillcroft)	242	137	N/A	N/A
(S. Rice)	N/A	N/A	93	55

*No Projection of demands for vehicles turning left onto transitway
N/A - Vehicles operating in nonconflicting manner "A-Direction"

The reserve capacity, in this analysis, is the actual capacity. The criteria within the Highway Capacity Manual calls for the reserve capacity to be calculated from the shared-lane capacity (8). Since the transitway is a one-way reversible operation, there are no shared-lane movements from the access ramp. Therefore, the two capacities are the same. It can also be shown that the reserve capacities are in direct correlation to the LOS calculations. This is evident when comparing the capacities in Table 7 to the LOS determinations of Table 6.

The LOS determination for the "A-Direction" access ramps were calculated using the procedures described earlier in the Highway Capacity Manual. The actual capacities derived from the unsignalized T-intersection analysis was utilized to calculate this LOS. While the conflicting movements (misguided paths) are potentially dangerous areas. The "A-Direction" access ramps are substantially easier in operation and analysis as shown in Table 6.

CONCLUSIONS

The study examined the length of acceleration lane, turning radii, and access ramp designs for transitway interchanges of the T-interchange design. The recommended minimum length of the acceleration lane is that necessary to accelerate transit buses to within 10 miles per hour of the transitway main lane approach speed. The values presented by Table 2 of this report should be used as guidelines. In addition, the recommended layout of Figure 9 should also be considered as the "ideal" design for radii, offsets, and tapers.

In summarizing the two designs for the access ramp approach to the T-interchange, several aspects were addressed. The possibility of constructing the "conventional" design was analyzed and it was discovered that it could be utilized. However, several potential problems do arise. The "conventional" design produces several conflicting movements during operation. The "reversible" design handles the movement of vehicles at grade where there are fewer conflicts and more control. There would be a requirement for some type of traffic control, for the "conventional" design, at the access ramp intersection with the transitway main lane. This would result in an increase in delay to vehicles required to stop. The necessary access restricted areas would increase the manpower required for set-up and take-down during operations. In addition to this, all ramps would not be operationally consistent, due to the placement of the access ramp in conjunction with the transitway centerline ("A-Direction" vs. "B-Direction"). A few of the T-interchanges that were analyzed had no demands of vehicles turning left from the access ramp onto the transitway. This is the most critical movement within the T-Interchange. Without this movement, the levels-of-service determined are quite acceptable. However, once there is a demand established for this crucial movement, the LOS will deteriorate dramatically. The "reversible" design would handle this movement, at-grade, where speeds would be lower and conflicts reduced. Considering the operation and configuration of both designs, it is the recommendation of TTI that the "reversible" design be implemented as the more appropriate T-Interchange.

REFERENCES

1. Bus Acceleration and Turning Tests, Technical Memorandum prepared for Metropolitan Transit Authority of Harris County, Gulf Freeway Transitway Work Order 0013, Texas Transportation Institute, October 1986.

2. Bus Acceleration Characteristics, Technical Memorandum prepared for Metropolitan Transit Authority of Harris County, Katy Freeway Transitway Work Order 0013, Texas Transportation Institute, October 1987.

3. Highway Design Division Operations and Procedures Manual, Texas State Department of Highways and Public Transportation, 1986.

4. Mounce, J.M. and Stokes, R.W., Manual for Planning, Designing, and Operating Facilities in Texas, TTI Research Report 425-2, Texas Transportation Institute, September 1985.

5. Lomax, T.J., Transitway Width Assessment, TTI Research Report 339-3, Texas Transportation Institute, November 1984.

6. A Policy on Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials, 1984.

7. McCasland, W.R., Operational Impacts of Alternative Designs for Ramp Intersections on Two-Directional Transitways, Texas Transportation Institute, July 1986.

8. Highway Capacity Manual, Transportation Research Board Special Report 209, 1985.

9. Assessment of Alternative Transitway Improvements, FM 1960 to Downtown Houston, Texas Transportation Institute, September 1986.

10. Carpool Demand On the North Transitway, Preliminary Estimates, Texas Transportation Institute, January 1987.

11. Unpublished Carpool Projections, Texas Transportation Institute, February 1987.