U-TACV PATRONAGE ANALYSIS

Prepared for

The Cities of Dallas and Fort Worth
and the North Central Texas
Council of Governments

by

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I. INTRODUCTION

In 1971 the North Central Texas Council of Governments (NCTCOG), with the Cities of Fort Worth and Dallas and several suburban cities, jointly initiated a series of public transportation studies. The principal purpose of these studies was to develop a comprehensive program for improvement of public transportation service in the North Central Texas Region. Individual studies were supported by the Regional Public Transportation Study, which prepared recommendations for a Regional Public Transportation Framework. Subregional Studies then detailed specific aspects of the Regional Framework plan and, along with short-range Bus Operational Studies, prepared a program for public transportation service improvements.

Preliminary results of the Regional Study indicated demand potential for an express transit route between Fort Worth and Dallas, serving the Regional Airport. The demand was due to major growth in the Mid-Cities between Dallas and Fort Worth, influenced by the DFW Airport, and to limited highway capacity available to serve travel demands of that development. Only SH 183 effectively serves traffic in this corridor and its design capacity would be exceeded.[1] The proposed Trinity Route would provide some but not sufficient relief. It is therefore apparent that transit service in the corridor, in addition to the

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1 "Travel Forecasts", Technical Report No. 9, Alan M. Voorhees & Associates, Inc., March, 1975.

Trinity Route, could provide important relief, handling trips to the downtown areas of Dallas and Fort Worth and to major employment areas along the route studied. In addition such a line operating at high speed could provide good service for trips to DFW Airport and between the central business district (CBD) areas of the two cities.

U-TACV FEASIBILITY STUDY

These results of the Regional Study culminated in an expanded study effort aimed at better defining the feasibility of the service in the corridor. In particular, the new work concentrated on feasibility of the very high-speed Urban Tracked Air Cushion Vehicle (U-TACV) system. The high-speed (150 mph) system was most attractive because it would serve longer, non-stop trips to DFW Airport and between the CBD areas much better than conventional express transit and would serve shorter trips as well. The U-TACV Feasibility Study was necessary because numerous factors about the U-TACV system were unknown or questioned and because local governments were interested in developing such a system, if it were feasible, to serve regional travel needs and trips to the Airport.

U-TACV HARDWARE

The U-TACV system considered in this study was a generic hardware type rather than a manufacturer-specific system.

Considerable information about hardware performance was provided by two manufacturers that competed for U.S. Department of Transportation contracts to design and build a prototype vehicle for testing in Pueblo, Colorado.[2] The U-TACV system is air levitated, supported on a thin cushion of air separating vehicle from guideway.[3] It is propelled by a linear induction motor built into the guideway. The vehicle can accelerate and decelerate at average rates of at least 3 mph/sec. It can operate at speeds up to 150 mph.

Certain additional design criteria important for engineering studies were based upon the Rohr design, which was selected for testing at Pueblo, but were confirmed by LTV Aerospace Corp. as being capabilities of their design. Those factors which had some effect on patronage estimates included minimum radius of curvature (R = 8500 feet)[4] which affects turning speed. Also it was confirmed that vehicles could operate in trains and in either direction, with certain modifications to the basic design. These two factors affect system capacity because train length influences train capacity and dual direction operation reduces reversal time at each end of the guideway.

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2 LTV Aerospace Corporation, Dallas, Texas
Rohr Industries, Inc., Chula Vista, California

3 "A Preliminary Engineering Report on the Dallas/Fort Worth Regional U-TACV System", Parsons, Brinckerhoff, Quade & Douglas, Inc., and Shimek•Roming•Jacobs & Finklea, November, 1973

4 At 150 mph; absolute minimum R = 1500 feet at 15 mph

REPORT ORGANIZATION

The U-TACV Study, as with the Regional Study, was a multidisciplinary effort. The different aspects of the work included patronage forecasting, engineering, environmental impact studies and financial analysis. The work in each of the areas is reported in separate technical reports listed in Appendix A.

This report describes the studies covered in the Patronage and Revenue Analysis. Chapter II describes the Background preliminary analyses undertaken to narrow the possible route alternatives to the one for which detailed studies were pursued. Chapter III describes the Travel Forecasting methodology and results. In Chapter IV, detailed analyses of the patronage forecasts are described. The estimates of Revenue and Operating Cost for the system are explained in Chapter V. Study of the potential for Goods Movement on the U-TACV system is detailed in Chapter VI. Conclusions of the entire series of demand oriented studies are presented in Chapter VII.

II. BACKGROUND

The Regional Public Transportation Study examined several different types of hardware for transit service in the region. The results of those analyses ultimately led to selection of the general corridor location and the hardware type for more detailed analysis in the U-TACV Study. Consideration of several specific route alternatives within the general corridor were also performed as part of the U-TACV Study. The route selected for detailed patronage, engineering and environmental analysis is described at the conclusion of this chapter.

REGIONAL STUDY ALTERNATIVES

The Regional Study was designed to examine several different kinds of transit hardware in order to determine how levels of service inherent with that hardware would satisfy travel demand.[5] Four different hardware types and service levels were tested in the intercity corridor providing airport service. The four hardware types were all tested along the same basic alignment since it presented, clearly, the most attractive demand potential in the airport vicinity. The hardware examined included buses, conventional express rapid transit, personal rapid transit (small vehicle systems) and U-TACV. Patronage estimates for each of the Regional Study test systems indicated that they would attract demand consistent with their service

5 Regional Public Transportation Study, Final Report, February, 1974

level in each case. Each demand level was sufficient to warrant further consideration of the corridor for improved transit service.

Particular emphasis was placed on the intercity airport corridor because of heavy travel demands, highway capacity restriction and need for good airport service. The interest focused on the relative desirability of high-speed U-TACV service versus conventional express rapid transit. Detailed comparisons of these two hardware types indicated that the U-TACV was superior, primarily because it would reach higher speeds between stations thereby reducing travel times.[6] This was particularly important for express services with limited stops between the downtowns and the airport. What remained unanswered were questions of operating and capital costs of such a system and effects on patronage of certain variations in line haul and feeder service levels.

Because of its ability to serve longer trips being made in the corridor, the U-TACV system was designated as the service level in the Preliminary Public Transportation Framework. The Preliminary Framework system, designated R1, was then further studied in Subregional Public Transportation Studies for Fort Worth, Dallas and the Mid-Cities. These studies more carefully defined locational and service aspects of the Framework system through a process of detailed review and analysis, including extensive citizen response through local community meetings.

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6 "Travel Forecasts", op. cit.

In each of these studies, the attractiveness of the system became even clearer than it had been in the analyses which led to the Framework.

U-TACV ROUTE ALTERNATIVES STUDY

The Subregional Studies proceeded concurrently with the U-TACV Study and so had benefit of certain information prepared there. That information included a two-stage screening process in which a wide range of possible alternative route locations were reduced to the one on which detailed analyses were reported. Only the route alternatives were considered since hardware alternatives had been reviewed in the Regional Study.

The first stage screening considered twelve possible locations. These are shown in Figure 1. The twelve were generally scored according to engineering and environmental criteria as well as considerations of service and patronage potential.[7] Detailed cost, patronage and environmental analyses of the alternatives were not prepared however. The alternatives were ranked and grouped so that three major competitive route locations emerged.

The three main alternative route locations are shown in Figure 2. These three were subjected to more thorough analysis in order to select a single location for detailed study. There

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7 PBQ&D, Inc., et. al., op. cit.; "Environmental Impact Analysis For a Proposed U-TACV System in the Dallas/Ft. Worth Region", Barton-Aschman Assoc., Inc., February, 1974

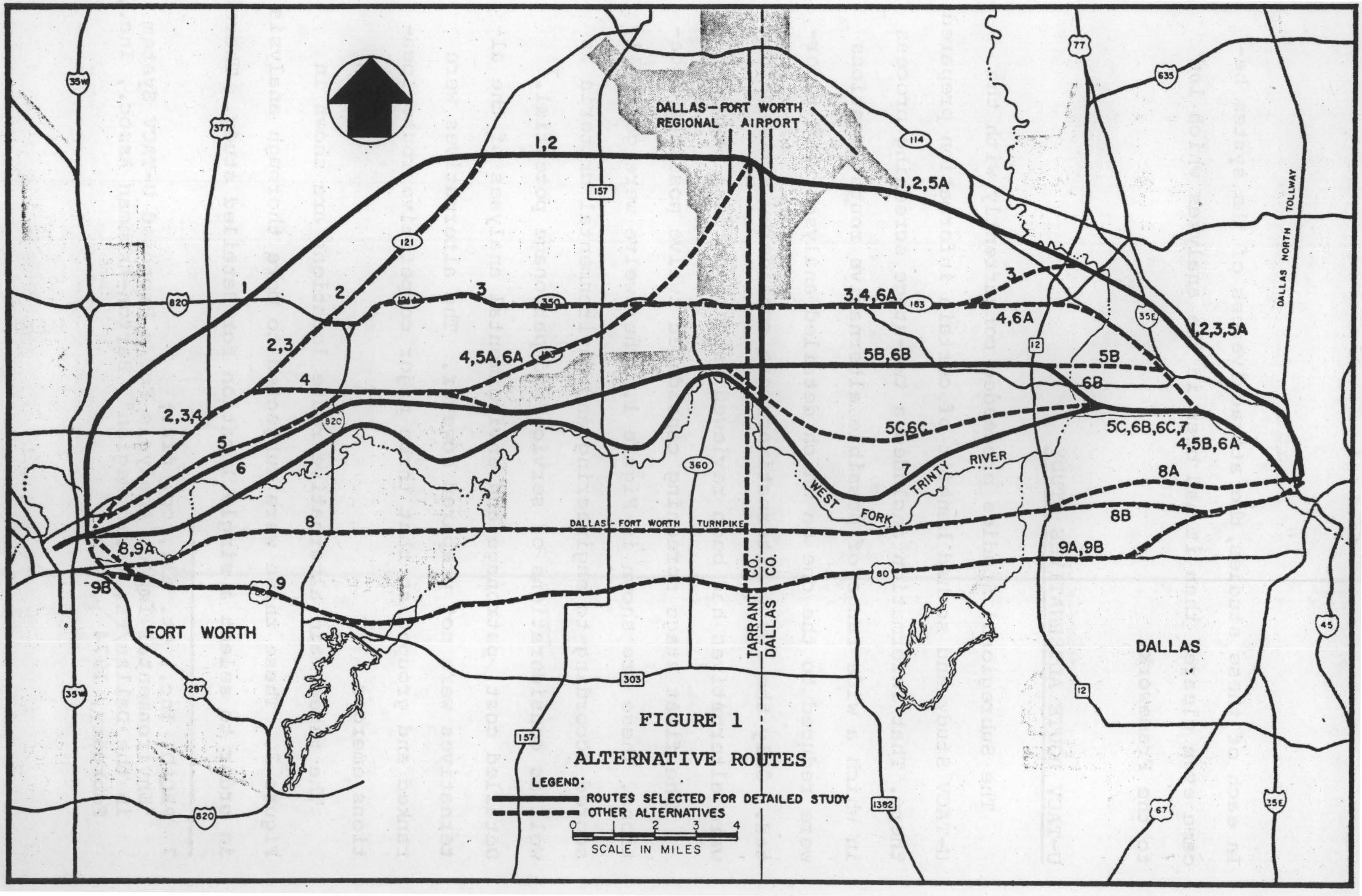
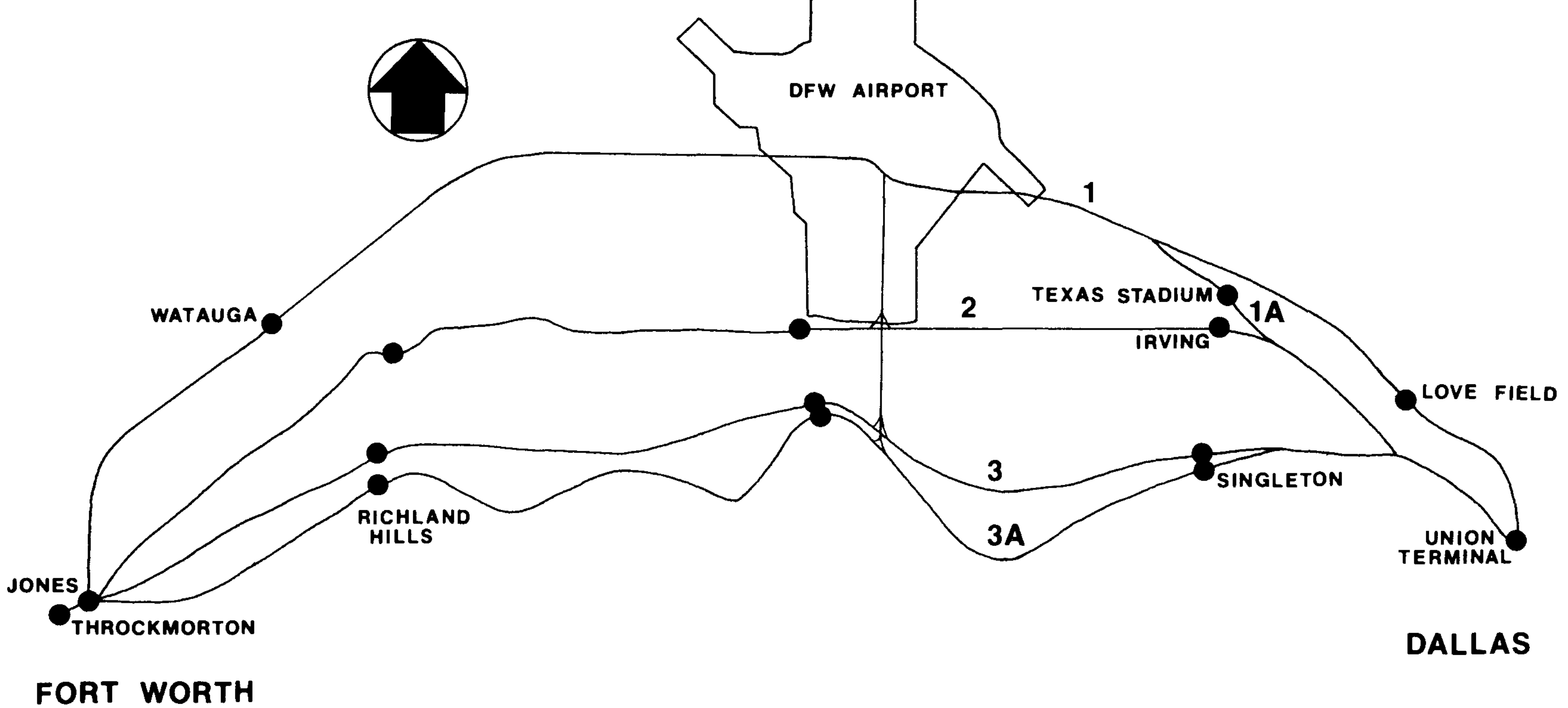


FIGURE 1
ALTERNATIVE ROUTES



Route 1 (1,2,3,5A)
Route 2 (2,3,4,6A)
Route 3 (4,5B,5C,6,6A,6B,6C,7)
Route 3A (4,5B,6A,7,8,9A)
(Reference Figure 1)

FIGURE 2

MAJOR ALTERNATIVE ROUTES

0 1 2 3 4
Scale in Miles

were also slight variations of alignments one and three, termed 1A and 3A, which were considered primarily from engineering, cost and environmental aspects. Their patronage potential did not vary significantly from the primary alignments (1 and 3) except that 1A served Texas Stadium rather than Love Field. Demand to the former would be heavy and concentrated on days of football games; demand to the latter would be spread throughout the year. Substantial industrial activity will remain near Love Field after commercial air traffic relocates to the DFW Airport.

Alternative 1 followed a northern path across the Mid-Cities area, passing east-west through the center of the Airport. Alternatives 2 and 3 were near one another and approached the Airport from the south. Both of these routes served the Airport with a spur located in the center of the Airport access road. Route 2 generally followed the Rock Island Railroad, and Route 3 was farther south, generally following the route of the proposed Trinity Route Tollroad. More precise descriptions of these locations are provided in the engineering report.[8]

Detailed patronage estimates for Alternative 2 were generated as part of the R1 network in the Regional Study. The R1 travel forecast for Alternative 2 included work, airport and other trips. The R1 preliminary framework was a comprehensive regional transit system providing express services in several

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8 PBQ&D, Inc., et. al., op. cit.

corridors in each major city and in three corridors in the Mid-Cities area. Ridership estimates on any particular line in R1 therefore assumed a high level of feeder service from other express trunklines located throughout the Region. If such a system were not available in its entirety, ridership estimates on any particular line would necessarily be less. The R1 estimates did not, however, reflect any change in the current orientation of travel to use of the automobile. Such changes might be expected in response to major improvements in public transportation service, such as R1 represents, and can certainly be anticipated due to increased cost and difficulty in travel as a result of shortages in energy supplies. It was, however, felt that these two factors, the impacts of energy shortages and the reorientation of attitudes toward transit travel, offset the likelihood that the entire regional system will not be operating by 1990. The R1 patronage estimates were therefore considered acceptable for initial evaluation of the three alternative corridors in the U-TACV Study, as well as for detailed analyses of corridors in the Subregional Studies.

Patronage estimates for the other two major alternatives were developed from the R1 figures. Alternatives 1 and 3 both served the Dallas and Fort Worth CBD's as well as the Airport so that patronage differences from Alternative 2 would be mainly due to different development areas served along the routes. The patronage estimates for Alternatives 1 and 3 were computed by estimating the difference in size of the passenger sheds (the number of possible patrons within a three-mile station service area). For each station along the three alternatives the population and employment within the three-mile service area were calculated. The ratios of population and employment served at each station by Alternatives 1 and 3 to that served by similar stations on Alternative 2 were then computed. These ratios were used to factor the boarding and alighting passengers respectively estimated for Alternative 2 in the R1 computer testing. The estimates of boarding and alighting passengers for each station along Alternatives 1 and 3 were then used to adjust link volumes between stations. The revised link volumes for Alternatives 1 and 3 and the original volumes for Alternative 2 from the R1 estimates are shown in Figure 3.

The patronage estimates shown in Figure 3 provide sufficient information to assess patronage potential of the three alternatives. Volumes at the maximum load points in Dallas were the highest observed on the three routes. Those volumes, in the 30,000 to 35,000 daily range were low by comparison to typical rapid transit lines but were consistent with the capacity of multiple car U-TACV trains. Such volumes cannot be expected to provide sufficient revenue to pay costs of operating the system.

The maximum load point, the link where highest riding occurs, is probably the most useful means of comparison. That volume is usually the criterion for system and operations design, indicating the maximum demand that can be expected on the system.

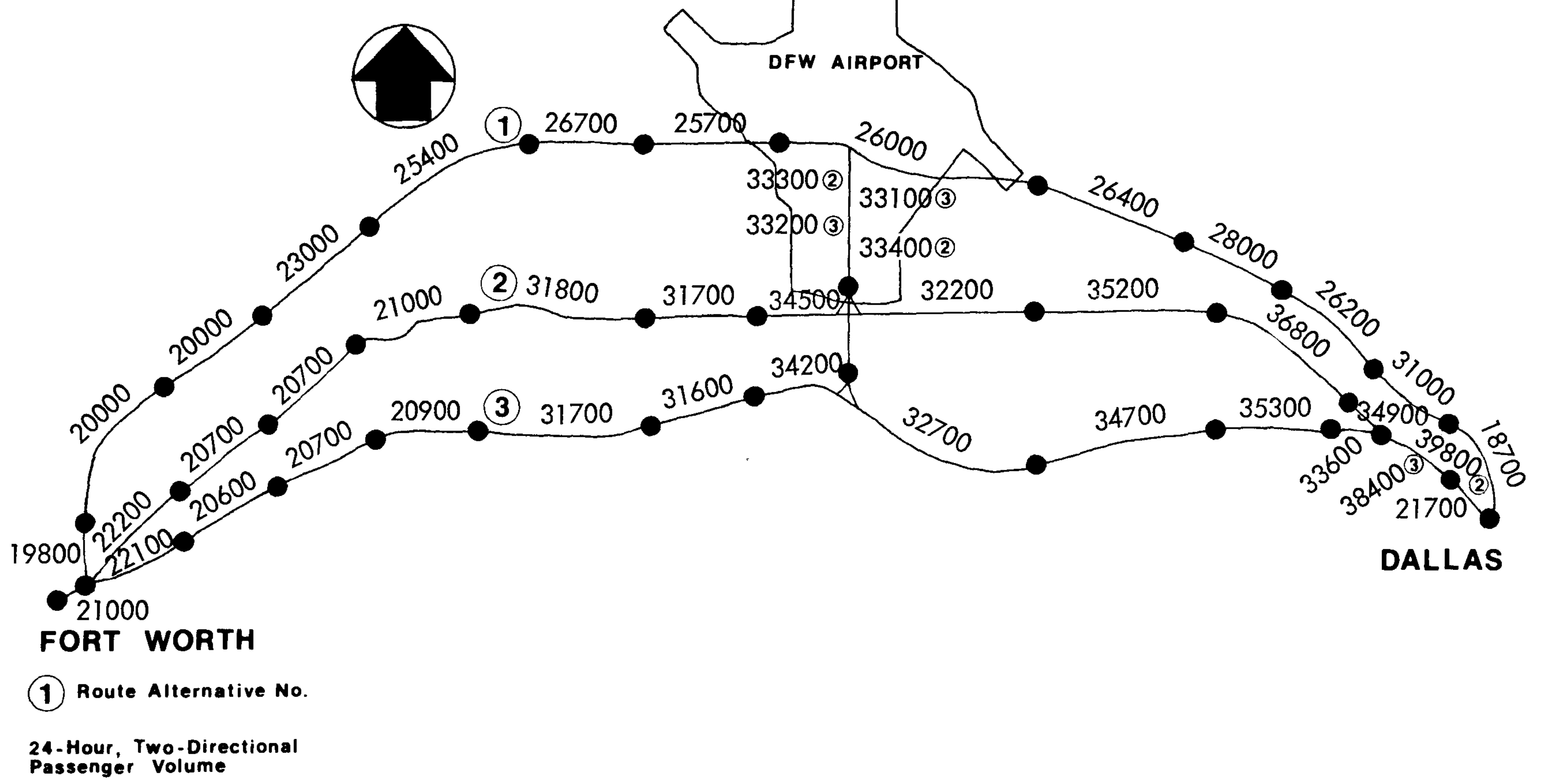

FIGURE 3
U-TACV PATRONAGE

0 1 2 3 4
Scale in Miles

Consideration of maximum load points on either side of the Airport is appropriate since locations of the U-TACV line in Tarrant and Dallas Counties could differ as long as they meet at the Airport.

In Tarrant County the maximum loadings occurred near the Airport. For Alternative 1, it was farther west than for the other two. Alternatives 2 and 3 loadings were very similar but Alternative 1 was a very poor last. Locations of Routes 2 and 3 do not differ much in Tarrant County, and either would be much better than Route 1. Their superiority over Route 1 was due mainly to the proximity of the Loop 820 Station to Hurst and the Meadowbrook area east of Fort Worth. Volumes east of that station were much higher than volumes on Route 1. The Loop 820 stations on all three routes served Richland Hills and Haltom City about equally well except that heavy eastbound traffic is more likely to use the Route 2 and 3 stations than the Route 1 station. Such traffic would have to go north, away from its normal direction, to the Route 1 station.

In Dallas County the maximum loading on all three routes occurred at approximately the same relative location. Alternative 2 was highest, with Alternative 3 somewhat lower, and Alternative 1 the lowest. Route 2 appears to be considerably better than either of the others.

The patronage estimates on Alternative 3 must be interpreted carefully with understanding of its shortcomings. The population and employment along each route were estimated for the R1 forecasts using a procedure which is sensitive to transportation accessibility. Those activity forecasts assumed that the U-TACV line would be in approximately the same location as Alternative 2. The influence of the U-TACV line would therefore have allocated activities near Alternatives 2 and 3, to the disadvantage of Alternative 1. Had activity forecasts considering the Alternative 1 location been available, the passenger shed ratios of population and employment likely would have yielded greater patronage for Alternative 1. Rather than guessing at what difference would occur, the magnitude of patronage differences between Alternatives 1 and 2 was discounted somewhat with the result that Alternative 1 was not as bad as it first appeared.

The degree of such underprediction is proportional to the amount of developable land along the route location. Since much of the land along Alternative 3 (southern) is developed and now has good access, it was felt that patronage estimates for this route were sufficiently accurate. The land along Alternative 1 (northern), however, is now relatively undeveloped and many locations lack adequate accessibility. For these reasons it was felt that patronage estimates for Alternative 1 may be as much as 20 percent low along certain portions of the route. The exact magnitude of the patronage potential could not be determined, however, until revised activity distributions were prepared, based upon the final U-TACV location. The activity estimates for the R3 forecast were revised to account for this change.

From the analysis described above, it can be seen that the patronage potential for all three locations is quite similar, with Alternatives 2 and 3 serving existing development and Alternative 1 serving new development. While the patronage for Alternative 1 may not match Alternatives 2 or 3 by 1990, this location might still be considered since the U-TACV could precede and hence mold new development to intensified areas near U-TACV stations. This would provide a unique opportunity for modern transit-oriented development in the corridor.

The three alternative route locations were also analyzed in a similar manner with respect to engineering, environmental and cost criteria. The northern alignment (Alternative 1) in Tarrant County was rejected from the environmental standpoint. The southern alignment (Alternative 3) was rejected from engineering and cost standpoints as well as because it was not in sufficient proximity to existing or planned activity locations. The Alternative 2 routing was therefore chosen for Tarrant County. Alternative 3 was rejected in Dallas County on a basis similar to that for which it was rejected in Tarrant County. Alternatives 1 and 2 in Dallas County were quite similar, but due to engineering considerations and the service implications of handling trains at the Airport, Alternative 1 was considered most favorable.[9] Briefly, it was decided that use of a spur into the Airport and the attendant construction and operational problems would be severely detrimental to service. Eliminating the spur in favor of extending AIRTRANS* south to the U-TACV line was also rejected from a service standpoint because of slow travel on AIRTRANS.

Choice of Alternative 1 in Dallas County would permit a route through the Airport without any spur so that U-TACV movement could be continuous. Alternative 1 was also attractive because of the opportunity to guide new, transit-oriented development. Development along Alternative 2 was already established in a low-density, highway orientation and would have had to be redeveloped to provide good transit accessibility. The final selection was therefore Alternative 1 through northwestern Dallas County, down through the Airport, and across Alternative 2 to Fort Worth.

SELECTED ALIGNMENT

The route selected as a result of the screening processes described above is shown in Figure 4. The route is approximately 39.6 miles long from the Central City Station in Fort Worth to the Union Terminal Station in Dallas. There are fifteen

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9 PBQ&D, Inc., et. al., op. cit.

* The DFW Airport People Mover system

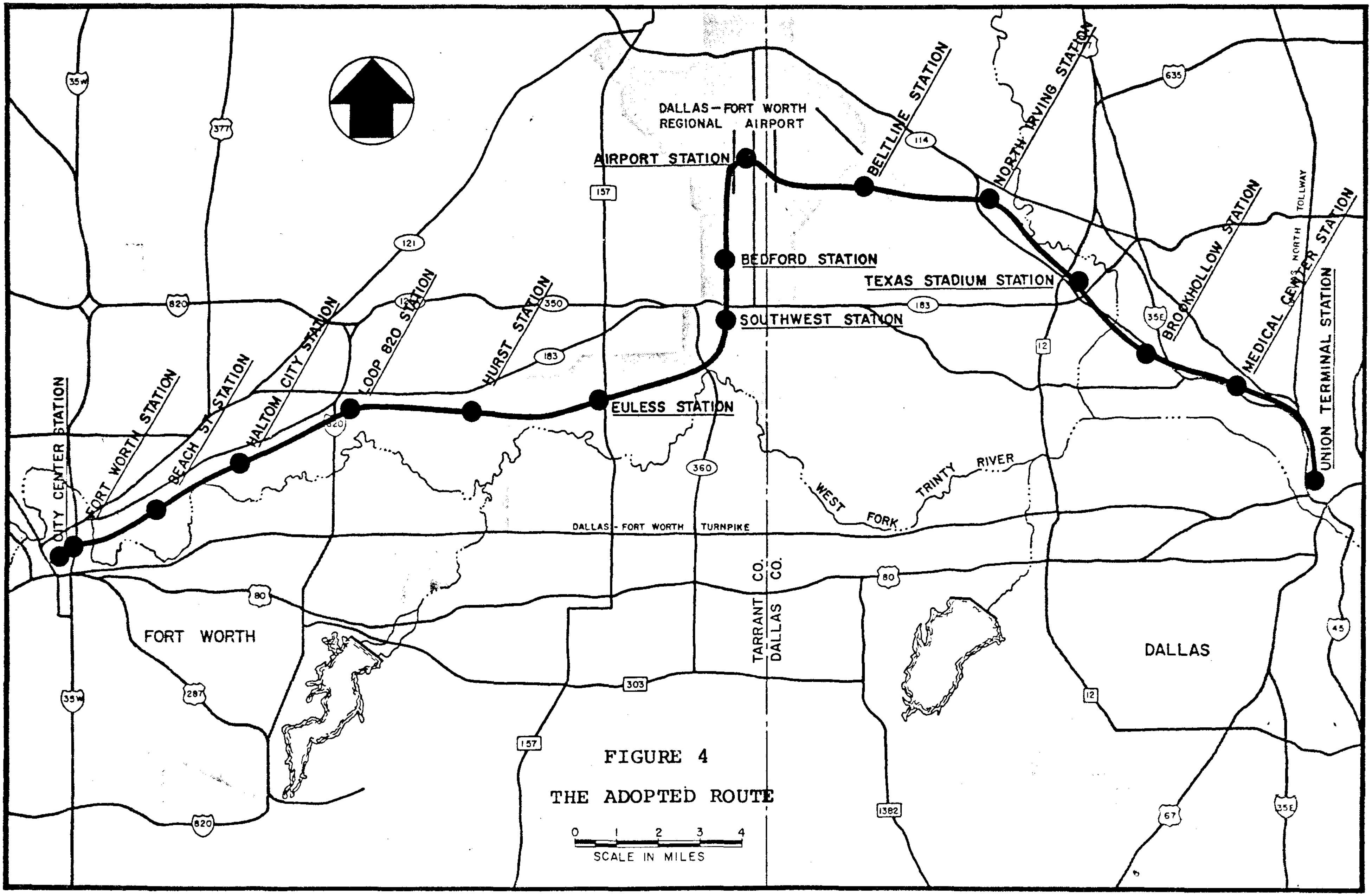

FIGURE 4

THE ADOPTED ROUTE

total stations along the route. The station locations are identified in Table 1 according to the cross street at which the stations were located. Detailed locations of stations are described in the engineering technical report.[10]

From downtown Fort Worth, the selected route follows Fourth Street east from the Central City Station located at Fourth and Throckmorton Streets, to the Fort Worth Station at Calhoun Street. The route then follows along Fourth Street beneath the Texas & Pacific Railroad and over the Trinity River and Interstate Highway 35W until it meets the Chicago, Rock Island & Pacific Railroad tracks at Sylvania Avenue. The route then follows on the north side of the Rock Island Railroad with a station at Beach Street, where it crosses over the railroad. The next stations are located at Carson Road in Haltom City and at Loop 820. The alignment continues along the south side of the Rock Island tracks to a station at Hurst and then one at Euless. Just west of State Highway 360, the route crosses over the Rock Island tracks and then State Highway 360, proceeding northward through the Great Southwest International Airport to the DFW Airport. Southwest Station is located just south of State Highway 183. The route continues northward to the Bedford Station approximately one mile north of State Highway 183. The route continues northward, eventually turning east and entering

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10 PBQ&D, Inc., et. al., op. cit.

TABLE 1

STATION LOCATIONS
SELECTED U-TACV CORRIDOR

STATION NAME	LOCATION
CITY CENTER	Fourth Street at Throckmorton Street
FORT WORTH	Fourth Street at Calhoun Street
BEACH STREET	Rock Island Railroad at Beach Street
HALTOM CITY	Rock Island Railroad at Carson Road
LOOP 820	Rock Island Railroad at Interstate Loop 820
HURST	Rock Island Railroad at Bell Spur Road
EULESS	Rock Island Railroad at FM 157
SOUTHWEST	South of SH 183 at GSW International Airport
BEDFORD	North of Access Road, SW Corner D/FW Airport
AIRPORT	Between Spine Roads, South of Communications Bldg., D/FW Airport
BELT LINE	Carbon Road at Belt Line Road
NORTH IRVING	Spur 348 West of Trinity River
TEXAS STADIUM	North of SH 114, West of Spur 482
BROOKHOLLOW	SH 183, East of Dividend Drive
MEDICAL CENTER #1	Rock Island Railroad, North of Amelia Road
*MEDICAL CENTER #2	Rock Island Railroad at Wycliff Avenue
UNION TERMINAL	Dallas Union Terminal, West of Houston Street

* Included in patronage estimates for 1990 only.

a tunnel beneath the runways of the DFW Airport to Airport Station located at approximately the center of the two spine roads serving the Airport. From there, the line proceeds east and then southeast to a point approximately two hundred feet north of Carbon Road. The route then parallels Carbon Road to the east. Belt Line Station is located approximately one-half mile west of Belt Line Road. The route then bends southeast again, crossing SH 114. The North Irving Station is located just west of the Trinity River along Spur 348. From that point the route proceeds southward to SH 114 and then along the north side of that road southeasterly, passing on the northeast side of Texas Stadium north of SH 114. The route then crosses over SH 183 east of Texas Stadium and parallels it on the south side to the Brookhollow Station between Dividend and Currency Drive. The route then passes over Interstate Highway 35E and the Rock Island Railroad, paralleling the railroad on its south side to the Medical Center Station located just south of the Parkland Hospital Complex. The route then crosses over the railroad track near the Dallas North Tollway ramps to Interstate Highway 35E, proceeding on the north side of the railroad into the Union Terminal Station at Young and Houston Streets in downtown Dallas.

Discussions in the remainder of this report regarding patronage estimates, revenues and operating costs associated with the U-TACV system operation are all based upon this alignment.

More exact details of locations of stations and the system guideway, as well as curvature and grades are provided in the report describing the engineering analyses conducted in this study.[11]

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11 PBQ&D, Inc., et. al., op. cit.

III. TRAVEL FORECASTING

The travel forecasting procedures used to estimate ridership on the U-TACV system were developed in the Regional Study. The procedures are described in general terms in this chapter. Considerably more detailed discussions of those procedures can be found in technical reports of the Regional Study.[12] Also included here are more detailed discussions of certain modifications to the basic procedures, designed particularly for analysis of the U-TACV system. The results of person-travel forecasts for 1980 and 1990 are summarized, and traffic forecasts for the U-TACV system are discussed in detail. Chapter IV presents analyses of the effects of various factors on U-TACV system ridership.

FORECASTING PROCESS

The travel forecasting process used here consisted of several mathematical models used sequentially to estimate several characteristics of travel. These models were developed from travel patterns in the Region observed in a 1964 travel survey conducted by the Texas Highway Department (THD). The travel patterns reflected by the survey data were related to socio-economic and transportation system data so that forecasts of such data could be used to forecast travel pattern characteristics.

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12 "Travel Model Criteria", Technical Report No. 2, Alan M. Voorhees & Associates, Inc., 1973
"Travel Model Calibration", Technical Report No. 7, Alan M. Voorhees & Associates, Inc., March, 1975.

The travel models used here and developed in the Regional Study were designed to forecast person-travel on both transit and highways. Separate models were prepared for home based work trips, home based non-work trips and non-home based trips.[13] From forecasts of population, employment and income, the number of trips expected for each purpose was estimated by the Trip Generation Model. The distribution or pattern of these trips was then prepared using a Trip Distribution Model, which allocates trip origins among likely destinations. The person trip patterns were then allocated to the highway or transit system by the Mode Split Model, based upon the service offered by each travel mode. Finally, trips for the three purposes were combined and Traffic Assignment Models were used to assign trips by each mode to appropriate facilities of that system.

Transportation Network

The travel forecasting models rely extensively on information about transportation systems and the service they provide. The reason for developing new models in the Regional Study rather than using vehicle trip models previously prepared by THD was to interject cost and service factors into the travel forecasting process.[14] Including service and cost factors in the models was necessary because the transit systems being considered represented major service improvements over the bus

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13 Home Based: trips to and from home

14 The Texas Highway Department had developed travel models for estimating motor vehicle trips in its 1964-1967 Regional Transportation Study.

systems currently operating. In addition increasing highway congestion represents a deterioration in service levels, and increased travel costs are anticipated in response to energy shortages.

In order to reflect these service levels in the travel models, transportation system networks were prepared for the highway and transit systems. These networks were designed for computer processing and described in detail the levels of service on both modes throughout the Region. The networks were line diagrams on which were placed distances and operating speeds for all but minor travel facilities. The transit networks also included information about headways, interarrival time between transit vehicles. Specialized computer programs were used to process rudimentary network data to obtain the travel time, distance and cost between any two points in the Region. Networks representing 1964 transit and highway service were used to develop the travel models in the Regional Study and future year networks were used to forecast travel patterns. The future networks were the object of these studies since they provided estimates of the need for and use of proposed transit systems.

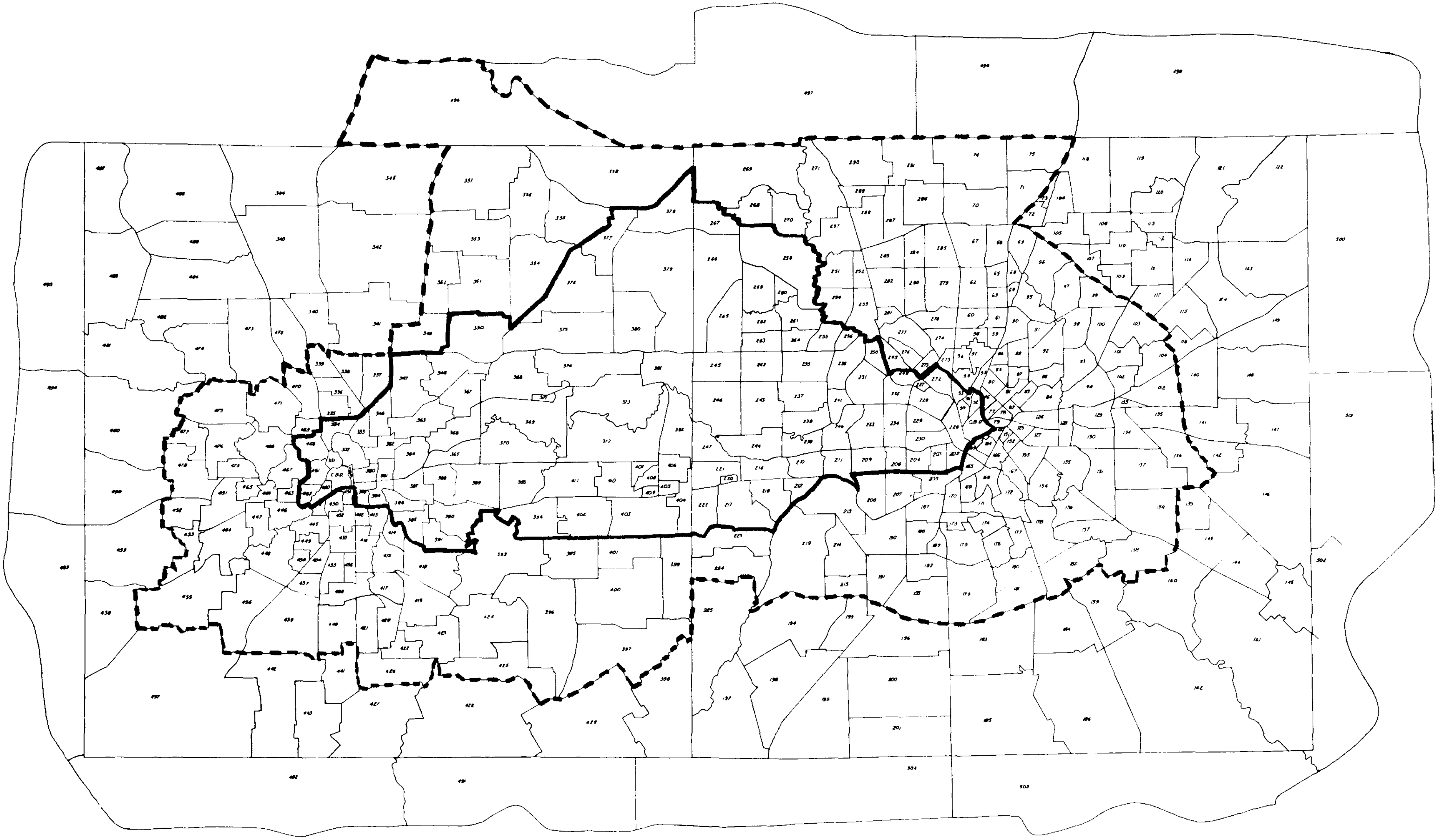
Analysis Areas

One additional aspect of the travel forecasting process was the zone system used to facilitate computer processing of all regional data. Zones were geographic entities into which the

Region was subdivided. The zones used in this study were called Regional Analysis Areas (RAA's), and all socio-economic data were coded as totals for each particular RAA. Thus there were population and employment totals and median family income for each RAA. The transportation networks were prepared to estimate travel service from each RAA to every other. There were 504 RAA's in the intensive study area for Regional Study work. In the U-TACV Study however more information was desired about service and response to the areas along the U-TACV route; therefore more and smaller zones were coded in the general service area along the proposed route. Figure 5 shows the intensive study area and the RAA's used in the Regional Study. Also shown is the boundary of the U-TACV Study subarea within which zones smaller than RAA's were used. (The smaller zones are not shown.) The zones used within the subarea were the same as 'centroid districts' used by the Texas Highway Department. Replacing the RAA's with centroid districts inside the subarea yielded a total of 859 zones for U-TACV Study data processing and network coding.

U-TACV STUDY INPUT

Travel forecasting for the U-TACV Study was based upon information prepared for the Regional and Subregional Studies and the Multi-Modal Transportation Planning Program, and by the Texas Highway Department. Where not described in detail,



LEGEND:

- ——— 2369 Zone Level (THD)
- - - - 504 RAA Level (NCTCOG Regional Analysis Areas)

FIGURE 5

REGIONAL ANALYSIS AREA DESIGNATIONS

WITH U-TACV STUDY AREAS OUTLINED

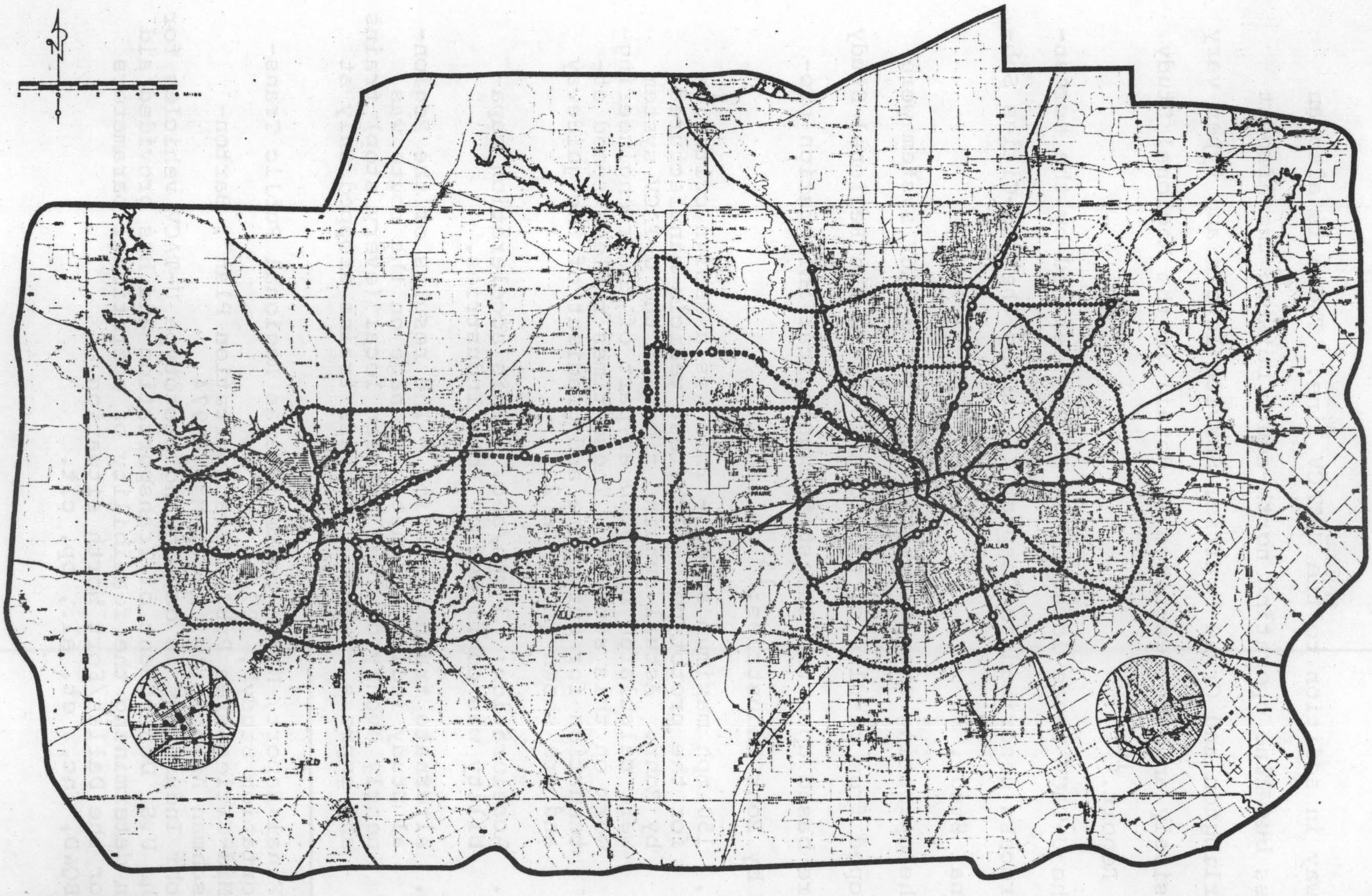
information and procedures used were virtually identical to those used in the Regional Study.[15]

Transit Network

The transit network used for forecasting 1990 travel in the U-TACV Study was the R3 network prepared in the Multi-Modal Program. That network was the Recommended Regional Public Transportation Framework, which resulted from review and revision of R1, the Preliminary Framework. The review process occurred in the Subregional Studies, which prepared certain refinements and further detailing of R1. The R3 network provided comprehensive express transit service throughout that portion of the Region in which anticipated service levels approaching those of R3 will be available in most of the R3 corridors. The patronage estimates and related material prepared in the U-TACV Study must be interpreted with the understanding that the full R3 system was assumed operative for these forcasts.

The R3 network is shown in Figure 6. The R3 system has nine radial express transit lines in Fort Worth, four of which are rapid transit operating on exclusive guideways. There are five radial exclusive guideway lines in Dallas and six express bus facailities, one of which is circumferential. In the Mid-Cities area, there is one intercity express transit line on exclusive

15 "Travel Forecasts", op. cit.



LEGEND

- High Speed Transitway
- Exclusive Guideway Transit
- High Level Bus Service
- Station Locations

R$_3$ TRANSIT NETWORK

FIGURE 6

guideway in addition to the U-TACV line. There is also an express bus line operating north-south between the Airport and Arlington and Grand Prairie. Service levels and types vary extensively and are described in detail in the Regional Study Final Report.[16]

The U-TACV route location in R3 was defined by the screening process described in Chapter II and by the Mid-Cities Subregional Study.[17]

The operating characteristics for the U-TACV system were developed from results of previous tests in the Regional Study and are based upon the latest technological information provided by Rohr Industries:[18]

1. 150 mph maximum speed - This was a design criterion for the prototype U-TACV test vehicle manufactured by Rohr. Actual running times of the U-TACV system were calculated by PBQ&D as part of their engineering work on this study.[19] These times reflect speed attenuation for curvature and gradient of the guideway and are shown in Table 2.

2. Acceleration: 3 mph/sec. - This acceleration capability was confirmed by Rohr Industries.

3. Alternate train operation - The results of the Regional Study indicated that patronage on the route was nearly evenly divided between local (every stop) trains and express trains. (Express trains stopped only at

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16 "Final Report, North Central Texas Regional Public Transportation Study", 1974
17 "Mid-Cities Area Public Transportation Plan", Barton-Aschman Associates, Inc., May, 1974
18 Rohr Industries is developing prototype U-TACV vehicles for the U.S. Department of Transportation and has provided aid in determining the feasibility of operational parameters for the Dallas/Fort Worth situation
19 PBQ&D, Inc., et. al., op. cit.

TABLE 2

U-TACV SYSTEM
STATION-TO-STATION TRAVEL TIMES

LOCAL LINE

Origin Station	Destination Station	Separation (miles)	Actual Total Travel Time* (minutes)
City Center	Fort Worth	0.47	1.40
Fort Worth	Beach Street	2.63	3.30
Beach Street	Haltom City	2.15	2.80
Haltom City	Loop 820	3.20	3.70
Loop 820	Hurst	2.76	3.40
Hurst	Euless	3.48	3.80
Euless	Southwest	3.79	4.00
Southwest	Bedford	1.30	2.10
Bedford	Airport	2.82	3.70
Airport	Belt Line	2.75	3.60
Belt Line	North Irving	3.35	3.70
North Irving	Texas Stadium	2.65	3.30
Texas Stadium	Brookhollow	2.31	3.00
Brookhollow	Medical Center #1	2.40	3.00
Medical Center #1	Medical Center #2	1.30	2.00
**Medical Center #2	Union Terminal	2.50	3.00

EXPRESS LINE

Origin Station	Destination Station	Separation (miles)	Actual Total Travel Time* (minutes)
City Center	Fort Worth	0.47	1.40
Fort Worth	Loop 820	8.00	7.20
Loop 820	Airport	14.14	8.90
Airport	Texas Stadium	8.75	6.10
Texas Stadium	Union Terminal	7.97	5.40

* Includes station dwell time. These times also reflect delays due to scheduling and to curvature gradient restrictions.

** Included in 1990 Computer Network only.

the Airport, the loop freeways and the CBD's.) Use of express trains permits intercity and Airport trips to take maximum advantage of the U-TACV high speed. Riders boarding at intermediate local stations can transfer to express trains for faster service.

4. Headways - 5 minutes for both express and local trains: Results of the Regional Study indicated that there would be sufficient demand to run U-TACV trains at 5-minute headways for each service. The composite 2.5-minute headway was considered the maximum frequency possible with available control systems.[20]

5. Station Dwell (Table 3) - Station dwell (stop) times were assigned based upon anticipated patronage levels: heavier demands require longer stops. Stations where air traveler boarding would be heavy also needed more time for baggage handling.

6. 25¢ Base fare; 5¢ zone fares - This was approved by the Study Directors Council as a base condition for preliminary planning and analysis. This is the same base fare used throughout the R3 system. This relatively low fare rate was chosen because it would yield a good patronage on which to base the analysis of patronage response to fare variation in the U-TACV Financial Studies.

Travel forecasts on the U-TACV system in 1980 were prepared using a 1980 regional transit network. All operating and service characteristics of the U-TACV line were the same for the 1980 and 1990 forecasts. The remainder of the regional transit system was considerably different in 1980 than the R3, 1990 system. Exclusive guideway facilities were much less extensive and service levels were consequently lower in 1980. Operating characteristics on the facilities available were, however, ressonably consistent with similar facilities in the 1990 system.

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20 PBQ&D, Inc., et. al., op. cit.

TABLE 3

U-TACV SYSTEM
STATION DWELL TIMES

Station	Station Dwell (seconds) Local	Express
City Center	15	15
Fort Worth	15	30
Beach Street	15	
Haltom City	15	
Loop 820	15	30
Hurst	15	
Euless	15	
Southwest	15	
Bedford	15	
Airport	15	60
Belt Line	15	
North Irving	15	
Texas Stadium	15	30
Brookhollow	15	
Medical Center #1	15	
*Medical Center #2	15	
Union Terminal	15	30

* Included in 1990 Computer Network only

Details of the 1980 regional transit network are provided in Technical Reports of the Multi-Modal Transportation Planning Program. The 1980 express transit lines assumed for the U-TACV Study are shown in Figure 13.

Highway Network

The travel forecasting models also require information about the level of service on highways which offers an alternative to transit travel. Comparison of the transit and highway service levels is used to allocate person trips to each mode: 'modal split'. The highway network information is also used for trip distribution and for assignment of highway traffic. The latter function is primarily useful in impact analysis and was not pursued since the U-TACV Study was to determine the feasibility of a particular transit facility rather than investigating traffic impact. Therefore no highway traffic assignments are reported here.

The highway network used in this study was the same as that used with the R3 transit system in the Regional Study and Multi-Modal Program analyses. That network was a 'test' highway system based primarily on the 1985 plan adopted by THD in 1967. A map of the test highway system is shown in Figure 7. The test highway system was developed and coded by THD. Summary information about that network was provided for use in the travel work in this study.

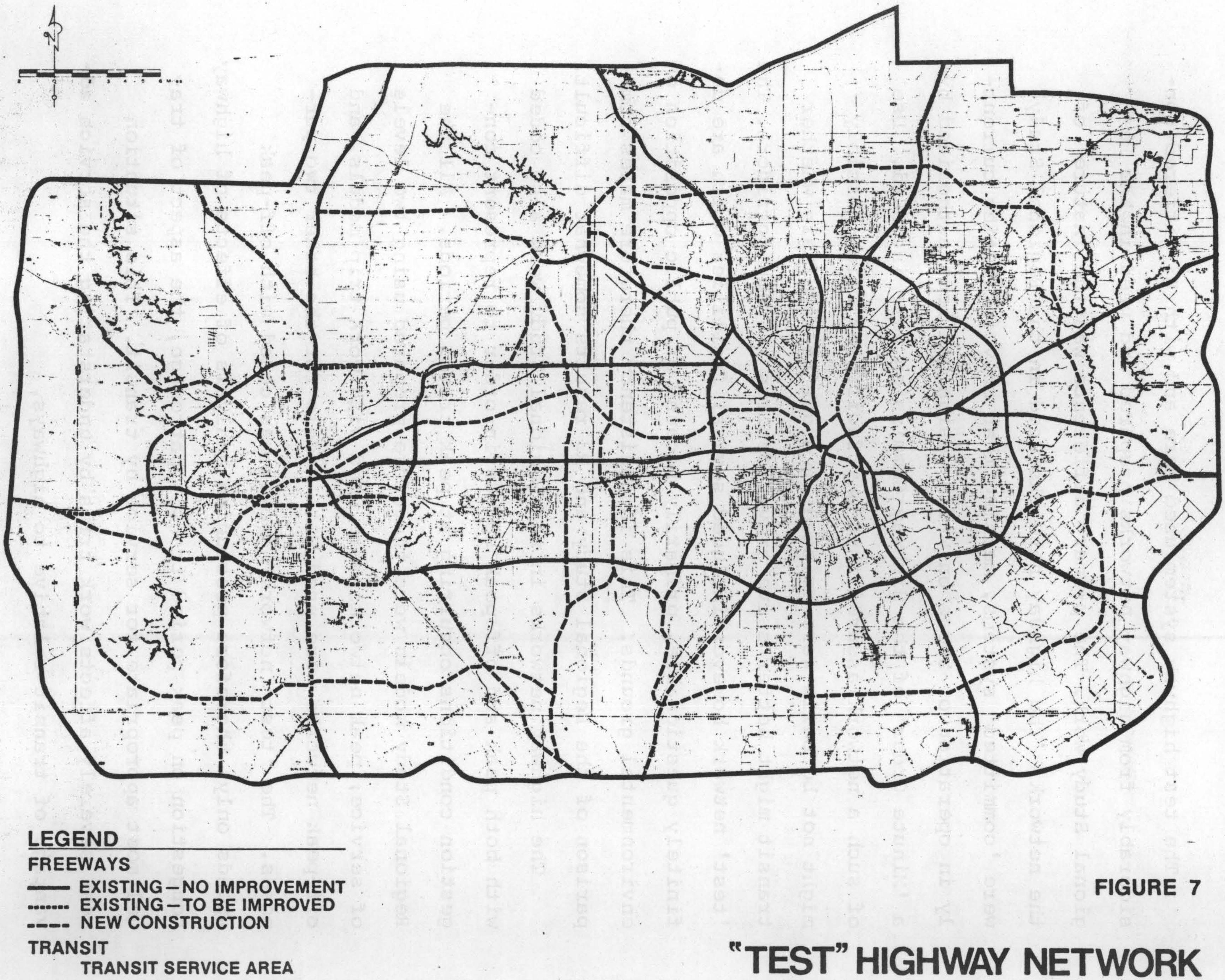

FIGURE 7

"TEST" HIGHWAY NETWORK

The test highway system used here and with R3 differed considerably from highway networks prepared and used in the Regional Study work. The primary difference was the 'nature' of the network. The highway networks used in the Regional Study were 'committed' systems, meaning that only facilities currently in operation or those on which design had been authorized by a 'Minute Order' of the Highway Commission were included. Use of such a network assured that any facilities which possibly might not be built were omitted in order to ascertain whether transit might better serve travel desires in such corridors. The 'test' network however included several facilities which are definitely questionable, primarily because of public opposition on environmental grounds. This inconsistency therefore makes comparison of the Regional Study and R3 results somewhat difficult.

The highway networks in the Regional Study were also coded with both peak and off-peak speeds in order to represent congestion conditions occurring at peak travel periods. All the Regional Study models were therefore prepared using two levels of service; peak networks were used with work trip models, and off-peak networks were used with models for the other two purposes. The 'test' network however was coded with off-peak speeds only, therefore precluding analysis of effects of highway congestion on peak period transit patronage, the aspect of travel most appropriate for service by transit. This situation most severely affects work trips by understating the service advantage of transit relative to highways.

As compensation for these two factors adverse to apparent transit system service advantage, the R3 transit networks were not processed with off-peak headways. The off-peak transit service had been used to develop travel models for non-work trips. The effect of this was to overestimate the non-work transit trips and thereby to compensate for the underestimate of transit work trips. Comparisons of R3 results and data used in the U-TACV Study to travel forecasts from the Regional Study will therefore show disparities in ratios of work and non-work trips.

The 1980 highway network used to estimate 1980 U-TACV traffic used highway facilities which are programmed for completion by that time. Because so few years remain before 1980, the new highway facilities which will be operating then are currently being designed or constructed. There is therefore little room for conjecture about what facilities will be available. The 1980 highway network was coded by NCTCOG as part of the Multi-Modal Program. For consistency in the U-TACV Study, however, only off-peak period highway speeds were used in processing for the 1980 travel models even though peak speeds had been coded.

Network Coding

Coding and processing the transit and highway (1980) networks were carried out in accordance with procedures defined for the Regional Study.[21] The coding process involved mapping

21 **"Network Development and Coding Manual", Technical Report No. 8, Alan M. Voorhees & Associates, Inc., March, 1975.**

facilities in each network to scale and identifying simple segments of the network called 'links' by 'node' numbers at link intersection points. The links were measured and coded for computer processing. Transit lines were designated by the links they traversed. Headways were coded for all lines, and speeds were coded to represent service levels on all links. Specialized computer programs then checked the network representations and prepared 'skim trees' indicating the time and distance involved in traveling between any two zones in the area by transit or automobile. For all network coding and other computer processing a special set of zones called 'TRAA's' was used. These numbered 859 for the entire intensive study area. The TRAA's were defined using RAA's outside the U-TACV subarea and Centroid Districts within the subarea. Some aggregation of original RAA's was used outside the service area of the Regional Transit System.

SOCIO-ECONOMIC FORECASTS

Forecasts of 1990 population, employment and income for each TRAA were originally prepared by NCTCOG as part of the Multi-Modal Program. The forecasts were developed by allocating regional control totals among RAA's using the Urban Growth Simulation Model (UGSM).[22] The UGSM works from allocations of basic

22 "Application of the Urban Systems Model (USM) to a Region - North Central Texas", Vol. I, Alan M. Voorhees & Assoc., Inc., October, 1972.

employment, allocating population and then non-basic employment successively in accordance with transportation accessibility to basic employment and population respectively. The transportation system used to calculate accessibility for the UGSM runs in the R3 forecasting process assumed that the U-TACV line would be located on the selected alignment described in this report. The amount of activity allocated was limited by capacities defined in accordance with land use plans prepared by the respective governmental units. Median household income for each RAA was defined in accordance with population density and accessibility, and consideration was given to the age of development in the area.

The RAA totals were then split among the survey zones comprising each RAA. This was accomplished by the cities, counties and THD personnel in order to retain consistency for the THD land use data bank, which is maintained at the survey zone (6900) level of detail with data collected in the 1964 land use survey. The 1990 population and employment for all RAA's in each governmental jurisdiction in the Region were then submitted for review by agencies who developed the traffic survey zone data in each jurisdiction. The revised forecasts returned by those agencies were then normalized against regional control totals and reaggregated to TRAA's for use in estimating person trip attractions and productions for 1990.

The 1980 socio-economic forecasts were prepared by NCTCOG as part of the Multi-Modal Transportation Planning Program. The forecasts were prepared for TRAA's since they would not be used in the THD data file and because they would only be used for forecasting 1980 trips for the U-TACV Study.

The 1980 forecasts were developed by interpolating between 1970 Census and employment survey data and the 1990 USM forecasts. This approach was considered sufficiently accurate for the use intended.

In Table 4 the 1980 and 1990 forecasts are compared to 1964 and 1970 data to indicate growth rates. The summaries show that major population growth is anticipated for suburban areas in both counties, but the two largest cities will remain static. The heaviest growth in the Region will occur in the Mid-Cities area, both in the south in Arlington and Grand Prairie and along the proposed U-TACV route in Irving, Hurst, Euless and Bedford. Employment growth in Dallas and Fort Worth will continue but larger increases were shown for suburbs. It is also important to note that constant dollar incomes will increase nearly 100 percent over 1970 levels by 1990. This indicates that travel cost increases may be considerably less important than time savings in the future.

TRIP GENERATION

The numbers of trips starting and ending in each TRAA for each purpose were computed using trip generation model rates. The trip generation models used in the U-TACV Study were slightly

TABLE 4

REGIONAL SOCIO-ECONOMIC DATA SUMMARY
TRAVELING FORECASTING INPUTS
(Intensive Study Area)

	POPULATION	EMPLOYMENT	INCOME*
1964	1,792,200	692,300	5,200
1970	2,106,300	966,900	10,400
Growth from 1964	17.5%	39.7%	100.0%
1980	3,086,200	1,368,100	13,800
Growth from 1970	46.5%	41.5%	32.7%
Dallas	26.1%	22.2%	
Irving	61.1%	59.5%	
Farmers Branch	33.7%	42.3%	
Richardson	47.0%	32.5%	
Garland	73.6%	56.2%	
Mesquite	92.7%	123.6%	
Remainder of Dallas County	105.4%	157.1%	
Grand Prairie	59.7%	95.4%	
Fort Worth	20.0%	27.3%	
Remainder of Tarrant County	90.7%	163.5%	
Hurst-Euless-Bedford	89.9%	114.1%	
Arlington	52.9%	62.0%	
Remainder of Intensive Study Area	102.1%	46.5%	
1980	3,939,000	1,765,800	28,600
Growth from 1970	87.0%	82.6%	175.0%
Dallas	34.1%	62.6%	
Irving	75.9%	135.9%	
Farmers Branch	80.7%	243.8%	
Richardson	107.8%	103.7%	
Garland	184.8%	114.8%	
Mesquite	184.2%	143.8%	
Remainder of Dallas County	293.5%	244.3%	
Grand Prairie	152.9%	333.9%	
Fort Worth	36.1%	33.9%	
Remainder of Tarrant County	177.6%	292.4%	
Hurst-Euless-Bedford	137.9%	90.3%	
Arlington	149.3%	83.3%	
Remainder of Intensive Study Area	214.5%	230.9%	

* Average Median Family Incomes of Dallas and Tarrant Counties; Inflated Dollars

modified from those used in the Regional Study but the same general approach was used.[23] The trip generation model estimates the number of trips for work and for other purposes that can be anticipated from each residential area. These 'home based' trips were estimated according to the income level forecast for each TRAA. The trip rates used in this study and for R3 forecasting were continuously variable functions of income rather than discrete rates for different income strata used in the Regional Study. The home based work and non-work trips and non-home based trips per person were estimated using the curves shown in Figure 8. The appropriate trip rates were multiplied by the population forecast for each TRAA to obtain trip productions. The total numbers of trip productions estimated for each purpose are listed in Table 5. The non-home based productions were merely used as a control total to normalize non-home based trip attraction estimates.

The trips attracted to each TRAA were estimated from relationships, each of which utilized basic and non-basic employment and population. This procedure also differed from previous Regional Study models which had used simple rates. The trip attraction models used in the U-TACV Study and for R3 are shown in Figure 8. The non-home based trip origins and destinations were generated using the same model. The trip attractions in each TRAA for all purposes were normalized so that the regional total

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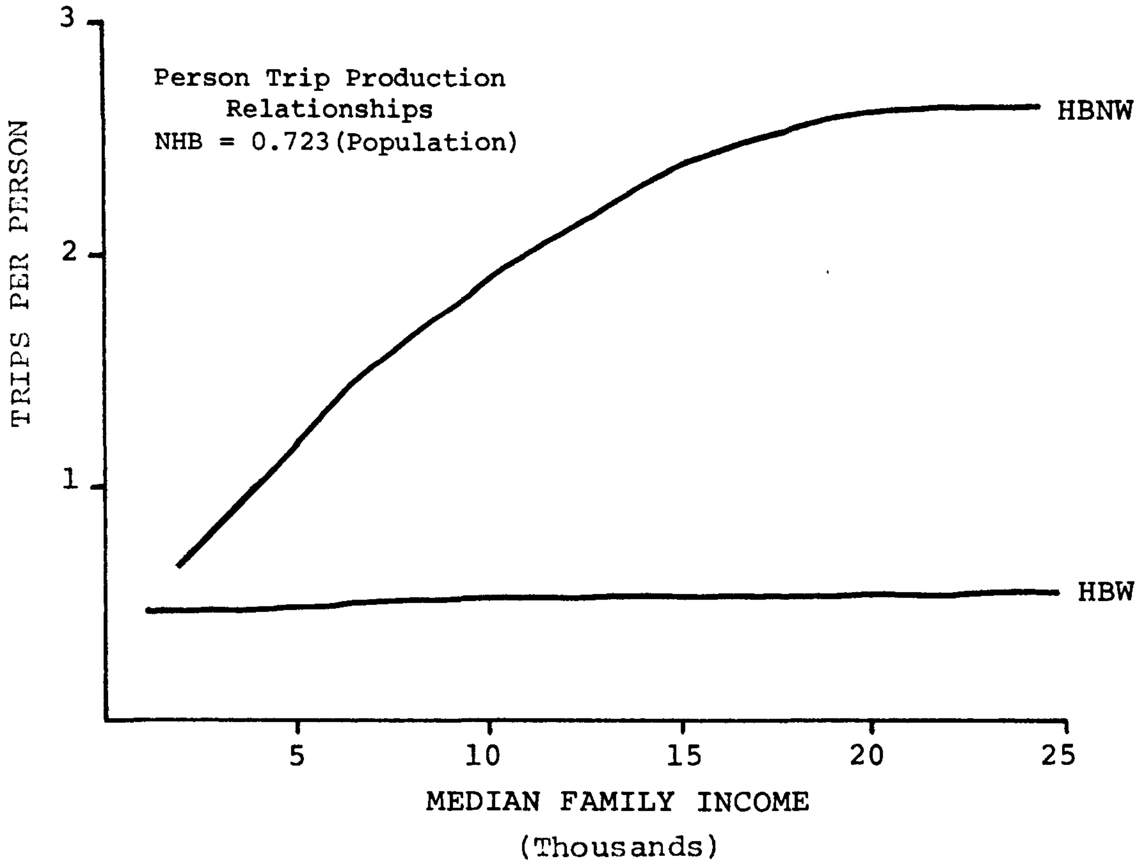
23 "Travel Forecasts", op. cit.



TRIP ATTRACTION MODELS
FACTORS FOR RESPECTIVE INDEPENDENT VARIABLES

	Basic Employment	Non-Basic Employment	Population
Home Based Work	1.114	0.260	0.329
Home Based Non-Work	1.494	6.800	2.312
Non-Home Based	0.039	0.340	0.296

FIGURE 8

TRIP GENERATION MODELS

TABLE 5

REGIONAL TRAVEL ESTIMATES
Person Trips by Purpose

	Home Based Work	Home Based Non-Work	Non-Home Based	Total
1964	952,700	3,017,900	1,227,200	5,197,800
1970*	1,196,100	4,071,000	1,470,800	6,737,900
Growth from 1964	25.6%	34.9%	19.8%	29.6%
1980	1,650,600	7,133,000	2,354,100	11,137,700
Growth from 1970	38.0%	75.2%	60.0%	65.3%
1990	2,146,400	9,840,600	3,212,400	15,199,400
Growth from 1970	79.4%	141.7%	118.4%	125.6%

* Preliminary Estimates

for each purpose matched the regional total for productions estimated with the trip production models.

Table 4 shows the population and employment totals for the Region to indicate the anticipated growth in activities that generates trip growth. The additional trip growth is due to increases in real income, which are also shown in Table 4. The 1980 trip ends were estimated in the same manner as the 1990 R3 forecasts and are shown in Table 5.

AIR PASSENGER TRIPS

One additional type of trip particularly important for the U-TACV Study but not estimated in the regular trip generation process was air passenger trips. These are such a small portion of total regional travel that only specialized surveys can be used to estimate their propensity in particular areas. Estimates of resident and non-resident air passenger trips for each RAA were prepared as part of the NCTCOG Air Systems Study.[24] The air passenger trips in each TRAA were estimated as a function of zonal income and proximity to the DFW Airport. Air passenger trip estimates were prepared for each TRAA for both 1980 and 1990, based upon estimates of daily airport traffic originating in or destined for loactions in Dallas and Tarrant Counties, 29,700 for 1980 and 55,300 for 1990. Distribution of these passenger

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24 Landrum & Brown, "Airport System Plan for the North Central Texas and Texoma State Planning Regions", March, 1975

origins and destinations in the two counties in 1990 are shown in Figure 9.

In addition to air passengers it was necessary to estimate two other types of airport-oriented trips: visitor trips related to air travelers and for casual touring. Related visitors are those accompanying air passengers and casual visitors are primarily sightseers. The trip rates for both visitor groups were estimated from data collected in a survey at Cleveland Hopkins Airport.[25] Use of that data was desirable because the survey was conducted after the Airport Rapid Transit was operating there. Also, Hopkins Airport is approximately fifteen miles from downtown Cleveland so conditions were quite similar to those being examined for the U-TACV System. The percentages of casual and related visitors versus air passengers boarding and alighting were estimated from the Cleveland data and used to calculate visitor trips to the DFW Airport. The percentages used were 40 percent for related visitors and 10 percent for casual visitors.

TRIP DISTRIBUTION

The trip distribution models used for R3 and the U-TACV Study, both for 1980 and 1990, were nearly identical to the models previously used in the Regional Study. The model formulation is

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25 "Survey Results", Cleveland-Hopkins Airport Access Study, U.S. Department of Transportation, June, 1970

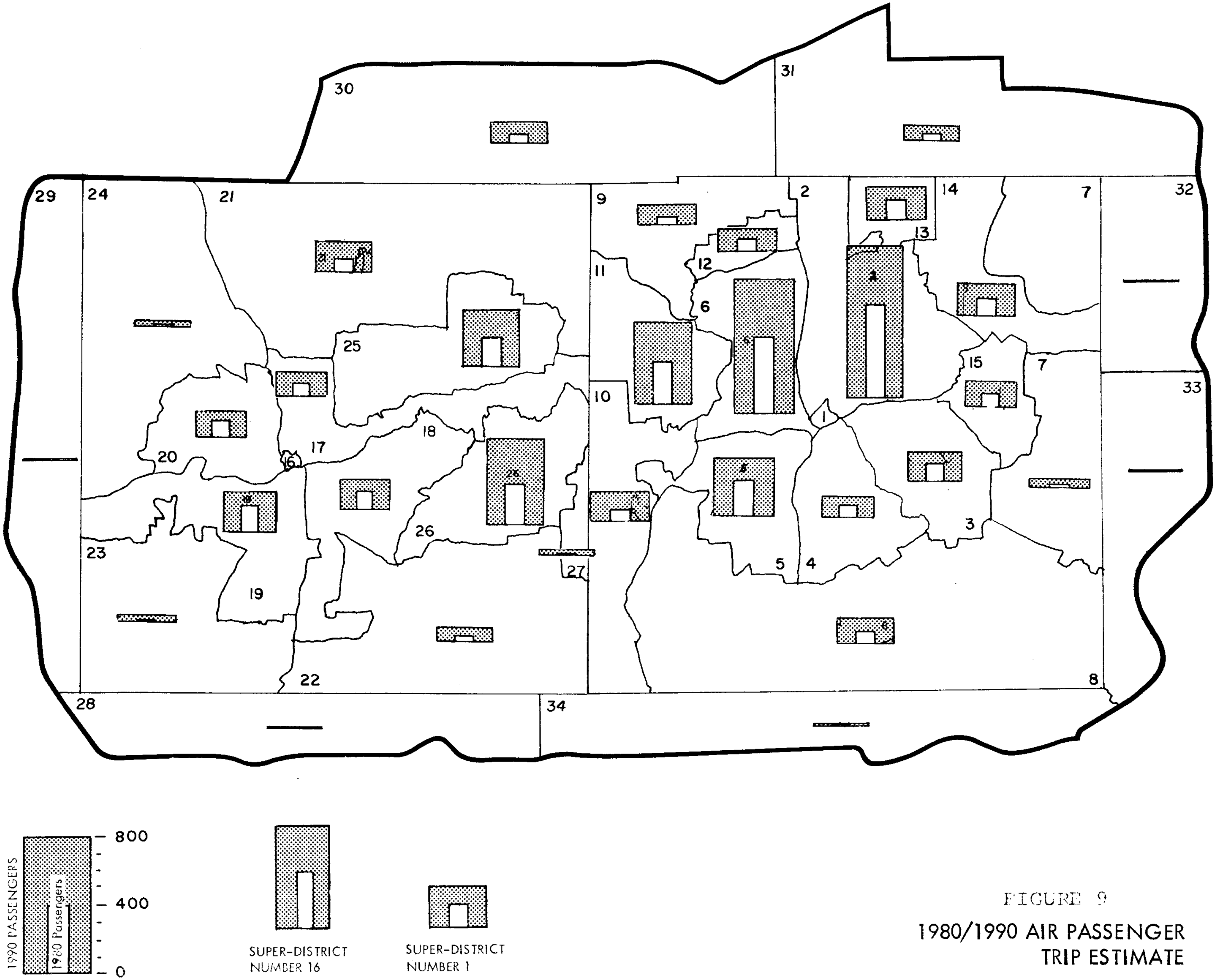

FIGURE 9

1980/1990 AIR PASSENGER TRIP ESTIMATE

essentially the gravity model but includes some mechanical revisions developed by THD to improve program operation for their studies. The gravity model states that travel between zones is proportional to the amount of trip productions and attractions in the zones and inversely proportional to a power function of the distance, time or cost separating the zones. The original Regional Study models had been calibrated with trip length frequency curves using data on 1964 highway travel times. The Regional Study forecasts had been notably insensitive to transit service, however, particularly in corridors where traffic congestion was anticipated to be heavy and where express transit had been provided as relief. Travel in such corridors was heavily restrained because of the overloading and consequently attenuated speeds. Particularly because of the anticipated impact of the U-TACV system, it was desirable to have trip distribution sensitive to good transit service so that trip patterns could be influenced by good accessibility provided by transit.

The trip distribution forecasts used here were therefore prepared using 'minimum time' skim trees. These were developed by comparing total interzonal travel times (skim trees) for automobile and transit travel. The lesser value was used in the minimum time skim tree. This was consistent with the calibration because in 1964 highway times were always better than the travel times on the bus system operating then. The results reflected improved levels of accessibility in corridors where express transit was provided, particularly in the intercity U-TACV corridor.

However, as mentioned previously the real effect of transit service, to provide an alternative in heavily congested highway corridors, could not be reflected because the highway network provided by the THD did not account for congestion. As a result, only the U-TACV corridor provided a significantly different travel time than on highways, and that was only for longer trips, for which the 150 mph speed could be most effective.

The person trip pattern forecast for 1990 using the R3 transit and highway assumptions were heavily related to suburban areas of Dallas County, as shown in Figure 10. The heaviest movements occurred between outlying and central city fringe districts of Dallas. Corridors north and northeast from Districts 2 and 3 were very heavy. The U-TACV corridor from Dallas was heavy all the way into Tarrant County but diminished west from there. These movements reflect the importance of outlying districts for trip generation, both in residential and business areas. Travel into the Dallas CBD is heavy, but it is less than travel between suburban areas. Tarrant County districts show the same pattern at a somewhat reduced scale. Travel to District 20 from Districts 21 and 24 is heavier because of through travel between 21 and 24. These patterns emphasize the importance of providing good transportation service in the U-TACV corridor to serve demand which overlaps between the two counties. The is the longest heavy-demand corridor in the region.

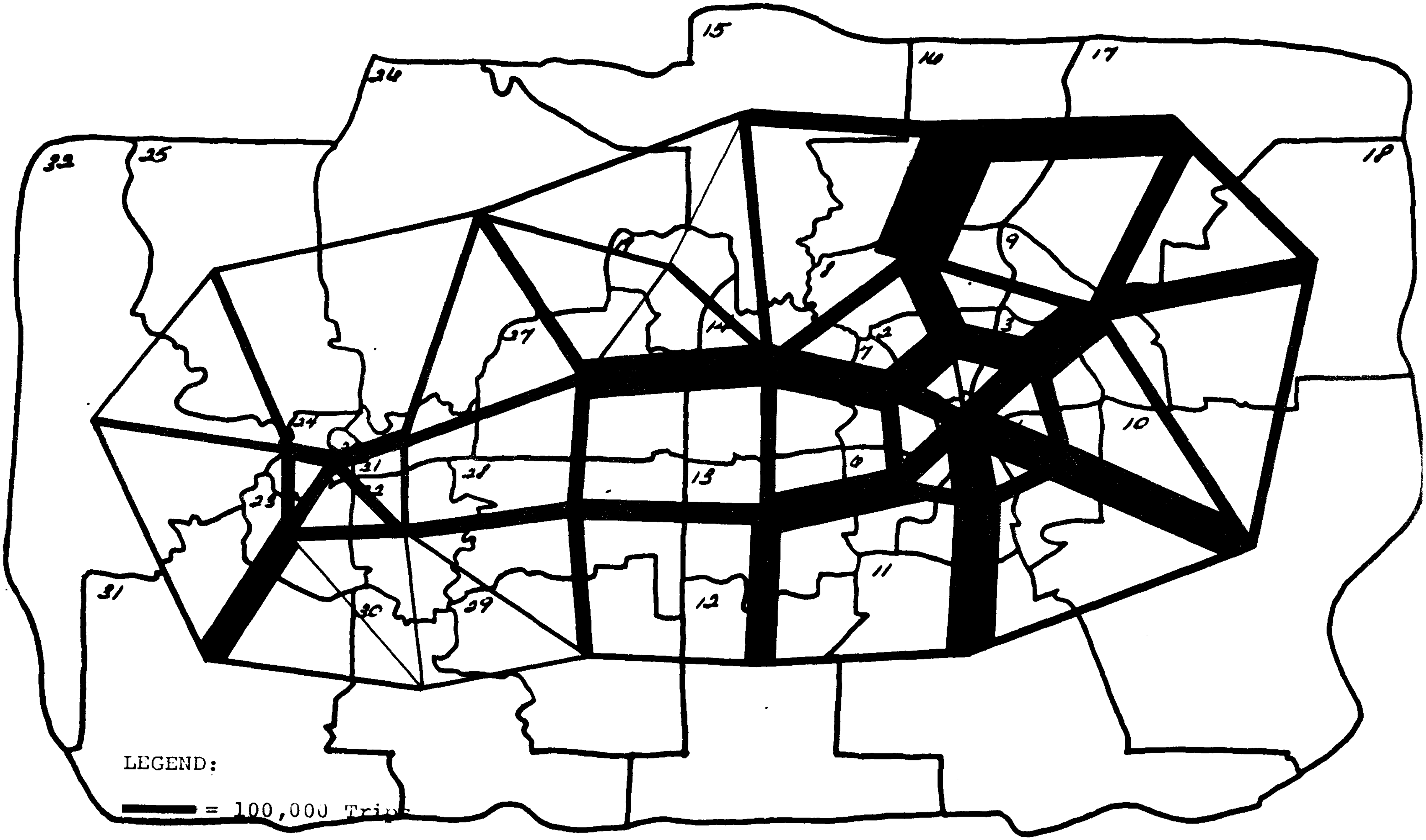

FIGURE 10

R3 TOTAL PERSON TRIPS

MODE SPLIT

The modal split procedure for the U-TACV Study was the same marginal utility technique used in the Regional Study. For each trip interchange the disutility for auto travel and the disutility for transit travel were computed. Disutility is a composite of travel cost and travel time. In computing the disutility for transit for each zonal interchange, the following factors were considered:

- Transit cost - computed utilizing base fare, zone fare and any transfer fare.
- Transit running time - computed by summing the riding time on each transit route utilized.
- Access time - any auto connector time was added to the transit running time along with a ten-minute penalty to reflect the disutility of the auto access trip. Walking time associated with a transit ride, both at the beginning and end of the trip, and all wait times, including initial waiting time and transfer time were factored by 2.5. This 2.5 factor is based upon empirical experience and reflects the undesirable effects of walking and waiting for transit service.

The disutility for automobile journeys between zones considered the following factors:

- Auto cost - auto operating and parking costs incurred for each trip; the operating cost was calculated at 9.5¢ per mile, twice that used for model calibration, to reflect effects of reduced gasoline supplies. This was greater than the 20 percent increase used for Regional Study forecasts.
- Auto time - running time for automobile travel between the zones including the terminal time required to walk from the parking lot to the ultimate destination. The terminal time was factored by 2.5 for consistency with the treatment of transit access time.

The marginal utility for zonal trip interchange was computed by subtracting transit disutility from auto disutility. For each particular disutility value there is a propensity to use transit called modal split, or the percent of person trips using transit and auto. The relationship between modal split and marginal utility was developed from observations in the THD origin-destination survey. These data are shown in Figure 11. The observed relationship was then mathematically fitted to the Type I Asymptotic Extreme Values distribution discovered by Gumbel.[26]

The Gumbel curve has been successfully fitted to modal split relationships for several major cities. These curves are shown on Figure 12. The parameters of the distribution have also been related to factors representing attitudinal response to transit so the curve can be used to examine the effects of attitude change as transit service improves. The attitudinal factor explains the difference in marginal utility-mode split relationships between Dallas/Fort Worth and eastern cities. It implies that improved transit service is self-perpetuating (to some extent), increasing the acceptability (transit choice) in response to improved service even more than straightforward disutility changes reflect.

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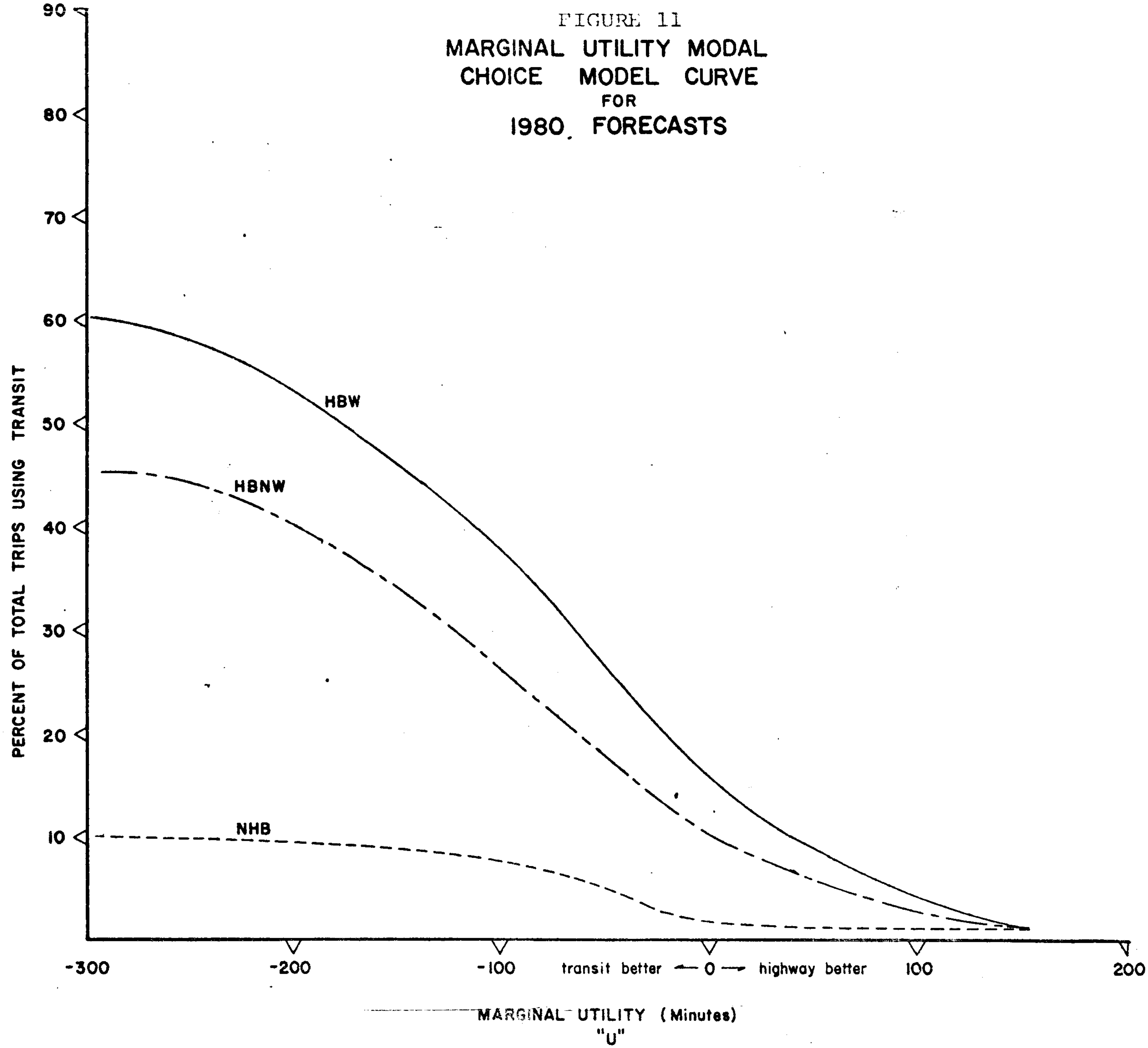
26 Gumbel, E.J., Statistics of Extremes, Columbia University Press, New York, 1958

FIGURE 11

MARGINAL UTILITY MODAL CHOICE MODEL CURVE FOR 1980 FORECASTS



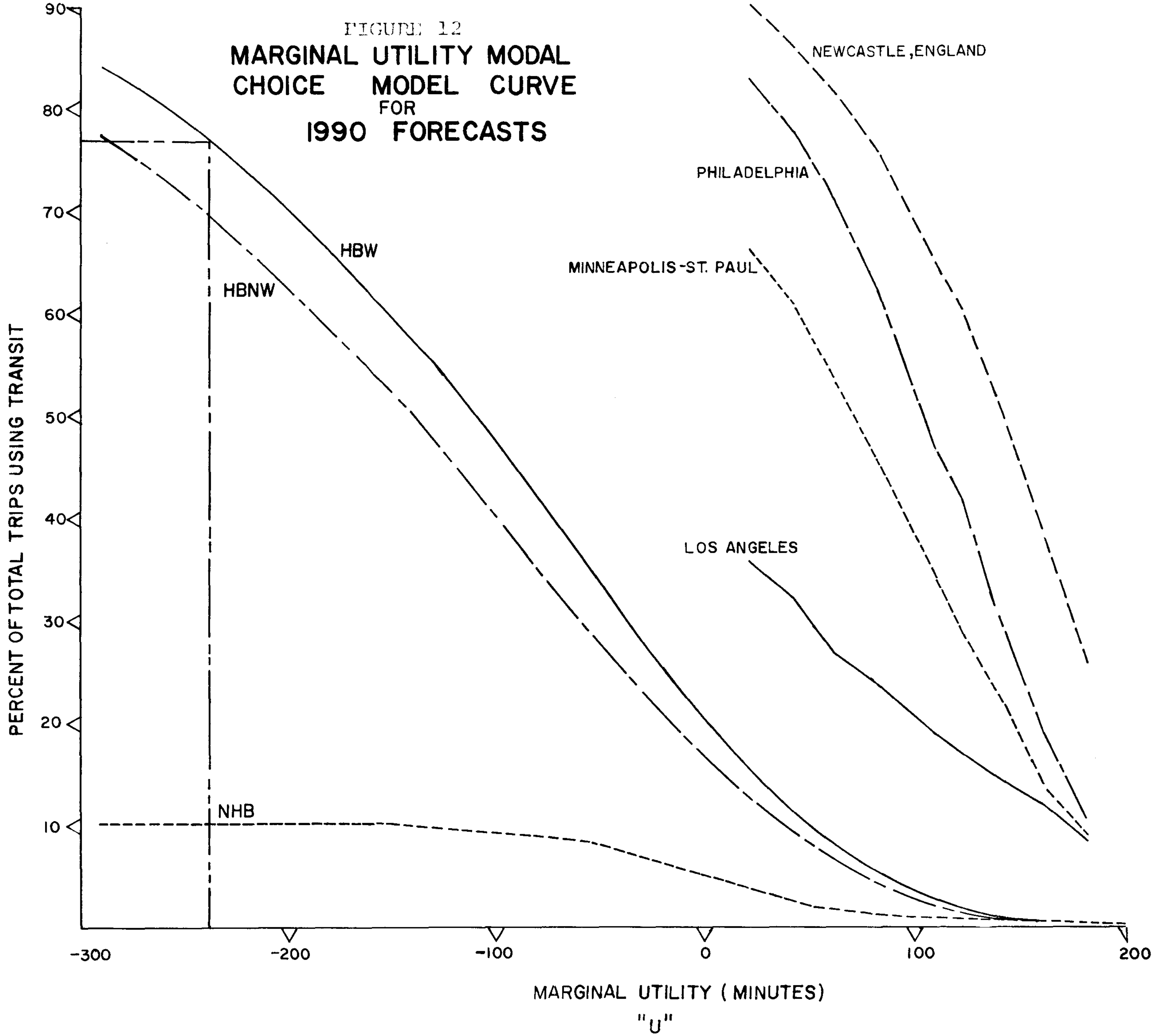


FIGURE 12
MARGINAL UTILITY MODAL CHOICE MODEL CURVE FOR 1990 FORECASTS
NEWCASTLE, ENGLAND
PHILADELPHIA
MINNEAPOLIS-ST. PAUL
LOS ANGELES
HBW
HBNW
NHB
PERCENT OF TOTAL TRIPS USING TRANSIT
MARGINAL UTILITY (MINUTES)
"U"
90
80
70
60
50
40
30
20
10
-300
-200
-100
0
100
200

The mode split models used for estimates of 1990 transit ridership in this study were adjusted upward to reflect attitudinal changes in response to development of a major regional transit system. The models used for 1980 estimates were not changed from the results developed with basic survey data and were therefore identical to the Regional Study models. Two 1990 estimates were prepared with adjusted models. The 'most likely' estimate was developed using curves adjusted to reflect one-half the increase in seat miles represented by the R3 transit network. One-half the increase was used because full attitudinal change may not be possible by 1990. An 'optimistic' estimate was developed by adjusting the curves to reflect the full R3 seat mile increase over existing service. Such a change in public attitude is theoretically possible but not too likely. Such adjustments were possible in the U-TACV Study but not in the Regional Study because the relationships between different model curves and service levels had not been developed at the time Regional Study forecasts were prepared. The mode split curves for the three purposes for the 1980 and the two 1990 forecasts are shown in Figures 11 and 12.

Airport Trip Mode Split

Work trip travel to the Airport by transit was predicted by the traditional home based work mode split model. The mode split for air passenger and visitor trips was related to the work trip model by using relative mode choice responses observed in Cleveland for airport mass transit riders. The Cleveland survey indicated that the modal split characteristics for the three special groups were as follows:

Traveler Type	Mode Split
Employee	11.0%
Air Passenger	14.5%
Travel Related Visitor	4.0%
Casual Visitor	31.0%

Air passengers have a propensity to use transit that is $\frac{14.5}{11}$ = 1.3 times that of employees. The work mode split for any marginal utility was therefore factored by 1.3 to estimate the likely transit propensity of air passengers. For each zone the number of air passengers was multiplied by 1.3 times the work mode split to estimate the number of air passengers using transit.

For related visitors the propensity to use transit is $\frac{4}{11}$ = 0.36 that of employees. The number of related visitors was multiplied by 36 percent of the work mode split to estimate the number on transit.

The propensity of casual visitors to use transit is $\frac{31}{11}$ = 2.8 times that of employees. The number of casual visitors riding transit was therefore estimated by factoring the work mode split by 2.8 and multiplying by the person trips estimated as previously described.

The results of the mode split estimates regionwide for the R3 system are shown in Table 6. The 1964 transit riding and mode split are shown for comparison. The 1980 and both 1990 mode split forecasts are shown for three purposes and include total airport trips. The 1980 results show substantial increases in transit use. The attitudinal effects in the 1990 models and completion of the entire regional system showed significant effect on transit ridership.

TRAFFIC ASSIGNMENT

The transit trips estimated with the modal split model for each of the three major purposes, work, non-work and non-home based, were combined to obtain a total average daily transit trip table. This trip table describes the transit trips between all zone pairs in the study area. The transit trip table prepared in the modal split model is called a 'P & A' table, meaning that the trips are in production to attraction format. This means that the trips are not evenly balanced between origin and destination. Trips produced in each zone and attracted in other zones are shown going from the production to the attraction zone. In the case of work trips, for example, if one assumes that two work trips are produced daily for each person going to work, the P & A trip table shows two trips going from the residence or production zone to the attraction zone where the traveler works. Because the P & A trip tables were assigned to the transit networks, the results appear to be heavily

TABLE 6

REGIONAL TRANSIT AND AUTO TRAVEL
Person Trips by Purpose

		Home Based Work	Home Based Non-Work	Non-Home Based	Total
1964	Transit	66,800(7.0)*	74,700(2.5)	15,100(1.2)	156,600(3.0)
	Auto	885,900	2,943,200	1,212,100	5,041,200
	Total Person	952,700	3,017,900	1,227,200	5,197,800
1980	Transit	140,600(8.5)	392,100(5.5)	28,700(1.2)	561,400(5.0)
	Auto	1,510,000	6,740,900	2,325,400	10,576,300
	Total Person	1,650,600	7,133,000	2,354,100	11,137,700
1990	Transit	303,400(14.1)	826,200(8.4)	61,000(1.9)	1,190,600(7.8)
	Auto	1,843,000	9,014,400	3,151,400	14,008,800
	Total Person	2,146,400	9,840,600	3,212,400	15,199,400
2000**	Transit	453,400(21.1)	950,100(9.7)	47,900(1.5)	1,451,400(9.5)

* Percent Transit of all Person Trips
** High level patronage estimates for 1990 would occur around 2000 under normal growth conditions.

directionally imbalanced. Directional balance is achievable, however, merely by dividing the trips in each direction by 2 and allocating equal numbers in each direction.

The P & A format was retained in order to enhance understanding of the directionality of travel in cases where loadings on the network are heavily directional. It can generally be assumed that many more trips are produced in the area from which the line is coming and attracted to the area to which the line is going, thereby enhancing the understanding of location of production and attraction areas in the region.

One other aspect of traffic assignments is the relationship between total daily and peak period travel. Traffic assignments prepared and discussed here were for total daily travel. In order to obtain peak period volumes from these numbers however, it is merely necessary to factor the total daily trips by approximately 17 percent to obtain an estimate of peak period two-directional travel. Factoring the two-directional peak period traffic by 80 percent will provide an estimate of the peak direction of travel in the peak period. These factors are general, of course, and can only be applied with care for specific locations. They do however give a reasonable estimate of the nature of peak period traffic demand that is likely to occur.

The traffic estimates discussed here are for 1980 transit travel forecasts and the 1990 most likely transit travel forecasts. The discussions in this report will be confined to the traffic demand on the U-TACV line and to characteristics of trips boarding that line from other portions of the regional system or from feeder services operating in the Mid-Cities area to the U-TACV stations.

1980 Ridership

Assignments of 1980 travel estimates to the U-TACV system indicated a maximum load point of approximately 64,000 average daily trips occurring in Dallas County between the Brookhollow and Medical Center stations. Traffic all along the Dallas County portion of the line from the Airport east was near 60,000, varying from a low of 58,000 just east of the Airport to the maximum load point volume just cited. The total traffic estimates on each of the links are shown in Figure 13. Traffic on the Tarrant County portion of the system had a maximum load point volume of 50,300 on the link just west of the Airport. The lowest volume in Tarrant County was about 40,200 trips observed just west of Loop 820.

Traffic on the line is heavily oriented to the express services, which in Tarrant County usually carries better than 80 percent of the traffic on any given link. The proportion on local service in Dallas County is somewhat higher however, although it never exceeds 40 percent of the traffic on any link. This is an indication of the attractiveness of the two levels of service and how the attractiveness differs in the two counties. Only the express service is a significant competitor to

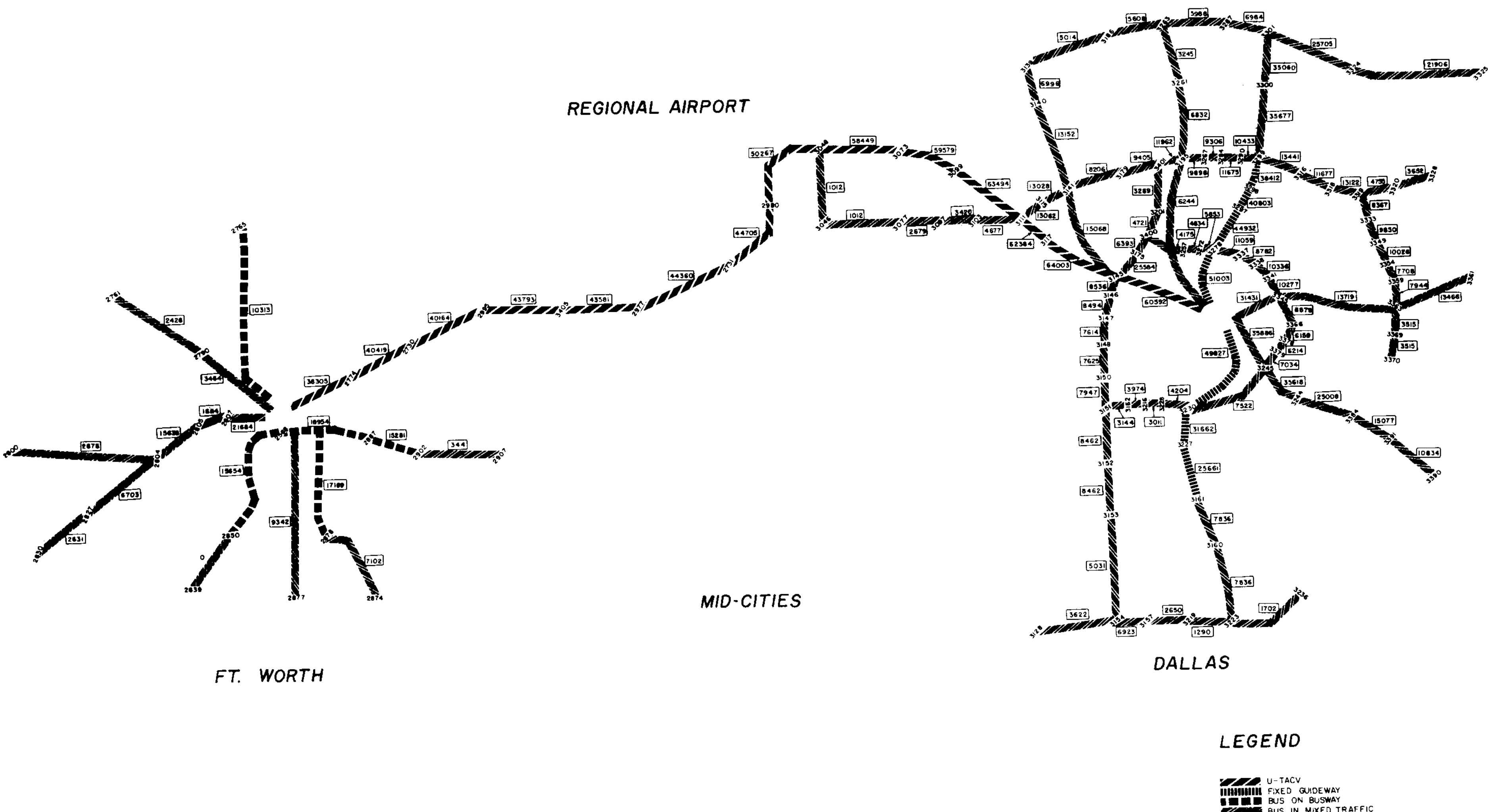


FIGURE 13

TOTAL TRAFFIC ESTIMATES
ON EACH LINK - 1980

highway service in Tarrant County, where highway speeds can be considered less constrained by traffic congestion. In Dallas County, however, traffic in the corridor along the U-TACV line will probably be quite heavy, thereby contributing to heavy traffic congestion and constrained speeds. As a result the local services offered by the U-TACV are quite competitive for attracting travel.

In either county, however, the principal attractiveness of the U-TACV system is the high-speed express service offered between major station points. This is important in considerations of design of the system, particularly with respect to turn-backs at the Airport for Dallas County trains. It is anticipated that every other local train could be turned back at the Airport rather than proceeding on through Tarrant County because of the low local traffic volumes in Tarrant County.

It is not immediately clear whether the high speed of the U-TACV system is the major factor in the attractiveness of the express service or whether it is the limited number of station stops. However, it is anticipated that reduced top speeds of the vehicles on the line would probably have less effect than increasing the number of stops the trains would have to serve. This is primarily pointed out in the cost estimates in Chapter V, where time spent cruising is shown to be less than 50 percent of the trip time for either express or local trains. Considerable time, however, is spent accellerating and decelerating. Reducing the top speed would therefore merely increase the time spent cruising, probably by a minimal amount, whereas adding station stops would have considerable impact in the acceleration, deceleration and dwelling time percentages.

It is important to consider which stations served by the two U-TACV lines serve the most riders. The boarding and alighting volumes for both local and express trains at each station are shown in Table 7. In Tarrant County alternate stations appear to have very low traffic volumes. The four alternate stations (nodes 3410, 2730, 3405 and 2731) have total volumes boarding and alighting the local trains of 1000 or less. One of those four is Fort Worth station, a subway terminal on the east side of the Fort Worth CBD. That station is also served by the express line from which only 2100 riders board and alight daily. The station is therefore serving only approximately 3100 passengers each day.

Most of the Fort Worth CBD passengers are proceeding to the City Center station, at which 32,150 persons board and alight from the express trains and 5100 passengers board and alight from the local trains. It is apparent therefore that these two stations could and should be consolidated, especially considering the high cost of building subway stations.

The other three alternate stations in Tarrant County probably could be deleted from the system as well because of their low volume potential. None of them were served by the express line, and all of them had very low local train boarding and

TABLE 7

1980 STATION VOLUMES
U-TACV SYSTEM
(City Center to Union Terminal)

Station Node Number	Station Name	Local			Express			Grand Total
		East Bound	West Bound	Total	East Bound	West Bound	Total	
2530	City Center	1,928	3,220	5,148	24,059	8,094	32,153	37,301
3410	Fort Worth	2,007	925	1,004	580	1,534	2,114	3,118
2774	Beach Street	4,074	4,339	8,413				8,413
2730	Haltom City	0	0	0				0
2995	Loop 820	2,943	1,004	3,938	12,400	5,829	18,229	22,167
3405	Hurst	554	334	888				888
2977	Euless	2,819	1,254	4,073				4,073
2731	Southwest	642	393	1,035				1,035
2980	Bedford	6,422	1,642	8,064				8,064
3048	Airport	7,223	2,938	10,161	11,112	7,919	19,031	29,192
3073	Belt Line	3,879	1,581	5,460				5,460
3099	North Irving	5,146	2,017	7,163				7,163
3111	Texas Stadium	10,275	2,047	12,322	14,390	4,238	18,628	30,950
3117	Brookhollow	2,933	2,670	5,603				5,603
3145	Medical Center	21,247	12,176	33,423				33,423
2688	Union Terminal	10,371	11,338	21,709	28,317	10,566	38,883	60,592

alighting volumes. These low volumes can be explained by the fact that development in the general area of the corridor, even by 1990, has quite low density, therefore generating less travel demand at these stations. Some development between 1980 and 1990 might, however, increase the attractiveness of such stations because of additional residential and activity growth near them and the resulting increase in traffic demand at these locations.

In Dallas County all of the stations had local line boarding volumes better than 5000 riders daily. Two stations were just slightly more than 5000, the stations at Belt Line Road and at Brookhollow (nodes 3073 and 3117). In Tarrant County only two stations, the ones at City Center and at Beach Street, had boarding and alighting volumes in excess of 5000 persons daily from the local line. The City Center station in fact had lower volumes than either the Belt Line or Brookhollow stations in Dallas County, but the Beach Street station was 8400, higher than any of the non-express stations in Dallas County except for the Medical Center station.

In Dallas County the Loop 12 station at Texas Stadium had daily volumes of 12,300 on the local line and 18,600 from the express line, indicating the effect of transfer to bus service operating on Northwest Highway and Loop 12 as well as westward along State Highway 193 in Irving. Local volumes at the Loop 820 station in Fort Worth were 3900 daily, but the express train volumes were 18,200, quite comparable to the express volumes in Dallas County at Texas Stadium. The Medical Center station in

Dallas boarded 33,400 persons daily from the local line only, handling therefore the third highest total daily traffic of any station on the line. The City Center station in Fort Worth was second with 37,300 and the Union Terminal station in Dallas was tops with 60,600, the latter two including both local and express riders.

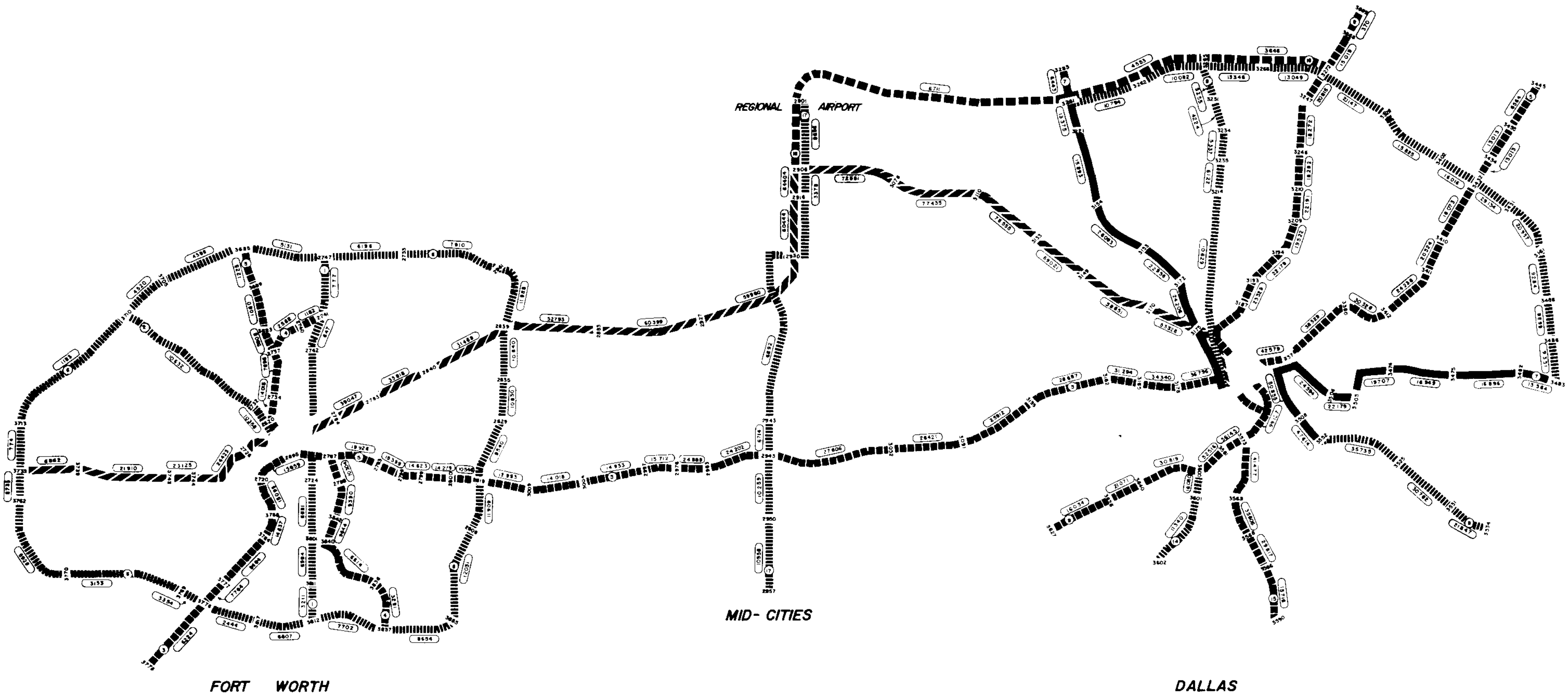
The 1980 volume estimates indicate that it is appropriate to consider initial (1980) construction of only the stations served by express trains and the Medical Center station. Other stations had such low volumes that their near-term feasibility was doubtful. These stations could be added later, perhaps by 1990, as nearby new development generated sufficient demand. In fact service areas previously handled by these intervening stations could probably be handled quite well by the major stations at the Airport and at the loop highways. Assuming that persons boarding at local stations did not use the system at all would reduce ridership on the U-TACV system by less than 40 percent. It is probably reasonable, however, to assume that a good portion of that ridership, for instance 50 percent of it, might in fact find its way to other stations thereby reducing ridership by less than 20 percent.

Reducing the number of stations by ten would reduce station costs somewhat and have an impact upon the capital cost of providing the system. Continuing to provide feeder service to the same area would increase feeder bus operating costs. Reducing the number of stations would reduce U-TACV operating costs by reducing the amount of acceleration and deceleration required at the reduced number of stations. People originally boarding at the express line stations would be offered a higher level of service and would therefore be more likely to use the system, tending to offset the loss in ridership among people who would have used eliminated stations. They would instead have to reach express stations by feeder buses, a substantially lower service level.

In summary, in 1980 there would be approximately 115,600 persons using the U-TACV line on an average day. Of those about 29,000 would board and alight at the DFW Airport, 37000 would be served by the City Center station in Fort Worth, 33,000 would be served by the Medical Center station in Dallas and 60,000 would be served by the Union Terminal station in Dallas. Stations at the loop highways would handle about 22,000 at Loop 820 in Fort Worth and 31,000 at Loop 12 in Dallas. These are the stations which, from a patronage point of view, appear to be the most reasonable to build for initial service on the U-TACV line.

1990 Ridership

The 1990 traffic assignments shown in Figure 14 indicated that the maximum load point for the entire line would be approximately 78,600 persons between the Texas Stadium and North



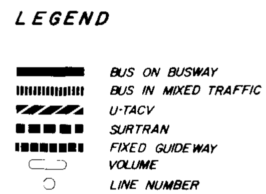


FIGURE 14

1990 R3 U-TACV LINE RIDERSHIP

Irving stations in Dallas County. The lowest line volume in Dallas County occurred between the Medical Center and Union Terminal stations; it was 51,500 daily riders. In Tarrant County the maximum load point was immediately west of the Airport, where 64,400 daily riders were carried. The minimum ridership on the Tarrant County portion of the system occurred just west of the Loop 820 station between that station and the Haltom City station, where 31,500 daily riders were carried.

A significant reorientation of the traffic between the express and local lines occurred between 1980 and 1990, indicating an impact that could well be attributed to the increase in highway traffic congestion in the U-TACV corridor. Whereas the express services heavily dominated service on the line in 1980, major increases in ridership by 1990 were observed primarily in the local services, and express traffic dropped somewhat.

This, of course, could also be attributable to the changes in the feeder services provided in the major cities, since major improvements in transit service were proposed between 1980 and 1990 with completion of the Regional Public Transportation System. In fact, feeder service to the west of Fort Worth was significantly improved since the U-TACV line was extended to Loop 820 west of the city, thereby providing direct service from that portion of Fort Worth to the Regional Airport and Dallas. It is in that portion of the city that the major segment of its airport users reside.

West of the east Loop 820 station in Tarrant County, well over half of the ridership is carried on the local lines, indicating that major boarding of the express line occurs at the Loop 820 station. The traffic assignments indicate that over 25,000 persons will board at that station daily eastbound and that the greater portion of those will, in fact, continue all the way to Dallas, where 22,700 persons alight the express line at Dallas Union Terminal. East of the east Loop 820 station over half of the ridership is carried on the express line.

The same general phenomenon, a major increase in the local service proportion of ridership, occurred in Dallas County, but in no case did the local line carry more than half of the riders. In every case however the local service carried better than 30 percent of the volume on any given link.

Station boarding changed in a manner which reflected the increased importance of the local service for 1990 travel. All local stations boarded much heavier volumes than in the 1980 estimates as shown in Table 8. Only the Euless and Southwest stations had boarding volumes less than 5000 daily for the local service (nodes 2937 and 2930). Five other stations had boarding volumes significantly less than 10,000 persons daily for the local lines. These were the Fort Worth station, the Beach Street station, the Haltom City station and the Bedford Station in Tarrant County and Medical Center Station #2 in Dallas County. (It should be noted that the 1990 U-TACV network had one additional station, called Medical Center #2, between the Brookhollow and Medical Center #1 stations of the 1980 network, node 3170. The node numbers for the first four

TABLE 8

1990 STATION VOLUMES
U-TACV SYSTEM
(City Center to Union Terminal)

Station Node Number	Station Name	Local East Bound	Local West Bound	Local Total	Express East Bound	Express West Bound	Express Total	Grand Total
2654*	City Center	3,847	6,399	10,246	7,778	893	8,671	18,917
2784	Fort Worth	2,832	5,422	8,254	882	448	1,330	9,584
2783	Beach Street	2,126	5,525	7,651				7,651
2840	Haltom City	2,536	6,405	8,941				8,941
2839	Loop 820(east)	10,291	4,821	15,112	25,336	736	26,072	41,184
2883	Hurst	12,287	3,373	15,660				15,660
2927	Euless	2,520	983	3,503				3,503
2930	Southwest	2,243	835	3,078				3,078
2916	Bedford	5,487	1,061	6,548				6,548
2906	Airport	6,358	6,211	12,569	7,154	11,622	18,776	31,345
3078	Belt Line	15,640	5,342	20,982				20,982
3110	North Irving	8,539	2,375	10,914				10,914
3133	Texas Stadium	8,577	1,339	9,916	12,105	2,951	15,056	24,972
3149	Brookhollow	13,216	2,698	15,914				15,914
3170	Medical Center #1	4,858	2,243	7,101				7,101
3175	Medical Center #2**	5,568	7,876	13,444				13,444
2578	Union Terminal	7,072	9,149	16,221	22,713	12,584	35,297	51,518

* Riders boarding or alighting western extension from City Center station in Fort Worth not included; riders onboard at City Center station also not included.

** Included in 1990 patronage estimates only.

stations cited previously were 2784, 2783, 2840 and 2916, respectively.) Boarding volumes at the Loop 12 station in Dallas for the local line were just barely under 10,000 at 9900.

It is apparent that other than the five stations cited above, the local stations will draw significant patronage in 1990 and therefore should be implemented between 1980 and 1990 if, in fact, they are not included in the 1980 system. It would probably be appropriate to consider consolidating service from the Beach Street and Haltom City stations in Tarrant County into one station because of their low volumes. Fort Worth station, just east of the CBD would handle a total of nearly 18,000 daily riders considering both local and express services. This is a major increase from that observed in 1980. Some portion of that increase however may have been derived from the City Center station where patronage dropped from the 37,000 in 1980 estimates to just over 30,000 in the 1990 figures.

The 1990 station boarding indicated that 56,000 people would board at the east Loop 820 station in Fort Worth, a significant increase beyond the 22,000 estimated in 1980. This is most likely attributed to the improved feeder service offered by express buses operating on Loop 820 in the completed Regional Transit System in 1990. These services are apparently attracting ridership away from radial lines in Fort Worth that in 1980 brought riders into the downtown City Center station for boarding the U-TACV system. This also explains a portion of the decrease in boarding at the Fort Worth City Center station.

Station volumes at other express stops, at the Airport and in Dallas County increased significantly although volumes at the east Loop 820 station in Fort Worth jumped only about 10 percent. Boarding at the Union Terminal increased nearly 20 percent. Volumes at the Airport station increased by over 40 percent.

The drop in riders at the Loop 12 station in Dallas (Texas Stadium) is probably best attributed to changes in the feeder service as well as addition of the high-speed express line out the Stemmons Freeway. That express line will attract a good portion of the riders in the northwest quadrant of Dallas, whereas the U-TACV line was carrying those riders in the 1980 estimates. In addition, there was a line west from Texas Stadium to Irving providing high level feeder service to Texas Stadium station of the U-TACV line for 1980. That line has been routed south along Loop 12 in the 1990 system, serving more of a circumferential feeder function than had been supplied previously.

Table 9 summarizes 1990 station-to-station travel handled by the U-TACV and is significant to indicate travel patterns which were observed between respective stations. The table shows the heavy predominance of trip destinations into Dallas County from stations both in Dallas and Tarrant Counties. The line is therefore serving activities along the U-TACV corridor in Dallas County as well as providing service to the Regional Airport and downtown Dallas. The volumes shown there are of

TABLE 9

STATION-TO-STATION VOLUMES
U-TACV SYSTEM
(City Center to Union Terminal)

STATION TO

STATION FROM	City Center *1	Fort Worth *2	Beach Street 3	Haltom City 4	Loop 820 *5	Hurst 6	Euless 7	South-west 8	Bedford 9	Airport *10	Belt Line 11	North Irving 12	Texas Stadium *13	Brook-hollow 14	Medical Center #1 15	Medical Center #2 16	Union Terminal *17	TOTALS
1	0	0	955	329	141	179	100	100	0	2139	256	209	1630	441	488	649	4009	11,625
2	0	0	80	36	25	17	5	7	1	753	13	4	34	10	8	7	95	1,095
3	1754	1503	0	192	61	33	11	10	7	236	21	9	17	45	22	22	47	3,990
4	2416	1732	866	0	132	203	68	69	29	277	111	67	101	237	98	104	366	6,876
5	1321	917	369	130	0	1209	514	320	84	2755	734	475	5014	641	703	744	10245	26,175
6	548	323	137	191	881	0	529	572	501	1609	1204	501	921	1707	419	513	2069	12,625
7	92	39	17	23	161	316	0	0	0	165	168	72	125	247	62	76	323	1,886
8	20	11	2	2	32	72	18	0	45	206	221	79	121	202	51	50	125	1,257
9	102	110	23	15	45	101	0	68	0	580	783	466	275	1418	363	369	520	5,238
10	187	73	9	13	134	270	106	255	244	0	857	215	740	449	138	124	767	4,581
11	106	63	7	24	81	135	66	169	143	2670	0	1291	2397	3020	732	850	2807	14,561
12	24	21	5	3	17	48	18	51	45	500	598	0	1089	2085	586	429	795	6,314
13	45	32	4	5	46	55	16	47	17	1466	407	527	0	1073	651	471	2481	7,343
14	6	1	4	1	5	10	3	7	8	693	49	93	92	0	18	18	21	1,029
15	5	2	1	1	2	1	1	1	2	263	21	28	39	99	0	36	76	578
16	5	1	1	1	7	17	16	7	3	1124	179	129	125	293	457	0	336	2,701
17	637	343	33	25	213	58	60	66	18	9755	567	256	1319	1323	1320	5481	0	21,474
TOTALS	7268	5171	2513	991	1983	2724	1531	1749	1147	25191	6189	4421	14039	13290	6116	9943	25082	129,348
(Trips Between West Fort Worth and Intercity Line, Through City Center Station, No. 1)																		
East Bound		2619	358	117	94	101	55	65	46	1502	175	167	634	1584	407	770	4703	13,397
West Bound		699	790	957	538	210	31	7	117	71	57	12	20	11	0	30	259	3,809
GRAND TOTAL		8489	3661	2065	2615	3035	1617	1821	1310	26764	6421	4600	14693	14885	6523	10743	30044	146,554

* Express Stations

course production and attraction volumes indicating that trips produced in Tarrant County, i.e., from people living there, are using the U-TACV system to gain access to attractions, i.e., employment and other activities, in Dallas County.

The single biggest attractor is the Dallas CBD, at the Union Terminal station. Major attractions occur at both Texas Stadium and the Brookhollow station. Ridership to the two Medical Center stations in the 1990 system was also quite high. The second highest single station however was the Airport station, attributable primarily to air passenger and related trips. Of trips to the Airport, 21 percent originate in Fort Worth boarding at or west of the east Loop 820 station. An additional 5.6 percent boarded the U-TACV line west of the City Center station so that the Fort Worth contribution to Airport demand was 26.8 percent. Trips from Dallas boarding at or east of Loop 12 were 42 percent of Airport trips. An additional 11.9 percent boarded at stations between Loop 12 and the Airport.

These figures indicate that, as would be expected, about one-third of Airport patronage is coming from Tarrant County and two-thirds from Dallas County. The linkage described between stations in this table can be useful for consideration at some later time of designing particular U-TACV line services to connect heavily related stations. This would reduce operating costs and increase effective operating speed between major stations by eliminating the needs to stop at intermediate stations at which very few productions or attractions are observed.

Traffic Assignments Summary

The traffic assignments for 1980 and 1990 have indicated that the U-TACV system will attain a great portion of its growth as soon as it is implemented but that significant additional patronage will be generated by improved feeder services provided when the completion of the Regional Public Transportation system is realized by 1990. Comprehensive feeder services at a lower level of service were provided for 1980, but the extensive exclusive guideway service in the 1990 system as well as population and employment increases in the ten-year period produced sizable increases in U-TACV patronage.

As would be expected, traffic is much heavier in Dallas County than Tarrant County, and the system is providing a means of good accessibility from Tarrant County residential areas to activities located in Dallas County, particularly in the City of Dallas. The U-TACV system is providing good service to the Regional Airport, the second largest attraction station on the system, but service to downtown Dallas and downtown Fort Worth as well as to major points in-between is attracting the greatest portion of riders. It is apparent therefore that the system is not just an Airport service but it is providing truly regional transportation service for people living in the two counties desiring to engage in activities which would otherwise be quite distant and difficult to reach by private automobile operating on a congested highway system.

IV. SENSITIVITY ANALYSIS

The 1980 and 1990 transit travel forecasts were useful for evaluating the impact, feasibility, design and cost of the U-TACV system. It is important, however, to be able to ascertain the effects that variations in policy and operational changes from those assumed in these estimates might have on U-TACV ridership. In order to assist in determining this, sensitivity analyses were performed to investigate the relationships between patronage and various service parameters, fare structure and other aspects of the U-TACV system. The sensitivity analyses developed procedures and preliminary information on the response of patronage for the U-TACV system to variations in levels of operating and policy parameters, providing a definitive tool with which to evaluate the cost/revenue/service relationships to patronage of the U-TACV system. These procedures will be a useful tool for determining the effectiveness of various mass transit investment policies for the U-TACV system or other portions of the Regional Public Transportation System.

The sensitivity analysis of patronage to various operating and policy parameters was performed in two distinct but complementary ways. The first analysis was mathematical sensitivity analysis. In this analysis a mathematical dissection of the modal split model was performed to ascertain the quantitative effects on ridership of variations of levels of service. The second portion was a subarea analysis[27] in which the subarea directly served by the U-TACV system was isolated and examined in detail. This analysis consisted of varying U-TACV service levels and using the model to test effects on patronage. The subarea analysis provided verification of the mathematical sensitivity analysis and useful patronage estimates for different U-TACV service levels.

MATHEMATICAL SENSITIVITY ANALYSIS

There are two possible approaches for determining the sensitivity of U-TACV ridership to varying system parameters. The first is to modify the parameters and run the patronage models to determine the effect on ridership (this is the approach used in the subarea analysis described later in this chapter). The second approach is to analyze mathematically the 'elasticity' of patronage (model output) to changes in system parameters (model input). Elasticity is defined as the percent change produced in model output (patronage) due to a one percent change in an input parameter (U-TACV level of service). The model can be said to be 'elastic', 'perfectly elastic' or 'inelastic' depending on whether the elasticity is greater than, equal to or less than one. For the mathematical sensitivity analysis, the input parameters examined were auto cost factors and U-TACV

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27 **"Procedures for Transit Subarea Analysis", Addendum to U-TACV Patronage Analysis Report, Alan M. Voorhees & Associates, Inc., March, 1975.**

fare and service characteristics, and the output evaluated was patronage.

Sensitivity to Feeder Service

The elasticity analysis was broken down into two steps, one for the feeder system serving the U-TACV line, considering the effects of varying feeder service levels, and one for the U-TACV line itself, considering effects of varying U-TACV service levels.

For the feeder service sensitivity analysis a set of standard conditions was assumed as a base for comparison of effects. The assumed base conditions for this analysis are shown in Table 10. They were selected because they were typical of feeder services and auto factors in the U-TACV corridor. The equation used to calculate marginal utility is shown as part of Table 10 along with a description of the individual factors in the equation. Also shown in Table 10 is the extreme values equation for the modal split model, which uses values of marginal utility to calculate modal split.[28]

The sensitivity analysis of feeder system parameters was conducted by varying the service parameters in the utility equation individually, holding others constant while each was changed. The sensitivity was developed by observing change in modal split as each variable changed independently. The change in independent variables represented changes in feeder system service and

28 The extreme values formulation of the mode split model was discussed on page 52.

TABLE 10

FEEDER SYSTEM SENSITIVITY ANALYSIS TYPICAL U-TACV CORRIDOR BASE CONDITIONS

Highway Distance	= 10 mi.	Feeder Bus Speed	= 20 mph
Highway Speed	= 35 mph	Feeder Bus Fare	= 30¢
Parking Cost	= $2.00	Average Income	= $15,000
Walk Time to Feeder Bus	= 6 min.	Auto Terminal Time	= 5 min.
Average Bus Headway	= 15 min.		

MARGINAL UTILITY: $U = 2.5\ (Tw+Ta-At) + (TR-AR) + \dfrac{(F-P-Ac)}{I/4(60)2080}$

For the base conditions above:

Tw = Transit wait time (½ headway) = 7.5 min.
Ta = Transit access time (walk time) = 6 min.
At = Auto terminal time = 5 min.
Tr = Transit run time (distance/speed) = 30 min.
Ar = Auto run time (distance/speed) = 17 min.
F = Transit fare = 30¢
P = ½ Park cost = $1.00
Ac = Auto operating cost = (4.76¢/mi.) x 10 mi. = 47.6¢
I = Income = $15,000 x 100 cents/dollar = $15\text{x}10^5$ cents

Therefore:

U = 2.5

EXTREME VALUES EQUATION:

$$MS = e^{-e^{\alpha(u+\mu)}}$$

α and μ are parameters determined by regression analysis using observed travel pattern

α = .00774
μ = 68
Using U = 2.5, Mode Split (MS) = 19%

therefore were changes in transit disutility. Figures 15, 16 and 17 were developed to indicate the effect on modal split of changes in feeder system access time, run time and cost. These parameters are for the feeder system in the U-TACV corridor and do not relate to the line haul portion of the U-TACV trip. All curves in these figures meet at the abscissa value 1X, which is the base case given in Table 10 and for which mode split was calculated as 19 percent, the ordinate value for the intersection point. Figure 15 suggests that terminal times affect U-TACV patronage in a fairly linear manner. Given the base condition used in this analysis, modal split is slightly more sensitive to feeder headway than to access time and more sensitive to these considerations than to auto terminal time.

Figure 16 demonstrates that transit (feeder) and auto speed changes have nearly hyperbolic relationships to modal split. Patronage is more sensitive to changes in feeder system speeds than auto system speeds because the base value for transit is much lower than auto. It is particularly interesting that great increases in feeder system speed will yield less than a 10 percent change in modal split while severe decreases in speed from the base value will drive patronage to zero (100 percent auto).

Figure 17 shows the sensitivity of U-TACV patronage to economic factors of the feeder system. The modal split is most sensitive to parking cost; increases in fares and income produce about equal effects on patronage.

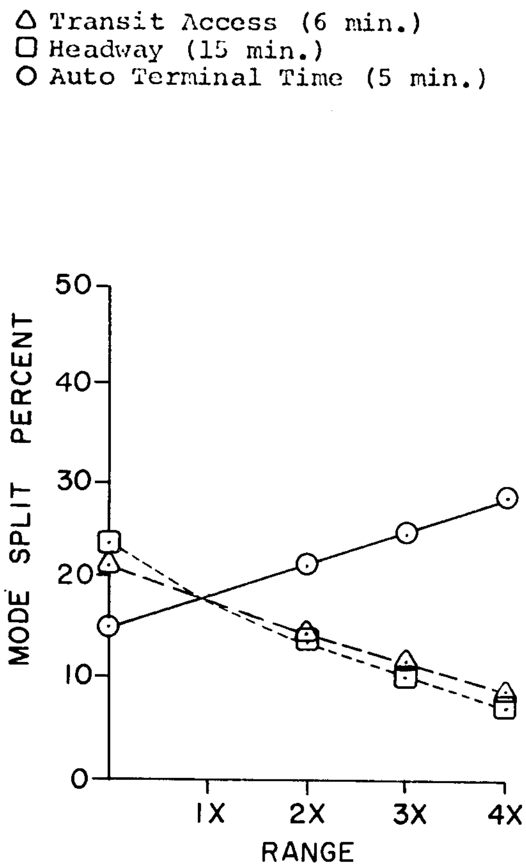


FIGURE 15

ACCESS TIME SENSITIVITY

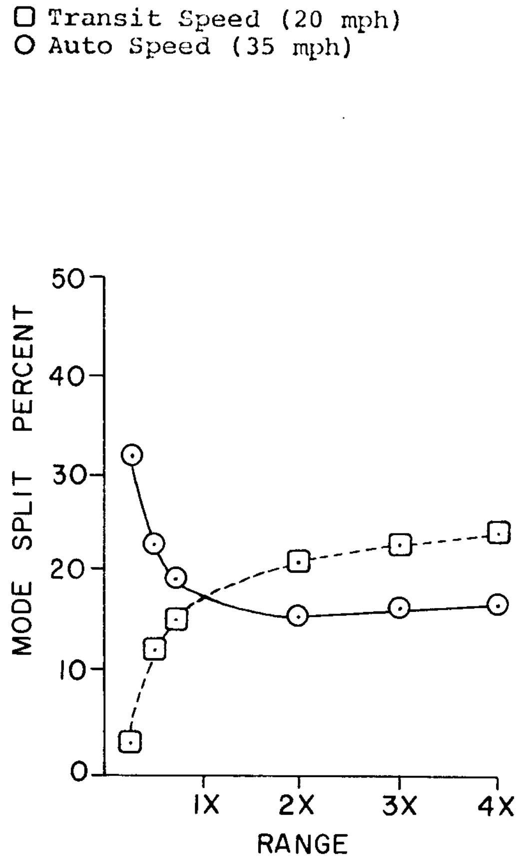


FIGURE 16

RUN TIME SENSITIVITY

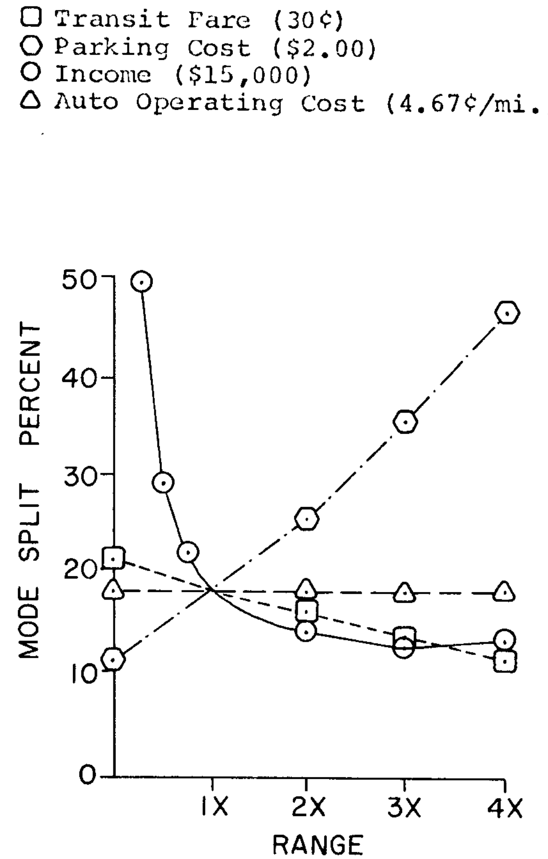


FIGURE 17

COST SENSITIVITY

(For all these relationships 1X is the base value given in Table 10 and shown in parentheses in the legends here)

These estimates of the sensitivity of patronage to feeder system parameters must be interpreted with knowledge that the base values (i.e., those values which are assumed to be typically representative of the service area) have a great influence on the relative impact of the variables. For instance, patronage from a low income zone will be much more sensitive to changes in income than would patronage from a high income zone. And sensitivities shown are all affected by the base values assumed for feeder system service.

The general conclusions which can be drawn from Figures 15, 16 and 17 can be useful for interpreting the appropriate direction to proceed for improving transit ridership. Significantly the two most important factors are the most and least easily affected, respectively, parking cost and income. Parking policies are readily implemented and can have direct or indirect impact on parking charges. Changes in auto operating costs with increased gasoline prices apparently have little impact. Reducing transit fare also would return relatively small patronage increases. Increased transit speed, by using exclusive guideways, seems not to be particularly effective either. Reduced highway speed, due to congestion, would be quite important however. These kinds of considerations are helpful for planners and operators to demonstrate to policy-makers the most fruitful pursuits to effect change.

Elasticity Analysis

The elasticity of any modal split element is not constant throughout the range of possible values. The understanding of U-TACV patronage sensitivity can therefore be broadened when an analysis of elasticities is developed. Elasticity is the incremental change to be expected in a dependent variable due to an incremental change in an independent variable. Elasticities are important for developing a generalized understanding of how change in one variable affects another.

The relationship describing the percent change in modal split for a one percent change in any utility element is shown below. It was derived from the extreme values formulation in Table 10 in the manner shown in Appendix A.

$$\text{Percent Change} = A_0 C \alpha e^{\alpha(A_0 C + B + \mu)}$$

where: A_0 = Initial value of element
C = Utility coefficient of element
α, μ = Model parameters
B = Combined base disutility of all other elements

Using this formulation and any base value, modal split elasticity and change due to varying feeder system parameters can be determined in the same manner as described previously. Since the range of possible combinations of feeder and line haul levels of service is great, this relationship is critical to the determination of realistic patronage estimates for any unique situations tested.

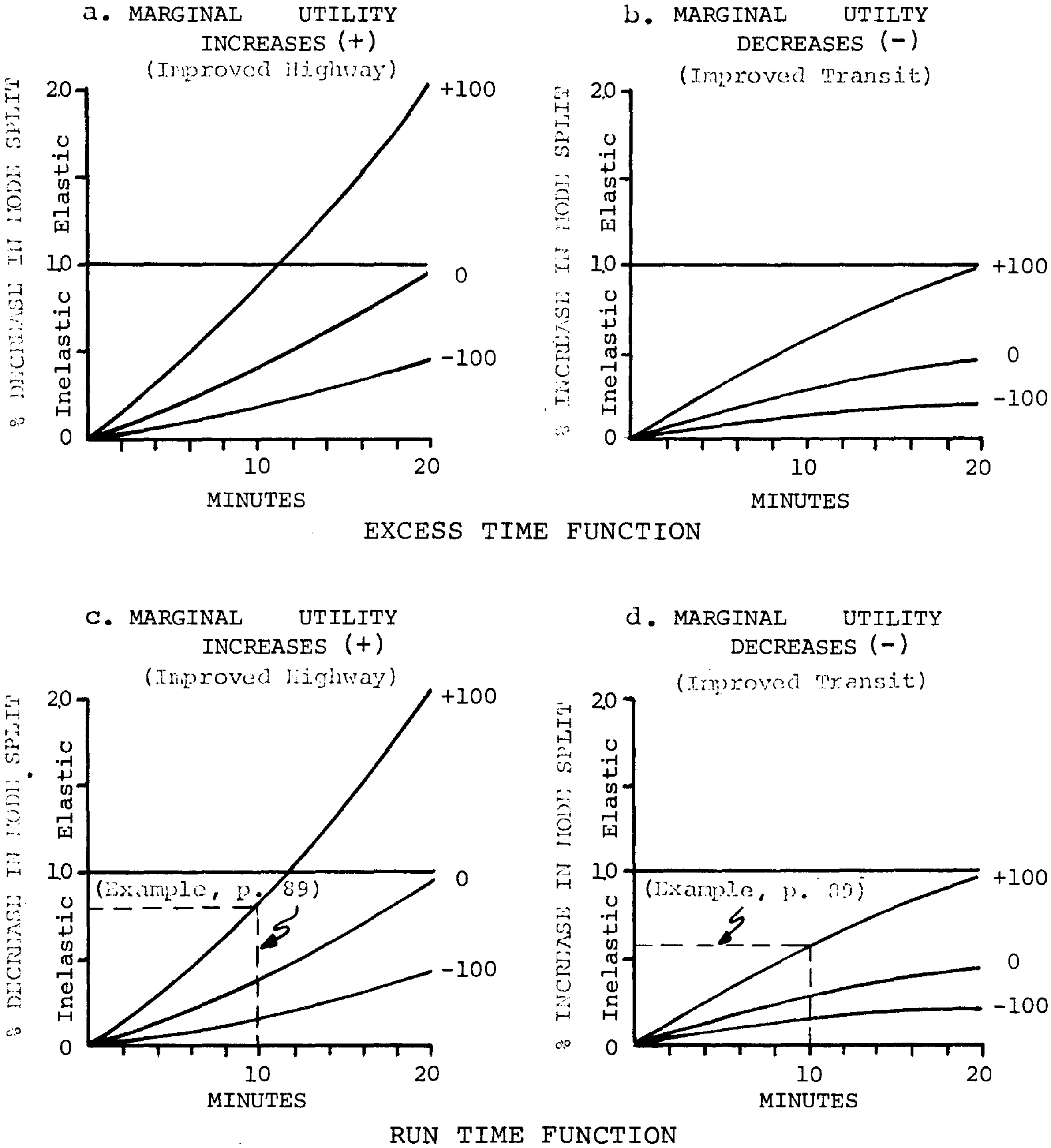
Sensitivity to U-TACV System Parameters

When the elasticity equation shown above is applied to service parameters for the U-TACV system, the relationships shown in Figures 18 and 19 can be developed.

To deal with the base values implied in the coefficient 'B' of the elasticity equation, the concept of 'regional level of service' must be considered. If transit service for any particular interchange is poor, it would be difficult to make enough improvements to yield a major change in transit choice. If however transit service for that interchange were good and mode split was correspondingly high, the change in patronage due to even rather small service improvements would be good.

For each relationship in Figures 18 and 19, three curves are drawn, each representing different regional transit service levels. These curves represent different levels of system quality from elements whose sensitivity is under consideration. The values '+100', '0' and '-100' are the combined base values ('B') of marginal utility, excluding the element being analyzed. They can be interpreted as representing 'low level of transit service' (+100), 'good level of transit service' (0) and 'high level of transit service' (-100), respectively. The entire 1990 Base Regional Transit Network reflects a condition of 'good' transit service (0).

Figures 18 and 19 show elasticity of each parameter in the disutility equation, the percent change in modal split for a



LEGEND: +100 = Low level of transit service
0 = Good level of transit service
-100 = High level of transit service

FIGURE 18

PERCENT CHANGE IN MODAL SPLIT
DUE TO 1% CHANGE IN
OPERATING SYSTEM PARAMETERS

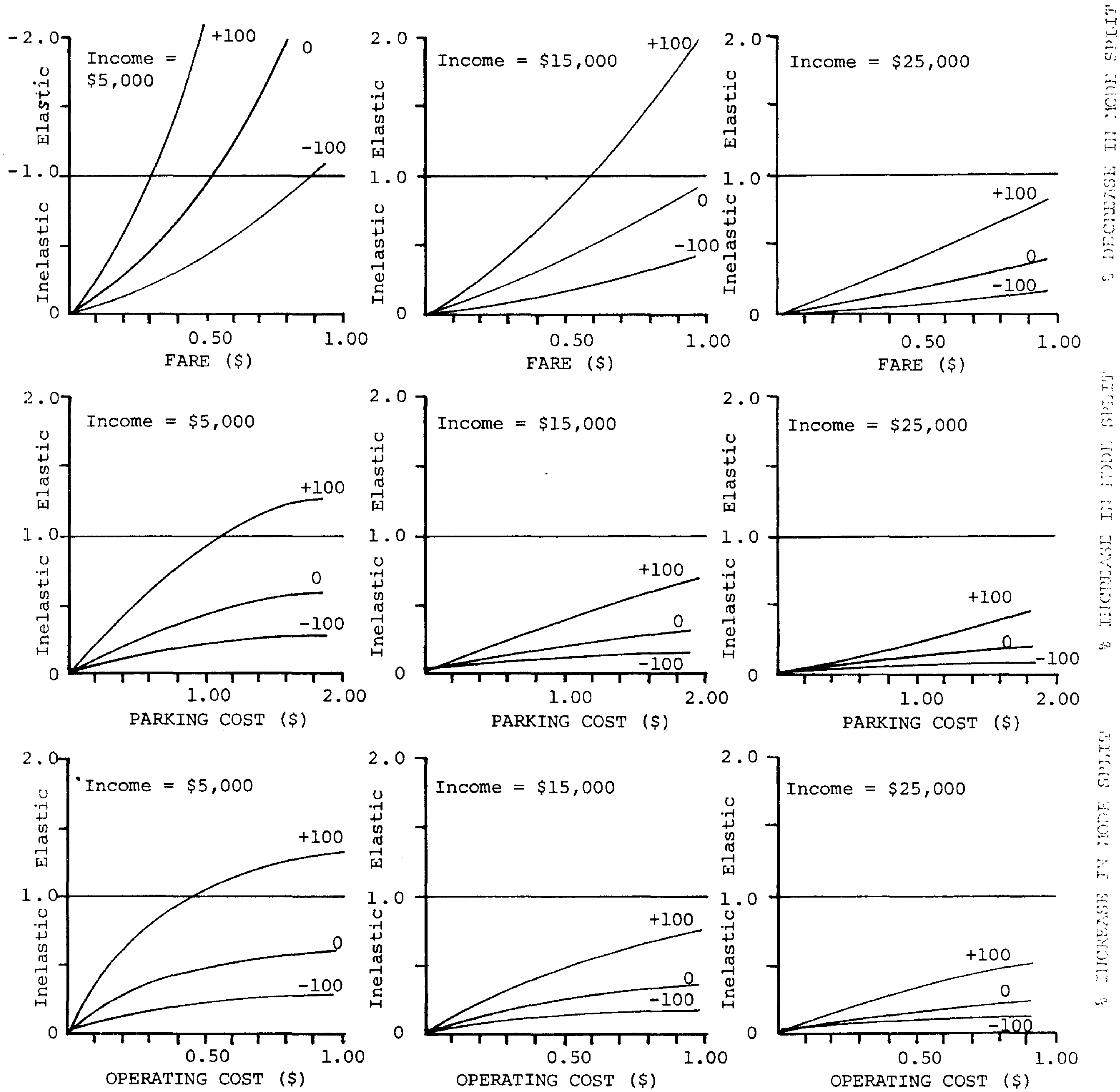


FIGURE 19

PERCENT CHANGE IN MODAL SPLIT
DUE TO 1% INCREASE IN COST

LEGEND: +100 = Low level of transit service
0 = Good level of transit service
-100 = High level of transit service

one percent change in each system parameter. Figure 18d shows an example analysis of the elasticity of modal split with respect to run time. For a particular zonal interchange where transit service is 'low' (marginal utility = +100) and the U-TACV run time is 10 minutes, a 0.6% increase in modal split would occur in response to a 1% decrease in run time. From Figure 18c, a 1% increase in run time would decrease mode split by 0.8%. Both of these effects are less for situations having better transit service (0 and -100). Thus, for good services, service improvements return marginally less for service improvements than for bad services. For bad services, further deterioration yields more decay in mode split than improvements yield increases, but for good services the changes are nearly the same.

Figures 18 and 19 demonstrate that modal split is generally inelastic with regard to U-TACV operating system parameters when the level of transit service is good. When service is not good, changes in the U-TACV system have a much more dramatic effect on patronage. This seems to say that U-TACV service must be especially good in an environment where the subregional systems feeding it do not provide good service. But after a regional system such as R3 is complete, the speed of service in the subject corridor could be varied without drastic effects, e.g., not using U-TACV in the corridor.

The effects of changes in fare, parking cost and income as shown in Figure 19 are predictable. Higher income people are less likely to make a change in mode due to cost adjustments than those from lower income groups since cost variations are less important to them.

For modal split decreases the elasticity is greater than for modal split increases. This is due to the fact that at any point on the extreme values distribution curve, an improvement in service quality would yield fewer passengers than would be lost by an equal decrease in service. This is quite significant for the U-TACV analysis since reducing service on the U-TACV or on any of the systems feeding the U-TACV will result in significant patronage reductions for the U-TACV itself. The magnitude of these changes can be read directly from Figures 18 and 19 by noting the change in marginal utility between the +100, 0, and -100 curves and the resulting patronage changes.

U-TACV PARAMETER OPTIMIZATION

When analyzing the sensitivity of U-TACV patronage to system parameters mathematically, it is possible to examine system optimization. Traditionally optimization has utilized the cost/revenue ratio so a test of the effectiveness of this measure was performed.

Decisions relating to transit service are often concerned with allocating limited financial resources so that maximum return (in terms of service, patronage, etc.) on investment is achieved. For the U-TACV system, for instance, the operating agency could assign any number of vehicles to a particular route (within the range of feasible headways). If more vehicles were added, the cost would increase but patronage and revenue would also increase. It can be demonstrated that for any particular area there is an optimum headway which will minimize the cost/revenue ratio. This relationship of cost/revenue ratio to service (headway) is illustrated generally in Figure 20. A similar analysis can be developed for each of the system attributes in the disutility equation.

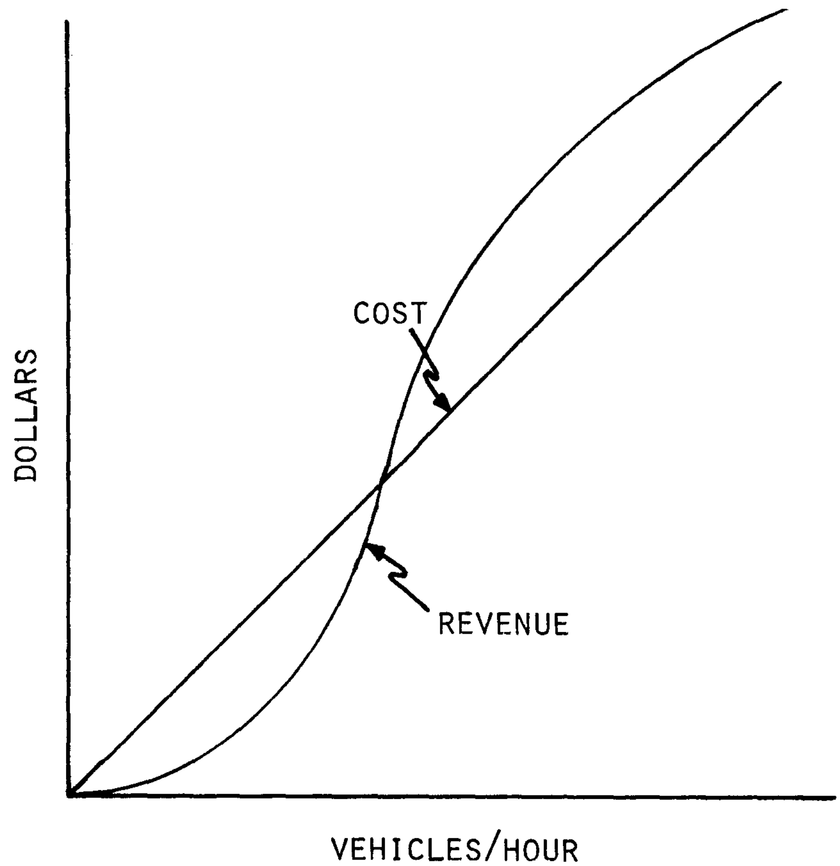
An optimization analysis of U-TACV headway and fare was prepared using the cost/revenue ratio. This was done to see if the cost/revenue ratio could be used to determine the optimum headway and fare for U-TACV.

The mathematical procedure for optimization relies on simple calculus and the extreme values theory. This theory states that if a function is real, continuous and bounded, at least one maximum and one minimum exist. The location of a maximum or minimum point is determined by setting the first derivative of the function to zero. Thus the cost/revenue ratio (C/R) would be optimized if the derivative of the C/R function is zero.

The marginal utility relationship can be simplified as follows, assuming all variables but headway to be constant:

$$U = 2.5\ Tw + K_0$$

Where: U = Marginal disutility
Tw = Headway
K_0 = Combined marginal disutility of all other elements



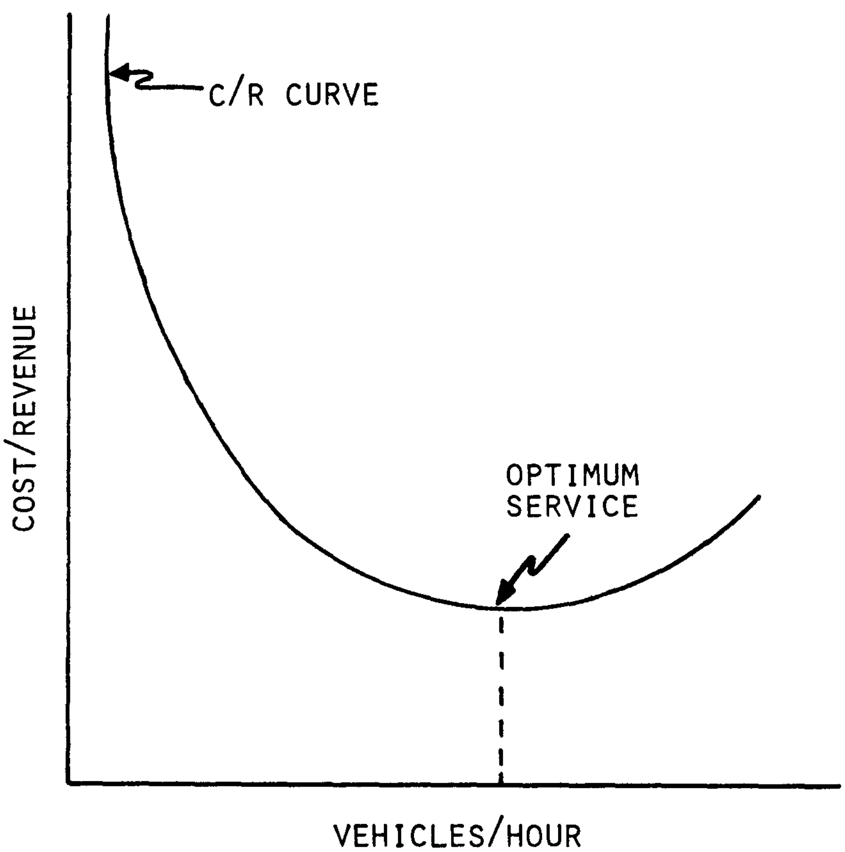


FIGURE 20

OPTIMIZATION OF HEADWAY
SCHEMATIC DIAGRAM

But: $T_w = \frac{1}{2}$ Headway $= \frac{60}{2B}$ (1)

Where: B = Vehicles/hour
$U = 75/B + K_0$

Based on the extreme values distribution, modal split is a function of marginal utility (a variable) and the calibrated constant parameters α and μ:

$$MS = e^{-e^{W}}$$

Where: $W = \alpha(U + \mu)$

$$= \alpha(75/B + K_0 + \mu)$$

which simplifies to: (2)

$$W = 75\,\alpha/B + K_1$$

Where: $K_1 = \alpha(K_0 + \mu)$.

It can be assumed that operating cost is proportional to the number of buses used on a route:

$$C + K_2B \quad (3)$$

Where: C = Cost
K_2 = Proportionality constant

Similarly revenue is proportional to the number of passengers which in turn is proportional to modal split:

$$R = K_3MS = K_3\, e^{-e^{W}} \quad (4)$$

Where: R = Revenue
MS = Modal split
K_3 = (Total person trips)x(fare)

The cost/revenue ratio is calculated from equations (3) and (4) as:

$$C/R = \frac{K_2B}{K_3e^{-e^{W}}} = K_4B\ e^{+e^{W}} \quad (5)$$

This function is minimized by setting the first derivative to zero, i.e.:

$$\frac{d(C/R)}{dB} = \frac{d(K4B\ e^{+e^{W}})}{dB} = 0$$

This simplifies to: $$B\ e^{W} \left(\frac{dW}{dB}\right) + 1 = 0 \qquad (6)$$

From above: $$\frac{dW}{dB} = \frac{d(75\alpha/B + K_1)}{dB}$$

$$= \frac{-\ 75\alpha}{B^2}$$

Therefore equation (6) becomes: $$\frac{75\alpha}{B}\ e^{W} = 1 \qquad (7)$$

The optimum cost/revenue, as a function of the number of vehicles, is given by combining equations (5) and (7) as:

$$C/R = K_4\ B\ e^{B/75\alpha} \qquad (8)$$

This can be demonstrated graphically by plotting representative values of C/R for three levels of marginal utility (K_0) as shown in Figure 21.

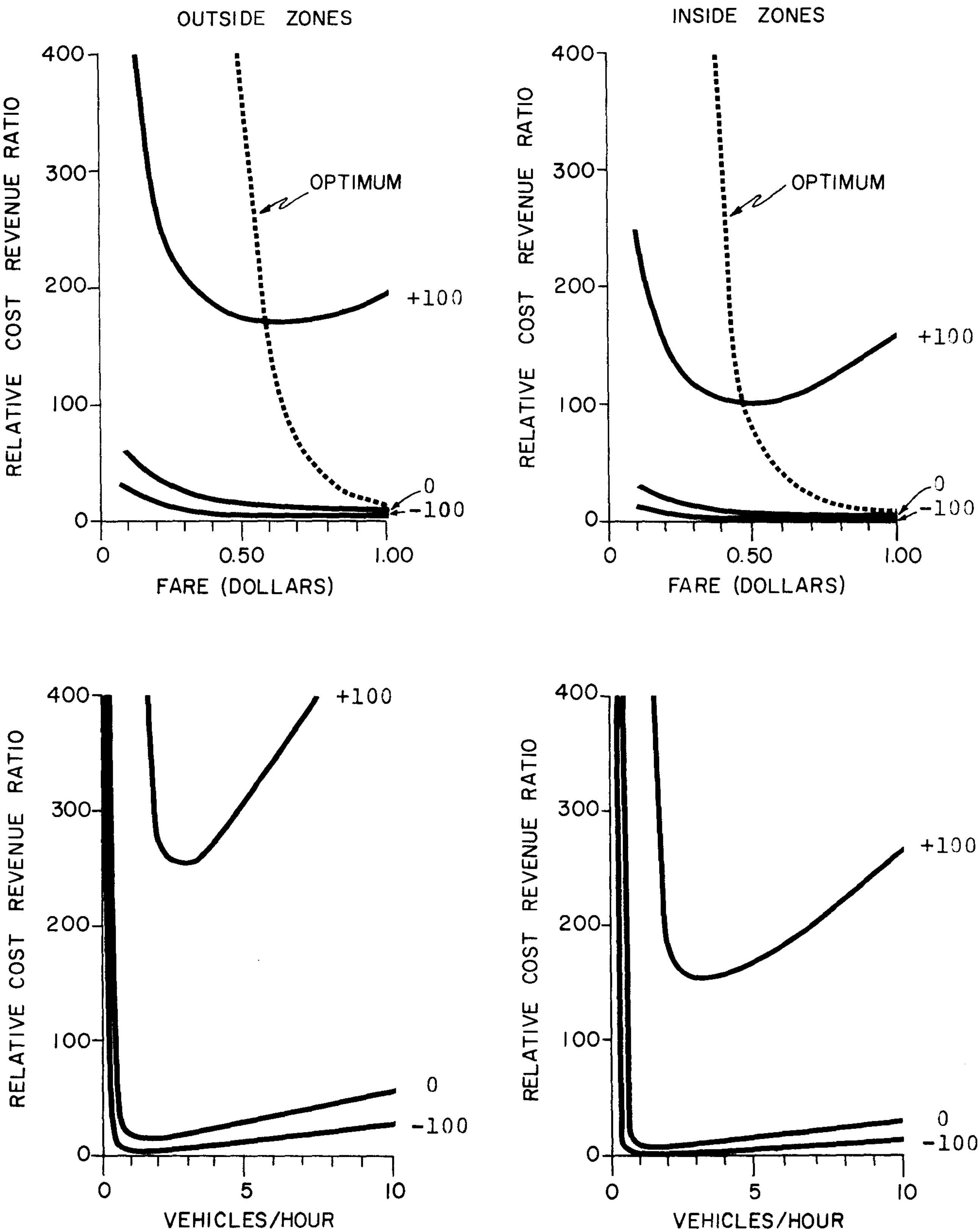
In a similar manner it can be shown that transit fare can be optimized with respect to the cost/revenue ratio. Equations (7) and (8) are paralleled in the fare analysis by:

$$\frac{A\ \alpha\ F}{1}\ e^{W} = 1 \qquad (9)$$

and $$C/R = \frac{K_4\ e^{\ I/A\ \ \alpha F}}{F} \qquad (10)$$

Where: $A = 2080(60)4$

Fare curves are also shown in Figure 17.



LEGEND: +100 = Low level of transit service
0 = Good level of transit service
-100 = High level of transit service

FIGURE 21

SYSTEM PARAMETER OPTIMIZATION

Figure 21 is a rich source of information pertaining to general principles of U-TACV system design. Most notable is that the optimum headway provides such a low level of service. This figure indicates that one vehicle, every 45 minutes to an hour, would yield the maximum return for investment. Such service, however, would likely be unacceptable for work trips in the peak period and quite possibly would be overruled by load factor criteria or general service policy for the U-TACV system.

The optimum headway curve also points out a weakness in the specification of marginal utility which must be assessed. The U-TACV system is oriented to three high-density nodes, the two central business districts and the Regional Airport. With these orientations the work trip, shopping trip and air passenger trip will be important service considerations. Work and air passenger trips must be made so that the trip is completed before some prescribed time. If headways are long the patron may have to leave his home earlier than he would like and be faced with a period of dead time at his destination.

This dead time can be thought of as transit 'terminal time' and is relatively unimportant when headways are less than about one-quarter hour. But it begins to become a significant factor beyond that. The transit terminal time does not yield readily to detailed analysis. Longer headways are uncommon in most systems and when long headways do occur, the schedules are arranged to minimize transit terminal times. Thus in actual surveys the terminal time phenomenon is usually statistically insignificant relative to other access time components.

For the U-TACV system the effect of the transit terminal time can be evaluated by analysis of a hypothetical condition where schedule arrangement does not attempt to minimize terminal time. Such a condition would be approximated if a number of routes connecting to U-TACV had long terminal times or if work hours or airline departures were broadly staggered. In such cases the transit terminal time for U-TACV would approach one-half the headway and the total excess time component would be:

$$E = T_A + T_W + T_T,$$

But $T_T = T_W = \frac{1}{2}$ Headway

Therefore $E = T_A + 2T_W$

The effect of transit terminal time on the cost/revenue ratio optimization curve is also shown in Figure 21. In actual system design the true optimization curve would lie somewhere between the two curves shown, depending upon specific scheduling and other system details.

Another interesting conclusion from Figure 21 is that the optimum level of fares ranges from $.40 up. The optimum fare curve tends also to level off rapidly as fares are raised, indicating that the cost/revenue ratio is not particularly sensitive to fares if the other disutility components are such that a high level of transit service is provided. In other words at such levels of operation the gain in revenue by increased fares would be very nearly matched by loss in patronage.

From consideration of optimization of U-TACV headway and fare based upon the cost/revenue ratio, it is apparent that the level of service provided at 'optimum' levels of cost/revenue would be unacceptable on a service basis. This indicates that maximization of revenue and minimization of cost are not sufficient to give even a rough indication of an optimum system. The planner must achieve a tolerable deficit/service level rather than simply optimizing mathematically.

The mathematical sensitivity analysis, elasticity analysis and parameter optimization do not replace the judgment of the system designer and policy makers. These techniques are tools to aid in analysis of the U-TACV system and must be used within the context of the engineering, cost and political factors that affect system feasibility. The mathematical sensitivity analysis is important however because proper use of these tools can be invaluable to U-TACV system planners as the concept becomes reality.

These analyses have been based on the assumption that the R3 Regional Public Transportation System would be operating to provide service to the U-TACV system. If those facilities are not built the effects on patronage of changes in various operating factors could be quite different than those shown. This is the reason for showing conclusions for three levels of transit service. If the R3 system utilized as input to this analysis is not constructed, the effect of operating parameter changes on ridership will increase. The mathematical sensitivity is not linear in nature; if less than half the regional system is constructed, it can be expected that the sensitivity of patronage to U-TACV operating parameters will be greater than twice that at the base level.

SUB-AREA ANALYSIS

Sub-area analysis procedures are methods for studying in detail selected areas within a larger system. The primary advantage in using the sub-area technique is the ability to examine any reasonable detail of selected areas repeatedly at a minimum cost, within the context of the trip-making characteristics of the region.

The purpose of the sub-area analysis was to examine the U-TACV operating parameters and operation of the feeder/distribution systems in the U-TACV corridor to ascertain their impact on U-TACV patronage. This procedure, along with the mathematical sensitivity analysis, provides a comprehensive set of techniques for definitive evaluation of the U-TACV patronage.

The U-TACV sub-area analysis was performed in two distinct steps. The first step was 'detailing'. The detailing was done by preparing the R3 transit network in a way to ease the sub-area analysis. The detailing made use of specially fine-grained levels of zonal, line-haul and feeder/distribution configuration within the sub-area (U-TACV corridor) and progressively more aggregated levels outside the area. The areas of differing zonal detail are shown in Figure 5 .

By properly detailing the 1990 R3 regional transit network when it was coded initially, an additional step to develop a sub-area network was avoided.

The second step for sub-area analysis was 'isolating'. This involved separating the U-TACV corridor from the rest of the regional network and area for detailed subarea analysis. The U-TACV sub-area was somewhat larger than the area for which detail was needed. This was to assure that major activity areas such as the CBD's and places where substantial access and egress would be provided were included. The sub-area chosen closely paralleled the first level of zonal detail shown in Figure 5 .

Sub-Area Procedures

In order to accomplish the isolation of the U-TACV sub-area from the rest of the R3 transit network it was necessary to develop a schematic network. The schematic network was a very much simplified representation of the R3 transit network in the sub-area. The schematic network was used with a specialized computer program to extract trips using that portion of the regional transit system which was in the sub-area from trips throughout the rest of the system. The details of this procedure are described in a memorandum prepared as part of the Multi-Modal Program.[29] The results were trip tables of all person and transit trips in the U-TACV corridor.

The sub-area transit network was then extracted from the full R3 regional transit network. This was done to test the effects of changes in various factors on transit travel in

29 "Procedures for Transit Subarea Analysis", op. cit.

the corridor. The sub-area transit network was prepared by reprocessing data for the detailed transit network in the sub-area to obtain an independent U-TACV corridor network.

After the trips and network for the U-TACV sub-area were isolated, alternative schemes for the U-TACV system and its feeder network were developed and tested. Conditions in the rest of the region were assumed constant for these tests. The marginal utility changes resulting from system changes were processed, and the resulting modal split change was computed. The transit ridership resulting from the revised modal split was then compared with base values to determine the net effect of the service changes tested.

The procedure allowed for economical and effective analysis of several alternatives within the sub-area and provided for regional integrity of the total person trip-making characteristics. For the sub-area tests it was assumed that the distribution of regional trips would remain the same and that only the modal split percentages would vary, due to changes in sub-area service characteristics.

Sub-Area Test Schemes

Initially, a test was performed using only the base system in order to examine the validity of the sub-area model. The results of this test were within 4 percent of the total ridership isolated for the U-TACV corridor from the 1990 regional modal split analysis. This total transit ridership became the basis to which each of the alternative schemes was compared. Using information from the mathematical sensitivity analysis as guidelines, several sub-area tests were performed to quantify the impact of variables considered the most significant for U-TACV patronage. Three alternative schemes were tested:

- Accessibility of U-TACV feeder/distributor systems
- U-TACV operating cost characteristics
- U-TACV station accessibility.

Alternative 1: Accessibility of U-TACV Feeder/Distributor Systems

The purpose of this scheme was to quantify the impact of providing a lower level of feeder/distributor service within the U-TACV intensive study area. Providing headways of 20 minutes on all feeder buses serving sub-area origins and destinations during the peak hour resulted in a 12 percent decrease in total transit ridership. This can be interpreted to mean that a decrease in the level of service provided on feeder/distributor systems can have a major impact on sub-area patronage regardless of the level of service provided in the non-sub-area corridors.

Alternative 2: U-TACV Operating Characteristics

The second scheme examined the impact of reducing the level of service, specifically line-haul frequency, on the U-TACV express and local service. This scheme compared a composite headway of 10 minutes on the U-TACV alignment as opposed to the 2.5-minute headway used in the 1990 regional test. Results of this test indicated an 8 percent decrease in the total transit ridership. In retrospect, however, the full impact of frequency variation is largely dependent upon the line-haul facilities provided in the non-U-TACV corridors. The 8 percent decrease therefore represents the impact on U-TACV patronage in the sub-area only, with a high level of transit service in the non-U-TACV corridors.

Alternative 3: U-TACV Station Accessibility

Three stations west of the Airport Station and two stations east of the Airport Station were removed from the U-TACV local line operation. These stations represented the lowest projected usage as observed in assignment for the full R3 system. Results of this test yielded only a 2 percent decrease in total transit ridership. Closer examination at each subset of zones served by the removed stations indicated that either (1) the additional transit run time incurred to reach the U-TACV service was not significant; or (2) the amount of transit patronage originally served was relatively small.

V. REVENUE AND OPERATING COSTS

Revenue and operating costs for the U-TACV system were prepared from traffic estimates for 1980 and 1990. The 1990 traffic estimates used were those for the most likely case rather than the optimistic estimate. The reason for this was that the most likely traffic estimate was consistent with the physical facilities provided for which cost estimates had been prepared as part of the engineering studies in this program. The vehicular requirements to handle the demands of the optimistic patronage estimate would have dictated significantly larger stations and materially changed other aspects of both construction and operation from those which were assumed for the physical facility design and cost estimating.

REVENUE ESTIMATES

Estimates of the revenue for the U-TACV system were calculated by proportioning total regional system revenues to individual operating components based upon the passenger miles of service provided by each component. The basic revenue per day for each patronage estimate was calculated by multiplying the transit trip table (zone-to-zone transit trips) by the zone-to-zone fare matrix. The fare matrix included initial boarding fares as well as transfer and zone fares and was prepared as part of the transit network processing. The average daily revenues are summarized in Table 11. Revenue shown for

TABLE 11

REVENUE ESTIMATES
INTERCITY U-TACV SYSTEM
(1980 and 1990)

	1980	1990	2000**
Daily Total System Riders	571,100	1,094,300	1,451,400
Daily Total System Passenger Miles	6,867,900	10,000,800	13,965,400
Daily Total System Revenue	$ 261,500	$ 482,700	***
Daily U-TACV Riders	115,600	146,600	204,200
Daily U-TACV Passenger Miles	2,011,100	2,294,600	3,059,900
Daily U-TACV Allocated Revenue	$ 76,600	$ 110,800	$ 147,800
Annual U-TACV Estimated Revenue*	$24,435,400	$35,345,200	$47,148,200

* Based on annualization of 319; see Table 12, p. 116.

** High level patronage estimate for 1990, would occur in about 2000 under normal growth.

*** No detailed revenue estimates were prepared for the high level patronage estimates.

the year 2000 is based upon the high level patronage estimate, believed achievable by the year 2000 if patronage grows at normal rates between 1980 and 1990. Revenues shown in the table were estimated for the entire system operating on an average day in the year indicated.

The table also indicates the average daily ridership of the U-TACV system in each of the forecast years. The major factor in the increase between 1980 and 1990 is completion of the regional system. The increase between 1990 and 2000 is primarily attributable to the change in development patterns which will occur after the regional system is built, providing more development within good accessibility of the transit system. It is this kind of development and patronage impact which is difficult to forecast without an extensive iterative travel forecasting and activity allocation process.

The basis for allocating revenues among the various services in the regional system was the passenger miles of service provided by each mode and line. The proportion of total passenger miles provided by U-TACV was used because it allocates revenue generated in accordance with service provided rather than merely tabulating fares collected on the U-TACV system. The latter approach would have understated U-TACV revenue because the remainder of the regional system fed U-TACV. The percentage of total passenger miles on U-TACV was multiplied by the total daily system revenue to obtain the revenue allocated to the

U-TACV system for an average day. The daily revenues were then factored by an annualization factor of 319 to obtain an estimate of annual revenue for the U-TACV system. Allocating revenues to the various components of the regional system in this manner may appear to be somewhat arbitrary, but it is in fact quite equitable, being perfectly consistent with the passenger service provided by each aspect of the regional system. Use of this procedure permits returning to the various system components, in the record books at least, compensation for the amount of service to passengers they have provided. This approach does, however, tend to over-reward higher capacity systems which usually also serve longer trips. Such systems also usually have higher operating costs in order to provide the higher capacity, higher speed service.

OPERATING COST ESTIMATES

The operating costs for the U-TACV system were prepared using procedures developed by the Rohr Corporation. Rohr has done extensive work in cost analysis of the operation of their prototype vehicle and was able to provide valuable inputs with respect to the amount of power required to operate that vehicle. In addition, however, Rohr has also prepared estimates of the cost to operate all other aspects of a complete U-TACV transit system. They have cooperated extensively with all contractors on this project, providing several different operating cost estimates based upon different types of operation. The cost estimates described here were prepared as part of this study but were based upon the techniques and procedures used by Rohr in previous estimates.

The operating cost estimates were accomplished in several discrete steps, each of which will be described here briefly along with summaries of the results. The details of these cost estimates are provided in Table 12 subsections whose numbers correspond to numbers in each section heading. Detailed backup for many of the assumptions and factors in the Rohr estimates that were used here are provided in a separate Rohr report.[30]

I. Operating Plan

The basic element of the cost of operating the U-TACV system is determining the amount of service that will be provided. That service dictates the operating plan, which describes how trains will be operated throughout the day, the week and the year. The operating plan designed for purposes of preparing the operating cost estimates is described in Table 12.

U-TACV trains would be operated in local and express modes. Local trains would stop at every station. Express trains would stop only at two stations in downtown Fort Worth, at Loop 820

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30 "System Cost Analysis", Urban Tracked Air Cushion Program, Phase II, Report 2.16, Rohr Industries, Inc., April, 1973.

TABLE 12

I. OPERATING PLAN

U-TACV OPERATING COSTS

Time From–To	Hours	LOCAL Daily Hdwy.	LOCAL Daily Cnst.	LOCAL Daily Train Trips	LOCAL Daily Car Trips	LOCAL SS & H Hdwy.	LOCAL SS & H Cnst.	LOCAL SS & H Train Trips	LOCAL SS & H Car Trips	EXPRESS Daily Hdwy.	EXPRESS Daily Cnst.	EXPRESS Daily Train Trips	EXPRESS Daily Car Trips	EXPRESS SS & H Hdwy.	EXPRESS SS & H Cnst.	EXPRESS SS & H Train Trips	EXPRESS SS & H Car Trips
2400-0500	5	--- No Service								--- No Service							
0500-0700	2	10	4	12	48	15	2	8	16	--- No Service							
0700-0900	2	5	5	24	120	15	4	8	32	5	6	24	144	15	4	8	32
0900-1600	7	10	4	42	168	15	4	28	112	0	4	42	168	15	4	28	112
1600-1800	2	5	5	24	120	15	4	8	32	5	6	24	144	15	4	8	32
1800-2400	6	10	4	36	144	15	2	24	48	--- No Service							
Annual Vehicle Trips						179,040								135,360			
Total	24			138	600			76	240			90	456			44	176

	Local Daily	Local SS & H	Express Daily	Express SS & H
Daily Car Miles @ 79.2 (two ways)	47,520	19,008	36,116	13,940
Annual Miles 254 daily, 111 SS & H	12,070,080	2,109,888	9,173,464	1,547,340
Daily Hours: Express - 52 min. Train:	225	124	78	38
Local - 98 min. Car:	980	392	395	153
Annual Hours: 254 daily Train:	57,251	13,779	19,812	4,233
111 SS & H	248,920	43,512	100,330	16,983

Total Annual Miles in Daily Service: 21,243,544
Total Annual Miles in SS & H Service: 3,657,228
Total Annual Miles in All Services: 24,900,772

Total Annual Hours:

	Train	Car
Daily:	77,063	349,250
SS & H:	18,012	60,405
Total:	95,075	409,655

TABLE 12

U-TACV OPERATING COSTS

Time		LOCAL						EXPRESS					
		Daily			SS & H			Daily			SS & H		
From	To	Train Trips	Equiv. Vehs.	Equiv. Veh. Trips	Train Trips	Equiv. Vehs.*	Equiv. Veh. Trips	Train Trips	Equiv. Vehs.	Equiv. Veh. Trips	Train Trips	Equiv. Vehs.	Equiv. Veh. Trips
2400	0500	---	---	---	---	---	---	---	---	---	---	---	---
0500	0700	12	3.5	42	8	2	16	---	---	---	---	---	---
0700	0900	24	4.25	102	8	3.5	28	24	5	120	8	3.5	28
0900	1600	42	3.5	147	28	3.5	98	42	3.5	147	28	3.5	98
1600	1800	24	4.25	102	8	3.5	28	24	5	120	8	3.5	28
1800	2400	36	3.5	126	24	2	48	---	---	---	---	---	---
Annual Vehicle Trips				519			218			387			157
Total (Annual)				131,826			24,198			98,298			17,094
Daily Car Miles @ 79.2 (two ways)					156,024						115,392		
Annual Miles } 254 daily 111 SS & H							271,416						

* Equivalent Vehicles: because of aerodynamic drag effects, interior vehicles on trains having more than two cars require less power for motive force (Table 12, Section V, p. 116).

in Fort Worth, at the Airport, at Loop 12 in Dallas and at the Dallas Union Terminal. No U-TACV trains would be operated from midnight to 5:00 in the morning. Local service only would be operated between 5:00 A.M. and 7:00 A.M. and between 6:00 P.M. and midnight. For two-hour peak periods in the morning and afternoon, both local and express trains would be operated at five-minute headways, an effective 2.5-minute headway for the system. Between 9:00 A.M. and 4:00 P.M. both local and express trains would be operated at ten-minute headways, providing an effective five-minute headway for the entire system. U-TACV service on Saturdays, Sundays and Holidays would be operated at fifteen-minute headways from 5:00 A.M. to midnight. Express service would be operated only between 7:00 A.M. and 6:00 P.M., the same as daily operating hours for the express line.

II. Operating Assumptions

A. Trip Time Allocation - Train operations analysis prepared by PBQ&D as part of the engineering studies indicated that the express trains could make a round-trip in 52 minutes. Local trains would require 98 minutes for a round-trip. Based upon the operating characteristics and station stopping plans described previously, it was calculated that express trains would spend about 59 percent of each trip at cruise speed, 28 percent accelerating and decelerating and 13 percent in stations. Local trains would spend 43 percent of their trip at

TABLE 12

U-TACV OPERATING COSTS

II. OPERATIONS ASSUMPTIONS

	Total	Dwell	Cruise	Acceleration & Deceleration
A. Express Trip Time -	52 min.	6.75 min.	30.71	14.54 min.
Percent of Trip	100.0	13.0	59.0	28.0
Local Trip Time -	98 min.	8.00 min.	42.1	47.9 min.
Percent of Trip	100.0	8.2	43.0	48.8

Acceleration & Deceleration 0 ⟷ 150 mph requires 0.8340 min.

Local Trains - 14 stations, 2 direction, accel. + decel. } (0.834) (2) (2) (14) = 46.70
City Center to Fort Worth - 36 sec., twice 1.20
47.90 min.

Express Trains - 4 stations, 2 direction, accel. + decel. } (0.834) (2) (2) (4) = 13.34
City Center to Fort Worth - 36 sec., twice 1.20
14.54 min.

Dwell: Local Trains - 15 stations twice at 15 sec. = 450 sec.
Turnaround at Union Terminal = 30 sec.
480 sec; 8.0 min.

Express Trains - Airport 60 sec., twice = 120 sec.
Union and Texas Stadium 30 sec., twice = 120 sec.
Fort Worth and Loop 820 30 sec., twice = 120 sec.
City Center = 15 sec.
Turnaround at Union Terminal = 30 sec.
405 sec; 6.75 min.

		Trip Time	Headway 5^m	Headway 10^m	Headway 15^m
B. Trains Required:	Express	52m	11	6	4
	Local	98m	20	10	7

C. Consists Required:	1980 Local	1980 Express	1990 Local	1990 Express
Maximum load point volumes	25,100	46,900	35,800	42,700
Using 17% peak hour, 70% directional	3,000	5,600	4,300	5,100
Using 80 passengers per car and 5^m headways	3.1	5.8	4.5	5.3
	4	6	5	6
Actual Load Factor	1.04	1.30	1.19	1.18
(Crush Load Factor = 1.33)				

cruise, 49 percent accelerating and decelerating and 8 percent in stations. The lower percentage of time in station dwell for local trains is due to the fact that the trip is longer; the lower percentage yields a greater amount of time spent in station dwell. In addition, express trains have longer dwell times than local trains, primarily to facilitate handling of baggage. Table 3 in Chapter III lists the station dwell times for local and express service at each station. These figures are primarily important for calculating the power requirements for operating U-TACV trains.

B. Trains Required - The number of vehicles required to operate the system are calculated by considering the time necessary for a round-trip for each service and the number of vehicles on each train during peak periods. For local trains requiring 98 minutes for a round-trip, 20 discrete trains are required to maintain a five-minute headway. For express trains, which require only 52 minutes for a round-trip, 11 trains are required to maintain a five-minute headway.

C. Consists Required - The maximum load point volumes for local and express trains in 1980 and 1990 dictated the peak period vehicle demand. In 1980, 38 vehicles on local trains and 70 vehicles on express trains would be required; in 1990 the vehicle requirements were 54 for local and 64 for express trains. Four-car local trains and six-car express trains in 1980 and five-car local trains and six-car express trains in 1990 would be necessary to handle the traffic estimated at the headways specified.[31] Train lengths were reduced somewhat in off-peak hours and for Saturday, Sunday and Holiday service. For these consists and the patronage estimated, it is anticipated that peak period load factors for local trains will be approximately 1.19 in 1990 and 1.04 in 1980, and for express trains 1.18 in 1990 and 1.30 in 1980. Crush load estimated by the Rohr Corporation for 60-seat vehicles is 1.33 or 80 passengers. The operating plan and consists described require approximately 314,400 annual vehicle trips. There would be 21,243,500 annual vehicle miles in daily service and 3,657,200 annual vehicle miles in Saturday, Sunday and Holiday service, totalling 24,900,700 annual vehicle miles. Daily car hours were estimated at 349,200. Saturday, Sunday and Holiday car hours were 60,400 for total annual car hours of 409,600. The annualization of operating figures was based upon 254 average weekdays and 111 Saturdays, Sundays and Holidays.

D. Vehicles Required - In 1980 the peak period consist would be four vehicles for local operation and six vehicles for express. Adding 10 percent of the total peak vehicle fleet for spares dictates that a total vehicle buy for 1980 operation would be 161 vehicles. For 1990 operation express consists would still be six cars, but local consists would be five. Assuming that 10 percent spares would be adequate, a total buy of 183 vehicles would be necessary.

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31 Assumes entrainment possible and stations would be long enough to handle multiple-car trains.

E. Annualization - It was found that 16 percent of the riders on the U-TACV system were air passengers or visitor related travelers. It was assumed that an annualization factor for these types of trips should be 365. For the other 84 percent of the trips on the U-TACV system a conventional annualization factor of 310, assuming approximately half service on Saturdays, Sundays and Holidays, would be appropriate. Weighting the annualizations by these two proportions indicated that the appropriate annualization for the entire system would be approximately 319.

III. Annual Patronage

Daily passengers for each year would be multiplied by 319 to obtain total annual passengers on the system. For 1990 the most likely patronage estimate was 46,765,400 per year, based on a daily ridership of 146,600 on the intercity portion of the line. This estimate assumes that the full R3 Regional Transit System would be in operation to carry riders to the U-TACV system. The 1980 daily patronage estimate was 115,600 and 36,876,400 annually.

IV. Annual Revenue

As indicated in the first part of this chapter, the estimated revenue is calculated by prorating total regional system revenue according to the number of passenger miles served by each system component. The U-TACV system in 1990 provided

TABLE 12

U-TACV OPERATING COSTS

D. Vehicles Required:

	(L) 1980	(E)	(L) 1990	(E)
Peak Trains	20	11	20	11
Peak Consist	4	6	5	6
Vehicles Operated	80	66	100	66
Spares (10%)	8	7	10	7
Total Vehicles	161		183	

E. Annualization:

16% of TACV riders to/from Airport (365 days)(.16)
84% conventional traffic pattern (310 days)(.84) } 319

III. ANNUAL PATRONAGE: 146,600 * 319 ≅ 46,765,400 (1990)
115,600 * 319 ≅ 36,876,400 (1980)

IV. ANNUAL REVENUE: U-TACV passenger miles = 2.295 million (22.9%)(1990)
2.011 million (29.3%)(1980)

Daily System Revenue	\$482,700 (1990)	\$261,500 (1980)
Daily U-TACV Revenue	\$110,800 (1990)	\$ 76,600 (1980)

U-TACV Annual Revenue \$35.345 million (1990)
\$24.435 million (1980)

V. DRAG REDUCTION ADJUSTMENT FOR INTERIOR CARS

Based on DOT Studies: $\frac{400}{1250}\left(\frac{\text{Drag}}{\text{Total}}\right)$ = 32% required to overcome aerodynamic drag

Reduce 400 x 75% = 300: $\frac{950}{1250} \cong$ 75% power required for interior vehicles

	Interior		End		Equivalent
2 Car Train	0		2		2
3 Car Train	(1 x .75)	+	2	=	2.75
4 Car Train	(2 x .75)	+	2	=	3.5
5 Car Train	(3 x .75)	+	2	=	4.25
6 Car Train	(4 x .75)	+	2	=	5.0

Weighted Vehicles, Peak Loading:
Local Trains = 20
Consist = 5 } 20 x 4.25 = 85

Express Trains = 11
Consist = 6 } 11 x 5 = 55
140 peak equivalent vehicles operating

VI. DEMAND REQUIREMENTS

		Local		Express	
	HP	% Time	Usage	% Time	Usage
Acceleration	4650	24.4	1135	14.0	651
Deceleration	-1870	24.4	-456	14.0	-262
Cruise	2700	43.0	1161	59.0	1593
			1840		1982
Equivalent Peak Vehicles Operating			85		55
			156,400		109,010

22.9 percent of the total passenger miles. The total average daily revenue for the entire regional system was estimated at $482,700 of which $110,800 was allocated to the U-TACV system based upon its proportion of passenger miles of service provided.[32] Annualizing the daily revenue with a factor of 319 used for calculating annual patronage, the 1990 U-TACV system revenue was estimated at $35,345,200. This revenue is based upon 1967 dollars and the basic fare structure reported previously having a 25¢ initial boarding fare. The 1980 daily allocated revenue was $76,600, and the annual revenue in 1980 was estimated as $24,435,400.

V. Drag Reduction Adjustment

Studies done for the U.S. Department of Transportation have indicated that 32 percent of power requirement for U-TACV vehicles is required to overcome aerodynamic drag. It was reasoned however that a considerable amount of this drag would be reduced on interior vehicles of trains having more than two cars. Accurate estimates of the amount of reduction in drag that would be achievable were not immediately available from Rohr, but indications were that 75 percent reduction in aerodynamic drag would be possible. This would yield a reduction in power required for acceleration, deceleration and cruise for interior cars of about 25 percent.

32 In terms of 1967 constant value dollars. Inflation effects will be dealt with in "Financial Analysis", Wilbur Smith & Associates,

In order to simplify power requirement calculations, an equivalent train length was calculated assuming that interior cars of multiple-car trains would require only 75 percent of the power of exterior vehicles. Thus the equivalent train length of a two-car train would be two, but for a six-car train it would be five. In the latter case, four cars require 75 percent of the power of lead and trailing vehicles, effectively requiring the power of three cars; adding the leading and trailing vehicles yields the five-car equivalent train length estimate.

VI. Demand Requirements

The most important aspect of information provided by Rohr was the amount of horsepower (HP) required by the U-TACV system for acceleration, deceleration, cruise and dwell. Accelerating at 3 mph/second from 0 to 150 mph requires 4650 HP. Decelerating at the same rate using regenerative LIM (linear induction motor) braking yields an equivalent of 1870 HP. When cruising, the vehicles require 2700 HP apiece. In dwell, i.e., when they are not moving, vehicles consume 825 HP for levitation only.

To calculate power demand requirements a weighted peak demand was estimated. To do this the percent of time accelerating, decelerating and cruising was multiplied by the horsepower required for each. This was done individually for local and express services. The number of equivalent peak vehicles operating was then multiplied by the total housepower required for operation. To that was added the horsepower required for dwell.

The results indicated that total peak power demand for local trains was 163,000 HP. For express trains the peak power demand was 116,000 HP. Adjusting for terrain and converting to kilowatts, the total peak power demand for train operation was approximately 218,500 kilowatts. The power required for operating stations and yards was estimated at 4,250 kilowatts. Assuming losses were 18 percent, the total peak power demand for the system was estimated at 262,850 kilowatts, which is approximately 26 percent of the current capacity of the Texas Electric Service Co. in Tarrant County.

VII. Energy Required

Calculation of the energy necessary for operating the system required computing the number of horsepower hours, for each service individually, necessary to operate trains throughout the year. The horsepower required for each aspect of the trip, acceleration, deceleration, cruise and dwell, was multiplied by the amount of time that horsepower was needed. Each trip of an express train required 1719 HP hours. Each local train trip required 3005 HP hours. These were multiplied by the annual equivalent vehicle trips considering reductions in the power requirements for interior vehicles. Dwell power, of course, was then multiplied by true annual vehicle trips since aerodynamic drag is not reduced when vehicles are not moving.

Total power required for express train operation in a year is 210,947,300 HP hours. Local train operations require 488,546,500 HP hours annually. These estimates were for the 1990 system operation and would be reduced only slightly for 1980 operation because of the smaller consists for local trains. Adjusting for terrain factors and converting to kilowatts yielded an annual energy requirement of 550,260,270 kilowatt hours.

For 16 stations operating 19 hours a day, 365 days a year, and yards and shops operating 24 hours a day, 310 days a year, 31,460,000 kilowatt hours annually would be required. Considering losses of 18 percent, the total energy demand for the system for 1990 was estimated at 686,429,900 kilowatt hours.

VIII. Power Cost

Based upon rates for power supplied by Texas Electric Service Company, it was estimated that demand charges for the system for an entire year would be approximately $4,078,600. Energy charges would be approximately $3,787,500 per year. Total power costs would be $7,866,100.

IX. Other Operations Costs

Appropriate wage rates for labor classes employed in the system were estimated at $7.00 for train operators and mechanics, $5.00 for station attendants and $10.00 for train controllers. These rates were factored by 1.11 to reflect that such people would be paid for 2080 hours although working only 1872 hours. This accounts for 13 days each vacation and sick leave. From the operating schedule described previously, the number of manhours for train operations was calculated at approximately 113,116 annually. At $7.78 an hour, this would mean a cost of $880,000 annually for train operation. Train controllers costs were estimated at $623,700. At five major stations there would be two attendants. At 11 others there would be only one attendant. The cost for station attendants was calculated to be $1,943,400.

Maintenance costs were of several types. Labor costs for maintenance of way and structures was estimated at $686,300 for 123,400 annual manhours. Materials for way and structure maintenance were estimated to cost $2,254,800. Labor for vehicle maintenance was estimated at $2,758,800. Materials for vehicle maintenance were estimated at $5,760,800. Five percent maintenance contingency was included and eight percent of total maintenance cost for maintenance management was also added, yielding a total maintenance cost of $11,588,700 annually.

General and administrative costs were estimated at $268,700 a year. Insurance costs for accidents other than to employees were estimated at $622,500. The total operations cost, not including power required, was $15,927,000 annually.

TABLE 12

U-TACV OPERATING COSTS

	HP	Local % Time	Local Usage	Express % Time	Express Usage
Dwell Power	825	8.2	68	13.0	107
Actual Peak Vehicles Operating			100		66
			6800		7062
Total Peak Power Demand			163,200		116,072
Terrain Power Factor			1.07		1.02
Conversion to KW			0.7457		0.7457
Peak Kilowatts Demand			130,200		88,300
				218,500	
Stations (16) and Yard (1) @ 250 KW				4,250	
				222,750	
Losses (18%)				40,100	
Total Demand Requirement				262,850 KW	

VII. ENERGY REQUIREMENTS

A. Acceleration and Deceleration

	Express	Local
Acceleration Power	4650 HP	4650 HP
Acceleration Time	7.27 min.	23.69 min.
	563 HP Hrs.	1856 HP Hrs.
Deceleration Power	-1870 HP	-1870 HP
Deceleration Time	7.27 min.	23.69 min.
	- 227 HP Hrs.	- 746 HP Hrs.
Net Acceleration/Deceleration Power Per Trip	337 HP Hrs.	1110 HP Hrs.
B. Cruise Power	2700 HP	2700 HP
Cruise Time	30.71 min.	42.10 min.
	1382 HP Hrs.	1895 HP Hrs.
C. Dwell Power (Levitation)	825 HP	825 HP
Dwell Time	6.75 min.	8.00 min.
	93 HP Hrs.	110 HP Hrs.
D. Power Required		
Acceleration, Deceleration, Cruise per Trip	1719 HP Hrs.	3005 HP Hrs.
Annual Equiv. Vehicle Trips	115,392	156,024
Annual Motive Power Requires	198,358,848 HP Hrs.	468,852,120 HP Hrs.
Dwell Power	93 HP Hrs.	110 HP Hrs.
True Annual Vehicle Trips	135,360	179,040
Annual Dwell Power Required	12,588,480 HP Hrs.	19,694,400 HP Hrs.
Total Annual Power Required	210,947,328 HP Hrs.	488,546,520 HP Hrs.

TABLE 12

U-TACV OPERATING COSTS

Terrain Factor	x1.02	x1.07
Conversion (HPH ⟶ KWH)	0.7457	0.7457
	160,449,490 KWH	389,810,780 KWH
	550,260,270 KWH	
Stations: (16) @ 250 KW (19 hrs.) 365 days		27,740,000 KWH
Yard and Shops: 500 KW, 24 hrs. 310 days		3,720,000 KWH
Subtotal		581,720,270 KWH
Losses (18%)		104,709,648 KWH
Total Energy Demand		686,429,918 KWH

VIII. POWER COST

A. Demand Charges

First 20 KW	$ 50.35
Next 180 KW	305.28
Remaining 262,650 KW @ $1.378	361,931.70
	$362,287.33
Primary Service Credit	
First 200 KW	$ 42.40
Next 800 KW	102.40
Remaining 261,850 KW @ $0.085	22,257.25
	($ 22,402.05)
Net Demand Charge per Month	$339,885
Annual Cost for Demand	$4,078,623

B. Energy Charges

First 100,000 KWH/mo @ $986.78	$ 11,841.36
Remaining 685,230 MWH @ $0.551	3,775,617.30
Annual Energy	3,787,459

C. Grand Total Annual Power Cost $7,866,081

use $7,866,100

IX. OTHER OPERATING COSTS

A. Wage Rates (without benefits)

Train Operators - $7.00 per hour	$ 7.78
Train Controllers - $10.00 per hour	11.11
Station Attendants - $5.00 per hour	5.56
Mechanics - $7.00 per hour	7.78

Benefits accounted for by using $\frac{\text{2080 hours paid}}{\text{1872 hours worked}}$ = 1.11 times labor

13 days vacation
13 days sick leave

TABLE 12

U-TACV OPERATING COSTS

B. Transportation

No. operators required --

	Time	Hours	Local Hdwy.	Local Trains	Local Manhours	Express Hdwy.	Express Trains	Express Manhours
Daily	0500-0700	2	10	10	20	--	--	--
	0700-0900	2	5	20	40	5	11	22
	0900-1600	7	10	10	70	10	6	42
	1600-1800	2	5	20	40	5	11	22
	1800-2400	5	10	10	50	--	--	--
					220			86
SS&H	0500-0700	2	15	7	14	--	--	--
	0700-1800	11	15	7	77	15	4	44
	1800-2400	2	15	7	14	--	--	--
					105			44

(220+86)(254) = 77,724
(105+44)(111) = 16,539
94,263 annual manhours
+ 20% for scheduling 18,853
113,116 manhours
per hour $7.78

$880,042

C. Train Controllers

Annual Operating Hours 19(365) = 6935

Factor: Route Miles = 39.6; Annual Psgrs. = 53.37 } $\frac{(39.6)53.37}{500}$ + 2 = 6.2269

43,184

Plus 30% 12,955

56,139 hours 56,139
$11.11 per hour
$623,706

D. Station Attendants

Attendant Hours: 5 major stations with 2 attendants = 10
11 other stations with 1 attendant = 11
21
19 hours daily, 2 directions } 38
365 days } x 365 = 291,270
+ 20% 58,254
349,524
@ $5.56 per hour $1,943,353

TABLE 12

U-TACV OPERATING COSTS

E. Maintenance

1. Way and Structure: 1500 (39.6 route miles) = 59,400
   1200 (53.37 psgrs/year) = 64,044

   123,444 hours
   @ $5.56 $686,348

   Maintenance Materials: .014 (39.6 route miles) = 0.5544
   .019 (53.37 psgrs/year) = 1.0140
   $\$1.5684 \times 10^6$
   .6864

   Total Way & Structure Maintenance $2,254,800

2. Vehicles

   Manhours per car: (0.016)(60=veh. wt. 1000's)+1.0=1.96
   Operating Fleet = 166 cars
   -20
   1.0-(146 x 0.006) = 0.27

   (1.96)(.27)(.67)= 354,600
   x$7.78= 2,758,800

   Vehicle Maintenance MH = (.04)(Fleet Cost=.787x183) = 5,760,800
   Total Vehicle Maintenance $8,519,600

3. Maintenance Contingency - 5% of Maintenance Costs = $ 538,700

4. Maintenance Management:

   8% of Total Maintenance Labor: .08(3,445,148) ≅ $275,600

5. Total Maintenance $11,588,700

F. General and Administration

   80
   39.6 route miles
   149.1 = $(2 + \frac{39.6}{50}$ route miles) (53.37 annual passengers)
   $\$268.7 \times 10^3$

G. Insurance 0.025(24,900,772) = $622,518

H. Total:

Transportation	$ 880,000
Control	623,700
Stations	1,943,400
Maintenance	11,588,700
Gen. & Admin.	268,700
Insurance	622,500
TOTAL	$15,927,000

X. TOTAL OPERATIONS AND MAINTENANCE

Power	$ 7,866,100
O & M	15,927,000
	$23,793,100

Per Car Mile 95.6¢

X. Total Costs

Combining the total power costs and operations and maintenance costs yielded an annual figure of $23,793,100 per year in 1975 dollars. This was a cost of approximately 95.6¢ per car mile of operation. This cost does not include any figure for depreciation or replacement of vehicles.

ANNUAL OPERATING NET

The costs and revenues calculated in the manner described previously were combined to obtain estimate of the net operating results which could be expected for the U-TACV operation. Prior to preparing this summary, the operating costs only were escalated to account for cost increases which might be expected due to inflation and increased labor rates. The rate of increase was obtained from experience observed with operating costs of the Dallas Transit System. These appeared to be the most appropriate increase rates available. The costs were grown from 1975 base figures for the 1990 costs at a straight-line increase of eight percent annually, thereby indicating a 40 percent increase between 1975 and 1980. The 1990 escalated operating costs were approximately $52,344,800.

Revenues were not increased for either escalation or other kinds of fare increases, and the basic fare structure was assumed to be constant. This was done primarily to give an indication of the nature of increase which might be necessary to offset increases in operating costs due to various types of escalation. Variations in revenue between 1980, 1990 and 2000 were strictly due to increases in patronage, changes in the nature of travel on the system, and consequent changes in the fare charge structure. The revenue shown is annual revenue allocatable to the U-TACV system based upon passenger miles of service provided by it. Deficits were then calculated as the difference between the cost and revenues for each year. Table 13 summarizes the results of the deficit calculation indicating that the operating deficit of this system can be expected to rise by approximately $500,000 annually to an estimated total deficit of over $20 million by the end of the century. This deficit would occur if no fare increases are made over the base fare assumed. The base fare assumed is lower than that charged currently in either Fort Worth or Dallas.

TABLE 13

ESTIMATED OPERATING RESULTS
U-TACV SYSTEM

YEAR	COST	REVENUE*	DEFICIT
1980	$33,310,300	$24,442,100	$ 8,868,200
1981	35,213,800	25,531,000	9,682,800
1982	37,117,200	26,619,900	10,497,300
1983	39,020,700	27,708,700	11,312,000
1984	40,924,100	28,797,600	12,126,500
1985	42,827,600	29,886,500	12,941,100
1986	44,731,000	30,975,400	13,755,600
1987	46,634,500	32,064,300	14,570,200
1988	48,537,900	33,153,100	15,384,800
1989	50,441,400	34,242,000	16,199,400
1990	52,344,800	35,330,900	17,013,900
1991	54,248,300	36,512,400	17,735,900
1992	56,151,700	37,693,800	18,457,900
1993	58,055,200	38,875,300	19,179,900
1994	59,958,600	40,056,800	19,901,800
1995	61,826,100	41,238,200	20,587,900
1996	63,765,500	42,419,700	21,345,800
1997	65,669,000	43,601,200	22,067,800
1998	67,572,400	44,782,700	22,789,700
1999	69,475,800	45,964,100	23,511,700
2000	71,379,300	47,145,600	24,233,700

* Revenue for traffic on U-TACV lines between Dallas and Fort Worth; does not consider traffic on U-TACV west of City Center station in Fort Worth.

VI. GOODS MOVEMENT ANALYSIS

The U-TACV system appears to offer a good opportunity for moving certain goods between major activity centers and the Airport. The system would serve the CBD's of the major cities of course but it also would serve an existing major industrial corridor in Dallas (along the Stemmons Freeway) and a proposed industrial corridor in Fort Worth (along the Trinity Canal). It also has stops at loop freeways in both cities which could provide for good collector/distributor service, precluding the need for longer truck trips to the Airport.

In analyzing the potential of the U-TACV system for goods movement, an evaluation of the characteristics of the goods most amenable to this system was performed. As a basis for this evaluation, several references of past work were used: Summary Report of Preliminary Goods Movement Data, North Central Texas Council of Governments, December 1972; Goods Transportation in Urban Areas, Committee 6K, The Institute of Trafic Engineers; and Urban Commodity Flow, Special Report 120, The Highway Research Board.

Based on this past work, a set of criteria was established to determine the potential of U-TACV for moving each class of goods. Once this potential was established, the projected demand for U-TACV goods movement was developed based both on potential and the attitudes of shippers toward U-TACV for moving their goods.

CLASSIFICATION OF POTENTIAL GOODS

Several criteria were defined for determining if goods were appropriate for movement on the U-TACV system. These generalized criteria permitted elimination of certain kinds of commodities from further consideration and concentrating detailed analysis on only those categories of goods that have reasonable potential for U-TACV movement. The criteria are not mutually exclusive but rather were designed to be cascaded as a series of sequential screens to select those commodities which are most appropriate for using the U-TACV. The following preliminary potential criteria were utilized:

Possibility for containerization: The majority of goods which will be moved on the U-TACV system will be in containerized cartons or palletized. This is to facilitate handling operations, thereby reducing loading and unloading time at airplanes and at the U-TACV stations. Goods which are now shipped in standard containerized cartons will have a greater tendency to use U-TACV than those which either require very costly changeover or for which it is impossible.

Time constraints: Goods which are now shipped with critical time constraints are applicable for use of the U-TACV system. Goods moved on the surface transportation system are subject to delays and traffic. Even air transportation, such as helicopters, is subject to problems such as severe weather conditions. The U-TACV system can provide a quick, reliable service to move goods which have time constraints.

Movements Between Airport and Dallas/Fort Worth: As the number of trips from the Dallas and Fort Worth CBD's increases, so does the feasibility for using the U-TACV system. Since the U-TACV system will provide direct access to the Airport, goods which move along that corridor should find it attractive to use the U-TACV system. Goods which are moved from either of the CBD's to the Airport and between the CBD's with no intermediate stops would be ideal for the U-TACV system.

There is significant goods movement to the CBD's from locations along the U-TACV route. This may represent a considerable number of truck trips into the CBD's. The U-TACV system could help consolidate some of these trips.

Using the above criteria, goods were categorized as to their potential for U-TACV movement. These categories were developed with the assistance of responsible personnel associated directly or indirectly with commodity movements through organizations listed below. Table 14 indicates this potential.

INSTITUTIONAL CONSIDERATION FOR U-TACV GOODS MOVEMENT

When examining the potential of a system for moving people, the analysis is concerned with public attitude and travel

TABLE 14

CRITERIA FOR DETERMINING
THE FEASIBILITY OF GOODS USING U-TACV

MAJOR COMMODITY CLASSIFICATION	POSSIBILITY FOR CONTAINERIZATION	TIME CONSTRAINTS	MOVEMENTS BETWEEN AIRPORT AND DALLAS/FORT WORTH	MOVEMENTS BETWEEN DALLAS/FORT WORTH & THE METRO AREA	CONSENSUS
U.S. Mail					
Airmail	High	High	High	Low	High
Regular Mail	High	Medium	Medium	Medium	Medium
Small Parcels					
Airmail	High	High	High	Low	High
Regular Mail	Medium	Medium	Low	High	Medium
Food	High	Medium	Low	High	High
Beverage	High	Medium	Low	High	Medium
Tobacco	High	Medium	Low	High	Medium
Textiles	Medium	Low	Low	Medium	Low
Apparel	Medium	Low	Medium	High	Medium
Furniture	Low	Low	Low	Medium	Low
Paper & Printing	High	Medium	Medium	High	Medium
Petroleum	Low	Low	Low	Low	Low
Machinery	Low	Low	Low	Low	Low
Transportation Equipment	Low	Low	Low	Low	Low
Technical Instruments	Medium	Medium	Medium	Medium	Medium

habits. When analyzing the potential for goods movement, however, the public attitudes and habits are not directly a significant factor. Rather the attitudes of various institutions (both public and private) affect the potential for goods movement. Existing freight carriers, regulatory bodies and freight associations will all have important influence on the success of U-TACV goods movement. For this reason and to obtain a clear picture of such effects on U-TACV goods movement potential, a series of interviews were held with representatives from several organizations.

- North Central Texas Council of Governments
- Texas Highway Department
- Dallas Chamber of Commerce
- Fort Worth Chamber of Commerce
- City of Dallas Traffic Department
- AIRTRANS System
- U.S. Postal Service
- REA Express
- Emery Air Freight
- United Parcel Service
- Dallas Delivery and Cartage Association

Individuals representing these organizations proved very helpful by discussing the feasibility for moving goods on U-TACV and by pointing out some of the potential problems that may arise. From these interviews it was concluded that:

- Time constraints are a big factor in the movement of air mail and parcels moved by air forwarders.

- There is a sizable volume of mail and small parcels moved daily between Love Field, Dallas and Fort Worth. This involves many trucks and results in high operating costs.

- Mail and small parcels seem very amenable to use on the U-TACV system.

- U-TACV system has to be dependable and secure to realize its full goods movement potential.

- Almost all air forwarders are anticipating moving their terminals to the new Airport.

- There may be interface problems for movement of goods between the U-TACV system and the AIRTRANS system.

- Local deliveries of small parcels would not be applicable for use of U-TACV.

- The bulk mail service will have very little impact on the new Airport.

- Suppliers could send material over the U-TACV system for concessions at the new Airport.

- Union Terminal would not be suitable for movement of goods. The area to the south of Union Terminal would be more applicable for goods movement because of railroad sidings and reduced congestion within the CBD.

- There are no immediately foreseeable problems with unions, with workers employed by U-TACV or its operation for moving goods.

COMPUTATION OF GOODS MOVEMENT POTENTIAL

Based upon the preceding analyses, several categories of goods were considered to have significant potential for use of the U-TACV system. The categories which present the highest potential were:

- Air Mail
- Air Forwarders (freight)
- Airline freight carried by national airlines

- Goods (especially perishable goods) that are shipped between the Dallas and Fort Worth CBD's
- Goods that are shipped between the Dallas and Fort Worth CBD's and the Regional Airport.

An estimate of the current total daily tonnage of these categories is as follows:

- Air Mail - 36,000 lbs./day (from interview)
- Air Forwarders (freight) - 600,000 lbs./day*
- Airline Freight - 700,000 lbs./day*
- CBD-CBD Goods - 1200 tons/day*
- Airport-CBD Goods - 4000 lbs./day (estimated)

These estimates represent a conservative calculation of the total daily goods movement that is most applicable for the U-TACV system. Since goods movement potential on the U-TACV system concerns institutional as well as physical constraints, the actual usage of the U-TACV for goods movement will be a policy controlled potential. Realizing this variability, a preliminary estimate of U-TACV goods movement potential can be developed as follows:

- Air Mail

  Total tonnage per day - 18 tons. Assume U-TACV 50 percent capture rate due to high Airport orientation, speed required and CBD orientation for the other trip end (Central Post Offices).

  50% X 18 = 9 tons/day.

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* From information in Chapter 6 of the summary report of Goods Movement Data, December 1972.

• Air Forwarder (freight)

Total tonnage per day - 300 tons. Assumes U-TACV 10 percent capture rate due to containerization potential and need for CBD transfer to truck for final delivery.

10% X 300 = 30 tons/day.

• Airline Freight

Total tonnage per day - 350 tons. Assumes U-TACV 10 percent capture rate as per Air Forwarder Freight.

10% X 350 = 35 tons/day.

• CBD-CBD Goods

Total tonnage per day - 1200 tons. This total tonnage is based upon the total regional estimate of freight carried. The CBD orientation of that freight as per the Summary Report of Goods Movement. Of the 1200 tons per day, 44% is classified in the categories most amenable to U-TACV (food, beverage, tobacco, textiles, apparel, paper products) yielding a total potential of .44 X 1200 = 528 tons/day. Assume U-TACV 5 percent capture rate due to the containerization potential of these goods categories and the necessity for CBD transfers to truck.

5% X 528 = 26 tons/day.

• CBD-Airport Goods

Total tonnage per day - 2 tons. This total tonnage is estimated for those goods most amenable to U-TACV (food, beverage, tobacco, textiles, apparel and paper products). Assume U-TACV 50 percent capture rate due to the ease of transfer at the Airport end of the trip and the amenability of these goods to U-TACV.

50% X 2 = 1 ton/day.

The total computed U-TACV potential is:

• Air Mail	9 tons/day
• Air Forwarder (freight)	30 tons/day
• Airline Freight	35 tons/day
• CBD-CBD Goods	26 tons/day
• CBD-Airport Goods	1 ton /day
TOTAL	101 tons/day

If four such cars were used, each on a different location, headways of better than one-half hour from each station would be possible. This would be a very attractive service level for any of the commodities considered.

All goods except for 26 tons between the CBD's would be going to the Airport, an average distance of 19.5 miles. This would be a daily movement of 1462 ton miles. Inter-CBD movement would travel 39 miles, for a daily ton mile figure of 1014. Assuming a ton mile charge rate of $1.10/ton mile based upon current high-speed cartage charges, the estimated usage would yield $2724 daily revenue. Using a factor of 280, which assumes half revenue on Saturdays and none on Sundays and Holidays, the annual revenue would be $762,700.

The cost of goods movement via U-TACV will be a function of the operating cost per vehicle mile and the loading-unloading methods used for the U-TACV goods movement system. A manual system would involve less capital expenditure than an automated containerized or palletized system but would be labor-intensive and would realize annual cost increases as labor rates rise.

If half the operating cost of four vehicles were allocated for the cost of the freight service, an equivalent of two vehicles would be operated daily from 5:00 A.M. to Midnight. On local trains that would require 96 one-way vehicle trips, 39 miles each, or 3744 daily vehicle miles. Using the average per mile cost of 96¢, the daily operating cost would be approximately $1800 and the annual cost would be $504,000, using the local train annualization factor of 280. Therefore an operating net of $258,700 may be possible to achieve. This would have to be balanced against additional capital costs for automated cargo handling.

Station modification to handle goods must be considered in the final design of the U-TACV system. The estimated potential demand and the associated operating net is a conservative figure that can be utilized in the final considerations of the feasibility of the U-TACV system.

VII. CONCLUSIONS

The demand and cost analyses presented in this report have indicated several important points about the feasibility of a U-TACV system between Dallas, Fort Worth and the DFW Airport. The conclusions must be considered with the environmental conclusions and the capital cost estimates in deciding whether to pursue development of such a system.

- The demand for a public transportation system in the corridor is sufficient to warrant serious consideration of an exclusive guideway system.

- Highway facilities in the corridor will be sufficiently loaded to effectively preclude effective service using buses in mixed traffic or exclusive lanes unless extensive ramp metering is employed. Ramp metering would not be recommended because of the absence of adequate parallel relief facilities, even if the Trinity Toll Road is built.

- Travel demand in 1980 is concentrated at major stations served by the express line as well as the Medical Center station in Dallas. By 1990 however demand at intermediate stations increases sufficiently to justify them. It is recommended that only express operations and stations be provided initially with local stations and service developed for 1990. This is based on demand only.

- Even for 1990 at least one and perhaps three or more stations could be eliminated due to low demands.

- Early (1980) service to two stations in the Fort Worth CBD is not justified. Serving only the Fort Worth station could reduce costs by eliminating need for a terminal. When the Fort Worth CBD subway along Throckmorton Street is developed however, extension of the U-TACV line to City Center should be pursued.

- Estimated demands would permit turning back every other local train from Dallas at the Airport. This would save perhaps up to 15 percent of operating costs.

- Operating costs per vehicle mile for U-TACV are not significantly different than conventional rapid transit. The cost per seat mile or per passenger mile is about twice that of rapid transit because U-TACV carries less than half the riders per square foot of vehicle floor area.

- U-TACV operating costs are higher because the vehicle must be levitated continually, even when stopped, and because of its high speed. The vehicle is also considerably heavier than rapid transit cars because of levitation and propulsion equipment carried in the car. The linear induction motor may also be considered less efficient than rotating motors.

- The higher operating costs for U-TACV increase the cost of handling the estimated traffic demand by nearly two over that which rapid transit would have. It is questionable whether the speed advantages offered by U-TACV are worth this difference. The cost disadvantage is even more important when the problems of system interfacing, duplicate shop facilities and hardware unknowns are considered.

- The fares assumed for U-TACV were low. A major increase in fares would affect patronage but the revenue increases resulting would likely overcome the operating deficit estimated. Fares at such high levels would not be desirable for the entire regional transit system.

- The sensitivity analyses indicated that patronage response to fare increases would generally be inelastic for income levels close to those anticipated in 1990; elasticity drops as income increases.

- Patronage increases in response to parking and auto operating cost increases are generally very inelastic except for low-income people having poor transit service. This indicates that auto travel cost increases will not return much patronage change although transit fare increases will yield more patronage loss.

- Attempts to optimize cost/revenue ratios will yield unacceptable service levels, i.e., few would ride so little service cost would be incurred; the costs of scale work against transit there since buses can only be so small.

- The sub-area tests indicated that greater headways on feeder buses (+ 1/3) would reduce patronage by only 12 percent. Increasing U-TACV headways to 20 minutes would drop patronage by 8 percent. Eliminating the five lowest volume stations reduced patronage by only 2 percent. These effects are confirmed by the operating system parameter elasticities in the sensitivity analyses.

The potential for goods movement appears to be relatively small but at competitive rates, the service may be revenue and profit producing. The cost of providing cargo handling facilities must be balanced against this marginal return.

In general the demand studies indicated that as part of the regional transit system, a U-TACV line between the cities and to the Airport would be well used, both by people and for cargo. Some of the stations might be eliminated or deferred to cut costs. The cost effectiveness of serving the corridor with a U-TACV system is however open to question.

APPENDIX A

DERIVATION OF ELASTICITY EQUATION

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DERIVATION OF ELASTICITY EQUATION

Given the Extreme Values equation relating mode split to marginal utility:

(1) $$MS = e^{-e^{\alpha(u+\mu)}}$$

where: MS is mode split in percent
α, μ are constants which are evaluated by regression analysis of observed data
u is marginal utility of travel (the difference between equivalent cost of travel by highway and transit)
e is napierian logarithm base

The utility can be disaggregated as follows:

(2) $$U = CA + B$$

where: A is any individual element of disutility, transit or highway
C is the constant coefficient of element A, if there is one
B is all remaining elements of disutility

The general slope of equation (1) with respect to equation (2) may be expressed as:

(3) $$\frac{\Delta MS}{\Delta A}$$

The change in mode split for a small change in A from a particular point A_0 is

(4) $$\frac{\Delta MS}{\Delta A} * \Delta A_0$$

The percent change in mode split from a given value MS_0 is

(5) $$\frac{\text{\% Change MS}}{100} = \frac{\left(\frac{\Delta MS}{\Delta A} * \Delta A_0\right)}{MS_0}$$

This leads to the equation for a 1% change in A which is termed the 'elasticity' of the element A. This equation follows from equation (5) by using the partial differential instead of the incremental notation and using the defined 1% for A:

(6) $$\frac{\%\ \text{Change MS}}{100} = \frac{\frac{\partial MS}{\partial A} * (0.01A_0)}{MS_0}$$

(7) $$\%\ \text{Change MS} = \frac{\partial MS}{\partial A} * \left(\frac{A_0}{MS_0}\right)$$

but:

$$\frac{\partial MS}{\partial A} = \frac{\partial}{\partial A}\left[e^{-e^{\alpha(u+\mu)}}\right]$$

$$= \frac{\partial}{\partial A}\left[e^{-e^{\alpha(CA+B+\mu)}}\right]$$

(8) $$= \alpha Ce^{\alpha(CA+B+\mu)}\ (-e)^{\alpha(CA+B+\mu)}$$

and: $$\frac{\partial MS/\partial A}{MS_0} = \frac{\alpha Ce^{\alpha(CA+B+\mu)}\ (-e)^{\alpha(CA+B+\mu)}}{e^{-e^{\alpha(CA+B+\mu)}}}$$

$$= \alpha Ce^{\alpha(CA+B+\mu)}$$

therefore: $$\%\ \text{Change} = \alpha CA_0 e^{\alpha(CA\ +B+\mu)}$$