Study of Alternative Transit Corridors and Systems
Prepared for Southern California Rapid Transit District

Technical Report, Part IX

Personal Rapid Transit

Prepared by

Kaiser Engineers/DMJM

Preparation of this Report has been financed in part through a grant from the Urban Mass Transportation Administration under the provisions of the Urban Mass Transportation Act of 1964 as amended.

ANALYSIS OF ADVANCED PERSONAL RAPID TRANSIT (APRT) CONCEPTS FOR THE LOS ANGELES AREA

SPECIAL WORK TASK AUTHORIZED BY
SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT
BOARD OF CONTROL
ON JANUARY 9, 1973

MARCH 1973

KAISER ENGINEERS/DMJM

TABLE OF CONTENTS

ANALYSIS OF ADVANCED PERSONAL RAPID TRANSIT (APRT) CONCEPTS FOR THE LOS ANGELES AREA

INTRODUCTION

This paper presents the results of a limited study of the application of APRT(1) as the primary mass rapid transit system for the Los Angeles Area. In this study, KE/DMJM has updated a continuing review of the literature on APRT and PRT; has had several conferences and detailed briefings from Aerospace Corporation personnel describing the system concepts, preliminary designs, and system cost estimates; and has prepared several network concepts, operational concepts, purpose design layouts, service constraints and requirements, and sketches of guideway and station requirements, configurations and potential impacts within the Los Angeles CBD.

Purpose

The purpose of this report was to present an objective evaluation of APRT. A continuous and concerted effort was exerted by the staff throughout this evaluation to remain neutral both in the manner of presentation of material in this report and in the analysis itself. The principal reason for this approach was that APRT, in comparison to the development of other systems, is in its embryonic stage. There is no consensus agreement on its proper role and function in the family of transportation systems, and discussions of the system quickly degenerate to biased reviews both pro and con. Consequently this leaves much confusion in both lay and professional sections about the system and its applications. The approach used in this analysis was to assume that the costs presented by the Aerospace Corp. would, as a natural course of events, change as it progressed to the design stage; that APRT technology and operation would be advanced to a ready-for-application stage, through on-going and proposed research and development.

This approach allowed the staff to concentrate on the applications of the systems and to define, within the time and funding limits of this effort, the extent of the system to serve the L. A. CBD and what it might look like.

(1) The term APRT has been used for the concept discussed in this report to differentiate the system from PRT; PRT involves somewhat larger (6 to 20 passenger) vehicles that may stop at intermediate stations. Examples of PRT include the Morgantown System and the systems demonstrated at Transpo 72.

Conclusions

The results of this review have reinforced the view that the APRT service concept could match the trip characteristics of the Southern California population more closely than other fixed-guideway transit systems.(door-to-door travel; in a private vehicle when the traveller is ready to leave). The study team believes that APRT can play a meaningful role in the evolution of a transportation planning concept of a family of transit services, as a collection/distribution system in low-to-medium population density areas and as a feeder system to line-haul mass transit stations. However, the team has several concerns in the application of the system, and has identified several problems which must be resolved before APRT can be recommended for any applications in Los Angeles. These include:

- By the hardware designer - to fabricate and demonstrate control equipment that will operate with sufficient reliability and accuracy to insure safe vehicle operation at short headways; to produce such equipment economically; and to complete the development of the equipment within the next few years.

- By the urban designer and architect - to develop means of integrating the APRT guideway and stations into the existing environment of streets and buildings to minimize the system's impact on its surroundings.

- By the urban planner and human factors analyst - to develop techniques to predict the reactions of transit riders to the ride and service characteristics of the system and the increased risks associated with short headway operations, and to determine the acceptability to community residents of the system's physical features.

Currently, increased interest in this country and efforts abroad are proceeding in second generation research and development and with the planning and implementation of pilot projects and test track operations to develop solutions to these problems.There have not been any APRT systems constructed in the U.S. as yet, but pilot systems are currently being installed in Germany and in Japan. APRT concepts were investigated in the U.S. as part of the 1967-68 HUD studies of new systems for urban transportation. Since then several agencies have initiated extensive studies on the APRT concept; these include the U.S. D.O.T. (through UMTA, the Office of High Speed Ground Transportation, and the Transportation Systems Center), the Applied Physics Laboratory of John Hopkins University, several faculty members of the University of Minnesota and other schools, and private companies such as Aerospace Corporation and TRW. The increased level of U.S. Government interest will probably result in serious funding commitments of the required magnitude to provide the necessary research and development that would place the United States in a similar position in advanced transportation technology as it now occupies in the space program. It is expected that further DOT research and development of APRT will be conducted with the National Aeronautics and Space Administration, and that a major development and test program will shortly be undertaken. Although no timetable has yet been established for development of APRT, the Aerospace Corporation has estimated that a system could be demonstrated on a test track by 1976, in a city by 1978, and could be available for installation and revenue service by the early 1980's. Aerospace's cost estimates for this development program range from $50 to $150 million.

The following sections of this paper present a definition of APRT, a discussion of short headway control concepts, a discussion of APRT analyses in other cities, and considerations of the applications of APRT in Los Angeles.

KE/DMJM would like to acknowledge the cooperation of representatives of the Aerospace Corporation's Urban Programs Division in this study. They provided information on the details of APRT design and operation concepts, and on the estimated costs of the system.

DEFINITION OF APRT

An APRT system consists of automatically controlled small vehicles (2-6 passenger capacity) that would operate on an extensive network of grade-separated guideways providing non-stop, point of origin to point of destination (home to work, home to shopping, etc.), service for the private use of a passenger and his party. Capacities to meet peak-hour travel requirements would be achieved through utilization of system control, propulsion, braking, vehicle control, and switching techniques which would permit close-headway (1/2 second and less) operation of the vehicles; it is this feature of high-capacity close-headway operations that is central to the whole concept.

Most of the APRT systems that have been proposed have included elevated guideways, with one-way guideways usually suggested. All station stops are off-line on bypass guideways to allow other vehicles to proceed non-stop to their destination stations. Guideways are typically spaced from 1/4 to 1/2 mile apart, and station spacings are about the same distance. Crossing lines in high density destination areas (CBD) are positioned and maintained at different elevations to eliminate the roller-coaster effect. Connections between lines are accomplished through ramps at intersecting points; deceleration and acceleration lanes for the intersection ramps may be off line to provide higher through speeds.

SHORT-HEADWAY CONTROL CONCEPTS

The primary technical problem for APRT systems is the development of safe, reliable, reasonably-priced control systems for short-headway operation. Automatic control systems may be classified in three categories: systems limited to long headways (30 seconds or more) employing conventional block control; systems operating at shorter headways using a modification of the conventional block control; and systems at short headways under the control of one or more large digital processors. The first of these classes is presently being implemented in advanced form in BARTD and in the Washington Metro and is essentially within the state-of-the-art (although problems with the BARTD system have been well publicized). The other two classes do have some unresolved problems. Conventional block control is inadequate at short headways, because the information available to the system is insufficient to permit proper control. Therefore, control studies have concentrated on various forms of continuous control for APRT applications.

Three basic concepts of continuous network control have been suggested by various investigators of APRT: the asynchronous, being implemented by Messerschmitt-Bolkaw-Blohm at their test track in Germany; the synchronous, as studied in detail by TRW under contract to the Office of High Speed Ground Transportation; and the quasi-synchronous, studied by the Aerospace Corporation.

The asynchronous approach is based on a principle of maintaining at least the minimum allowable separation between adjacent vehicles. Each vehicle must communicate with the vehicle preceding it to keep aware of that vehicle's motions. A difficulty with asynchronous control occurs at the intersection of two guideways; to insure that vehicle positions correspond on two merging lines, there must be communication between vehicles on both lines. Since at high line densities there is much interdependency between movements on both lines, it is likely that traffic control instabilities may occur at the intersection and that long lines of vehicles may have to be simultaneously maneuvered. Thus, it is desirable that a control means that can resolve conflicts between merging lines be provided.

The synchronous approach is based on a system of virtual slots that move along the network at the speed defined for each line. The slot size is at least the vehicle length plus the minimum allowable separation distance between vehicles. A central computer synchronizes overall network slot positioning and movements and the vehicles are centered in the moving slots. There is a trip scheduling function in which reservations are made for all slots to be used by a vehicle on its trip prior to departure from its station. Thus, a vehicle can depart only if the reservation computer can locate a slot reservation through to the desired destination. At peak demands, there may not be sufficient unreserved slots passing a given station to satisfy all the departure demands, and passengers and vehicles may be forced to queue while waiting for reservations.

The principal difficulty with the synchronous approach appears under emergency conditions; if a failure occurs that causes a vehicle to stop or to move from its slot, the reservations of all vehicles that are scheduled to use the line including the failed vehicle must be changed. The rescheduling and rerouting that would be required could be very extensive, particularly on a crowded network.

The quasi-synchronous approach overcomes the latter difficulty through the capability of maneuvering vehicles from slot to slot to resolve conflict situations. The vehicles receive discrete maneuver commands from control computers having cognizance over individual intersections and stations. A central computer is still needed to handle overall network functions such as routing and empty-car dispatching.

In this control concept, it is assumed that each vehicle has knowledge of its intended destination. As each slot enters the intersection control zone, wayside sensors determine whether that slot is occupied, and if so, what is the vehicle's destination. This information is transmitted to the intersection control computer. That computer determines from its control algorithms whether the vehicle should turn or go straight, and then determine which vehicles in a traffic stream must maneuver to maximize intersection throughput.

The central computer must input the routing instructions to intersection computers; these instructions may be changed from time to time to handle special loading situations or hourly variations in demand.

All of the control schemes have been tested through computer simulation and in model system operation, and have demonstrated feasible operation under various simulated loading conditions. <u>All schemes depend on the development of reliable computing, sensing, and communications equipment, and this is the critical element in the APRT development program</u>.

APRT ANALYSES IN OTHER CITIES

Studies of APRT applications have recently been conducted in several other cities, including Minneapolis - St. Paul, and Honolulu. In each case, the consultants conducting the studies have concluded that APRT should not be recommended as the primary rapid transit system, for the reasons discussed below.

In the Twin Cities, a computer model was developed on a limited portion of an APRT network including 22 stations immediately south of the Minneapolis CBD. In that simulation exercise, it was determined that maximum link flow requirements were more than 7,700 passengers during the peak hour, and that the average vehicle occupancy was approximately 2 passengers (the average was reduced by the number of empty vehicles circulating within the system to supply large-demand stations). However, to reach this occupancy factor the average wait time at a station was 3 minutes, since there were relatively few passengers arriving at a given station that desired the same destination. Even with the 2-passenger occupancy factor, the simulation model reflected considerable delays at network intersections, but it is recognized that the control algorithms used were not optimum.

The joint venture team that worked on the Twin Cities study (Simpson & Curtin, Midwest Planning and Research, DMJM, and Honeywell) recommended against selecting APRT for the region's mass transit system for several reasons. The primary reason was the high cost of the network needed to cover the whole region -- more than $3 billion, compared to $608 million for the recommended train system. It was recognized that an APRT system would have to operate with headways less than 1 second during peak hour, and the joint venture felt that the risk associated with completing development of a control system capable of short-headway operation in time that the system could be installed and operational by 1982 was too high to warrant recommendation of APRT over a conventional mass transit system. In addition, presentations of APRT models and drawings at Citizen's Involvement Meetings drew strong reactions against placing elevated guideways along residential streets; such placement would be necessary to complete a network in the Twin Cities.

DMJM'S Applied Technology Laboratory, in joint venture with A. M. Voorhees and Daniel Brand, Associate Professor of Transportation at Harvard University, has recently completed a special PRT study for the City, County, and State agencies of Honolulu, Hawaii. This study was to concern itself solely with current recommendation for a regional transit system for Honolulu and examine applications of PRT as an alternative. Several networks and systems were developed for consideration; one of the first semi-finals consisted of an extensive network (over 80 miles) with approximately 150 stations, penetrating the residential area, the major activity centers, and the CBD core. Preliminary analysis concluded that APRT (small 2-4 passenger vehicle; very close headway 1/3 to 1/2 seconds) would not be acceptable in Honolulu, (because of high costs and the environmental impact of extensive guideways and stations in residential areas and in the CBD core.)

Consequently, a modified PRT (People Mover) system and network was developed which consisted of 32.6 miles of one-way guideway and 77 stations. The system operation was based on the "batch" concept, wherein 3 car trains (20 foot vehicles) would operate on 12 second headways at maximum speeds of 35 mph. The trains would operate in a loop-shuttle fashion providing express service between specific stations.

In developing the operations plan for the modified PRT, it was found that over 1,300 vehicles would be required to handle the peak hour loads, as compared to 400 vehicles required for the recommended regional system.

The total capital cost (guideway, vehicles, and right-of-way) for the modified PRT system is approximately 250 million dollars, or 50 percent more than the recommended regional system. The conclusion reached from this analysis, based on cost and environmental impacts, was in favor of the regional system over a modified PRT.

SUGGESTED APRT APPLICATION IN LOS ANGELES

As part of a continuing study of APRT concepts, the Aerospace Corporation of El Segundo has developed several suggested networks for an APRT system in the Los Angeles area. DMJM personnel have met with the Aerospace study team on several occasions, and have been given detailed descriptions of the Los Angeles networks and of the costing model used for the Aerospace APRT system.

Aerospace's approach consisted of selecting certain areas of interest; 1) the south central corridor, 2) the Wilshire corridor, and 3) the CBD core area, and using average system costs laying out a network in each corridor with mileage equivalent in cost to the transit systems proposed to SCRTD by DMJM/Kaiser Engineers in 1968, to show that the APRT systems could provide considerably more coverage and better service levels for the same amount of money. Figure 1-4 show several of the alternative networks suggested by Aerospace. KE/DMJM has examined these networks, and has concluded that while the system would have little difficulty in the collection stage, its inability to handle the distribution end of the trip in the high density areas is of serious concern. It was decided that the Los Angeles CBD portion of the network should be examined more carefully than apparently was done by Aerospace, and we have prepared some layouts of the networks required, and some possible alignment and station locations to handle the projected 1990 transit trips. That study is discussed in the following section of this report.

LOS ANGELES CBD CONSIDERATIONS

Network Design

Recent patronage potential studies conducted by KE/DMJM and the Central Cities Study by WMRT/DMJM/Voorhees for a 1990 regional transit system serving the CBD and the seven corridors in the Los Angeles region resulted in the line load diagram shown in Figure 5. These figures reflect a 7% diversion rate from automobile to mass rapid transit.[(1)] A breakdown of the above figures was made to show the number of transit riders with destinations in the CBD during the morning peak hour. These figures are shown in Figure 6. It should be noted that the percent diverted would increase considerably if stations were located closer to trip origins and destinations, and if broader coverage than that in the seven corridor area were to be provided as in an APRT system.

The following assumptions, based on information supplied by the Aerospace Corporation, were used in the analysis of APRT for Los Angeles.

1. Vehicle speed in the CBD would be 20 mph (or about 30 ft/sec).

2. The minimum practicable grid spacing in the CBD will be 1/4 mile on centers for each track. (Figure 7 shows the guideway length constraints that lead to this spacing.)

3. To minimize interchange problems it was assumed that only a single one-way main-line track would be allowed in any one street; acceleration/deceleration requirements for stations and intersections resulted in double guideways on the greater portion of most downtown streets.

4. North-South lines were assumed to be a constant 17'-6" above street level. East-West lines were assumed at a constant 26'-0" above street level.

5. Intersection ramps included a 10% grade on a tangent section, followed by a 69 foot radius curve.

(1) The 7% diversion is of trips within an assumed transit corridor approximately 2 miles wide and, not total trips in the Los Angeles area.

6. The unloading at stations was based on the "platoon" method of operation; i.e., a group of 6 vehicles would collect on a gate section upstream of the station platform, then advance to the platform as a "train." 80 feet was allowed on the off-line station guideway for this train forming operation.

7. The guideway capacity, at 20 mph, was assumed to be 2 vehicles per second, resulting in a 5 foot interval between 10-foot long cars.

8. An average of 5 slots out of each 6 on the main-line was assumed to be occupied, giving 2 veh/sec x 3600 sec/hr x .833 = 6000 vehicles/hour.

9. An average car loading of 1.5 passengers was assumed, giving a total line capacity of 9000 passengers/hour.

Since the total peak-hour demand to the CBD was 71,000 (Fig. 6), at least eight inbound APRT lines would be required to carry CBD riders only. The total peak-hour demand for travel toward the CBD also included 56,400 trips with destinations beyond the CBD (Fig. 5), for which at least six additional inbound lines would be required. It was assumed that most of the through-CBD demand would be satisfied by higher-speed lines that bypass the downtown, and a 10-line network was designed to carry the CBD-destination passengers and to provide internal CBD circulation. This network is shown in Figure 8; it contains 55 stations, with an assumed capacity of 1350 passengers/hour each. (1) However, the demand at some stations is higher than 1500/hour, requiring some form of double-platform arrangement.

This system was designed to carry the 1990 patronage demand under the 7% modal split assumed in the 1968 SCRTD study; most planners predict that the modal split would be considerably higher (20% to 30%) as a result of the improved level of service provided by APRT. Therefore, a network was developed with much higher capacity, as shown in Figure 9. Because the quarter-mile network spacing was still required to accommodate intersection and station ramps, it was decided to superimpose a separate guideway grid on the network shown in Figure 8, with the guideways on alternate streets from those of the basic network. The second network would not have any connections to the basic network within the CBD, but the parallel lines would be merged outside of the CBD, where the trunk-lines could have higher capacity at higher speeds (vehicles on lines which separate at 20-mph in the CBD could be accelerated to 40 mph outside the CBD, where larger station and intersection spacing are prevalent; two such lines

(1) Station capacity with a 6-vehicle platform and the 20-second time from station entrance gate to departure from the platform is 180 6-vehicle trains/hour, or 1080 vehicles/hour. However, only 5 of the 6 station spaces would be occupied on the average, reducing the station throughout to 900 vehicles/hour. At 1.5 passengers/vehicles, this gives 1350 passengers/hour.

could then be merged, since the 5-foot separation between vehicles is independent of speed). The 22-line 110-plus station APRT network shown in Figure 9 would have an hourly line capacity of 198,000 passengers, comparable to the 200,000-240,000 capacity of the 6-corridor mass rapid transit system previously studied for SCRTD; however, station capacity for the APRT network would be about 150,000 and additional stations would be required to increase capacity.

As Figure 9 clearly shows, an APRT network with sufficient capacity to serve the Los Angeles CBD will require a guideway on almost every street and a station in almost every block. Sketches of the guideway, intersections, and stations have been prepared to show how the system might be located within the street network; the next section of the report discusses these issues.

Guideway and Station Design

A detailed plan view of a typical guideway, station, and intersection layout as it might be installed along Hill Street is shown in Figure 10. In this example, it is assumed that vehicles on the Hill Street line are southbound, while those on First Street are eastbound and those on Third Street westbound. Intersection and station guideways have been designed to the limitations given in Figure 7, for a 20-mph line speed.

To provide footings for the columns for interchange ramps, it was assumed that the sidewalks would be expanded into the cross streets; the curb lanes would then be restricted for parking use only. (Placing of the footings under the street surface might be possible, allowing traffic in the curb lanes.)

In this example, the guideway has been located down the center of Hill Street, with columns along a street median and at a nominal 60 ft. spacing. However, the majority of the line includes dual guideways to accommodate station and intersection ramps; the 30 ft. column spacing recommended by Aerospace for the dual guideway have been assumed, although this spacing is considered to be conservative.

The Aerospace assumptions that off-line deceleration and elevation changes would be made on tangent sections of the guideway, with turns made on a level grade were used. Although the intersection ramps theoretically could be shorter if the grade changes were incorporated into the radius sections, the Aerospace Corporation has indicated that the additional off-line guideway length is required to allow space for vehicle maneuvering on the main-line to accommodate merging vehicles from cross lines. Figure 11 is a perspective drawing of a guideway and intersection design along the streets near the Los Angeles City Hall.

As indicated earlier in the report, the typical downtown station must be designed to accommodate at least 1000 vehicles per hour. The station platform was assumed by Aerospace to be 60 ft. long, to accommodate a six-vehicle "platoon".

Figure 12 includes plan and section views of a typical CBD station. Structural bents spanning the traffic lanes to the sidewalk area will be required to carry the loading platforms, the station entrance area, and an access ramp. Figure 13 is a perspective view of a station as it would be seen from the street; the background of this figure incorporates the guideway section shown in Figure 11.

Although the guideway location shown in the above figures, (Center-line of streets), is the most desirable in terms of shadowing of the sidewalks and storefronts and in accommodating stations and interchange ramps with minimal impact on adjoining structures, some of the downtown streets are too narrow for a center location to be feasible (unless one or more traffic lanes could be closed). In these cases the guideway would probably be located over the curb line or sidewalk, the station platform area might be narrower or might be located within or above existing structures, and interchange ramps might require modification or removal of structures on corner lots.

The examples shown are possible approaches to network layout and station design for APRT in downtown Los Angeles. These examples do illustrate the potential impact of such a system on the downtown environment, and they indicate some of the problems the urban designer must solve or the community must accept if such a transit system is to be selected as an alternative to the regional transit system.

System Costs

The Aerospace Corporation has developed a system cost estimate for a 100-mile network; based on 1972 dollars they estimate that the system would cost $510 millions, or $5.1 millions/guideway mile. This does not include costs for right-of-way acquisition or utility relocations. The unit costs are based on the assumption that no development costs will be included in production pricing.

Aerospace has also extrapolated the cost of the 100-mile network to larger systems for Los Angeles to match the dollars projected in the 1968 report, and escalated the costs to 1978 dollars; to be comparable to the 1968 report. The costs for these networks are shown in the titles of Figure 1-4. The estimates assumed that economics of scale would reduce unit capital cost to about $4.7 million/mile for a 200-mile system and $4.05 million/mile for a 500-mile system. However, the Aerospace cost estimates do not properly reflect the higher costs associated with extensive construction in a downtown area, and are therefore undoubtedly optimistic and quite low.

REFERENCES

J. E. Anderson, J. L. Dais, W. L. Garrad, A. L. Kornhauser - Personal Rapid Transit, A Collection of Papers on a New Type of Urban Transportation, University of Minnesota, Apr. 1972.

The Aerospace Corporation - High Capacity Personal Transit Systems El Segundo, California, Nov. 1971 (Rev. Jan. 1972).

E. J. Hinman, R. B. McDowell, R. A. Makofski, Control Considerations for Short-Headway ACGV Systems: Applied Physics Laboratory of John Hopkins University, Silver Spring, Maryland, Oct. 1971.

TRW Systems Group Report, Network Control Study, Prepared for USDOT, July 1970.

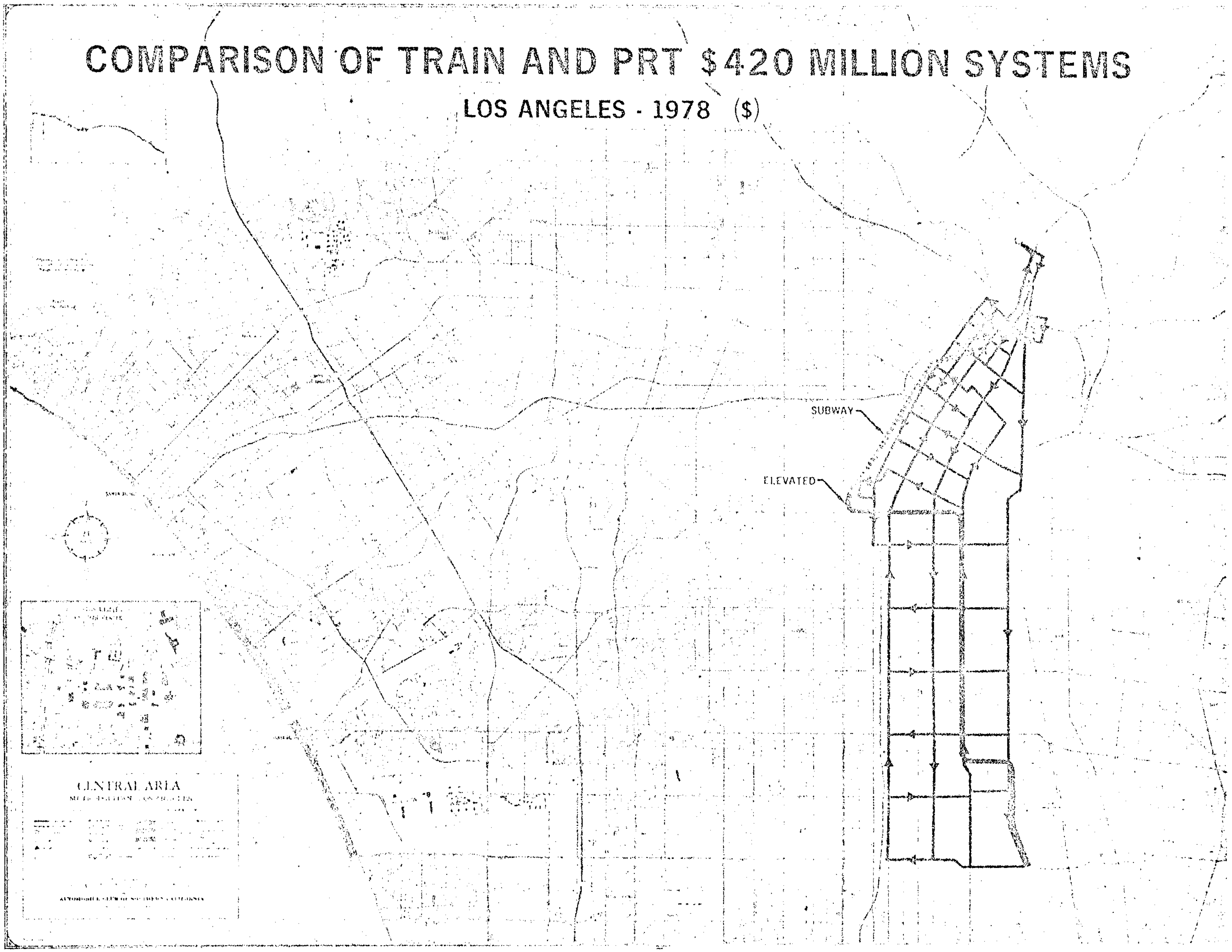
George Kovatch and George Zames, Personalized Rapid Transit Systems; A First Analysis, Transportation Systems Center, Cambridge, Mass., Aug. 1971.

J. E. Anderson - The Service Potential of Personal Rapid Transit and Its Application, University of Minnesota, 1972.

Heinz G. Loistner - PRT Technology, The Boeing Company, Seattle, 1972.

R. D. Kangras - Alternative Dual Made Network Control Strategies. Transportation Systems Center, Cambridge, Mass., Mar. 1972.

FIGURE 1

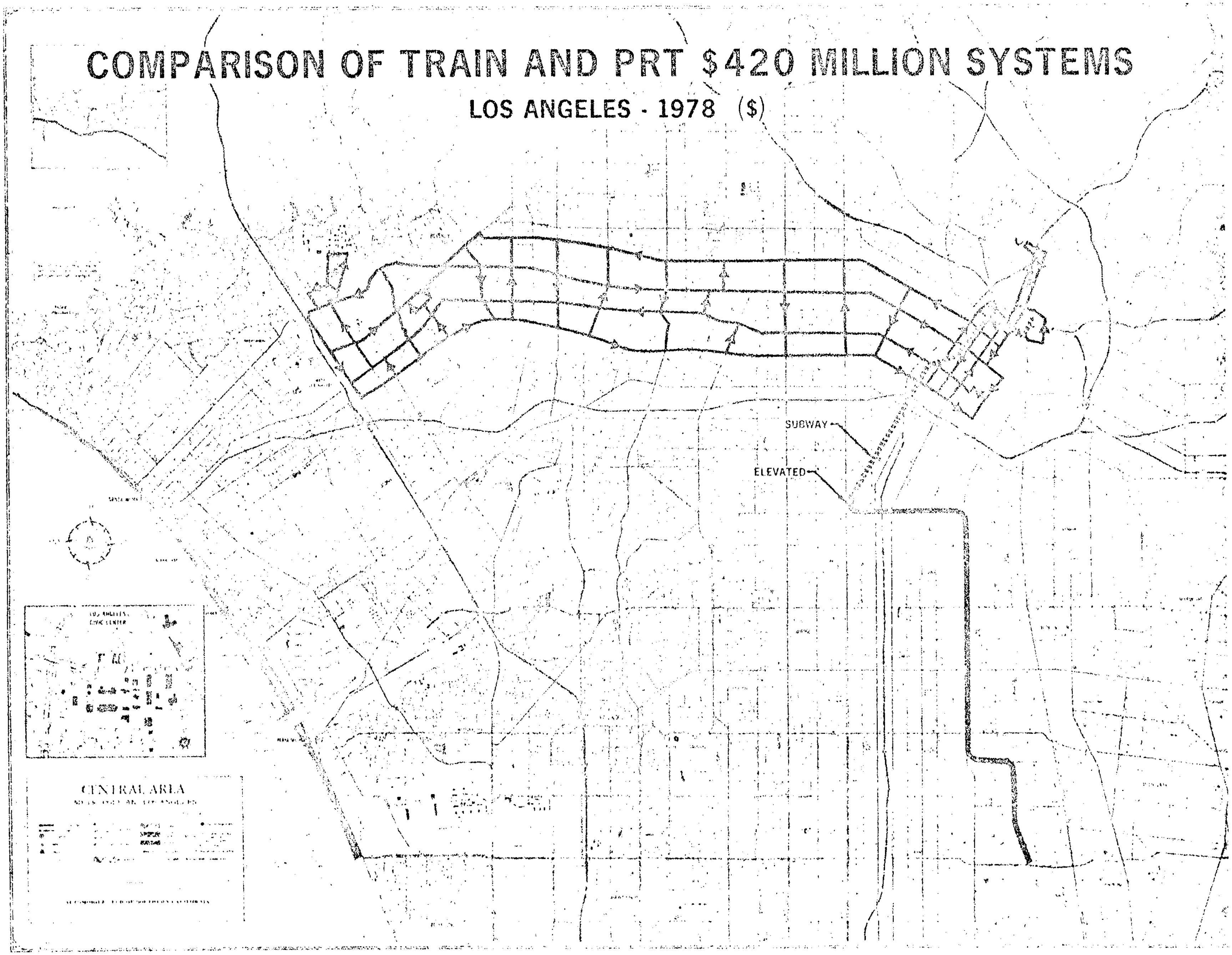


NETWORK DESIGNED BY AEROSPACE CORP.

FIGURE _

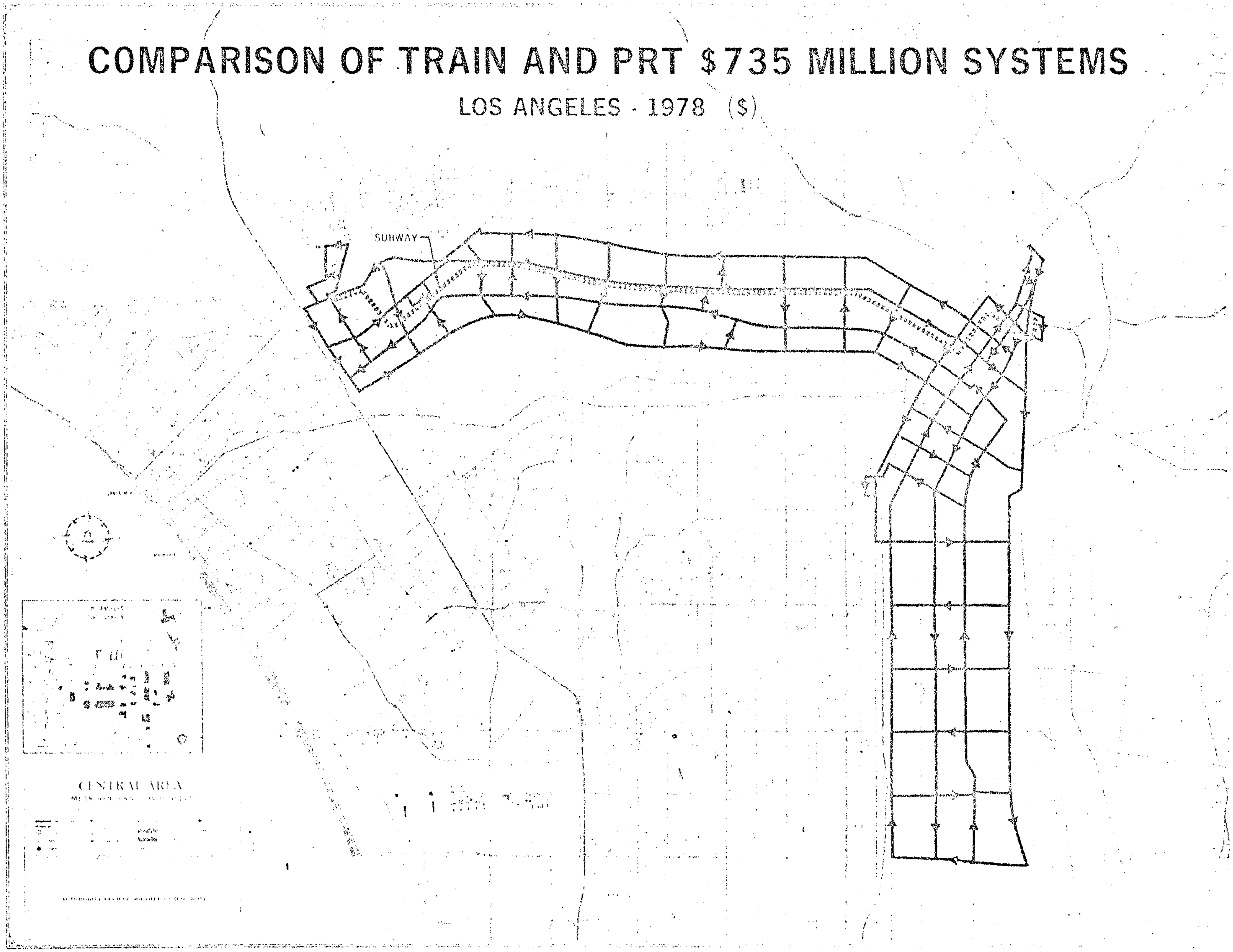
COMPARISON OF TRAIN AND PRT $420 MILLION SYSTEMS

LOS ANGELES - 1978 ($)



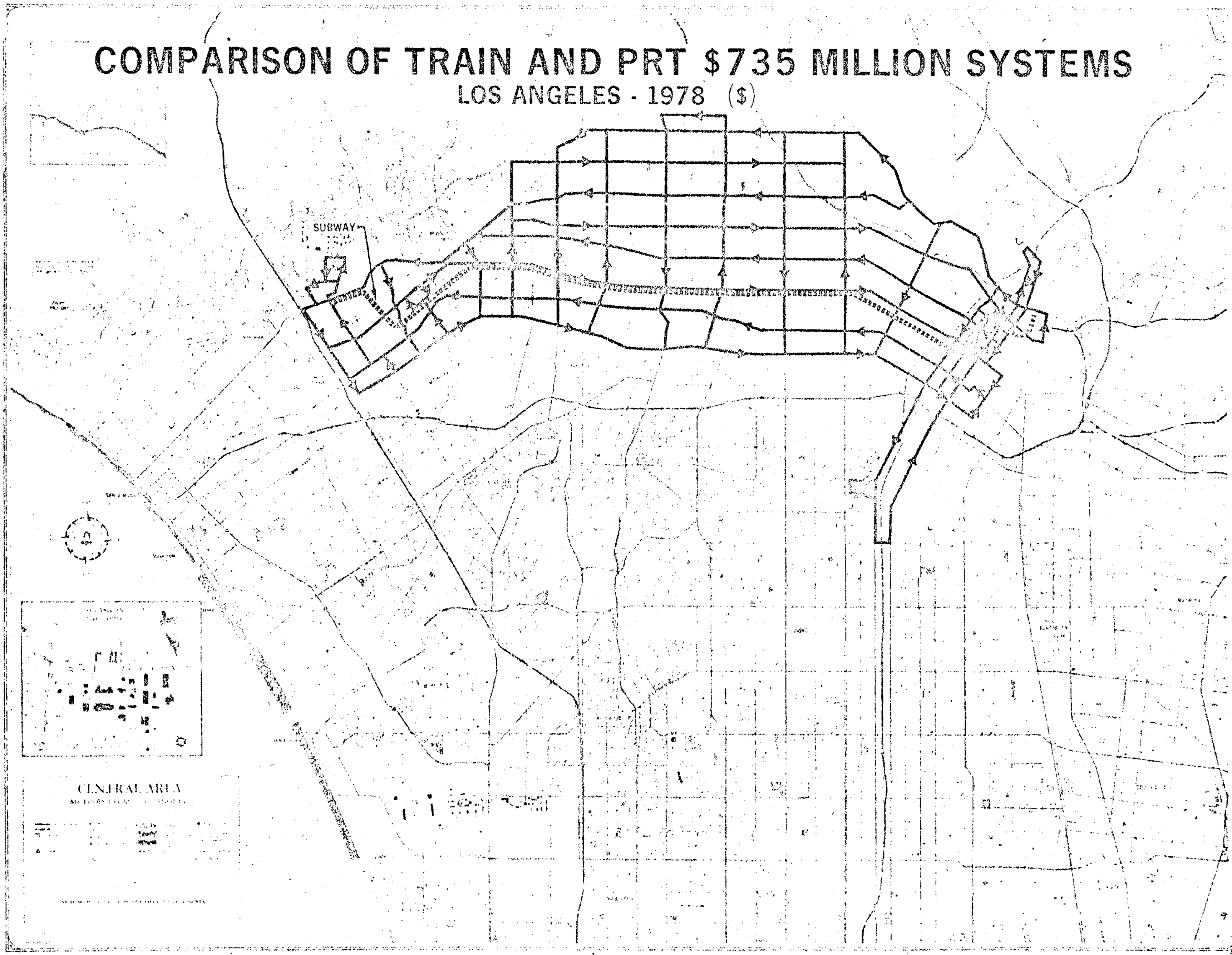
NETWORK DESIGNED BY AEROSPACE CORP.

FIGURE



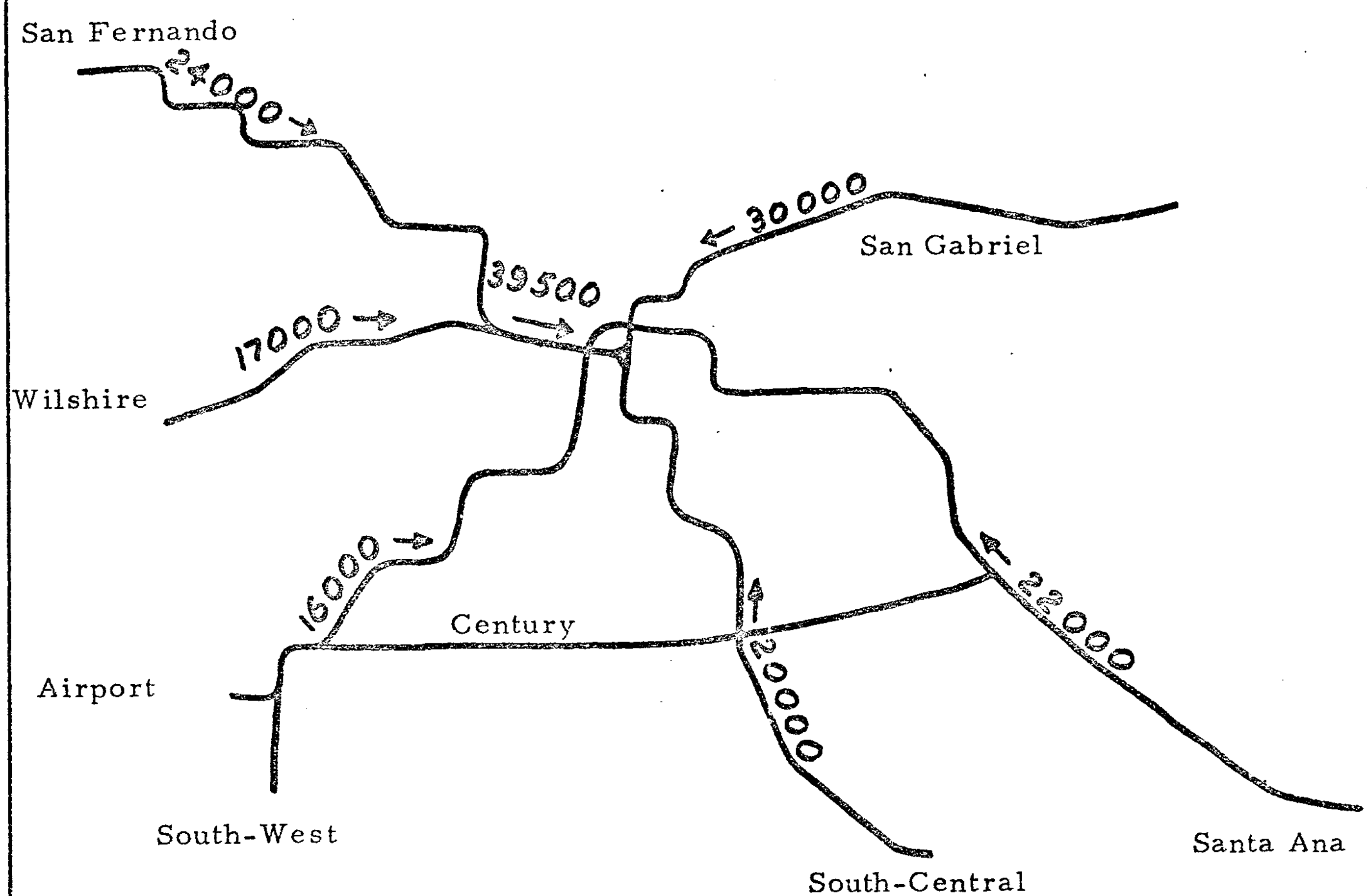
NETWORK DESIGNED BY AEROSPACE CORP

FIGURE



NETWORK DESIGNED BY AEROSPACE CORP.

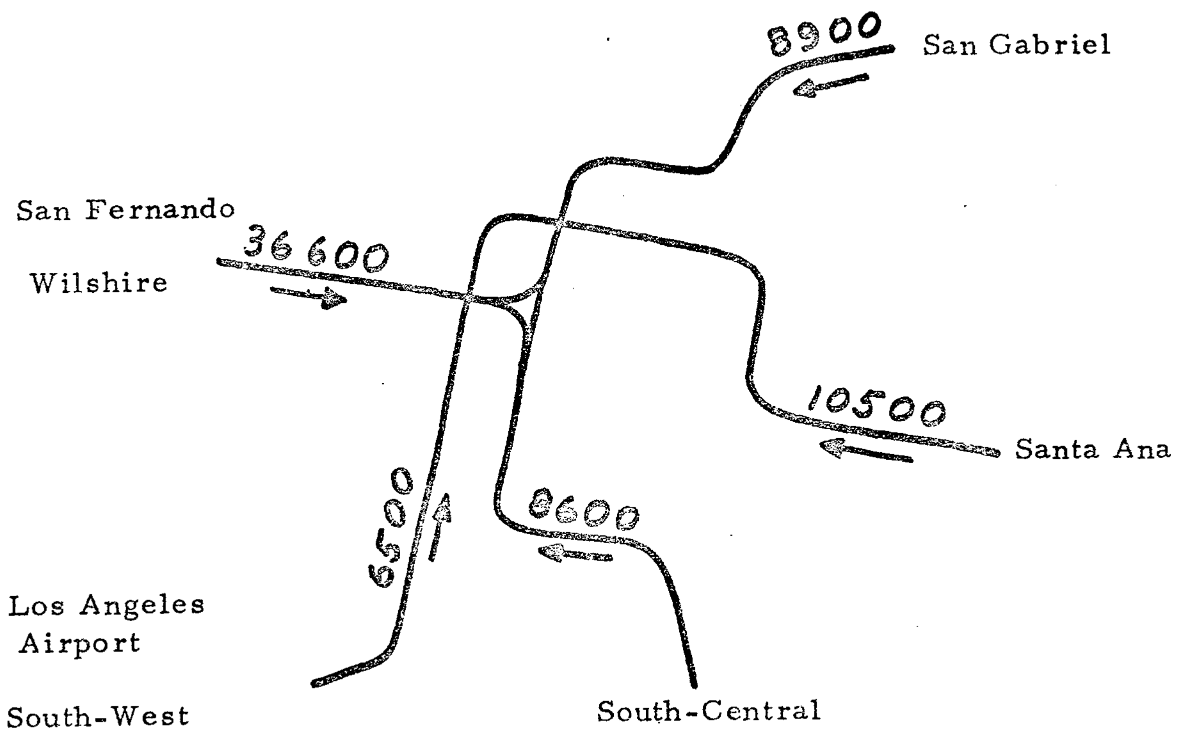
FIGURE 5



A.M. Peak Hour Inbound Flow All Patrons

Based on 1971 L.A.R.T.S. Seven Corridor Study for Mass Rapid Transit Patronage in 1990.

FIGURE 6



A. M. Peak Hour Flow of Patrons Bound to CBD Only.

Based on DMJM Breakdown of L. A. R. T. S. Figures for Mass Rapid Transit Patronage in 1990.

FIGURE 7.

Back-up calculation for assumptions (a) and (b).

Vehicle Speed 30 ft/sec. (20 mph) in CBD

Vehicle Acceleration .20g = 6.45 ft/sec.^{2} assumed linear to 20 mph

Vehicle Deceleration .20g = 6.45 ft/sec.^{2} assumed linear

Distance required to switch and clear through line = 110'

Distance required to decelerate 30 = 6.45 t ∴ t = 4.65'

$d = 1/2 \times 6.45 \times 4.65^2 = 70'$, Say 75'

Distance required for approach to station 80' i.e., Platoon Formation

Distance required for station 60'.

Distance required for platoon dispatch 80'

Distance required for acceleration 75'

Distance required for switch 110'.

Distance required for readjustment prior to next switch 50'

Distance occupied by switch 110'.

Distance occupied by gradient 10' @ 10% + VC_s 130' min.

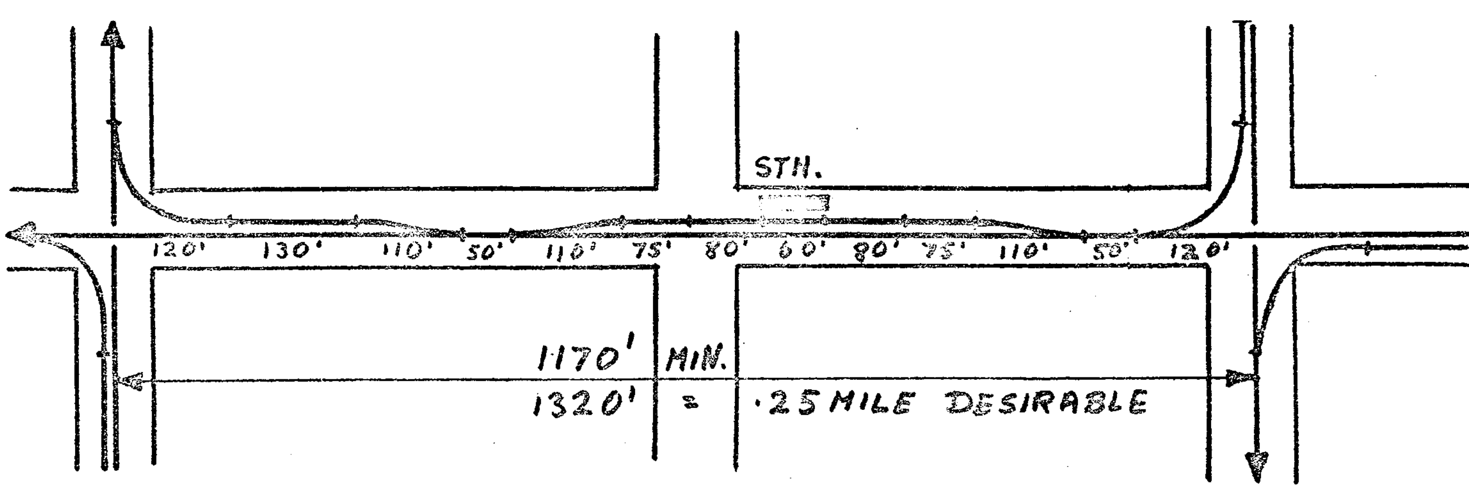
Distance occupied by diverging curve of 80' rad. + spiral = 120'

Distance required for merging curve + spiral = 120'

Distance required for readjustment 50'.

Distance required for switch; brings cycle back to origin ∴ Total required = 1170

120 + 130 + 110 + 50 + 110 + 75 + 80 + 60 + 80 + 75 + 110 + 50 + 120 = 1170



PERSONAL RAPID TRANSIT

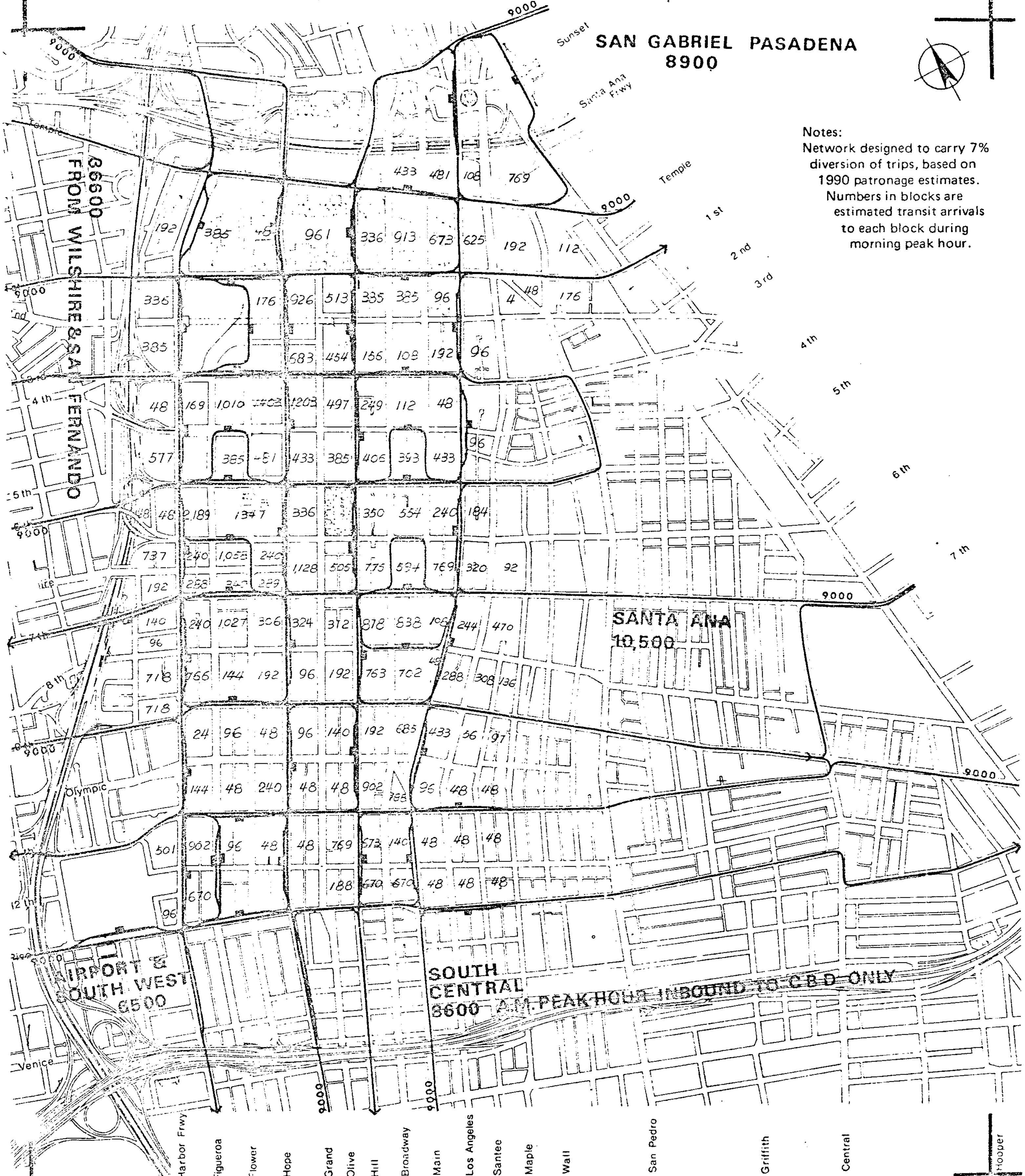


FIGURE 8. 70,000 TRANSIT RIDERS DESTINED FOR CBD ONLY
(Represents an average 7% diversion rate with 2 mi. tributary area of transit corridors.)

DMJM

DMJM

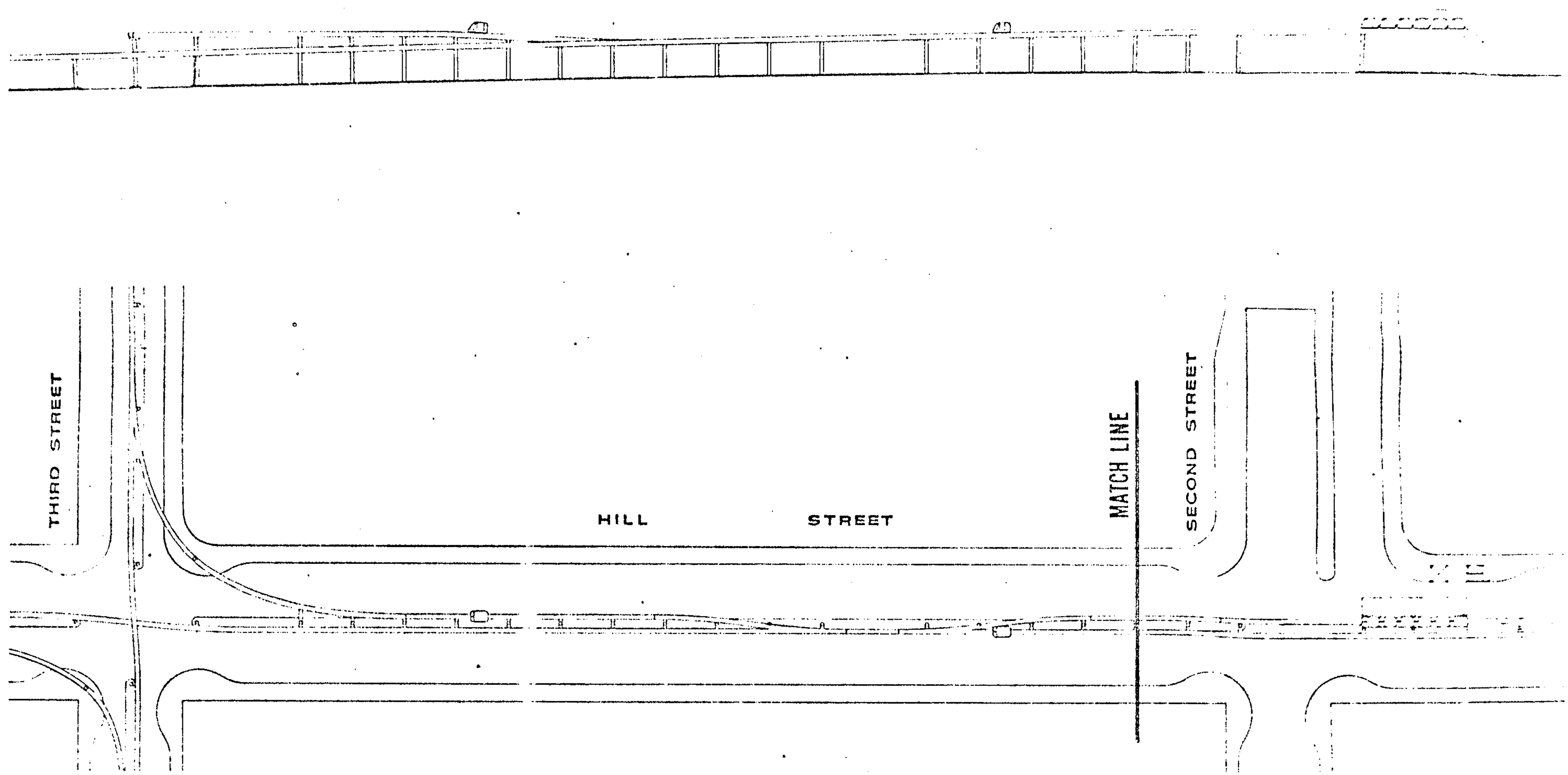
PERSONAL RAPID TRANSIT

FIGURE 9. 140,000 – 150,000 TRANSIT RIDERS DESTINED FOR CBD ONLY
(Represents an average 15% diversion rate within 2 mi. tributary area of transit corridors.)

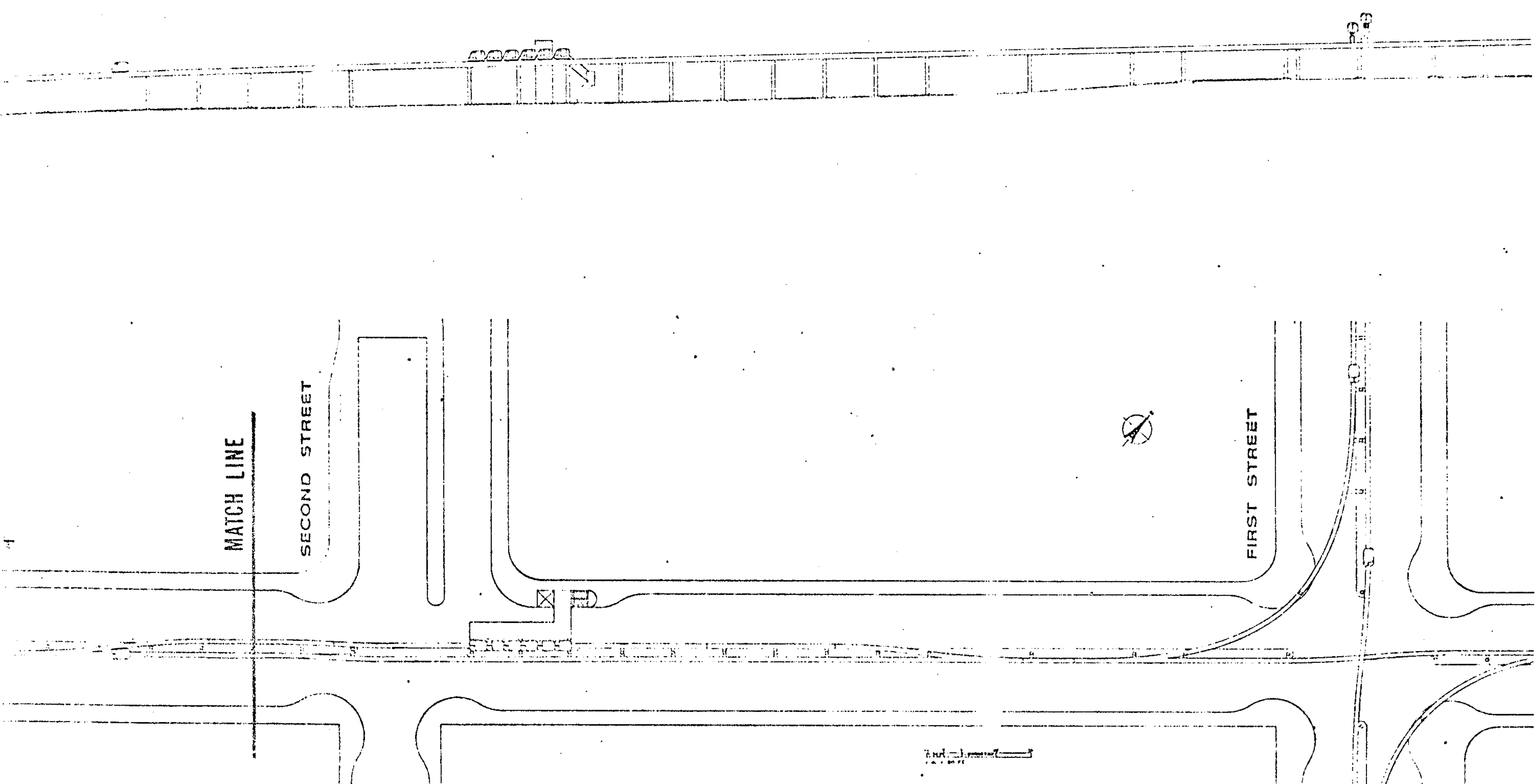
DMJM

DANIEL, MANN, JOHNSON & MENDENHALL

DMJM
DANIEL MANN JOHNSON & MENDENHALL
PLANNING ▪ ARCHITECTURE ▪ ENGINEERING ▪ SYSTEMS ▪ ECONOMICS



TYPICAL APRT GUIDEWAY LAYOUT LOS ANGELES CBD



TYPICAL APRT GUIDEWAY LAYOUT

LOS ANGELES CBD

DMJM
DANIEL, MANN, JOHNSON, & MENDENHALL

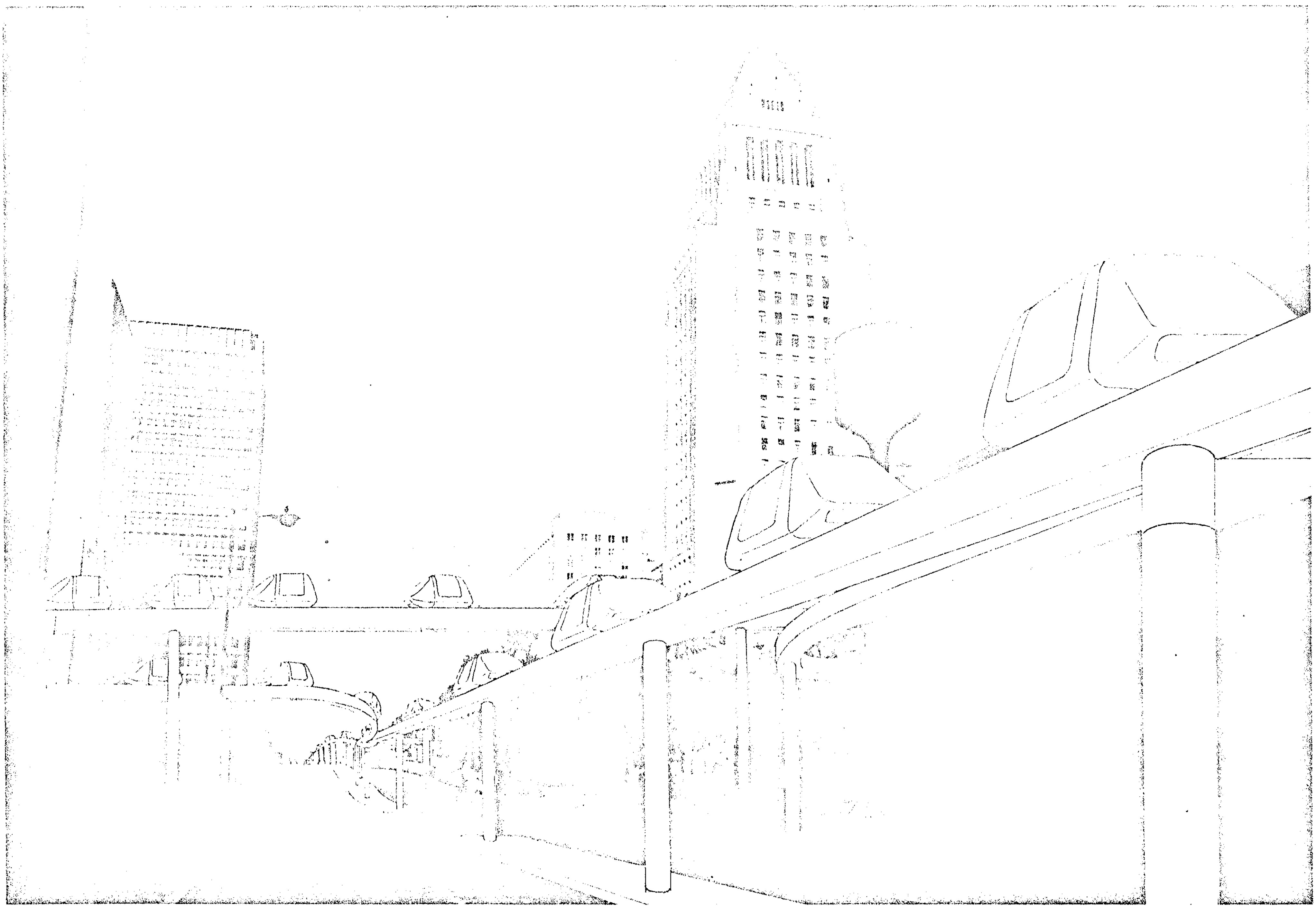
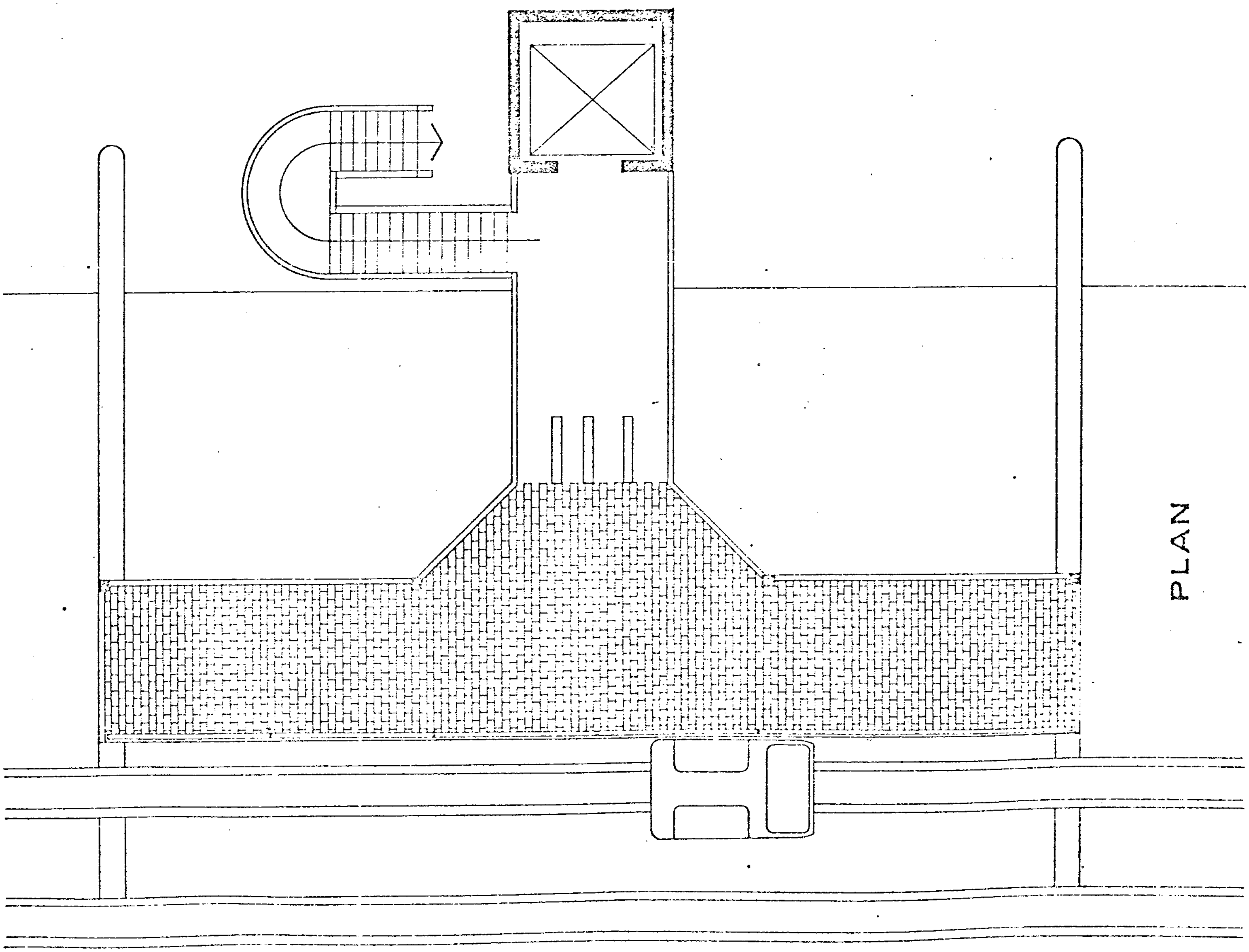


FIGURE 11

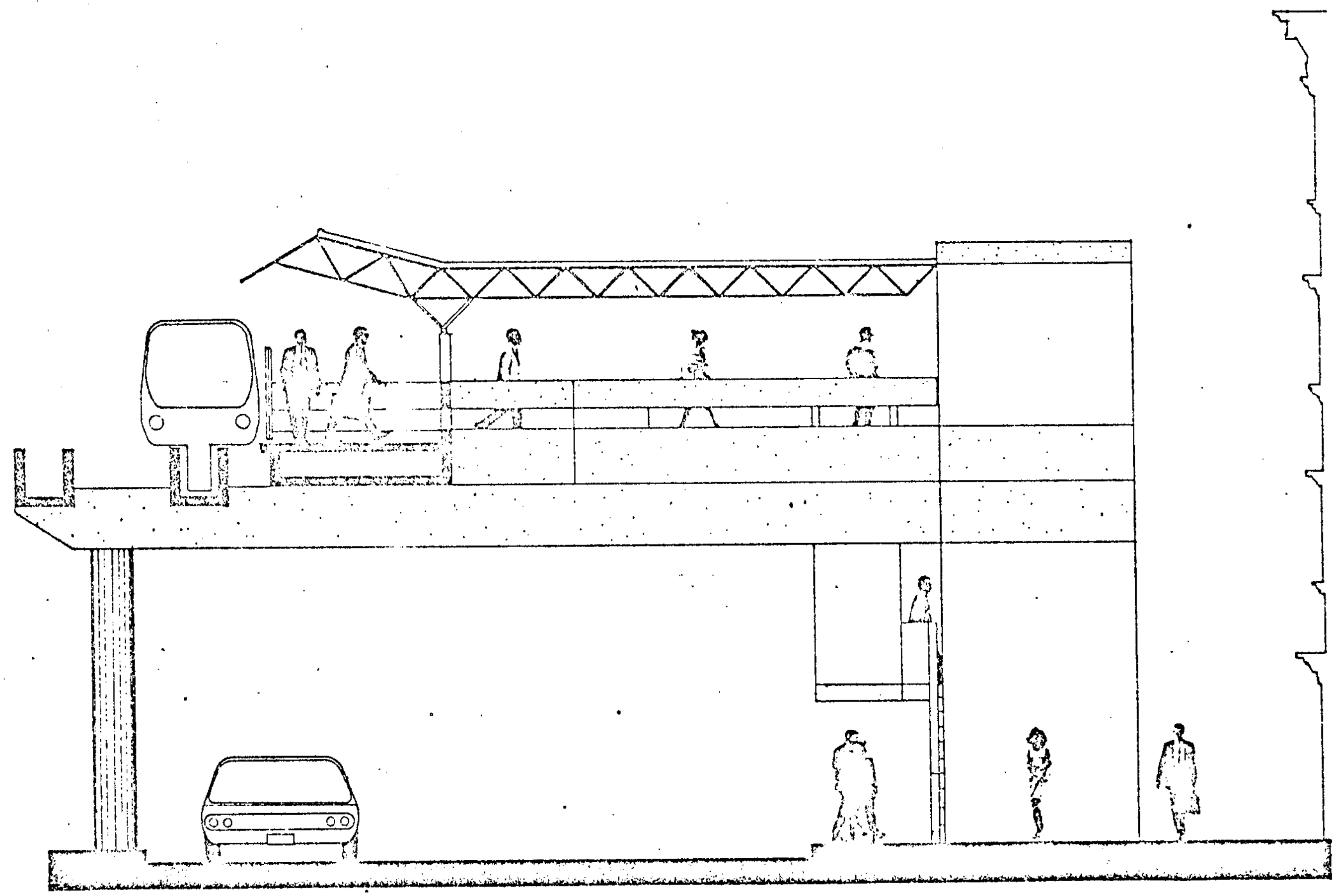
TYPICAL APRT STATION

PLAN



DANIEL, MANN, JOHNSON, & MENDENHALL
3250 WILSHIRE BLVD. • LOS ANGELES, CALIF. 90010 • AREA CODE 213 381-3663
PLANNING § ARCHITECTURE § ENGINEERING § SYSTEMS § ECONOMICS

DMJM



SECTION

DMJM
DANIEL, MANN, JOHNSON, & MENDENHALL
3250 WILSHIRE BLVD. • LOS ANGELES, CALIF. 90010 • AREA CODE 213 381-3663
PLANNING § ARCHITECTURE § ENGINEERING § SYSTEMS § ECONOMICS

TYPICAL APRT STATION

Continue Plan Refinement,

Analysis of Advanced Personal Rapid Transit for the Los Angeles Area (Supplemental Report)

KE/DMJM

April 1973

TABLE OF CONTENTS

Analysis of Advanced Personal Rapid Transit (APRT)
Concepts for the Los Angeles Area
(Supplemental Report)

INTRODUCTION

The report (March 1973) on Advanced Personal Rapid Transit (APRT) presented an objective analysis of APRT in the Los Angeles area as a potential candidate as a regional line-haul system. No opinions were expressed in this report as it was the feeling of the Joint Venture that the report should simply state facts and fundamental issues and allow the reader to draw his own conslusions. This supplemental report, however, readdresses some of the fundamental issues and presents conclusions.

CONCLUSIONS

The APRT system is well suited for medium density residential and commercial areas. It could be particularly well adapted as a support system to a regional line-haul transit line functioning as a collection/distribution system for widely spaced transit stations.

In our opinion, APRT cannot handle the distribution of peak-hour trips in dense areas such as the Los Angeles CBD and therefore is not considered to be a suitable substitute for a high capacity line-haul system.

A network for the Los Angeles CBD was analyzed using the transit diversion from the 1968 SCRTD study. Based on this study it was determined that 55 stations and aerial guideways on a 1/4 mile spacing would be required to handle CBD destinations only. This system did not allow for any expanded use of the system as might be expected from peripheral parking or internal CBD walk trips. A system of greater capacity would require superimposing a network of similar complexity or would require higher passenger loading of the vehicles. The first alternative would require a guideway on virtually every street with a station on nearly every block face. The second alternative would defeat the objective of APRT of providing no-wait, non-stop, origin-to-destination service on demand.

The APRT system is in its early developmental stages. Operating scale models have been built and various operating conditions simulated. There are, however, many areas of concern where no information is available and other areas where the information may be questionable. Specifically, these are:

- Required research and development necessary to implement a demonstration project
- Capital and operating costs of the system
- System safety with vehicles operating at speeds of 20 to 60 mph separated by five feet
- Human Factors such as motion sickness, crash survival anxieties, claustrophobia, acrophobia, disorientation, etc. associated with small vehicles operating at close headways
- System operational characteristics
- Environment impact of an aerial structure's grid network on residential and commercial areas
- Development of control systems capable of safely handling a large number of vehicles and origins/destinations at fractional second headways.

In view of the developmental and research work required to demonstrate the feasibility of the APRT system, problems associated with peak-hour distribution in dense areas, the unresolved human factors, questions concerning safety, and environmental issues, we cannot recommend the selection of Advanced Personal Rapid Transit (APRT) as a regional line-haul system.

DISCUSSION

The following is a discussion on several pertinent issues.

- Research and Development - APRT is in the early developmental stages. The Aerospace Corporation has estimated that, depending on the desired level of component reliability, 50 to 150 million dollars in research and development would be required before the system would be ready for test track operations. This could take place by 1976 if the necessary research and development were to start by the summer of 1973. They estimate that the system could be ready for an in-city demonstration by 1978-79 with production application to begin in 1980-1982.

  There are several important advanced concept PRT research and development projects taking place in France, Germany and Japan. The National Governments of these countries are heavily involved in sponsorship and funding of these efforts. These systems are all at the research and development or test track operation stages.

  In France, the National Government has funded a research project to examine the prospects of PRT-type technology from systems analysis to prototype demonstrations. Public reporting of the status of this work has been minimal, however, a test track is scheduled for operation in 1973-74.

In Japan, serious efforts to develop a PRT system are well advanced under the sponsorship of the Japanese Ministry of International Trade and Industry. A scale model non-network demonstration of Controlled Vehicle System (CVS) have been made at Higashiramurayama, Tokyo. A full test course is under construction with operation scheduled for 1974-75.

In Germany, PRT development is progressing at a steady pace. Two industrial firms, Demog and Messerschmitt-Bolkow-Blahm, are participating in a program funded by the central government to carry out an entire research, development, and prototype demonstration program leading to an initial version of a PRT Technology. A recently announced development schedule indicated completion of a 1/2 mile-prototype test track by 1973-74, with operation and expansion to a larger experimental network to study user acceptance in 1975-76.

- Capital Cost Estimates - Estimates of capital costs were made by the Aerospace Corporation. In the preparation of these estimates, extensive use was made of "learning curves" and "economies of scale" which in effect reduces the unit cost of vehicles and guideway structures as the quantity increases. Some economies could be realized in vehicle construction using mass production techniques and some would result from the repetitive type of construction envisioned. The amount, however, is difficult to determine unless a specific system is laid out and estimated.

Estimates of system costs on the order of 5.2 million dollars per mile have been announced. These estimates assumed economies of scale. Although a detailed review of the estimate was not made, it is apparent that there were certain omissions such as right-of-way costs and costs associated with the relocation of utilities.

- System Safety - The capacity of the APRT concept is based on vehicle operations at speeds of 20-60 mph with very short separations -- on the order of 5 feet irrespective of speed. In this concept, an undetected track blockage or a brick wall stop condition, could result in the first vehicle in a group impacting at line speed, with the second and subsequent vehicles likely to strike each other at somewhat reduced speeds. This problem is recognized and some type of passive passenger restraints (air bags) or possibly reverse seating to minimize injury in collisions is necessary. Since safety is the most important aspect, additional research is necessary before APRT can be considered acceptable as a public transportation system.

- Human Factors - Indications were that very little consideration had been given to the human factors aspects of APRT, with the possible exception of tolerance to accelerations and decelerations.

A detailed analysis of human factors was not made. Discussions were, however, held with Dr. Slade Hulbert of the Institute of Traffic and Transportation Engineering at UCLA, who is one of the most respected experts in human factors research in transportation. Dr. Hulbert indicated that very little research had been published concerning APRT human factors.

The human factors considerations can be divided into two categories, those affecting the users of the systems and those affecting non-users in the immedicate vicinity of the guideways and stations. In Dr. Hulbert's opinion, the concerns of the user would be more critical than those of the non-user; such factors as motion sickness, safety anxieties, disorientation from height and lack of visual references, and resistance to high-speed operations at close headways without an on-board operator are all concerns that need to be studied. The principal conclusions reached with Dr. Hulbert were that many of these factors could greatly influence the design of the system, the extent of which would not be known without research and analysis into the psychic response to the various simulated conditions.

The following is a list and summary of some of the factors discussed:

●● <u>Small-Vehicle Motion Sickness</u>: Due to the greatly increased levels and frequencies of accelerations, jerks, and visual angle rotations in APRT, travel in this type of transit may cause considerably more motion sickness than conventional transit or aircraft.

- Crash Survival Anxieties: Tight intervals and close headways generate and enhance anxieties for safety in collision. This may create some reluctance to use the system.
- Noise/Vibration to Surroundings: A totally unknown new spectrum of noise, vibration and high-frequency sensory emanations are transmitted by APRT to the nearby pedestrians, structure inhabitants, and office occupiers.
- Claustrophobia: A novel dimension of emotions will be opened by APRT in the discomforts and entrapment in a locked moving driverless container.
- Human Communications: The effects of total deprivation of external communications to a passenger in locked, small, fully-enclosed vehicles traveling at high accelerations and short headways is not known.
- Landmark and O/D Disorientation: Travel without personal control after launch in intricate guideway networks or mazes leads to high disorientation rates, particularly in missed-turn situations.
- Acrophobia: The fear of heights may be intensified for riders in small vehicles elevated to 2nd or 3rd story levels of nearby buildings.

- - Vandalism/Crime/Safety: The personalization of compartments or cubicles in public facilities may raise the rates of vandalism, crime, personal assaults, and robberies while proportionately increasing the user's fears and apprehensions of victimization.

- System Operations - To accommodate approximately 71,000 patrons arriving in the CBD during the morning peak hour, 55 off-line stations would be required. This assumes uniform distribution of trip ends. Each station therefore would be required to process 900 to 1,000 vehicles per hour.

  One method proposed is to process a platoon of six vehicles through the station in approximately 20 seconds. In this concept, six vehicles would collect on a station entrance gateway during a 20-second interval. The six vehicles would move up to the station platform at the same time as the six previous vehicles are leaving the platforms; the vehicles would travel 60 feet from the gate to the platforms. Passengers would then be unloaded from the vehicles and departing passengers would then be loaded, so that the six car platoon would be ready to leave within 20 seconds.

  A twenty-second interval to organize the vehicles, move them 60 feet, locate them precisely at the platform, open the vehicle doors, and unload and reload passengers is optimistic. In addition, the collection of 6 vehicles at the entrance gateway during the 20 seconds would be a probabilistic occurence; in many instances only 4 or 5 vehicles might be present. Thus the station's operational capacity after an actual simulation analysis of the system superimposed in the L.A. downtown could be somewhat lower than the figures cited. This would require more stations in the C.B.D. than previously identified. The actual design of a system following a simulation analysis, would define concentrations of destinations that could require multiple stations on many block faces.

- Wilshire Corridor Analysis - A limited analysis of the application of APRT to the Wilshire Corridor was made. Trip projections developed by the L.A. Department of City Planning, by A. M. Voorhees, and by DMJM have been used. It has been estimated that approximately 50,000 to 70,000 trips would arrive in the corridor during the morning peak hour (including some intra-corridor trips). If a relatively even distribution of trip ends is assumed throughout the corridor, it is possible to lay out an APRT network with one-way lines spaced at 1/4 to 1/2 mile intervals; station spacings would be the same.

  Although such a network could be planned using mostly major arterial streets and possibly freeways for right-of-way, it is possible that there would be locations at which the guideway might be obtrusive to streetside developments. In particular, guideways 17 or 26 feet above ground could cause serious aesthetic impact in single-family residential neighborhoods in this corridor.