TECHNICAL REPORT

ALTERNATIVE
TRANSIT CONCEPTS
ANALYSIS

HONOLULU RAPID TRANSIT PROJECT
PRELIMINARY ENGINEERING & EVALUATION PROGRAM
PHASE II

Prepared For

DEPARTMENT OF TRANSPORTATION SERVICES

CITY & COUNTY OF HONOLULU

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I. INTRODUCTION & SUMMARY

A. INTRODUCTION

This report presents the major findings of the alternatives analysis of transit concepts for Honolulu. The initial alternatives analysis was conducted in 1966-67 as part of the Oahu Transportation Study. In 1972, other alternative concepts were studied under the Preliminary Engineering and Evaluation Program - Phase I (PEEP I). As part of the PEEP II program, a review of all past alternatives was made and new alternatives were identified and analyzed. This report documents the analysis and comparison of alternatives and the selection of the most cost-effective concept. Refinements of the selected concept is presented in a separate report.

Both the land use and travel forecasts support a high level, line haul transit system to serve the major east-west transportation corridor of urban Honolulu. Within this transportation corridor are located all of the major activity and employment centers of the island. The outlying Windward, Central and Leeward districts would be served by express buses operating on highways and freeways and interfacing with the proposed line haul transit system in urban Honolulu.

Along this major transportation corridor are various transit service areas of low to medium density residential communities located in well defined valleys and ridges of the Koolau Range. These service areas have been served by well established bus routes for many decades with little likelihood of any major route changes anticipated in the future.

The well defined major transit corridor and local service routes of urban Honolulu forms a basic network configuration adaptable to most transit concepts. The optimum station locations are at major activity centers and at interface points with major feeder bus routes. Transit concepts conforming to this basic network configuration and station locations should provide optimum service quality with any differences in patronage due to variations in system length and operating characteristics.

B. TRANSPORTATION OBJECTIVES

Through various planning studies, the need for a high level rapid transit system to serve urban Honolulu has been determined. Under the current General Plan Revision Program conducted by the City's Department of General Planning, alternative land use policies were tested with different transportation policies. The study concluded that a high level rapid transit system is necessary to support the recommended land use policies. Further to the above, it is the stated policy of both the State and the City not to construct any new highways on Oahu after completion of the current Interstate Highway

System. Accordingly, a primary transportation objective is to develop a high level transit system to provide a balanced transportation system on Oahu that would meet future demands without the need for new highways.

To meet this objective, a transit system that would attract some 500,000 daily transit trips in 1995 is required. This daily volume translates into a line volume of approximately 20,000 passengers per hour during the peak period. Other basic objectives to be met are for a broad coverage system to provide transit service to all urbanized areas of the island and a system specially planned and designed for compatability with the unique environment and the limited land and financial resources of the island.

C. TRANSIT SYSTEM REQUIREMENTS

As previously stated, an anticipated level of demand of up to 20,000 passengers per hour is required in the major transportation corridor by 1995. In order to provide sufficient capacity for future growth, a system capacity in the range of 25,000 to 30,000 passengers per hour would be required. This level of system capacity falls between conventional line haul systems with the upper limit of 40,000 passengers per hour, mainly represented by the modern rail rapid transit system. The lower end of the line haul system capacity of up to 10,000 passengers per hour is usually represented by vehicle systems utilizing existing streets and highways such as conventional buses and street cars.

This level of demand requires a medium capacity system operating on exclusive, grade-separated right-of-way. Medium capacity systems can be provided by up-grading conventional buses to operate on busways or light rail transit (LRT) vehicles to operate on exclusive, grade-separated guideways. From the other end of the scale, the conventional rail rapid transit concept can be tailored down to a more modest size and lower speed vehicle system.

From the foregoing, it can be seen that if the level of demand were either at the lower or upper end of the scale, the type of system most suitable for application is readily determinable. The medium capacity demand poses some unique problems in that the conventional bus and LRT systems need to be up-graded to a higher level system operation that is not in common usage today with available operating experience and data. For example, the manual operation of buses on a busway with on-line stations and at headways of 10 seconds or less poses many questions as to system capacity and schedule dependability. The light rail transit system is planned to have merging and demerging operation with the capability of coupling and decoupling cars on the line. At headways of 4 minutes or longer, sufficient time should be available to perform these operations but at shorter headways of 2 minutes or less, the factor of safety is reduced and hence the dependability of the system is unknown.

Due to the lack of operating experience and data, considerable effort was applied to the development of the busway and LRT system plans. Physical and operating characteristics were carefully examined in the development of these plans so as not to bias any one concept relative to the others.

The concepts selected for evaluation are all multi-modal in that the feeder bus system comprising local and express buses operating in mixed traffic and reserved lanes is an important element common to all system concepts. The theory that no single mode can perform all functions as economically as a multi-modal system has been adopted. Further to the above, variations in modal operation have been carefully examined to utilize each mode in the most effective manner. For example, buses are operated on local streets in mixed traffic, on highways and freeways in both mixed traffic and reserved lanes, and on busways that have grade separated, exclusive right-of-way facilities. Similarly, the LRT system operates on tracks that are in streets with mixed traffic, in highways on exclusive rights-of-way but not grade separated, and in exclusive, grade separated rights-of-way.

These variations in the system facilities and operations permit each system to be tailored in part or in total to best meet both the service demands and physical route conditions existing in Honolulu.

D. ALTERNATIVE CONCEPTS DESCRIPTION

One of the first steps in the selection and analysis of alternative concepts was the study of a low capital investment alternative defined as the expanded bus concept. This concept provided improved bus service through the use of an expanded bus fleet to provide greater coverage and faster trip time to and within the urban core by greater use of reserved lanes in highways and freeways. The concept was found to significantly increase transit demand to nearly 370,000 daily passenger trips. Although this volume falls short of the primary objective of meeting the demand of 500,000 daily passenger trips, the overriding factor in eliminating the concept as the long-range transit solution for Honolulu was the physical limitation of the streets in downtown Honolulu to accommodate the required number of buses to meet demand. This analysis confirmed the fact that a high level system using grade separated, exclusive rights-of-way must be provided to meet the future needs of the island.

Based on previous studies of alternatives conducted for Honolulu, it was determined that the basic concepts warranting detailed analysis were the following:

- A short 7-mile busway system limited to the highly developed urban core area of Honolulu and the maximum use of existing highways and freeways in the remainder of the corridor to minimize capital cost.

- A light rail transit (LRT) system that optimizes its unique feature of operating flexibly through the use of grade separated or non-grade separated, exclusive rights-of-way and existing street rights-of-way in mixed traffic. Also the system would capitalize on the recent development of new vehicles which are trainable to units of 4 or more cars with the capability of coupling and de-coupling the cars on the main line. The 28-mile system would be supported by a feeder bus system comprised of local or express buses.

- A medium capacity fixed guideway system operating on grade separated, exclusive rights-of-way supported by a feeder bus system comprised of local and express buses. This concept, as well as the LRT system is a true bi-modal system that relies heavily on both local feeder bus service and on express bus routes to perform line haul functions in corridors which does not warrant the investment for grade separated facilities. This concept was developed and evaluated using 3 system lengths of 7, 14, and 23 miles to determine the comparative cost-effectiveness of express bus and fixed guideway services at the outer ends of the transit corridor.

As was previously stated, the choice of alignment and station locations is limited, such that, any concept utilizing grade separated roadways or guideways would generally follow the same route which was determined as optimal in terms of service quality and environmental and community factors. Based on the system network, modal split analysis was conducted and cost estimates developed for each concept. In addition to usage and costs, other measures related to technical, environmental and community factors were analyzed and a comparison of the relative merits and liabilities of various alternative made.

E. FINDINGS AND CONCLUSIONS

1. Operating and Travel Characteristics

Based on a carefully structured system network and operating plan, patronage estimates were developed utilizing the modal split model for each alternative concept. The results of this analysis projected all concepts to attract over 450,000 daily transit trips in 1995. This compares very favorably with the primary objective of having 500,000 trips on transit to attain a balanced transportation system on Oahu.

The table below summarizes the patronage and average trip speed of each alternative.

	BUSWAY	LRT	FIXED GUIDEWAY		
	7-MILE	28-MILE	7-MILE	14-MILE	23-MILE
DAILY PATRONAGE	456,300	474,500	462,000	473,300	490,000
AVERAGE TRIP SPEED	12.1	13.4	12.1	12.9	14.2

The patronage differences between alternatives are not dramatic and basically reflect the extent of grade-separated, exclusive guideway with its potential for increased travel speed. This is reflected in the peak hour average trip speed of the total system, i.e. including feeder buses, with the 23 miles of grade separated, exclusive fixed guideway system having the highest speed of 14.2 mph as compared to the 12.1 mph of the 7-mile busway and fixed guideway systems.

With the transit service coverage essentially the same and the service quality differing only slightly, based on the extent of the grade-separated line haul operation and the number of stations in urban Honolulu, transit availability or accessibility provided by the alternatives is considered to be nearly equal. This applies to transit availability to various geographical areas as well as to special segments of the population. Therefore, service quality is assumed to be the same and system usage is reflected in the patronage volumes of the concepts.

2. Capital And Operating Costs

One of the primary differences between alternative concepts is in the capital and operating costs associated with each concept. Capital costs clearly reflect the length of the system including the number of stations provided and the number of vehicles required for the anticipated patronage. Also influencing costs are the physical and operating features of the vehicle system such as its size, weight, length, speed, type of propulsion power, etc.

Aside from patronage volume, the primary factors influencing operating costs are manpower required to operate the system and the operating speeds of the system. Maintenance costs, of course, are determined by the extent of facilities and equipment in a system. Capital and operating costs, based on 1974 price levels, for the alternative concepts and measures of cost effectiveness are shown below.

			FIXED GUIDEWAY		
	BUSWAY	LRT	7-MILE	14-MILE	23-MILE
CAPITAL COST ($ MILLION)	414.41	667.51	398.68	517.32	647.90
ANNUAL CAP. COST ($ MILLION)	27.92	40.49	26.34	32.37	39.59
ANNUAL O&M COST ($ MILLION)	42.71	42.15	43.29	38.05	40.86
TOTAL ANNUAL COST ($ MILLION)	70.63	82.64	69.63	70.46	80.43
TOTAL COST/TRIP	51.3¢	57.7¢	49.9¢	49.3¢	54.3¢
BENEFIT/COST RATIO	1.15	1.13	1.20	1.28	1.25

One measure of effectiveness of a system is the cost per passenger trip which shows the 14-mile fixed guideway system to be superior with the lowest cost per trip of 49.3¢. Another measure of effectiveness is the economic benefits derived from system investments shown by the benefit-cost ratio. The fixed guideway concept is found to be clearly superior over other concepts.

3. Other Factors

In addition to transportation cost and service measures, other factors related to technical, environmental, and community factors were analyzed. Many of these factors are non-quantifiable and also many factors commonly analyzed are directly reflected in and are part of the cost and service factors. Only those key factors determined to be most relevant in assessing the merits and liabilities of the concepts were selected and ranked as shown below.

	BUSWAY	LRT	FIXED GUIDEWAY
. TECHNICAL RISKS			
- HARDWARE TECHNOLOGY	1	2	3
- SCHEDULE RELIABILITY	3	2	1
. DEVELOPMENT POLICIES	2	1	1
. ENVIRONMENTAL FACTORS			
- VISUAL INTRUSION	3	2	1
- NOISE	2	1	1
- AIR QUALITY	2	1	1
. RESIDENTIAL & BUSINESS DISPLACEMENT	3	2	1
. ENERGY	1	3	2

On technical risks for hardware technology, the differences are assumed to be relatively slight with the busway ranked the highest or best. However, for schedule reliability, there are pronounced differences between concepts with the fixed guideway ranked as the best.

Relative to the relationship of each concept to development policies, the fixed guideway and LRT concept are ranked as equal and being superior to the busway only by virtue of their greater length. Therefore, any differences between concepts are considered to be small.

In environmentally sensitive Honolulu, the 3 factors considered are all very significant with the fixed guideway showing distinct superiority over the other concepts. Similarly, with the shortage of developable land and housing on Oahu, any displacement of residents and businesses is of major social and economic concern which is minimized with the fixed guideway concept.

Hawaii is totally dependent on imported oil as its energy source, including for its power plants. Accordingly, the electrically-propelled transit cars of the LRT and fixed guideway systems would be dependent on imported fuel as well as the buses used for the busway concept. Based on fuel savings from diverted motorists and fuel consumptions in operating the systems, the net fuel savings is nearly comparable between the busway and fixed guideway concepts with the LRT concept providing the least amount of fuel savings.

4. Selection Of The Cost-Effective Concept

The fixed guideway concept returns the highest economic benefit for the dollars invested and also provides the most efficient system in terms of cost per passenger trip. Of the three different fixed guideway lengths analyzed, the 14-mile system is the most cost-effective segment to build prior to 1995.

The above findings supported by other technical, environmental and community factors clearly show the superiority of the fixed guideway concept over other concepts in meeting the long-range needs of the island. Refinement of this fixed guideway concept relative to its physical and operating features are described in detail in a separate report.

II. GROWTH AND FORECASTS

A. POPULATION AND EMPLOYMENT PROJECTIONS

The unique geography and topography of the Island of Oahu have, throughout the island's history, greatly influenced land use development and the transportation network. Development of Oahu has been conditioned largely by the geographic constraints imposed by the Koolau and Waianae Mountain Ranges and the constraint on urbanization imposed by the State's land use law. Urban development has been restricted primarily to a relatively narrow level area along the southern Leeward Coast of the Island. This area unable to accommodate unlimited growth, has developed considerably higher in density in the past several decades, creating a need for more intensive transportation facilities.

Population and employment projections to 1995 were prepared by the Hawaii State Department of Planning and Economic Development (DPED). The table below summarizes the DPED projections:

Year	Population	Employment
1970	630,500 *	315,780 *
1980	735,000	377,540
1995	924,000	518,140

* 1970 U.S. Census

These projections have been adopted by the Oahu Transportation Planning Program (OTPP) for use in its transportation planning process. OTPP performed many of the early steps necessary to convert population and land use forecasts into travel estimates, which were used in travel forecasting for the Honolulu Rapid Transit Program.

B. LAND USE FORECASTS

The future population and employment distribution is projected to generally follow the past locational trend with continuing intensification of the urbanized areas. Land use forecasting involved distribution of population and employment by census tract by the use of the land use model. Population and employment were allocated by type and with regard to uses permitted under the General Plan of the City & County of Honolulu.

In 1960, approximately 65% of the total island population resided within the central Honolulu area from Pearl City to Kahala. (See Figure II-1). Between 1960 and 1970 this area experienced a numerical increase of 46,500 people, but a percentage decline to 59% of the island-wide population. In this period, population increased in the Hawaii Kai area, Kaneohe and Kailua on the Windward side, Mililani and Waipahu in the Central valley, and Waianae and Makakilo on the

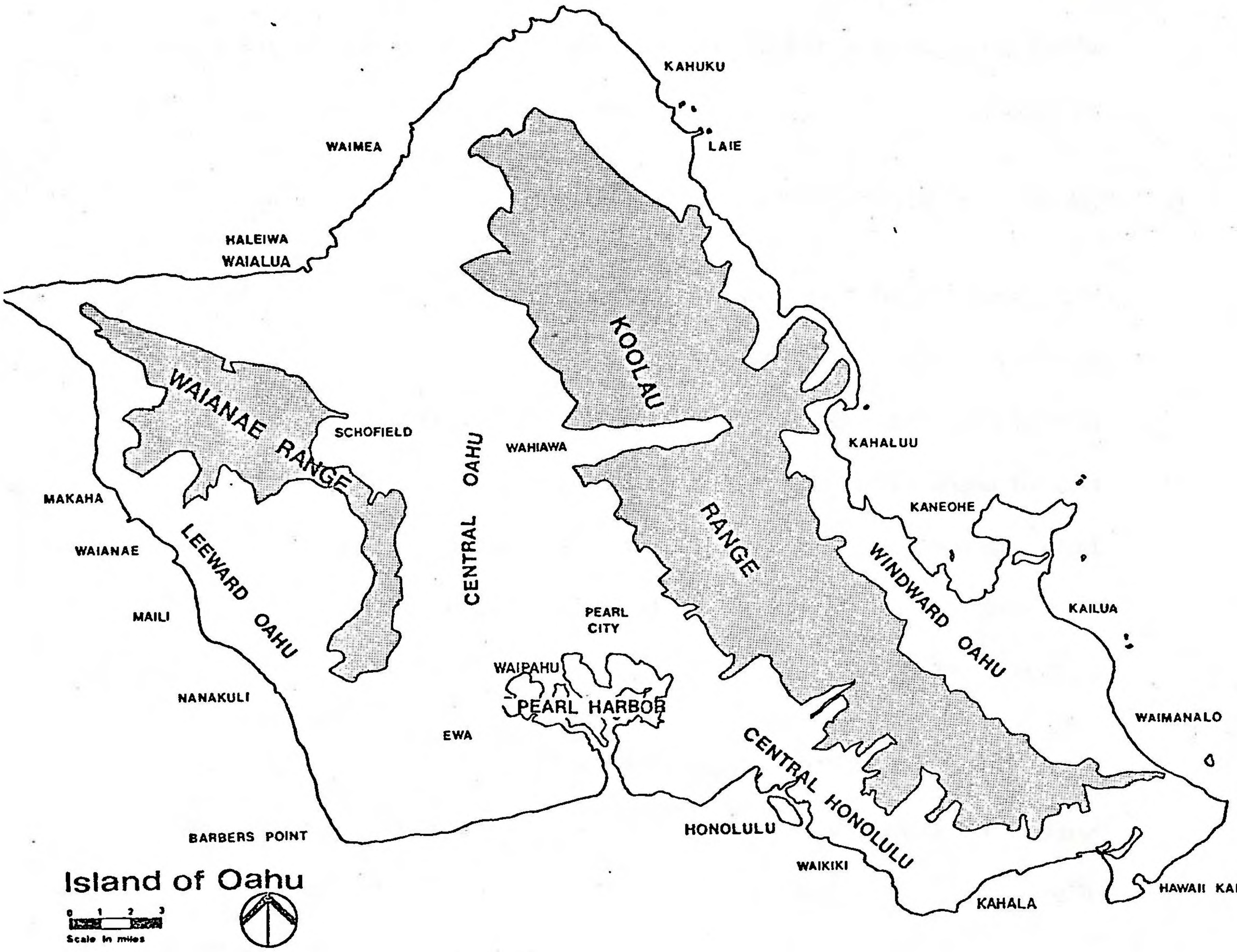

KAHUKU
LAIE
WAIMEA
HALEIWA
WAIALUA
KOOLAU
WAIANAE RANGE
SCHOFIELD
CENTRAL OAHU
WAHIAWA
KAHALUU
MAKAHA
KANEOHE
RANGE
WAIANAE
LEEWARD OAHU
WINDWARD OAHU
MAILI
PEARL CITY
KAILUA
WAIPAHU
NANAKULI
PEARL HARBOR
WAIMANALO
EWA
CENTRAL HONOLULU
HONOLULU
BARBERS POINT
WAIKIKI
KAHALA
HAWAII KAI
Island of Oahu
0 1 2 3
Scale in miles

FIG. II - 1

Leeward side of the Island. The 1995 output from the land use model projected a population of 510,000 for the urban area, or 55% of the total population. These figures substantiate the trend toward increasing suburban residential development on the Island.

A summary tabulation of 1980 and 1995 population and employment projections distributed to ten planning areas is shown in Table II-1. The locations and boundaries of these ten planning areas are shown in Figure II-2.

Relative to traffic patterns and volume, the most significant factor is the projected distribution of nearly 80% of Oahu's employment in the central core area of Honolulu from Pearl Harbor to Diamond Head. With most of Oahu's major activity and employment centers located in this intensively developed central core, travel demand will increase in the future.

C. TRAVEL FORECASTS

Travel forecasts which were prepared for the Rapid Transit Program were developed for planning years, 1980 and 1995. [1/] These forecasts were based upon population projections and characteristics including income and auto ownership in 159 travel zones and upon island-wide travel rates, labor participation, distribution of residences, jobs,

TABLE II-1: GROWTH ON THE ISLAND OF OAHU

Area	POPULATION						EMPLOYMENT					
	1970	%	1980	%	1995	%	1970	%	1980	%	1995	%
1	312,268	49.5	363,574	49.5	382,012	41.3	212,133	67.2	253,415	67.1	349,671	67.5
2	12,572	2.0	16,580	2.3	38,221	4.2	533	0.2	1,729	0.5	2,362	0.4
3	54,776	8.7	70,919	9.6	99,355	10.8	6,033	1.9	12,209	3.2	11,272	2.2
4	27,944	4.4	32,390	4.4	25,928	2.8	40,164	12.7	41,557	11.0	40,904	7.9
5	67,580	10.7	77,274	10.5	100,533	10.9	23,555	7.5	26,353	7.0	30,986	6.0
6	19,328	3.1	23,134	3.1	40,866	4.4	10,371	3.3	13,669	3.6	39,766	7.7
7	92,219	14.6	104,480	14.2	171,587	18.6	15,919	5.0	18,226	4.8	23,220	4.5
8	24,077	3.8	25,656	3.5	37,188	4.0	2,924	0.9	4,673	1.2	8,101	1.5
9	9,171	1.5	9,971	1.4	15,082	1.6	2,704	0.9	3,275	0.9	4,464	0.9
10	10,562	1.7	11,017	1.5	13,228	1.4	1,444	0.4	2,433	0.7	7,394	1.4
TOTAL	630,497		735,000		924,000		315,780		377,539		518,140	

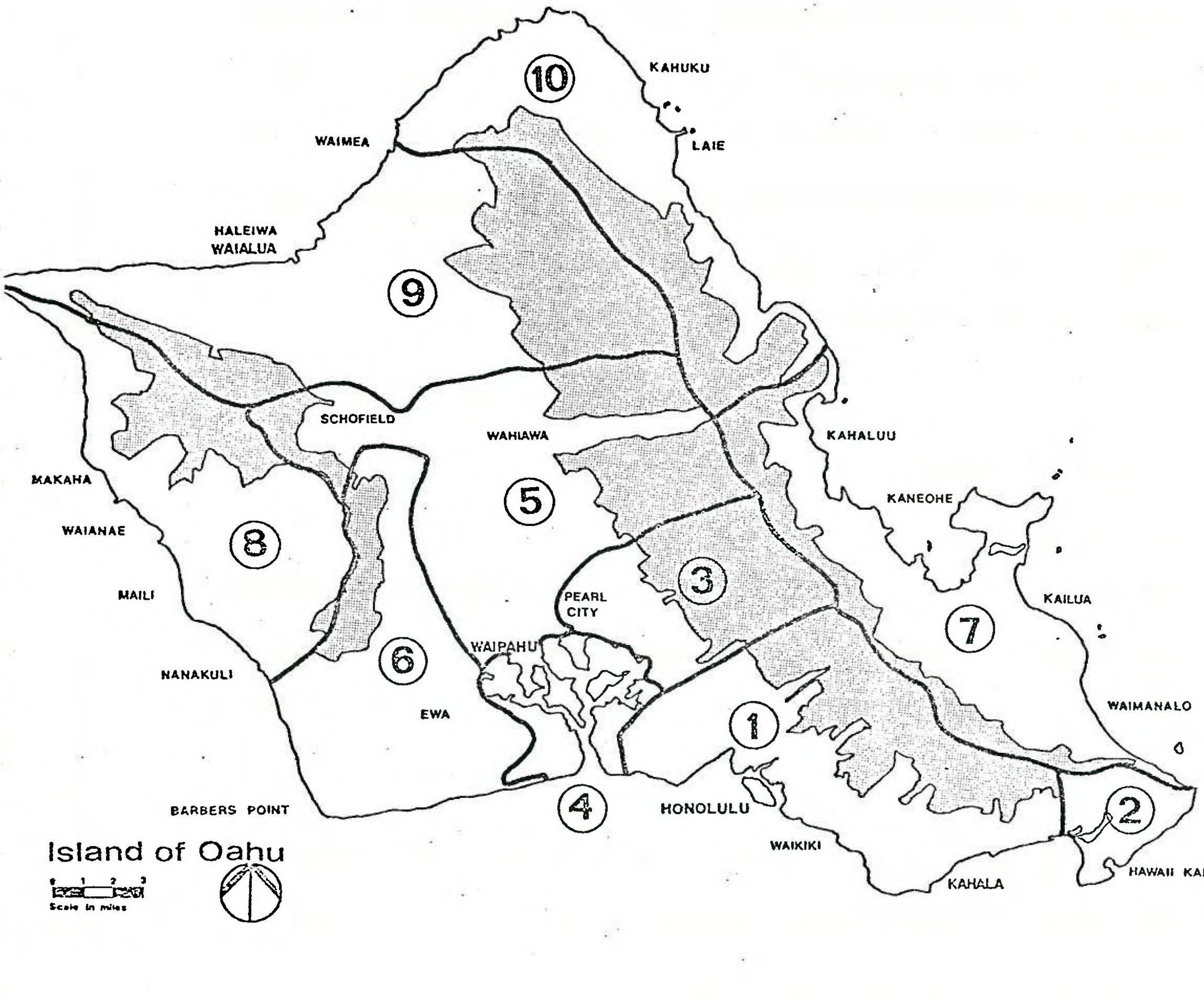


FIG. II-2. PLANNING AREA BOUNDARY MAP

recreation facilities and schools. The models used in travel forecasting were developed originally by the Oahu Transportation Study (OTS) and the Oahu Transportation Planning Process (OTPP) of the Hawaii State Department of Transportation, as successor to OTS, made the models available and provided much of the input data. The seven major models which were utilized were an economic, a land use, a car ownership, a trip generation, a trip distribution, a modal split, and an assignment model.

The economic model which was operated for the transportation analysis forecasted 51 jobs per 100 persons in 1980 and 56 jobs per 100 persons in 1995. The model also forecasted that family size will decline slightly. These forecasts, which reflect trends over the last decade, conform to those prepared by the U.S. Census Bureau and have been approved for planning purposes by the U.S. Dept. of Transportation.

For the purpose of analyzing overall patterns and of forecasting travel volumes on Oahu, certain important assumptions were made. It was assumed that the Manoa Campus of the University of Hawaii would be limited to an enrollment of 25,000 and that Waikiki would be limited to a total of 27,000 hotel rooms.

It was also assumed that in 1995 the islandwide highway network would consist of all currently existing or committed highways. The Federal Highway System on Oahu, which is scheduled for completion by 1980, consists of approximately 52 miles of freeway and is comprised of Interstate Highway H-1, H-2, and H-3. Completion of the highway system will improve access to the central Honolulu area, from the Leeward, Central and Windward regions of Oahu. With major concentrations of government, commerce and tourism, located in central Honolulu, it is forecasted that the H-1 (Lunalilo Freeway) will be heavily utilized and will become the critical link in the interstate system. The freeway designated H-2 which is presently under construction will extend from Wahiawa to Pearl City. When completed, the H-3 Freeway will provide the third trans-Koolau crossing to link Kailua-Kaneohe with the urban Honolulu.

Several other pertinent characteristics of automobile usage were also considered for the transportation analysis. Motor vehicle registration, which was approximately 320,000 vehicles in 1970,[2/] is projected to increase to nearly 500,000 vehicles in 1995.

This will result in a ratio of nearly 550 vehicles per 1000 persons. Thus the future number of motor vehicles on the island will continue to increase but at a decreasing rate. In 1970, over 1.5 million trips per day were estimated to have been made on the island. By 1995, it is projected that 3 million trips will be made. With demands for increased mobility, the total volume of trips will increase faster than population growth resulting in critical difficiencies in the existing street and highway system.

Results of the travel forecasts indicated that there will be an estimated 3,308,000 person trips made daily on Oahu in 1995. Table II-2 shows the daily distribution of the various trip purposes as a percent of all trips.

An estimated 367,950 total person trips will be made during an evening peak hour in 1995. The distribution of trip purposes in the peak hour is shown in Table II-2.

TABLE II-2: 1995 TRAVEL PROJECTION 1/
TRIP PURPOSE DISTRIBUTION

PURPOSE	DAILY		P.M. PEAK HOUR	
	TOTAL PERSON TRIPS	% OF TOTAL TRIPS	PEAK HOUR PERSON TRIP	% OF TOTAL TRIPS
HOMEBASE WORK	673,600	20.4	108,580	29.5
HOMEBASE SHOP	456,200	13.8	53,020	14.4
HOMEBASE SOCIAL/ RECREATIONAL	857,400	25.9	90,400	24.6
HOMEBASE OTHER	383,700	11.6	41,150	11.2
SCHOOL	288,000	8.7	28,840	7.8
UNIVERSITY OF HAWAII	33,400	1.0	3,610	1.0
NON-HOMEBASE	615,700	18.6	42,350	11.5
TOTAL	3,308,000	100.0	367,950	100.0

III. BACKGROUND OF LAND USE AND TRANSPORTATION PLANNING

A. GENERAL

Accelerated urban growth over the past decade on the Island of Oahu, has severely strained Honolulu's capacity to maintain its highly desirable social and physical environment. While growth in Honolulu has been accompanied by unprecedented prosperity, it has also caused new demands for municipal services, including a critical demand for transportation services.

These needs are recognized by the land use planning and transportation agencies of both the City and County of Honolulu and of the State of Hawaii. Planning policies have been proposed and adopted to meet urban growth requirements. Furthermore, it has been recognized that in order to effectively implement the land use policies of the City and County, transportation services must be provided in a manner which is consistent with and which reinforces these policies.

The land use and transportation objectives expressed by both State of Hawaii and City & County of Honolulu planning agencies serve as input and background to the establishment of planning objectives and design criteria for the Honolulu Rapid Transit System. The earlier studies and plans, which are briefly summarized in the following section, continually confirm the need for a rapid transit system and the overall goal of a balanced island-wide transportation system.

B. THE 1964 OAHU GENERAL PLAN

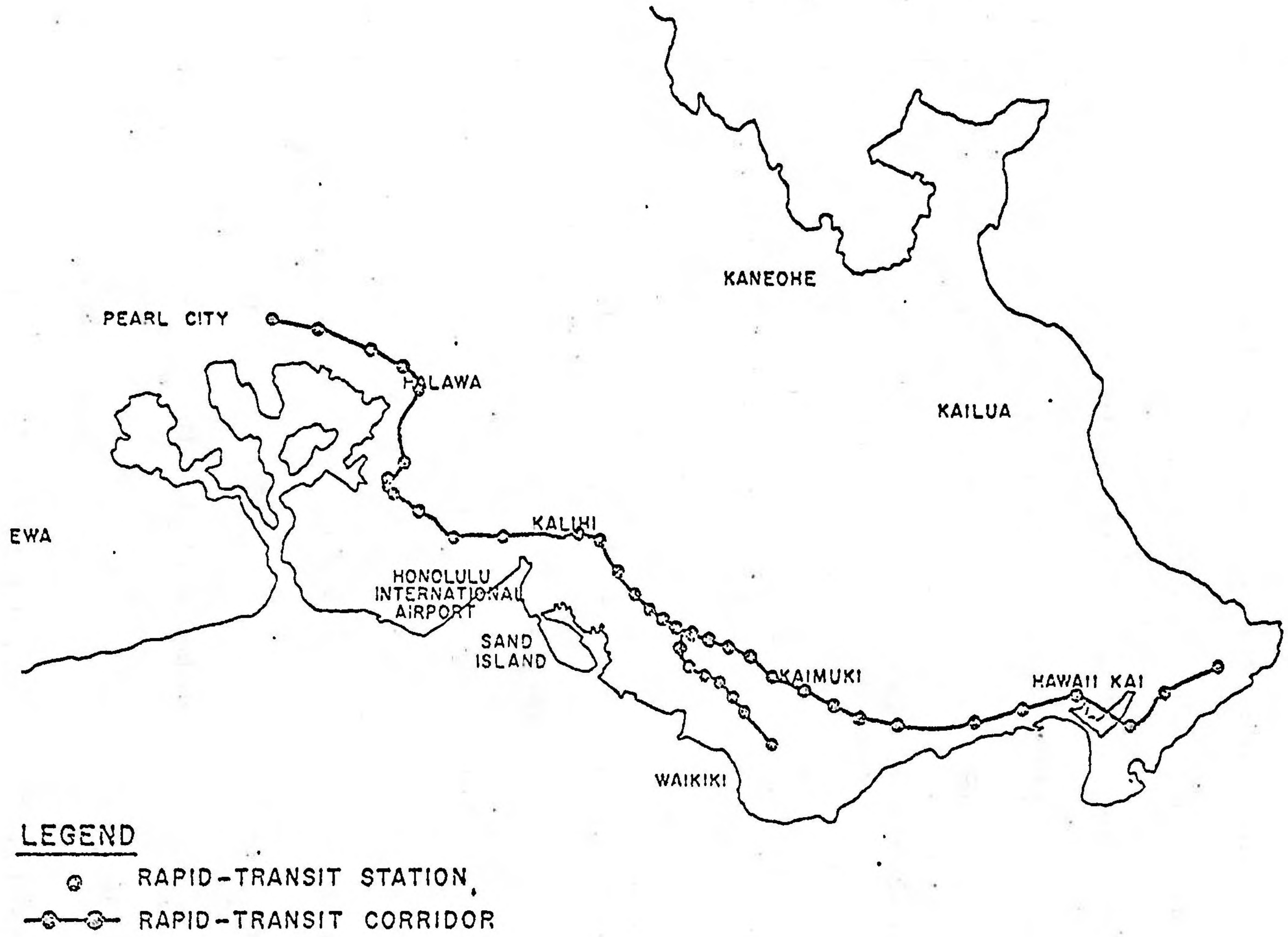
The Oahu General Plan, adopted by the City and County of Honolulu in 1964 is the Island's official land use policy. The Plan is designed to guide the coordinated development of the City and County and to promote the welfare of residents and visitors. The General Plan defines the most desirable land uses for transportation, residence, commerce, industry, agriculture, and recreation. Regarding transportation, the General Plan for Oahu states that: "The overall objective of a transportation plan is to provide a set of facilities for convenient, safe, quick and economical movement of people and goods between various points within the metropolitan area in harmony with the various land use patterns it serves". The Plan emphasizes that these facilities should facilitate travel from all points in the region within reasonable travel time and should offer a choice of transportation modes. The Plan recommends that the system be a combination of facilities which will provide the greatest efficiency at the least expenditure of resources, and that the system should be designed as an integral part of and complementary to land use patterns.

Although the basic intent of the General Plan endures, as specific conditions have changed, selected recommendations have been revised. A General Plan Revision Program is currently being conducted which is described in detail in a later section.

C. THE 1967 OAHU TRANSPORTATION STUDY

In 1967 a major step towards meeting the increasingly critical transportation needs on Oahu was made. The Oahu Transportation Study (OTS) was undertaken to establish a long range, comprehensive transportation planning process. This effort coordinated all other comprehensive planning efforts of the State and the City and County. In addition to the development of a transportation planning process, the study recommended a long range transportation plan, oriented towards relieving the heavily congested streets and highways on the island.

The OTS had the foresight to conclude, as early as 1967, that a rapid transit system would give balance to the existing transportation system. Figure III-1 illustrates the recommended transportation corridor. The OTS study recommended that rapid transit be adopted as a long range goal and that a short range interim program be initiated for improving and expanding the present bus system for integration into the express-feeder systems when the rapid transit facility is completed.



OTS RAPID TRANSIT CORRIDOR
OF RECOMMENDED MASS TRANSIT SYSTEM

FIG. III-1

D. THE 1972 HONOLULU RAPID TRANSIT STUDY

Since it was clear that an improved mass transit system could best serve the mobility needs of Honolulu, while protecting the social, ecological, and economic environment, the City and County of Honolulu initiated the Honolulu Rapid Transit Study (Preliminary Engineering Evaluation Program, Phase I). This comprehensive planning and evaluation program confirmed and substantiated the need for a rapid transit system, examined a variety of system alternatives, evaluated route locations, studied alternative vehicle types and engaged in environmental impact and cost-benefit analysis. PEEP I concluded that a medium capacity, fixed guideway system, supported by an extensive feeder bus system would be the most suited to the needs of Honolulu. Such a system would greatly aleviate critical rush hour congestion in urban Honolulu and provide a convenient, economic and pleasant travel mode. The transit plan recommended that a 22 mile fixed guideway supported by an island-wide network of local, and express buses be adopted as the long range public transportation system.

E. THE 1974 STATE OF HAWAII GROWTH POLICIES PLAN: 1974-1984 GENERAL PLAN REVISION PROGRAM

This plan which was published in 1974 by the State Department of Planning and Economic Development also confirmed the advisability of a mass transit system for Oahu. This document presents an analysis of alternative sets of State policies which can substantially affect the rate of expansion of Hawaii's population and economy. The recommended plan advises that a policy of "slowed growth" be adopted. This policy suggests a slowed growth rate of 1-1.5% annually, which is in general conformance with the growth projections used in rapid transit planning.

State policies regarding improved transportation services emphasize that in addition to increasing overall capacities, action should be taken to reduce travel by automobiles. Consequently, the State Plan recommends that public policy promote a variety of modes of public transport including mass transit. The Plan states that:

"A mass transit system is needed . . . . to accommodate . . . . growth and to avoid a deterioration in the quality of life for Oahu residents. Such a system will allow a low rate of conversion of valuable land into transportation uses, will help direct growth away from prime agricultural land, will conserve energy, will reduce per capita transportation costs for many and will allow a reduction in air pollution".

These State planning policies are designed to reduce traffic congestion, to encourage greater use of mass transit, and to support slowed growth on Oahu.

F. THE 1974 OAHU GENERAL PLAN REVISION PROGRAM

1. Alternative Development Policies

Currently the Department of General Planning of the City & County of Honolulu, as part of an on-going process, is developing a technical basis for revising and updating the City's General Plan. Although no specific policy or plan for the future development of the Island of Oahu is as yet officially adopted, the planning study examines and offers several alternative development policies. 3/

Based upon the revised City Charter, the General Plan for Oahu is no longer to be regarded only as a land use plan showing "where" activities should occur, but the Plan is to be a statement of community objectives to be achieved and of the policies through which such objectives can be attained. The Plan will become an integral part of the planning and decision making process of the City and County of Honolulu and will guide the formulation of programs and establishment of priorities for the attainment of the community's objectives.

The current revision program identifies and examines several alternative development policies which are designed to accommodate future population growth, which is one of the primary objectives of the City and County.

The three basic development policies defined and evaluated are described as follows:

- Intensive Development - Characterized by the restriction of future development to within the present urban boundary as defined by the General Plan adopted in 1964 and as revised since that date. This restriction would have the effect of limiting or slowing of both the population and economic growth of the island. Under this policy, it is assumed that Central Honolulu would continue to be the primary employment and government center of the island.

- Moderate Expansion - Characterized by the restriction of development within the present urban boundary with the possible exception of providing land outside the urban boundary to meet the housing needs of low and moderate income families. The employment pattern remains essentially the same as in the Intensive Development alternative with Central Honolulu being the primary employment and governmental center.

- Directed Growth - Characterized by the requirement that sufficient capacity be provided for residential and non-residential urban uses in programmed developments. These developments can occur through the expansion of the urban boundary. The amount of agricultural land released for urban use is dependent upon the programmed development of these new communities. These new communities are for all families of all income levels. The critical characteristics of this alternative is that non-residential land which could support substantial employment centers is provided.

Under each of the basic policies, variations in the development pattern were defined and considered for 3 levels of population.

- Population Level I - 924,000
- Population Level II - 1,157,000
- Population Level III - 1,398,000

For evaluation purposes, appropriate population levels were selected for each policy.

Each alternative policy was evaluated for its contribution to the attainment of community objectives. The objectives studied pertained to housing, transportation, educational facilities, supply and distribution of fresh water, waste water disposal system, agriculture and recreation. The evaluation was conducted on the basis of identifying relative benefits and costs incurred by the community in attaining these objectives for each of the alternative development policies at different population levels. The revision program was aimed at providing a course of action to direct, control or accommodate different population levels as they are reached.

The provision of adequate transportation services is one of the most important and costly functions carried out by government for the general public. The level of services required to provide mobility to the public and to the transportation of goods is directly affected by the alternative residential policies and the projected population growth. The relationship between the alternative policies at different population levels and the assumed transportation system was evaluated by the Department of General Planning on the basis of data developed under the Oahu Transportation Planning Process (OTPP) with appropriate modifications to meet the specific needs of the study.

The three basic alternative development patterns at select population levels evaluated in the transportation policy analysis were as follows:

- <u>INTENSIVE DEVELOPMENT</u>

A.	Population Level I 924,000	(Housing demand would consist of the maximum number of low density dwelling units.)
B.	Population Level I 924,000	(Housing demand would consist of the maximum number of high density dwelling units.)
C.	Population Level II 1,157,000	(Housing demand would consist of the maximum number of high density dwelling units. Supply of low density residential land was insufficient to support the maximum number of low density dwelling units.)

Since the major goal of this alternative is to limit growth, only the two lower population levels were included. Population Level III was not included primarily because all useable land within the urban boundary was already exhausted by Population Level II at the recommended densities.

- <u>MODERATE EXPANSION</u>

A.	Population Level I 924,000	(The Scenario tested assumed a substantial growth in the Ewa area.)

The magnitude of the unmet.housing demand by low and moderate income families was projected at approximately the 924,000 population level by a previous study. This magnitude was used to obtain the amount of residential areas required at high and low densities. The magnitude of the unmet housing demand at other population levels was not known, therefore, this alternative was not tested at any higher population level.

. DIRECTED GROWTH

A.	Population Level II 1,157,000	(Provision for growth in specifically directed areas, both residential and non-residential, which can occur through the expansion of existing urban boundaries. Ewa emphasis assumed.)
B.	Population Level III 1,398,000	(Same as Population Level II except at a higher population.)

Since it was determined by the Department of General Planning that the impact this alternative would have on the initially assumed transportation system would be most pronounced at higher population levels, only population levels II and III were tested. It is expected that additional facility costs and travel time losses incurred at population level I for this alternative will be similar to the projected costs and losses associated with the Intensive Development policy, Scheme B and Moderate Expansion policy, Scheme A.

For each alternative development pattern, in areas where travel demand exceeded the assumed existing transportation system's carrying capacity two alternative transportation policies were analyzed. In one policy, a sufficient number of new highway lanes were provided to meet auto demand and eliminate travel time losses. This is defined as the "Intensive Highway" policy. In the second policy, additional highway lanes are not provided beyond the base network in areas where additional transit capacity existed and where rapid transit extensions were warranted. This was intended to promote transit usage and is defined as an "intensive transit" policy.

- The specific alternative which is most likely to meet residential and related urban requirements at the least cost in terms of capital facilities as well as provide sufficient housing to meet the needs of the community is Directed Growth. This is a relatively compact form of urban development which is channeled into a new relatively high density population and employment center.

- The Ewa area is the best location for the major thrust of urban development to occur within the concept of Directed Growth. But the differences between Ewa and Central Oahu are not great and the choice must be conditioned upon the ability to formulate and effectively implement a housing program.

2. Transportation Policy Analysis

In the analysis of the "Benefits" and "Costs" to the community associated with each of the alternative development policies and their impact on the existing transportation facilities, the Department of General Planning in their General Plan Revision Program (GPRP) assumed an existing transportation system containing a highway network which included all primary facilities that exist today and H-1, H-2, and H-3 Freeways.[4/] In addition, a high-capacity rapid transit facility between Pearl City and Hawaii Kai with supporting feeder and express bus service was assumed fully operational.

To investigate the impact of the alternative development policies on the highway network, several strategically located cordons or corridor "screenlines" were established and an auto volume to capacity analysis was conducted at these screenlines. The capacities or service volumes used were based on level of service C or D.[5] Facilities in urban areas were generally assigned service volumes at the D level, while facilities in rural areas were assigned service volumes at the C level.

Each screenline volume was calculated by totaling the individual volumes projected for each roadway through which the screenline passes. The service volumes through each screenline were calculated similarly. A tabulation of the results of the volume versus capacity or service volume (V/C ratio) analysis for each of the six alternative development patterns (all with a high-capacity rapid transit system with attendant express and feeder bus service assumed operational) are given in Table III-1.

As can be seen in Table III-1, the street capacities are generally adequate at the 924,000 population level except in the Kalanianaole Highway corridor. Further it can be observed that streets in the urban core for populations greater than 1,000,000 would be highly congested and inadequate to meet the demand without additional facilities provided.

In addition to studies of projected vehicular traffic volumes, the Department of General Planning developed transit ridership volumes for both the rapid transit and feeder-express bus services. A

TABLE III-1: SCREENLINE VOLUME TO CAPACITY ANALYSES

		924,000 Population Level					
		Intensive Development Scheme A		Intensive Development Scheme B		Mod. Expansion Scheme A	
Screenline	Service Volume (Autos)	Volume (Autos)	V/C	Volume (Autos)	V/C	Volume (Autos)	V/C
Pearl Ridge	192,000	175,000	0.91	165,000	0.86	181,000	0.94
Liliha Street	278,000	251,000	0.90	254,000	0.91	251,000	0.90
Ward Avenue	369,000	324,000	0.88	340,000	0.92	323,000	0.88
Kahala-Aina Haina	60,000	83,000	1.38	71,000	1.18	72,000	1.20

		1,157,000 Population Level				1,398,000 Population Level	
		Intensive Development Scheme C		Directed Growth Scheme A		Directed Growth Scheme B	
Screenline	Service Volume (Autos)	Volume (Autos)	V/C	Volume (Autos)	V/C	Volume (Autos)	V/C
Pearl Ridge	192,000	223,000	1.16	227,000	1.18	204,000	1.58
Liliha Street	278,000	332,000	1.19	290,000	1.04	315,000	1.13
Ward Avenue	369,000	441,000	1.20	381,000	1.03	403,000	1.09
Kahala-Aina Haina	60,000	96,000	1.60	79,000	1.32	84,000	1.40

compilation of these volumes for each of the defined alternatives is shown in Table III-2. It was estimated that the peak hour, peak link rapid transit volumes would vary between 20,000 to 30,000 passengers in one direction. The variation is basically due to the difference in population levels. The table indicates that, in general, the Internsive Development policy will place a somewhat heavier requirement upon both the arterial and highway network and mass transit systems through the urban corridor.

In terms of the transportation policy analysis for the various development policies the findings were as follows:

- With a high capacity rapid transit system complementing the existing and planned streets and highways, the combined capacity would generally, meet the demand of a population level of 924,000 for all three of the alternative development policies; Intensive Development, Moderate Expansion and Directed Growth.

- The travel demand is not significantly affected in the urban core by different development alternatives up to the population level of 924,000.

TABLE III-2: PROJECTED TRANSIT TRIPS

	Total Daily Trips	Daily Transit Trips	Daily Rapid Transit Trips
Intensive Development			
Population Level I Scheme A	3,361,300	484,500	345,000
Population Level I Scheme B	3,361,300	497,000	348,200
Population Level II Scheme C	4,194,350	597,300	424,100
Moderate Expansion			
Population Level I Scheme A	3,361,300	489,400	343,900
Directed Growth			
Population Level II Scheme A	4,196,600	583,050	393,300
Population Level III Scheme B	4,994,500	644,500	417,900

Note: Population Level I - 924,000
Population Level II - 1,157,000
Population Level III - 1,398,000

- For population in excess of 1,157,000 and more specifically for 1,398,000 as tested, the development pattern under the Directed Growth policy shifts both population and employment to outer areas which would reduce the travel demand in the urban core somewhat, however, the demand is still higher than the combined capacity of the outbound existing transit and highway networks.

G. PLANNING OBJECTIVES AND CRITERIA

The development of a rapid transit system as an integral part of the Island-wide transportation system has been advanced through a series of land use and transportation planning programs at both the State and City levels. As early as 1967, the Oahu Transportation Study conclusively demonstrated the need for a rapid transit system to obtain a balanced transportation system. That study showed that rapid transit is more economical than a highway oriented system. The recent Oahu General Plan Revision Program also focused on the development of a balanced transportation system with a high capacity rapid transit system or a highway intensive alternative. The GPRP confirmed the OTS findings and concluded that the balanced transportation alternative was most supportive of the GPRP recommended land use policy.

Transit planning in Honolulu over the past decade has been guided by several basic objectives which reflect the island's unique social and environmental features. The high cost of living on Oahu creates serious economic constraints for many families and is directly related to a high labor participation rate. This factor causes many households to be highly dependent on public transit service. This is evident by the high patronage figures for the public transit system in Honolulu. To meet this high demand for public transit, an economical and extensive island-wide service for all is required.

The unique beauty and climate of the Island of Oahu mandates that special attention be given to the preservation of its natural assets. Air and noise pollution from transportation must be minimized, especially where "open-window" living is common and the dwellings are most easily penetrated by these pollutants. The sensitive and environmentally conscious planning and design of transit facilities is mandatory to avoid any detrimental effects on the natural beauty and on the activities of communities.

The selection of a transit system which will best meet the island's future needs requires a systematic evaluation process. The process must reflect community goals and be sensitive to community concern as well as to social, environmental, and economic considerations. The process must also permit a uniform evaluation of all qualitative and quantitative factors applicable for determining the effectiveness of the alternative system. The following criteria which reflect the basic goals for the island are defined to measure alternative transit concepts.

- An Island-wide transit system which will effectively service and interconnect the existing and future urbanized areas of Windward, Central, Leeward, and Honolulu districts and the various land use activities within the island.

- The development of a balanced highway-transit system that will reduce the need for additional new highways.

- A highly attractive transit system to serve the urban Honolulu travel corridor for the design volume of 25,000 to 30,000 passengers per hour.

- A fast, reliable and efficient rapid transit system that would minimize overall trip time at least cost on a long-run basis.

- A transit system that would best support the land use and development policies of the island.

- A transit system that would preserve and enhance the natural environment and cause minimum community disruption.

- A transit system that would support the national policy on energy conservation and preserve the limited land resources of the island.

IV. TRAVEL CHARACTERISTICS AND NETWORK DEFINITION

A. ISLAND-WIDE TRAVEL CHARACTERISTICS

1. Urban Honolulu And Outlying Districts

The most densely urbanized area of Oahu stretches from Pearl Harbor to Diamond Head. It is composed of many small urban concentrations which are strongly linked in function to the urban core of Honolulu. This dense urban area contains most of the island's industry, business, and government facilities and is the focus of major social, cultural, educational and recreational activities.

The urban area is approximately twelve miles long and two to three miles wide, with numerous developments extending into the valleys and ridges of the Koolau Range. It is characterized by a relatively narrow band of densely developed residential, commercial and industrial land uses. Development is generally most intense between the H-1 (Lunalilo) Freeway and the ocean, a distance of approximately one mile.

The suburban areas of the urban Honolulu district on the eastern end include developments adjacent to the Kalanianaole Highway extending to Hawaii Kai and on the western end developments in the Pearl City-Waipahu area. In the outlying districts, the principal communities are located in the Leeward area from Ewa to Waianae, the Central area from Waipahu to Wahiawa, and the Windward area, including

Kaneohe, Kailua and Waimanalo. Land use forecasts indicate that the pressures of continuing housing demand will intensify the development in urban Honolulu as well as generate more new growth in the outlying districts.

2. <u>Travel Characteristics</u>

Development of Oahu, like that of most mainland urban regions, reflects the automobile orientation of the past several decades. The island was developed in relationship first, to the early road system, which was replaced by highways and ultimately by the interstate system.

In 1972 there were 1,230 miles of paved streets and highways on Oahu. The existing and planned Federal interstate highway system (H-1, H-2, H-3) which comprises approximately 52 miles of freeways on Oahu, is scheduled for completion by 1980. (See Figure IV-1). It will provide improved access to urban Honolulu from the Leeward, Central and Windward districts of Oahu. With concentrations of government, commerce and tourism, located in urban Honolulu, the existing segment of the H-1 (Lunalilo Freeway) will be heavily used and will become the critical link in the interstate system. The freeway which is designated H-2, is presently under construction, and will extend from Pearl City to Wahiawa. The H-3 Freeway, when completed, will provide another link from the Kailua-Kaneohe area to urban Honolulu.

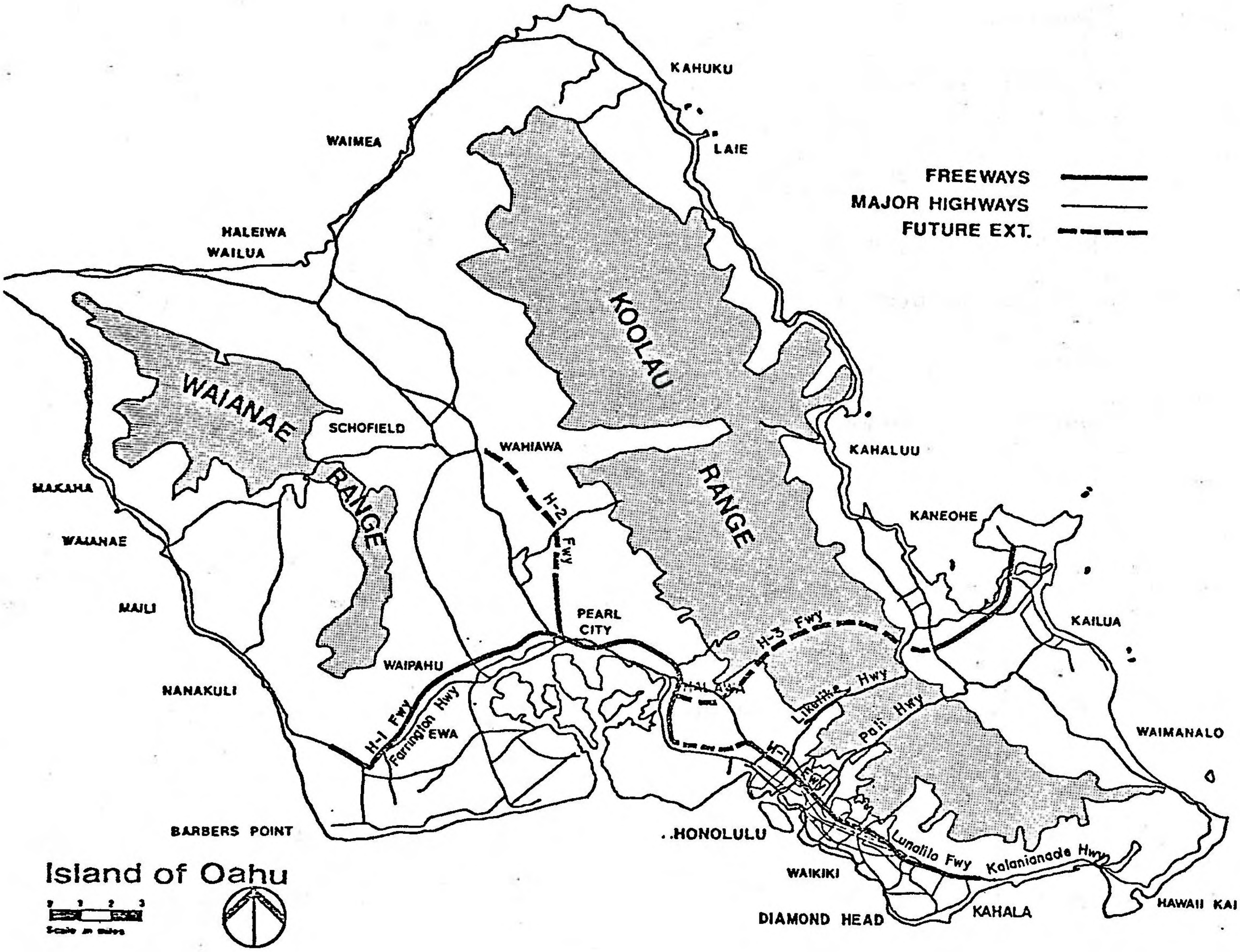


FIG. IV-1. HIGHWAY NETWORK — ISLAND OF OAHU

The travel pattern of urbanized Oahu is similar in intensity to that of many intermediate sized metropolitan regions in the United States, in that, the primary urban travel corridors radiate from the urban core in three directions. In the eastern direction, the corridor follows Kalanianaole Highway to Hawaii Kai. In the northern direction, the trans-Koolau corridor serves the Windward district. In the western direction beyond Halawa, the H-1 Freeway-Kamehameha Highway corridor, extends to the Pearl City area, where it bifurcates into two corridors serving the Central and Leeward districts. These three primary corridors funnel all traffic flows into the relatively narrow east-west movement channel of the Honolulu urban core. Due to the preponderance of employment and major activity centers concentrated in the urban core 350,000 to 400,000 average daily auto trips are projected for this main corridor by 1995.

In this urban core, there are several destination points in addition to the Central Business District (CBD). The most significant destinations are the Ala Moana Center, the Waikiki area, and the Hickam-Pearl Harbor military complex, with considerable importance given to the other points such as the University of Hawaii and the Honolulu International Airport. These major destination points form a geographically linear corridor pattern, beginning with the military complex on the western corridor end, the airport, the CBD and Civic Center, the Ala Moana center, and the Waikiki-University area.

The residential areas are characterized by density types: high density developments in the urban core, low-to-medium densities in the suburban areas and predominantly low density developments in the outlying districts. Within a ten mile radius of the CBD are located the major suburban communities of Hawaii Kai, Pearl City-Waipahu, and Kaneohe-Kailua in the Windward district. Within a radius of twenty to thirty miles are located the more distant communities of Wahiawa and Waianae in the Central and Leeward districts, respectively.

Travel on Oahu, as measured by automobile ownership and vehicle miles traveled has increased by about seventy five percent during the past decade. Proportionally this is a much greater increase than the twenty percent increase in population. Due to the increase in labor participation rate, work trips have also increased more rapidly than the population. The very rapid increase in overall travel has created a great demand for additional street and highway capacities. The development patterns of urban Oahu and their transportation demands are beginning to overtax the principal travel corridors with the major impact on the critical high-volume corridor in the urban core.

3. Accessibility To Urban Honolulu

The outlying districts of Oahu are served by modern highways and freeways providing easy access to urban Honolulu. The H-1, H-2, & H-3 Freeways serve the Leeward, Central, and Windward communities, respectively, and are all supplemented by one or more highways in the major travel corridors.

The Leeward and Central districts contain suburban and rural communities scattered over a large area. The rural communities are generally small and are typical of low density development. A relatively high percentage of the population in these communities fall into the lower income category.

In the Windward district are located the larger suburban communities of Kaneohe and Kailua. These communities are predominantly low to medium density developments for middle income families. On the southeastern end of this district is the semi-rural community of Waimanalo which has a relatively high percentage of lower income population.

With existing and committed highways and freeways providing fast and direct routes to central Honolulu, accessibility from these outlying districts is good and capacity is ample to accommodate future travel demands. As previously stated, these outlying districts have communities with higher percentages of low income households than is typical in other parts of Oahu. Consequently, there are more transit dependent households in these outlying communities but the dispersed pattern of development and its relatively small population poses certain economic constraints on the provision of more frequent service. The existing transit service provides bus routes to each of these low income areas with buses operating at minimum headways of 5-10 minutes during peak periods and at maximum headways of 10-15 minutes during off peak periods.

B. CHARACTERISTICS OF THE URBAN HONOLULU CORRIDOR

1. Land Use And Travel Demand Analysis

In Chapter II, forecasts of growth in population, employment, and travel demand for the Island of Oahu which formed the basis for transit planning were presented. A more detailed review of the forecasted growth and changes in urban Honolulu is presented in the following section.

Within the urban Honolulu area, from Pearl City to Hawaii Kai which is the span of the proposed transit corridor, past and forecasted population and employment is as follows:

	Population	% Of Total Island	Employment	% Of Total Island
1970	403,000	64%	259,000	82%
1995	569,000	62%	410,000	79%

The forecast indicates that there will be continued growth in both population and employment. However, in 1995, the percentage of population in urban Honolulu relative to the entire island drops from 64% to 62%. As the current urbanized area can accommodate increases only through reuse of existing developed land this drop reflects the pressure for more urban land in the outlying areas.

The employment forecasts indicate increased growth with a slight decline in percentage of the total located in urban Honolulu. This forecast reflects the continued growth forecasted in government, tourism and service types of employment in the Honolulu core area. Notable increases in employment are forecasted to occur in the following locations:

Districts	Employment 1970	Employment 1995
CBD - Civic Center	52,000	83,000
Waikiki	18,000	40,000
Ala Moana-Ward	18,000	30,000
Kakaako	17,000	26,000
Kalihi-Iwilei	30,000	56,000
Airport	15,000	21,000
Pearl Harbor-Hickam	40,000	41,000

The above projected employment will reinforce the continued growth and importance of the urban core and the attendant increase in travel demand. Adequate transportation facilities which are required for the efficient movement of goods and people is vital to the economic well being of the entire State.

The most critical transportation corridor on the Island of Oahu is the narrow east-west corridor spanning from Middle Street to the Diamond Head area. In this corridor where no new highways or freeways are contemplated, transportation capacity is most critical. Recent studies conducted under the TOPICS [6/] and National Transportation Need Study [7/] programs forecasted a serious deficiency in transportation capacity in this corridor.

An analysis of the screenlines on either side of the CBD-Civic Center area indicates an available capacity of some 280,000 autos per day on the western side and approximately 300,000 autos per day on the eastern side. (See Figure IV-2). Current volumes through these screenlines are approaching or have reached their design capacities. Based on travel demand forecasts, in 1995 the volume will exceed capacity by approximately 80,000 to 100,000 autos per day. Converting the daily auto trips to peak hour auto trips would result in approximately 6,000 autos per hour in each direction. The number of freeway lanes required to accommodate this projected volume will be 3 lanes based on 2,000 autos per hour per lane. Therefore, the

PRELIMINARY ROADWAY CAPACITY & VOLUME

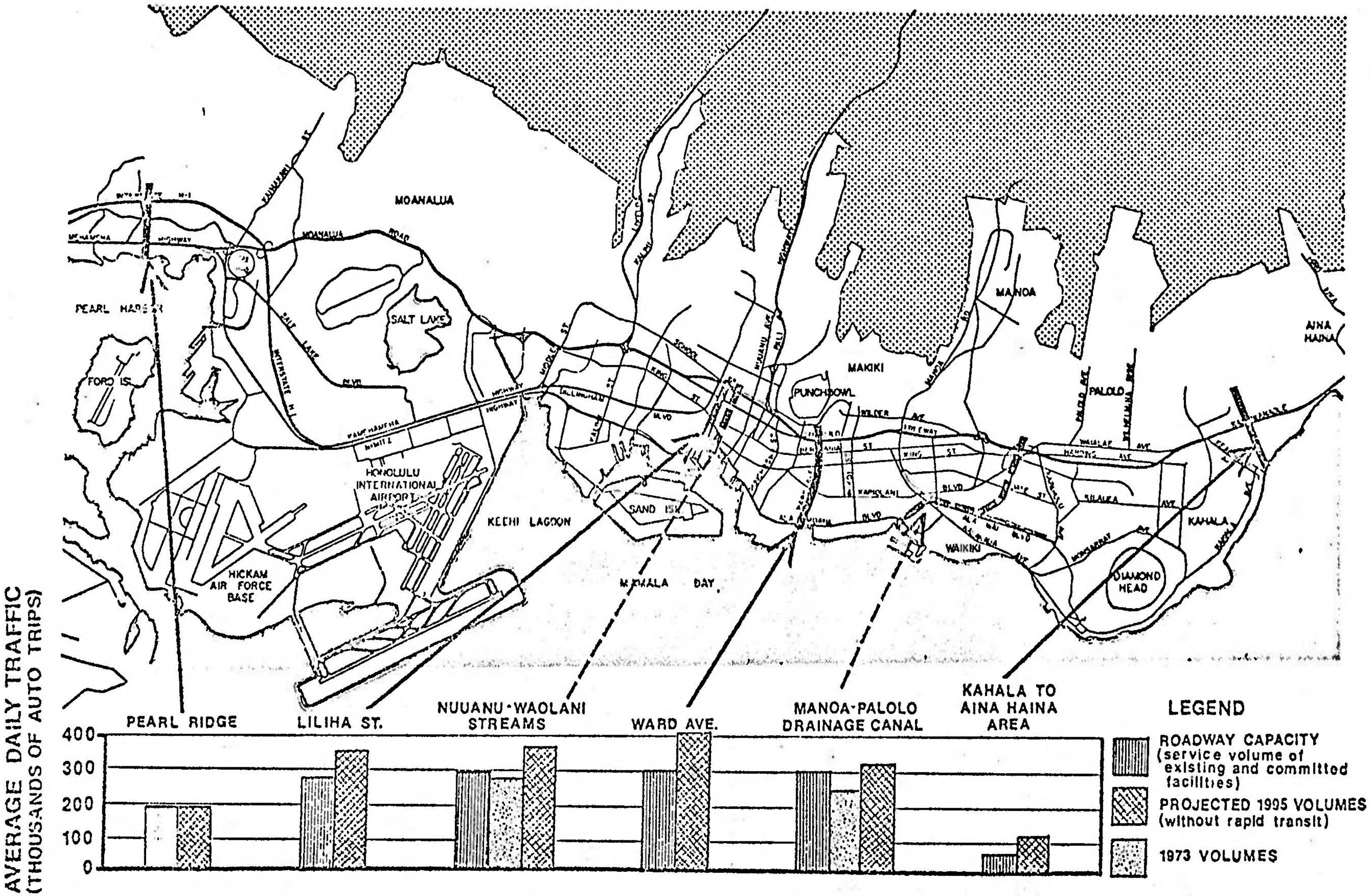


FIG. IV-2

primary objective of the transit program is to achieve an attractive system with sufficient capacity, which together with the existing highway capacity, can meet future travel demands in the urban core with as little disruption to the surrounding environment as possible.

2. <u>The Urban Environment</u>

As previously described, the urban transportation corridor is a relatively narrow strip of land which is approximately one mile wide. Located within this strip are the major activity centers which will be served by the fast link transit system. The lands around and between activity centers are intensely developed and interspersed only occasionally with small vacant parcels.

Due to the shortage of developable land on the island, land values in this area are extremely high. Lands in residential use are valued at approximately $10 per square foot and for apartment, commercial, and industrial uses at $20 per square foot or more. In addition to the high land value, existing improvements in the corridor range from single family dwellings to high rise, high value office and apartment structures. Acquisition of private lands for transit rights-of-way may be expensive and may create serious social problems relative to relocation of residents and businesses.

Unlike most mainland cities, Honolulu does not have existing railroads whose rights-of-way could be utilized as a transit route. There are no natural features, such as a major east-west watercourse whose banks might be used advantageously for a transit route to minimize disruption to existing communities. Therefore, any new transportation facility would require extremely careful placement and sensitive designs to minimize community impact.

The three basic alternatives which are available for transit route location and configuration are aerial structures in existing wide streets, aerial structures on private transit rights-of-way, and underground structures (subway) under existing street rights-of-way. The subway configuration causes minimum community disruption but is extremely costly and therefore should be limited in use to high value and environmentally sensitive areas such as the CBD and the historic Civic Center areas.

Aerial structures could be used in streets with right-of-way widths of at least 80 feet. In areas, where street widths are insufficient to minimize noise and visual intrusion to adjacent properties, the street should be widened or the route located off the streets on private properties. Of the three, the least costly alternative is the use of streets or highway rights-of-way. This is also the least disruptive to the community, in terms of relocation of residents and businesses.

The following guidelines are established in developing the route location and configuration for the transit system:

- Subway should be limited to the downtown area.
- Above ground configuration should be used wherever practical from the standpoint of least cost, rider preference, and reduction in energy consumption for cooling and ventilating underground facilities.
- Above ground way structures should be designed to minimize visual obtrusiveness and sensitively designed for compatability with the immediate environment.
- Vehicle system and way structure should be provided with special treatment to minimize noise intrusion to adjacent property.
- Route should be selected to minimize the requirement for acquiring private property due to extreme shortage and high cost of replacement housing and business structures.

C. TRANSIT NETWORK DEFINITION

1. Basic Island-Wide Line Haul Network

The basic line haul network utilizing express buses in mixed traffic or exclusive bus lanes and other forms of rapid transit systems considered in the analysis is depicted in Figure IV-3. The Leeward district would be served by an express bus route

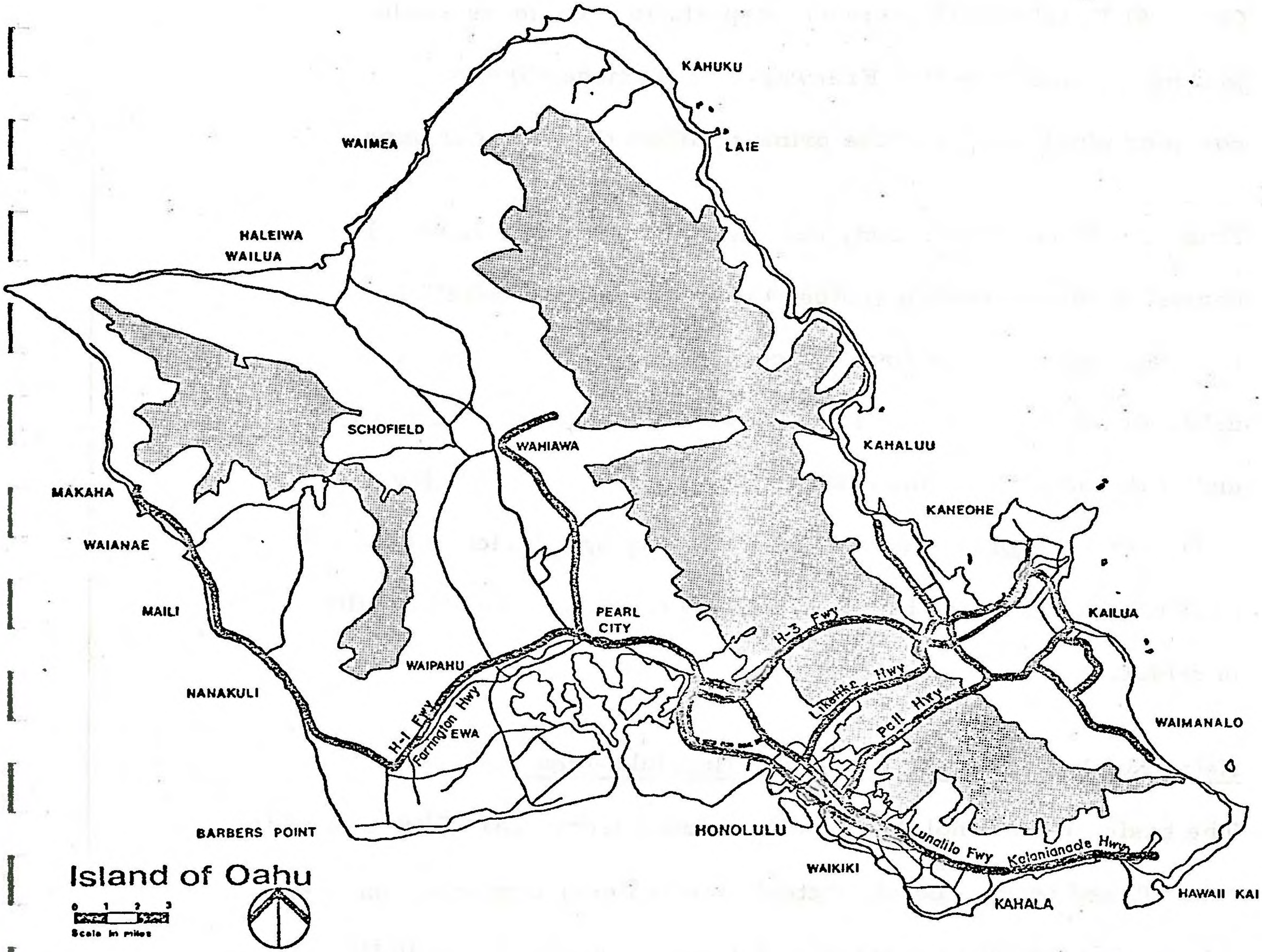


FIG. IV-3. BASIC LINE HAUL NETWORK

on the H-1 Freeway-Farrington Highway corridor to Pearl City. The Central district would be served by an express bus route on the H-2 Freeway-Kamehameha Highway corridor to Pearl City. At Pearl City these two transportation corridors would join into the common H-1 Freeway-Kamehameha Highway corridor which is part of the primary urban Honolulu corridor.

From the Windward district, the trans-Koolau corridor would consist of three possible routes, the H-3 Freeway, Likelike Highway, and Pali Highway, all converging into the primary urban Honolulu corridor. From Hawaii Kai, which is the eastern end of the urban Honolulu district, the corridor would follow the Kalanianaole Highway route. Thus all outlying districts would have transit corridors that feed into the primary urban Honolulu corridor.

2. Network Alternatives In The Urban Honolulu Area

The basic urban Honolulu corridor extends from Pearl City to Hawaii Kai. Based on service characteristics and environmental considerations, study of specific corridor locations was conducted in this critical corridor [8/]. The following identifies the corridor limits or alternative locations considered in the transportation analysis.

- Pearl City to Halawa - between H-1 Freeway and Kamehameha Highway
- Halawa to Middle Street - either the Moanalua corridor or the H-1 Freeway corridor
- Middle Street to Downtown - between King Street and Nimitz Highway
- Downtown - between Beretania Street and King Street
- Downtown to University - between Beretania Street and Kapiolani Boulevard
- University to Kahala - between Waialae Avenue and H-1 Freeway
- Kahala to Hawaii Kai - Kalanianaole Highway

Within the above described limits, alternative corridor routes were studied and are documented in separate reports. The selected alternatives are described below:

- Pearl City to Halawa - H-1 Freeway
- Halawa to Middle Street - H-1 Freeway
- Middle Street to Downtown - Dillingham Boulevard
- Downtown - Hotel Street
- Downtown to University-Kapiolani Boulevard and University Ave.
- University to Kahala - H-1 Freeway
- Kahala to Hawaii Kai - Kalanianaole Highway

For the route from Pearl City and Halawa, the H-1 Freeway route was selected due to least cost and disruption to communities 9/. Studies conducted on alternative corridors between Halawa and Middle Street indicated that the Honolulu International Airport is an important activity and employment center and should be directly served by transit. Consequently, the selection of the H-1 Freeway corridor over Moanalua Road corridor was made. Between Middle Street and Downtown, the Kalihi-Palama community stated its preference for the Dillingham Boulevard route due to environmental reasons 10/. In the downtown area, Hotel Street was selected due to its central location. Hotel Street will be converted to a pedestrian mall. Between downtown and the area of the University of Hawaii, studies indicated the greatest transit rider attraction is to Kapiolani Boulevard due to its direct service to Ala Moana Center and to its proximity to the Waikiki area 11/. From the University area to Kahala, the H-1 Freeway route resulted in the least disruption to adjacent communities 12/ and Kalanianaole Highway being the only viable route to Hawaii Kai.

The basic network in urban Honolulu would be a single line system from Pearl City to Hawaii Kai. The above described route locations will result in superior transit service to all major activity and employment centers of Honolulu. It was determined that a single line network concept could meet projected demands beyond the year 2000 without the need for a second parallel line 13/. It was also determined that a network consisting of more than one line would be beyond the financial capability of the City and also result in greater community disruption which would not be offset by added service benefits.

Due to a relatively large transit demand and importance of Waikiki to the economic well-being of the entire State of Hawaii, an additional consideration to the single line network concept was a branch or spur line to this area 14/. A detailed study of the spur line concept indicated that from an operational standpoint, it would cause the mainline system capacity to be constrained. As a result the system would be unable to meet projected demand without providing costly additional facilities. It was further established that due to the current uncertainty of Waikiki's future growth, the justification for the added expenditure for the spur line could not be supported. The network conceived as the most viable to serve urban Honolulu was a single line concept which would meet the future transit demands of the area and also be within the financial capability of the City.

3. Demand Analysis

Various networks analyzed for demand indicate a relatively high patronage attraction for a high level transit system. For the projected 1995 population level of 924,000, it has been established that a highly attractive transit system would be required to divert sufficient motorists necessary to balance travel demand with transportation facilities.

Based upon the current Oahu General Plan description of population and employment distribution, it was determined that a fixed guideway system, from Pearl City to Hawaii Kai, supported by an island-wide network of feeder and express buses would attract a total daily transit system ridership of 490,000 [1/]. Using the same transit network and varying the land use pattern in accordance with alternative development policies previously discussed, a range of 484,000 to 497,000 daily patronage on the total system, was obtained [4/]. These analyses support the validity of the patronage estimates relative to population and employment distribution.

Based on the above demand analyses, maximum peak period link volume on a fast link system was projected to be an average of 25,000 passengers per hour. A refinement of the peak hour factor adjusted the volume to nearer 20,000 peak hour volume. This volume is consistent with the total demand for transportation facilities in 1995 and would require no additional highways.

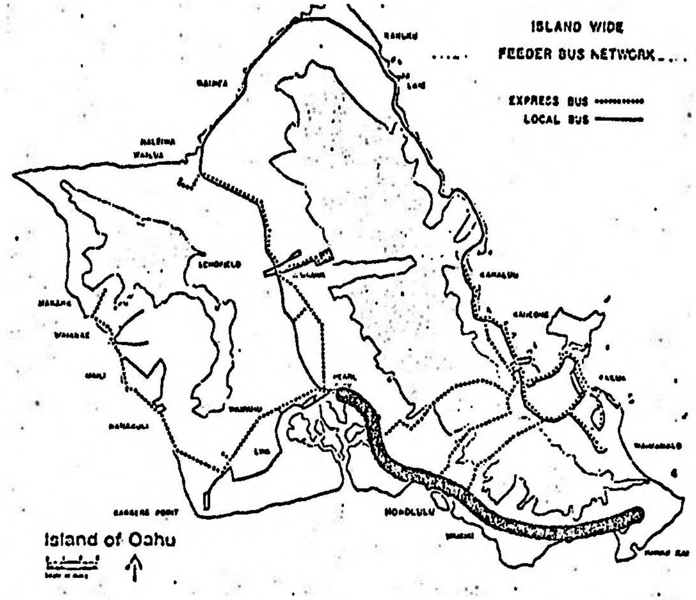
Therefore, one of the primary criteria for any fast link transit system is to meet future transportation demands of approximately 20,000 passengers per hour, each way, in 1995 and have expansion capability of up to 30,000 passengers per hour.

4. <u>Secondary or Feeder System Network</u>

With the exception of those residential developments in and along the major east-west transportation corridor, residential developments must be served by secondary or feeder route systems extending generally in the north-south direction. These routes are currently served by the local bus system. Only minor route modifications are anticipated for interface with most any line haul concepts. Data for current service levels and attendant patronage volumes and demand forecasts for future years have been developed and analyzed. Accordingly, adjustments to the feeder system network to complement any of the fast link concepts can be readily accomplished.

The basic feeder network concept applicable to most fast link transit concepts would be a series of local feeder and express bus routes as depicted in Figure IV-4. Some 300 route miles of express route and 250 miles of local feeder routes are required to complement a rapid transit system serving the primary travel corridor from Pearl City

Feeder Bus Network Map



—— FEEDER BUS
←—— EXPRESS BUS

RAPID TRANSIT STATIONS

1 PEARL CITY
2 PEARL RIDGE
3 HALAWA
4 PEARL HARBOR
5 AIRPORT
6 KEEHI LAGOON
7 KALIHI
8 IWILEI
9 FORT STREET
10 CIVIC CENTER
11 WARD AVENUE
12 ALA MOANA
13 WAIKIKI
14 DATE STREET
15 UNIVERSITY
16 6TH AVENUE
17 KOKO HEAD AVENUE
18 KAHALA
19 AINA HAINA
20 NIU
21 HAWAII KAI

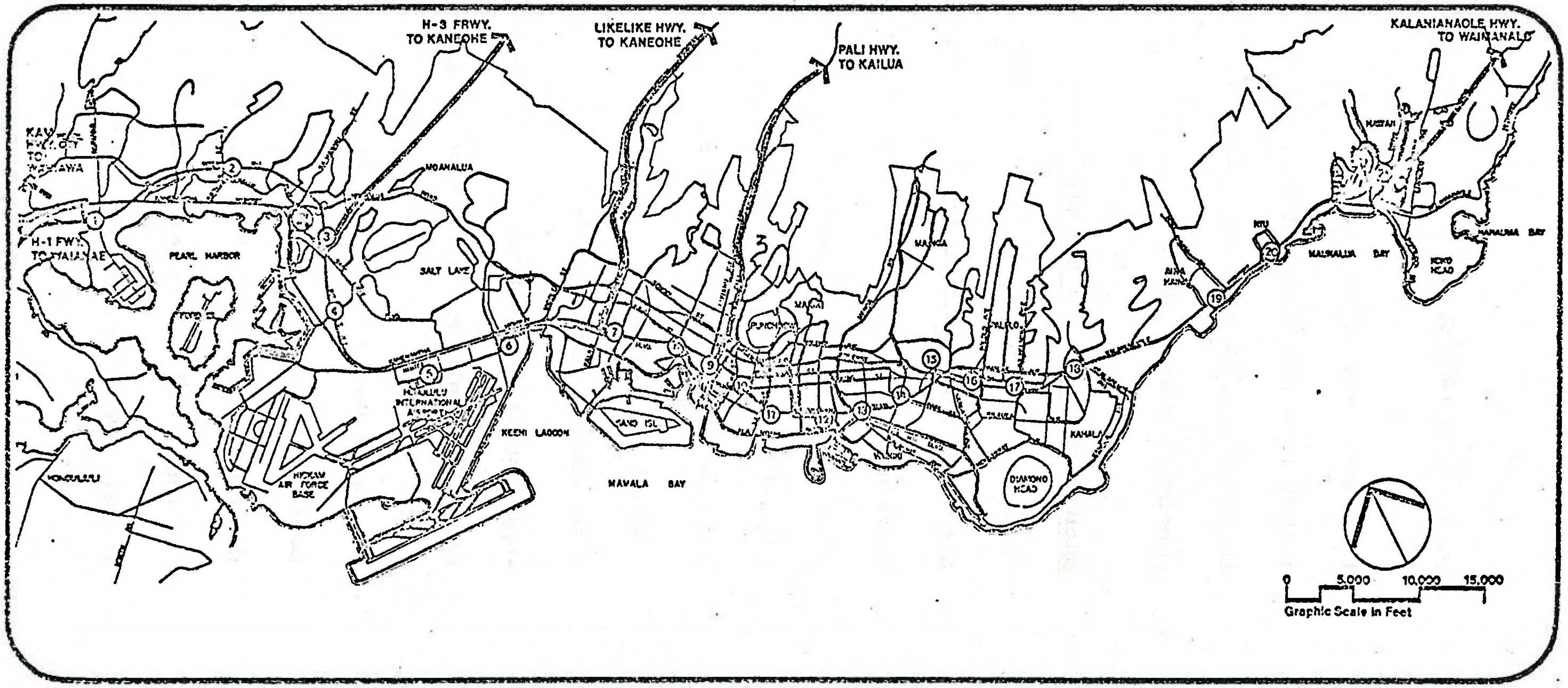


FIG. IV-4

to Hawaii Kai. If a shorter rapid transit system is provided, the express bus routes would have to be extended to the terminal stations with some extensions also made to certain feeder bus routes.

V. TRANSPORTATION NEEDS & SOLUTIONS

A. EXISTING BUS TRANSIT

In 1901, the first mass transit service in the City of Honolulu was started by the privately owned Honolulu Rapid Transit Company, Ltd. At that time, the company operated fifteen electric street cars on twelve miles of track.

Major improvements have occurred since that date. The City and County's on-going bus transit development program, which included the acquisition of the three major private companies providing scheduled service on the island, resulted in more reliable, better scheduled, and expanded bus service.

The present bus system, operated by the Department of Transportation Services of the City and County of Honolulu, serves the entire island with 244 scheduled buses operating on 28 local and three express routes. Total annual bus passenger volume in 1974 was over 40 million. This volume reflects an increase of more than 10 million passengers in the past year, due to the vastly improved services. The current fare structure is 25¢ for adults, 10¢ for students and free fare for senior citizens with free transfers. The annual passenger volume of over 40 million was comprised of approximately 25 million adults, 10 million students and 5 million senior citizens.

The total bus fleet is 333 vehicles. Of these an average of 244 are available for service. This low percentage of the fleet in operation is due to the old age of many buses and to the lack of adequate maintenance facilities to service the fleet.

B. SHORT RANGE BUS PLAN

The short range bus plan outlines the improvements to the bus system over the next six years, up to the projected opening of the rapid transit system in 1980 [15/]. Improvements have been phased into three increments to meet vehicle requirements which are necessitated by improvements in service, for new route structures and modernization, and to develop a bus system which could be easily integrated into the rapid transit system.

Below is a summary description of the three phased Bus Plan.

Phase I - The first phase of development will occur in 1975 and will involve replacement of older vehicles, permitting the scheduling of 290 vehicles while maintaining the present fleet of 332. Service on existing routes will be increased to meet demand.

Express bus service will be expanded and rerouted for improved service to the CBD, University of Hawaii and Pearl Harbor-Hickam from many areas of the island. New service will be introduced to many suburban areas. Many Leeward and Central Oahu lines will be rerouted non-stop via the reserve bus lane on Moanalua Highway. New local lines will also be added. On Windward Oahu local service will be replaced by express service. Several existing routes will be modified to compliment rather than duplicate new services. In addition, at least four specially designed buses for the handicapped are planned.

Phase II - The second phase of the Bus Plan will require 402 vehicles of which 362 would be available for service. During this phase, a semi-express line to service the same corridor as the rapid transit system from Kahala to Waipahu is proposed. This bus line will be referred to as Route A and will travel non-stop between locations at or near the proposed rapid transit stations. Service on many local and express routes will also be increased. Urban routes will be made into feeder routes by eliminating duplicate services. Bus service from Leeward and Central Oahu will be coordinated into Route A.

Phase III is planned to provide transportation service up to the time that the first segment of the rapid transit system is opened.

An extensive plan of bus lanes and busways is planned to service express and semi-express routes. These include, in the Kalanianaole Corridor, a busway on Kalanianaole Highway and an exclusive bus lane on the H-1 Freeway. On Windward Oahu, contraflow bus lanes on the Pali Highway and a busway on H-3 are planned. On the Leeward side exclusive bus lanes on the H-1 and on Moanalua Freeway are planned. A combination of bus lanes, exclusive busways and contraflow lanes are planned for Route A.

The following description summarizes the operations and costs of the Short Range Bus Plan.

The bus operations plan, includes the development of two maintenance yards, each with complete maintenance, administrative and clerical staffing for daily operations. One new facility at Halawa Valley will serve as the major repair yard for the entire fleet. The second, the present bus facilities in downtown Honolulu, at King and Alapai Streets, will be demolished and new shops and service facilities for 250 coaches on the same site will be developed.

Presently, there are 2,464 bus stops in Honolulu, 80% of which are unofficial. According to the new bus plan all bus stops will be identified by distinctive signs. In addition, route and schedule information will be displayed at selected stops, and fifty new bus shelters will be built.

The plan also includes a new park and ride program which is planned for the fall of 1975 when the scheduled vehicle size will be enlarged to 293. The first lots will be at the Halawa Stadium, Auliki Street in Kailua and Hawaii Kai.

The entire capital investment for the total short range plan is estimated to be approximately $25 million. This includes nearly $9 million to purchase new vehicles and parts and the remainder for support facilities.

Annual patronage in FY 1974 was 43.9 million passengers, including transfers, and is expected to increase to 68 million rides in FY 1980. Annual revenue is directly proportional to the annual patronage and will increase from $7.8 million in 1975 to $9.5 million in 1980.

C. CARPOOLING

One relatively simple and low cost approach to the transportation needs of Oahu is a carpooling program. As part of the study of transportation alternatives this approach was considered and analyzed.

The feasibility of a car pool program was analyzed from three perspectives. The first was the determination of the potential market for carpooling. This involved an estimation of the number of trips made on Oahu which have the necessary characteristics to become possible carpoolers. The second was a review of the probable effects of carpooling on the operation of the streets and highways on the Island, particularly during peak periods. The third perspective involved a summary of the results of past efforts to encourage carpooling on the Island.

1. Potential Market

Carpooling works most effectively for trips made daily between the same points at the same time. The repetitive nature of such trips allows people to match their patterns and to select mates for a trip. However, this repetitiveness is not characteristic of trips made for personal business, recreation, shopping, medical/dental visits, or virtually all non-work, non-school trips. Analysis of the composition of trips by purpose throughout the day, indicates that work trips constitute less than fifty percent of all trips during the peak hour and that peak hour trips constitute less than ten percent of the average daily traffic (ADT). In other words, peak hour work trips consist of approximately five percent of the ADT. Assuming that the peak-period traffic is twice the magnitude of the peak-hour traffic, the peak-period work trips would constitute ten percent of the ADT.

To reflect the magnitude of the potential carpool market, an analysis was conducted to determine the number of work trips that would be destined to the downtown area by automobile. Work trips were analyzed since they constitute the largest potential market for car-pooling and the downtown area was selected since it is the single largest destination on the island. The analysis was based on the assumption that the existing bus transit system in Honolulu would be in operation in 1995 with only a few improvements in service due to increased demand (baseline system). The analysis indicates that approximately 85,000 auto person trips per day will be made between the downtown area and the rest of the island of which 8,500 auto work person trips will be made during the peak-period. This volume of auto work person trips represents less than five percent of the total auto person trips made on the island during the peak-period.

These numbers were further analyzed to determine the number of auto trips from specific locations on the island that were destined to the downtown area. This analysis specified the approximate number of peak-period auto work person trips from specific zones, such as those from Hawaii Kai or Kailua, to the downtown area. The following table summarizes this information:

AREA	AUTO WORK PERSON TRIPS TO DOWNTOWN DURING PEAK-PERIOD
Hawaii Kai	650
Kailua	75
Kaneohe	50
New Town-Aiea	125
Mililani	50
Ewa	55

These numbers illustrate the relatively small proportion of motorists whose work trip characteristics would suggest that these motorists might be considered for carpooling.

2. Possible Improvements

To illustrate the importance of the non-work, non-school trips, an analysis was made utilizing the projected 1995 highway assignments obtained from a mode split based on a transit network comprised of the existing bus system in operation. It was assumed for the analysis that special incentives must be provided to the commuters to form carpools. One incentive which has been attempted is to provide an exclusive lane on freeways for carpools and buses. A hypothetical analysis of the available roadway capacity through urban Honolulu with an exclusive carpool-bus lane on the H-1 Freeway was made to determine the effect of this proposal.

It was assumed that one lane on the Lunalilo Freeway between Middle Street and University Avenue would be reserved for carpools. It was further assumed that fifty percent of all work trips by automobile would be carpoolers. This is an extremely optimistic percentage and as illustrated in the previous section would be difficult to achieve. The remaining automobiles projected for 1995 were assigned to the remaining two lanes of H-1 and other available streets in urban Honolulu. It was shown that even with this optimistic participation in the carpooling program, the peak-hour volumes would exceed available capacity by as much as 20% near the CBD area and that without high levels of participation by non-work, non-school trips in the carpooling program, congestion on the major highways and streets in urban Honolulu would be excessive. However, achieving higher auto occupancies for these trips would require either incentive matching or severe regimentation. Neither is a likely possibility.

3. Experience in Hawaii

The only major carpooling program in Honolulu was not successful. Early in 1974, the State of Hawaii Department of Transportation implemented a carpool matching program. Questionnaries were distributed throughout the Island of Oahu through banks, post offices, and other highly frequented locations. For carpooling purposes, the Island was divided into a grid pattern of zones. Anyone interested in participating in the carpooling program was asked to respond to the questionnaire and to indicate the location of his home, place of work, and the times when he travelled between these two points. Approximately 5,000 responses were received. Of these, only 150 were provided with the names of three persons whose work trip characteristics were compatible with their own. No follow-up was performed to determine how many of these 150 were successfully matched and formed a carpool.

4. Conclusion

From the findings of the various analyses conducted and presented above and also from the actual experience obtained in trying to initiate a carpooling program on Oahu, it is clear that carpooling alone would not be an adequate solution to the transportation problems on Oahu.

D. EXPANDED BUS SYSTEM

1. General

One possible approach to the long-range transportation needs for a region is to expand the existing bus system. This would be a relatively low capital investment solution. The expanded bus system would be planned to maximize its attractiveness by utilizing existing streets and highway without the addition of costly fixed facilities. This concept would attract less patronage than a high capital investment system and must be addressed to the regional goals and objectives relative to future transportation needs.

Based on the objective of providing a high level transit system to serve the mobility and accessibility needs of the island, an expanded bus system was defined and analyzed. Various bus routes on existing streets and highways both in mixed traffic and on reserved bus lanes where the highways are congested were analyzed. Routes were refined and system speeds adjusted to reflect the use of reserved bus lanes wherever it was considered appropriate.

2. System Operating Characteristics

Utilizing the modal split model, transit patronage volumes were developed and screenline analysis were made to verify the accuracy of the assumed bus operating speeds and the projected passenger volumes. Based on these volumes, basic bus requirements and operating characteristics were developed and are summarized below:

Annual Patronage	-	110.9 Million
Bus Requirement	-	728 (With 10% Spares)
Bus Miles Operated	-	35.1 Million Annually
Bus Hours Operated	-	2.1 Million Annually
No. of Bus at CBD Screenline	-	180 local buses and 190 express buses per peak hour

By improving accessibility to major activity centers with express bus services - aided by the use of reserved bus lanes on congested streets and highways, significant improvements in bus operating speeds were attained. This is reflected in the increased patronage projected for this expanded bus system over the current bus operations.

The number of buses required to meet this projected demand will result in a substantial increase in fleet use. This increase will be particularly significant in the volume of buses operating in the urban core leading to various activity centers and most importantly in the CBD - Civic Center area. The most critical part of high volume bus operation is the passenger loading and unloading function in shared rights-of-way with automobiles.

3. Street Capacity Analysis in the CBD

In the urban core area, the primary traffic movement is in the east-west direction. The CBD-Civic Center area is served by two major streets, Beretania and King. These are one-way streets which form a couplet. All other streets are non-continuous except for Vineyard Boulevard and Nimitz Highway which are located on the fringe of the downtown area.

The other alternative route in the downtown area is Hotel Street which is limited to exclusive bus use in both directions. Hotel Street is master planned to become a pedestrian mall anchored on the east end by the City Hall and the State Capitol and on the western end at Nuuanu Stream. Because the joint use of the Hotel Street mall for both high volume bus operation and for pedestrian use would be incompatible, the Beretania-King Street couplet was analyzed as the downtown bus route.

The major constraint on the successful operation of the Expanded Bus System (EBS) is its practicality on the streets of Honolulu. In fact, the analysis which was conducted on the EBS assumed that buses could be added to any line on which the projected patronage exceeded the coded capacity. The analysis also assumed that local streets have an unlimited capacity to accommodate buses. The assumption related to number of total buses required is a policy issue. However, the assumption related to the capacity of the local street is a real physical constraint.

The following section summarizes the most significant factors related to bus system capacity on existing streets. One major constraint is that the "flow through" capacity of a busway or street lane, between loading points, is far in excess of its capacity where loading and unloading is required. This is an especially relevant point on local streets because of the importance of the stops. Especially at the busier stops, buses in standard service may take up to 60 seconds to load and unload, limiting capacity to 60 buses per hour. By allowing more buses to load and unload at one time, the capacity can be increased. The size of the street block is the primary limitation. In Honolulu many of the busier stops such as those currently on Hotel Street do not have sufficient area to accommodate more than three buses at one time. EBS is further constrained by the necessity of maintaining minimum safe headways between buses.

The following summarizes the total number of buses that could be accommodated at a street stop if "platoons" of three buses were operated and the minimum safe headway between buses in platoons were 2 seconds:

	SECONDS
Time required to get first "platoon" underway	4
Time required for third bus to clear	9
Time required for first bus of second "platoon" to dock	9
Time required for third bus to dock	4
Maximum dwell time	60
Total	86

or

$\frac{3,600}{86} =$ 42 "platoons"/hour or 126 buses/hour

Therefore a bus route or corridor can only accommodate 126 buses/hour due to the constraint of inadequate loading and unloading operation associated with surface street operation.

A review of the loads on the 1995 EBS in the CBD indicates that the patronage requires 178 local and 193 expresses on the major bus corridor through the CBD during the peak one hour. The analysis clearly indicates that the bus network will ultimately require either rerouting of buses or reduction in service and consequent reduction in patronage.

4. Findings and Conclusions

The expanded bus system would provide improved service and would result in increased patronage over existing bus operation. It could be implemented with a relatively low capital investment but would require a high operating budget. Due to the physical constraint imposed by the downtown operation the system may be characterized as a low capacity one. Even with a relatively high operating speeds attainable from the outlying areas to the urban core, breakdown of traffic flow on surface streets in the CBD area would substantially increase the overall trip time and would significantly reduce patronage.

The attractiveness of this system, assuming the most optimistic condition in the downtown operation results in some 370,000 total daily passengers in 1995. However, the transit volume for a balanced highway-transit system is nearly 500,000 passengers per day. Because the expanded bus transit system does not meet the desired capacity objective, the construction of additional new highways in the urban core would be required with a bus dominant transit system. Therefore, it is concluded that the expanded bus system could not meet the basic system objectives of attractiveness and capacity as the long-range solution to meet Honolulu's transportation needs.

E. ALTERNATIVE LINE HAUL TRANSIT CONCEPTS

For purposes of the analysis, the expanded bus system was viewed as a low capital investment mass transit solution. The analysis concluded that the bus system would not meet the long-range transportation objectives of the City & County and that the bus system could not provide the required level of service to attract sufficient patronage to meet future demand, and to reduce the need for constructing additional new highways in the urban core of Honolulu. In particular it was concluded that by utilizing the available surface streets in the downtown area, the system could not provide sufficient capacity to accommodate the desired level of patronage volume. The analysis proved that without the use of exclusive right-of-way, no transit mode would have the capacity to meet the transportation needs of the island.

As previously indicated, the system should have a design capacity of up to 30,000 passengers per hour in each direction. In order to attract this volume of passengers, the system must provide fast and dependable service which cannot be attained without the use of exclusive rights-of-way for the line haul operation.

Other basic transit concepts which have been examined include the following:

- Waterborne transit utilizing ocean going hydrofoils
- Buses operating on exclusive busway
- Fixed guideway system utilizing conventional transit mode of operation
- Dual-mode and Personalized Rapid Transit (PRT) concepts

Both the dual-mode concept and the PRT system were dismissed as candidate systems due to insufficient evidence of successful operational experience at the date of the evaluation in 1971 [16/]. The PRT system was dismissed also because of its inability to meet system capacity criteria based on the lack of a proven and reliable control system. To date, the dual-mode equipment development has not advanced substantially farther. The PRT systems which are operating currently are serving primarily as people movers rather than line haul systems, and at much slower speeds than are required in Honolulu. Operation of the PRT system for conventional transit operation during peak periods, would require that it be modified to utilize larger cars operating in trained units.

Environmental and economic considerations are related to system capacity requirements in the evaluation of various alternative concepts. The intensely developed urban core of Honolulu limits the availability of suitable transit routes without causing significant environmental impacts. A concept requiring two or more parallel routes with the use of aerial way structures to meet the capacity requirement would not satisfy the environmental requirements. An alternative could be the use of underground configuration. However, this alternative would result in a system which may be too expensive. Even utilizing aerial way structures, two small parallel lines would cost more than a single line and would be less cost effective from the operational standpoint.

F. PREVIOUS ALTERNATIVES STUDIES

1. PEEP I Study

As part of the PEEP I program, completed in late 1972, a study of various alternative transit concepts was conducted. The study analyzed the bus, fixed guideway, and waterborne systems[17]. On the basis of various technical, economic, social, and environmental factors, a comparison was made between the various alternatives.

For the bus concept, a low capital intensive system that basically extends the current service level to 1995 was defined and used as the baseline system. The baseline bus system assumed use of the existing streets and highways. Its operating characteristics were comparable with current bus operations. The 1972 patronage volume was extrapolated to 1995 to reflect growth in population and total trips projected for the island. This resulted in a patronage volume of 188,000 passengers per day. Use of the baseline system provided the basis for measuring other alternative transit system concepts.

A second bus concept system, which was evaluated, was a busway system. The busways utilize exclusive roadway for providing high speed line-haul service. Two exclusive busway lengths of 22 and 19-miles were analyzed. For purposes of the comparative analysis, the 1995 patronage volume was assumed to be equivalent to the fixed guideway system.

The waterborne concept which was evaluated utilizes 250 passenger ocean-going hydrofoils to provide high speed line haul service. It was assumed that local and feeder services would be provided by either buses or by a combination of canal boats and buses. The analysis was made on two patronage basis: patronage volume equivalent to the fixed guideway system and patronage volume based on modal split analysis.

The fixed guideway concept which was analyzed was based on a 22-mile system with 20 stations, utilizing a medium capacity, rubber-tired vehicle. An island-wide network of local and express buses was provided to complement the fixed guideway system.

The results of this comparative analysis is summarized in Table V-1.

2. Joint State-City Study

After completion of the PEEP I Study, the City of Honolulu and the State of Hawaii jointly sponsored a study of an automatic rapid transit (ART) system and a review of the busway alternative study which was completed under PEEP I. The study defined and analyzed the ART operating characteristics, the network and travel characteristics, and economic and environmental factors [18/]. A comprehensive review of the previously described busway alternative analysis including review of the physical design, operating concept, and costs was conducted to determine the validity of the analysis and if any improvements could be made to the system.

TABLE V-1: SUMMARY OF ALTERNATIVE ANALYSIS - PEEP I

	FIXED GUIDEWAY	BUSWAY		WATERBORNE		
		A	B	1-A	1-B	1-C
LINE HAUL LENGTH (MI.)	22	22	19	22	22	22
NO. STATIONS	20	20	18	13	7	7
DAILY PASSENGER VOLUME	484,000*	484,000**	484,000**	484,000**	226,000*	185,000*
ANNUAL PASS. VOL. (MILLION)	146.2	146.2	146.2	146.2	68.3	55.9
FAST LINK VEHICLES	405	458	416	224	75	43
CAPITAL COST ($ MILLION)	577.8	537.7	482.4	935.7	377.0	244.9
ANNUALIZED CAP. COST ($MILLION) (30 YRS. @ 4%)	33.4	31.1	27.9	54.1	21.8	14.2
ANNUAL O & M ($MILLION)						
FAST LINK	17.0	23.6	20.4	76.6	25.4	14.6
FEEDER	19.0	19.0	20.0	16.9	8.5	7.4
TOTAL	36.0	42.6	40.4	93.5	33.9	22.0
TOTAL ANNUAL COST ($ MILLION)	69.4	73.7	68.3	147.6	55.7	36.2
COST/PASS. TRIP (¢)	47.5	50.4	46.7	101.0	81.6	64.8

* BASED ON MODAL-SPLIT ANALYSIS

** ASSUMED PATRONAGE SAME AS FIXED GUIDEWAY

3. State DOT Study

In 1974, the State DOT conducted a conceptual analysis of a tri-modal concept comprising fixed guideway, busway, and hydrofoil waterway systems. The concept optimizes the use of existing highway facilities for public transit and also utilizes the ocean waters surrounding the island for a supplemental water system during construction of the land-based systems.

The concept proposes the use of waterways from Hawaii Kai to developed areas around Pearl Harbor, the existing and committed highways west of Middle Street and east of the University of Hawaii, and the construction of a 7-mile fixed guideway system from Middle Street to the University.

G. FINDINGS AND CONCLUSIONS OF PREVIOUS STUDIES

Of the three basic alternative concepts studied - busway, water-borne and fixed guideway, the waterborne concept was found to be the least cost-effective. Because the waterborne system cannot penetrate the main activity centers as well as the land based concepts, it provides a lower level of service. This is reflected by the comparative patronage volumes. The high operating and maintenance costs of the hydrofoil system result in a cost per trip that is much higher than the land based systems. Accordingly, this waterborne concept was determined to be inferior to the other concepts.

The 19 - and 22-mile busway systems were analyzed using both standard 40 foot buses and a combination of standard buses and large articulated buses operating as captive vehicles on the busway. A special travel demand forecast for the system was not made for this analysis since the level of service was assumed to be nearly comparable to the fixed guideway system. The location of the route and stations are essentially the same as the fixed guideway system. The operating characteristics of the busway system were assumed to be nearly comparable with the fixed guideway system, or had a slightly lower average trip speed but had the advantage of eliminating transfers for certain bus routes. But the no-transfer advantage was assumed to be further offset by the greater schedule reliability and greater attractiveness of the fixed guideway system. It was concluded that, although the cost efficiency between the busway and fixed guideway was nearly comparable, the fixed guideway had overall advantages in terms of economic, environmental, and community factors.

The separate study conducted for the automated rapid transit (ART). system was found to have about equal attractiveness as the fixed guideway based on the best current predictions of the system operating characteristics. The ART system analyzed consisted of over 30 miles of two-way guideway with 77 stations as compared to the 22-mile, 20 station fixed guideway system. The cost of the ART system was about 15% higher than the fixed guideway system in both capital cost and annual operation cost.

It is interesting to note that the operating cost did not include train and station attendants for the ART while the fixed guideway system includes them. The fixed guideway system could, if it desired, operate without train attendants and also without station attendants as on the Lindenwold Line system Philadelphia. If the estimates were made on the same basis relative to the attendants, the O&M cost for the fixed guideway system would be significantly lower than for the ART system.

Relative to the attractiveness of the ART system, it was concluded that under the most favorable assumptions regarding operating speed, the ART would have a slightly greater patronage potential only during peak periods than the fixed guideway. This assumes a speed of 45 mph as compared to 35 mph used in the analysis with greater attendant risks and potentially higher costs. Based on this study, the State and City agreed to proceed with transit planning in Honolulu based on the fixed guideway concept.

H. SELECTION OF ALTERNATIVES FOR DETAILED STUDY

In summary, the waterborne system was found to be significantly inferior to land based transit concepts. Of the various land based transit concepts studied, the ART system was found to offer potential service equal to or slightly better than the fixed guideway system, but at a much higher cost and with significant risks of time and cost overruns. Accordingly, ART and the waterborne systems were then dismissed from further consideration, as potential candidate systems for Honolulu.

Although the busway systems were found to be less desirable than comparable length fixed guideway systems, a shortened busway system utilizing more of the existing highway facilities for fast link operation could result in considerable savings in capital cost. Accordingly, a minimum length busway system of about 7 miles from Middle Street to the University area was determined to be a viable alternative for further consideration.

A light rail transit (LRT) concept which is receiving serious consideration by many regions was also considered to be a viable alternative due to recent developments in new vehicle system. The three alternative transit concepts selected for further detailed evaluation are the 7-mile busway, the fixed guideway, the light rail transit concepts.

VI. THE BUSWAY TRANSIT CONCEPT

A. GENERAL

The flexible and versatile operating characteristics of a bus system will always play an essential part of any mass transit system. The buses can be routed over nearly any streets and highways to best serve the needs of an area without being tied-down permanently to a specific route. Service frequencies can be changed with ease to meet demand. The flexible bus system is characterized by a single vehicle performing both collection-distribution and line-haul functions which implies that a person could commute directly from his origin to his destination without making transfers. However, in actual bus system operation, all persons traveling on buses does not have the convenience of a "non-transfer" trip depending upon the location of his origin or destination and the operating bus routes.

In a metropolitan region, the line-haul function of a transit system generally applies to high volume travel corridors. Any transit system utilizing streets and highways in mixed traffic can only move as fast as the rest of the traffic. Therefore, in most major travel corridors, buses must operate on exclusive bus lanes or busways in order to provide any reasonable level of service.

Due to its flexibility and low capital investment, an expanded bus system was analyzed and found to have limitations as a long-range transit solution for the island as discussed in the previous chapter. In the evaluation of alternative concepts, a baseline bus system is defined as the basis for making comparisons. The baseline bus system would provide generally the same service levels in the year, 1995, as currently provided by the existing bus system as described in the previous chapter.

A busway system featuring a high level of service with dependable high speeds on the line-haul portion of the system and convenient transfer facilities was developed and analyzed. These high speeds are attained by the reduction of bus stops to a few selected locations along the high volume line-haul segment of the urban corridor and with the use of exclusive rights-of-way for both bus routes and stations. This chapter will be focused on the development of the busway operating concept and characteristics and the analysis of the total system concept.

B. BUSWAY SYSTEM OPERATING CONCEPTS

A high volume, high speed busway system with service to multiple destinations and with on-line stations as envisioned for Honolulu does not exist anywhere today. The only existing bus service that comes close to providing the type of high level bus service as assumed in this study is the El Monte Busway System in Los Angeles County, California. This system connects El Monte and the San Gabriel Valley to downtown Los Angeles and consists of approximately 11 miles of exclusive busway located in the San Bernadino Freeway with only two intermediate stops. The primary service is express service for patrons destined to downtown Los Angeles. This system has only recently been implemented and although highly successful, the line volume is considerably less than that anticipated for Honolulu. Therefore, there is a lack of operating experience for a high volume busway system with on-line stations. Unlike the busway system, fixed guideway transit systems are in operation throughout the world, with most systems operating with every train making a stop at each station.

Two basic busway operating concepts were examined. The first was the "single-file" concept where all buses must operate sequentially with no opportunity for passing other buses. The "single-file" concept would provide only two lanes throughout the busway system including the stations, thus resulting in minimum way and station structures. The second concept was the "flexible" bus concept where buses operate independently from each other and hence, it has complete operating flexibility at stations and ramps. The operating criteria used for buses were maximum speed of 50 mph, 2 mphps normal acceleration and deceleration rate, and 3 mphps maximum deceleration rate.

1. Single-File Concept

In order to determine a safe separation distance between buses at 50 mph, it was assumed that a bus, disabled or otherwise, could decelerate at 0.8 g which is maximum braking and equivalent to the maximum coefficient of friction on dry concrete. A trailing bus, at the maximum safe braking rate of 3 mphps would require approximately 600 feet, less the 100 feet stopping distance for the front bus, to come to a complete rest. Thus, a minimum of 500 feet separation or 7 second headway could be assumed a safe theoretical operating condition at 50 mph.

Under the "single-file" concept, two methods of operation were considered, the platoon method and the random method. The platoon method would require buses to operate in groups, maximum of 10 buses, with each bus pre-scheduled and assigned to operate in a particular platoon and also assigned to a specific place or slot in the platoon. The assignment of the buses to slots in the platoon is necessary for the convenience of the boarding passengers at stations since the platforms would be approximately 400 ft. long.

The second method of operation is the random method where each bus would operate independently from other buses. However, this method would require buses to be assigned to specified docking locations at stations, again for the convenience of the boarding passengers.

These two operating methods were examined as follows:

a. Line Capacity

In order to determine the line capacity of the platoon concept, the following calculations were performed:

First Platoon

Time required to dock all 10 buses:	63 seconds
Dwell time for the 10th bus:	30 seconds
Time for 10th bus to clear station platform:	17 seconds
Total time for entire platoon to dock and clear platform	110 seconds

Second Platoon

Time required for front bus to dock assuming bus begins normal deceleration after 10th bus of first platoon has cleared platform:	25 seconds
Total headway between platoons	135 seconds

Based on the above minimum headway, the theoretical maximum line capacity for a 10-bus platoon carrying 50 passengers per bus is 13,300 passengers per hour. This capacity is considered as theoretical only with the volume subject to probable decrease depending on the application of appropriate safety factors and various manual operating constraints.

For the random method, the comparable theoretical line capacity is approximately 25,000 passengers per hour, each direction based on a 7 second headway. It is cautioned that this theoretical capacity assumes no constraint at stations which will be discussed later.

b. Operating Considerations

In addition to the line capacity factor, various other factors must be analyzed to determine the feasibility of this concept. Unquestionably, the "single-file" concept has the inherent advantage of narrow busway and station structures but restricted operational flexibility.

The platoon method provides an orderly operation of the buses on the busway both from the schedule standpoint and the docking of the buses at stations. However, under the flexible mode of operation, i.e. bus performing both line-haul function on the busway and collection-distribution function on surface streets and highways, certain constraints are imposed as follows:

(1) Possible delays in arrival of buses operating on surface streets thus holding up the scheduled platoon operation.

(2) Special facilities required to maneuver buses entering the platoon into their proper slots plus the time required to do this.

(3) Reduced flexibility for maximum utilization of the bus fleet since all buses must have similar performance capabilities so as not to delay the entire platoon operation.

(4) Uneven loading of buses causing entire platoon to move according to the bus requiring the longest dwell time at station.

Buses operating under the random method would not have the constraints enumerated above for the platoon method. However, the random method has one serious drawback in that frequent queuing would occur. If the lead bus of a particular grouping of buses were assigned the entrance end of the platform for docking, it would hold up the entire group of trailing buses until it clears the dock.

Both methods appear to have serious negative features and it is difficult to assess them for determining the better method. Perhaps under a low volume operation, the random method may be more flexible while under a high volume operation, the platoon method would appear to be more orderly, safe, and easier to schedule.

c. <u>System Reliability</u>

The single-file concept, as was previously described, will not permit buses to pass other buses or by-pass stations. There is one major aspect of operations, system reliability or schedule maintainability that is crucial to rapid transit operation.

Mechanical failures in bus equipment are relatively frequent. Many transit properties experience road calls on the average of once for every 20,000 bus-miles of operation. With some 150,000 bus miles per day expected in 1995, this could mean some 7 or 8 road calls on mechanical failures occurring each day on the total busway system, including feeders. Although the probability of these road calls occurring on the busway and during peak periods would be less, it remains significant enough to justify sufficient width in the busway to permit safe by-passing of disabled buses, even at reduced speeds.

d. Station By-Pass

One of the key features of a busway system is its basic operating concept of flexible mode which permits the same vehicle to operate both on and off the busway and to run express by by-passing certain stations. A single-file concept will not permit this flexibility of operating express services. Additionally, there are other operational considerations that will be restricted by this concept.

It is more efficient, depending on the loading characteristics, to run certain buses back, or dead-head, to its terminal or starting point. Without a provision for station by-pass, this would not be possible.

Depending on the location and frequency of on and off ramps, disabled buses will have to be towed off the guideway. The removal of disabled buses by permitting them to by-pass stations would be more expeditious and hence less interrupting to the busway operations.

2. Flexible Concept

The second or flexible bus concept has the flexibility of operations with buses entering the busway at various points, running certain buses express and others local, dead-heading empty buses unconstrained through stations, etc. It would also permit greater capacity than the single-file concept, especially the platoon method, with theoretical volumes in excess of 20,000 passengers per hour in each direction. However, the way and station facilities require larger structures and consequently resulting in higher cost.

Since buses are individually steered or manually operated, they are capable of being driven on the street system, and therefore, can be operated in a variety of ways. Traditionally, buses are operated on local, limited stop, or express service basis on surface streets and highways. On busways, buses can also be similarly operated on a "local" basis with all buses stopping at selected stations, or on an express basis with the buses running non-stop from the origin to a major destination station.

There are principally four methods of operating buses on exclusive busways[19]. One method involves using buses in a similar fashion as most fixed guideway operations. There would be trunk line buses operating on the exclusive busways only and stopping at all stations. Passengers would have access to the trunk line buses through busway stations and would arrive at the stations by means of either separate feeder buses, walking, or driving to stations.

The second method is similar to the first in that the buses would operate only on the exclusive busway with separate feeder vehicles required to serve the stations. The difference is that the buses operate on an express basis. The buses, upon loading at certain stations, travel non-stop to a major destination station. This method allows higher speed service but reduces the frequency of service at each station.

The third method employs the advantage of the bus to operate on local streets and rove through the local neighborhood picking up passengers. Once full, it enters the exclusive busway by means of an on ramp and travels non-stop to a major destination point, such as the CBD area.

The fourth method of operating buses on exclusive busways is similar in operation to method three except stations are added at points where the buses enter or leave the busway by means of ramps. These stations provide passengers with the opportunity to transfer to buses going in directions other than the direction of the initial bus which they board in their local neighborhood.

These four methods of bus operation on exclusive busways can be combined to a certain point, either simultaneously, or at different times of the day depending upon the volumes and travel patterns.

Only methods of operations that require the same fixed facilities can be combined.

For this analysis, the system will utilize a combination of busway operating methods one and four, mentioned above, but with a slight change in operating method four in that there will also be some buses, besides the express buses, that enter the busway by means of bus on-ramps and act as local buses on the busway, stopping at every station, loading and unloading passengers. In the operations of the busway system, the flexibility inherent in bus operations has been recognized and appropriate turn-backs have been incorporated along with express bus service on the busway.

3. Selection Of Busway Operating Concept

A comparison of operating concepts is shown in Table VI-1.
A review of the comparison will indicate that the single file concept has serious deficiences and constraints that cannot be tolerated for an efficient, high capacity, rapid transit operation.

The two primary criteria in evaluating alternative concepts for busway operations are system reliability and provisions for express operations. These two criteria must be met in order to have a viable bus rapid transit system.

TABLE VI-1: COMPARISON OF BUSWAY OPERATING CONCEPTS

	Single File Concept: Platoon	Single File Concept: Random	Flexible Concept
Theoretical Line Capacity (50 passengers per bus)	13,300 passengers/hour	25,000 passengers/hour Constrained at station	25,000 passengers/hour Unconstrained at station
Time Required to Start Busway Operations	Poor - buses arriving at busway must wait for its designated platoon - buses entering platoon must maneuver into designated place or slot	Good - buses arriving at busway can enter freely	Good - buses arriving at busway can enter freely
Time Required to Operate Through Stations	Fair - free to dock at designated space - must wait for front buses to leave	Poor - must wait if designated space is ahead of docked bus - must wait for front buses to leave	Good - free to dock at designated space - free to leave station unconstrained
Overall Schedule Reliability	Poor - must wait for right platoon, must maneuver into proper slot, must wait for entire platoon to move through station	Fair - unconstrained at guideway entrance but constrained at station	Good - unconstrained at guideway entrance and at station
System Reliability	Fair - buses required to by-pass disabled buses on opposite lane when clear - easier and safer with platoons	Poor - buses required to by-pass disabled buses on opposite lane when clear - difficult with random method	Good - all buses free to by-pass disabled bus at any time but at reduced speed
Express Operation	Fair - possible use of reverse lane for by-passing outlying stations by use of radio communication to control passing operation - must operate two types of platoons, local and express	Poor - possible use of reverse lane for by-passing outlying stations but difficult for safe operation due to large number of individual buses to control	Good - all stations provided with by-pass lanes
Miscellaneous Through Operations	Poor - dead-heading buses and removal of disabled buses constrained	Poor - dead-heading buses and removal of disabled buses constrained	Good - dead-heading buses and removal of disabled buses not constrained

The additional major consideration which is the key feature of a flexible bus operation is the time savings and convenience of no inter-modal transfer. Although the convenience factor still remains, the time savings factor is seriously eroded with the single-file concept. For example, under the platoon method, if the headway of the platoons is 2 minutes, an entering bus that misses its platoon may have to wait at least 2 minutes or less for the next platoon, but most likely must wait for several platoons to go by before it can be assigned to proceed with its busway operation. Under the random method, depending on the location of the station docking slots and the number of buses ahead, a particular bus or buses could be severely delayed at stations. Consequently, the time savings due to "no-transfer" may be substantially exceeded due to the inflexible operating conditions of the single-file concept. It was concluded that the flexible concept would be superior to the single-file concept and thus selected for this evaluation.

C. BUSWAY SYSTEM OPERATING PLAN

1. System Route

The basic rapid transit corridor in urban Honolulu, from Pearl City to Hawaii Kai, has been defined in a previous chapter, as a single line route. The proposed route location, also previously described, is determined to be the optimum in terms of service and minimum disruption to the communities. On the western end, from Pearl City to Middle Street (just west of the Kalihi area), adequate roadway capacity exists to meet future travel demands upon completion of the interstate freeway system. This would permit the use of the freeway facilities for express bus operation, either in mixed traffic or on reserved lanes, at a relatively high speed. On the eastern end between Kahala and Hawaii Kai, the existing Kalanianaole Highway is planned to be widened with an exclusive reversible, at-grade busway in the center. Between the University area and Kahala, the existing H-1 (Lunalilo) Freeway would be the route of express buses operating in either mixed traffic or in reserved bus lanes. Based on the foregoing, the express bus operation west of Middle Street and east of the University area would utilize existing highway and freeway facilities to provide relatively high speeds.

Through the central portion of urban Honolulu, the bus route would be on a grade separated, exclusive right-of-way busway. The busway would be either aerial, at-grade or subway configuration with high capacity stations located at major origin or destination points. The 7-mile busway system route and station location as well as the express bus routes in the urban Honolulu area are shown in Figure VI-1.

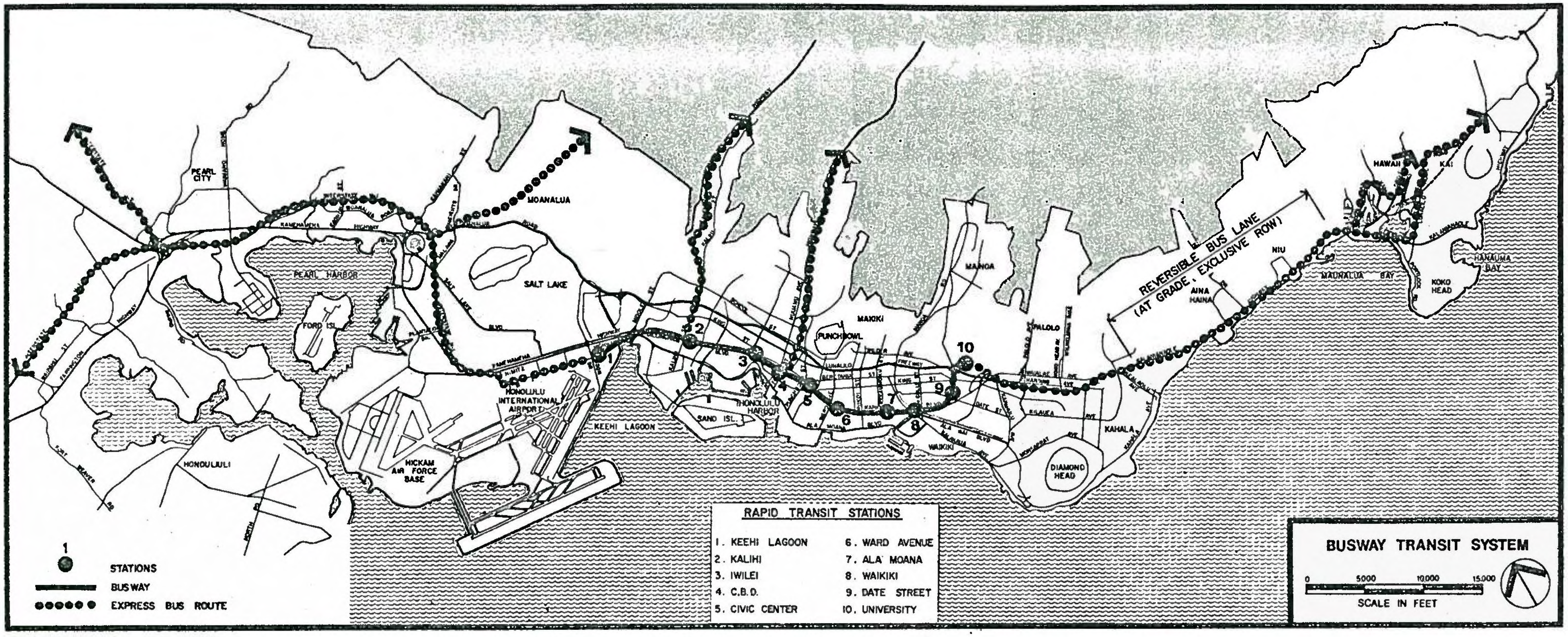

BUSWAY TRANSIT SYSTEM
0 5000 10,000 15,000
SCALE IN FEET
RAPID TRANSIT STATIONS
1. KEEHI LAGOON
2. KALIHI
3. IWILEI
4. C.B.D.
5. CIVIC CENTER
6. WARD AVENUE
7. ALA MOANA
8. WAIKIKI
9. DATE STREET
10. UNIVERSITY
STATIONS
BUSWAY
EXPRESS BUS ROUTE
REVERSIBLE BUS LANE
(AT GRADE, EXCLUSIVE ROW)
PEARL CITY
PEARL HARBOR
FORD ISL.
MOANALUA
SALT LAKE
HONOLULU INTERNATIONAL AIRPORT
HICKAM AIR FORCE BASE
KEEHI LAGOON
SAND ISL.
HONOLULU HARBOR
HONOULIULI
PUNCHBOWL
MAKIKI
MANOA
PALOLO
WAIKIKI
DIAMOND HEAD
KAHALA
AINA HAINA
NIU
MAUNALUA BAY
HAWAII
KAI
KOKO HEAD
HANAUMA BAY

FIGURE VI-1

2. System Operating Characteristics

On the busway, each bus was assumed to accelerate from 0-30 mph in 18 seconds and from 30-50 mph in 31 seconds. The buses were also assumed to decelerate at an average operating rate of 1.5 mph/second. The maximum scheduled speed for the buses was assumed to be 50 mph. If a bus passed through a station without stopping, the speed was assumed to be reduced to 30 mph through the station. To compute the scheduled speed and size of the bus fleet required for busway operation, the average dwell time at all stations on the busway was assumed to be 30 seconds. For buses to operate without delay in and out of stations, raised loading platforms would be provided. Also, the buses were assumed to be designed with a special device at each door sill which would extend outwards at the platform level to aid in loading and unloading passengers expeditiously. The average speed for buses stopping at every station along their route on the busway was approximately 23 mph while express buses average approximately 31 mph.

The type of buses or size that can be operated safely on the local streets or highways is governed by local traffic and state highway regulations plus physical limitations relative to street widths, curves and grades. For the line haul portion, the most economical size would be the largest bus that is available. However, since this concept basically calls for maximum non-transfer operation, the line haul buses must also perform the collection-distribution function which would limit the buses to a standard 40 ft. length. Therefore, within this analysis, standard 40 ft. buses were utilized in developing the busway system operating requirements and characteristics.

To provide a comparable quality of service, the design passenger loading per bus was based on a per passenger space allocation equal to that used in the fixed guideway system concept. The vehicle capacities presented in Table VI-2 is based on total floor area of the car including space occupied by seats.

TABLE VI-2 : VEHICLE CAPACITIES

Load Condition	Fixed Guideway		Bus	
	Sq. Feet/ Passenger *	Capacity	Sq. Feet/ Passenger *	Capacity
Seated	9.14	36	5.26	53
Normal (design)	4.57	72	4.57	61
Crush	2.99	110	2.99	93

* Total effective floor area for fixed guideway vehicle = 329 sq. ft. and for bus = 279 sq. ft.

Therefore, an average design load of 61 passengers per bus on the busway would provide a comparable quality of service to the expected patrons of the busway system as would be provided by any of the other alternative concepts evaluated.

It was assumed that buses would get on and off the busway at certain points along the busway. These points were at the proposed Keehi Lagoon, Kalihi, Waikiki, and University stations. These locations were selected to accommodate those high volume feeder bus routes operating in the system. It is also based on the feasibility of constructing the on and off ramps and also in consideration of their location relative to major destination points. For example, in the downtown area, the CBD and Civic Center stations which also had large numbers of feeder bus routes were not provided with on and off ramps because most of the passengers were destined to the immediate area. Express buses would either enter or leave the busway at the Keehi Lagoon, Kalihi or University stations. The express buses would then operate on the busway in an express mode and stop at only their entrance and exit stations to and from the busway and at the CBD and Waikiki stations. The CBD and Waikiki stations were chosen since they are the two largest destinations on the entire busway system. Feeder buses would get on or off the busway at the

Keehi Lagoon or Waikiki stations, and while on the busway, these buses would stop at every station. To serve passengers other than those mentioned above, there would be those captive buses that operate exclusively on the busway and stopping at every station.

In coding the busway transit system network used in the modal split analysis and transit system trip assignment computer models, it was assumed that all express buses operating to and from the Keehi Lagoon, Kalihi, and University Stations would be able to enter the busway and operate in an express mode to the ends of the busway. For example, express buses arriving at the Keehi Lagoon Station from Wahiawa could enter the busway and operate as an express to the CBD, Waikiki and University Stations. It was also assumed that all local feeder bus routes operating in and out of the Keehi Lagoon and Waikiki Stations would be permitted onto the busway at these stations and operate locally, stopping at every station, to the ends of the busway. Therefore, a feeder bus arriving at the Waikiki Station from Waikiki could enter the busway and operate locally to the Keehi Lagoon Station. The above assumptions used in the development of the busway transit system network for computer analysis would promote the major advantage of the busway system which is the reduction of modal transfers. But in the computation of scheduled bus requirements to meet system demand, bus turnarounds would be provided at the stations with on and off ramps to maximize the use of each bus but minimizing transfers and maintaining the required headway.

D. FIXED FACILITIES

An analysis of high speed bus operation on busways with on-line stations was conducted. With station spacing of approximately one-mile intervals, a bus can average 27 mph including stops at each station. On a conventional surface street operation, buses average between 10-12 mph in the urban areas. Hence, a speed of some 2.5 times the conventional bus operating speed is possible with busways. This higher speed results in both cost savings in terms of higher utilization of buses as well as significant time savings by transit patrons.

A busway lane can theoretically accommodate as many riders as a fixed guideway line in a line-haul operation. For example 500 buses per hour on a single lane would carry 30,000 passengers based on 60 passengers per bus. Assuming that buses would be operating at maximum speed of 50 mph, the headway would be 7 seconds resulting in a separation of 500 feet between buses. This separation should provide adequate braking distance for emergency stops. However, it should be pointed out that the above example merely shows the theoretical capacity of a bus lane with an uninterrupted and continuous flow of buses through a long segment of the busway without station stops. The operations of a large number of buses through an on-line station poses many problems and requires a detailed analysis of facility requirements.

1. Station Requirements

Based on the modal split and transit assignment computer models, it is projected that by 1995, the highest volume stations located in the CBD and Waikiki would have some 13,000 passengers boarding and alighting, in one direction, during the peak hour period. It is estimated that during this peak period, approximately 300 buses per hour will be operating in one direction, through the CBD station. Assuming equal loading on the buses, some 40-45 passengers per bus will be either boarding or alighting at this station. If each passenger takes 2 seconds to either board or alight, the dwell time in the station for the bus would be between 80 to 90 seconds.

In the analysis of busway station requirements, 2 seconds per passenger for either boarding or alighting from the buses was used in calculating the number of bus stalls required at each station. The two seconds per passenger not only reflects the time it would actually take the average passenger to board or alight from the bus, but also accounts for the manual operation of the doors for the buses. It is assumed that about seven seconds are required to dock one bus after the first has departed due to the large number of buses which are trying to operate in the station area.[18/]

At the CBD station, with 300 buses per hour being equivalent to a 12 second headway and the average dwell time and docking time being between 87-97 seconds per bus, theoretically a minimum of 8 bus stalls would be required. This theoretical minimum number of platforms does not make provision for the requirement that all buses must be assigned to specific platforms and thus preclude random parking at any available platform. Since all buses leaving the CBD or any other station will not be destined to the same location, specific platform assignment for each of the bus routes will be required. The number of additional platforms required to allow for this is a function of the number of different bus routes and the distribution of passenger volumes. To maintain flexibility in scheduling of buses in the future, a significant number of additional platforms would be required.

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It is also reasonable to assume that certain express buses may be carrying a full load of passengers mostly destined to a particular station. These buses could then require as long as 1.5 to 2 minutes to discharge the passengers. There may also be some instances when a number of the local buses will load and unload more than 45 passengers at a station, and thereby requiring a dwell time in excess of 90 seconds. In order to prevent excessive schedule delays in the system operation, there must be enough bus stalls to handle these unusual situations of longer than normal dwell time by a number of buses, thus constraining the free flow of other buses. Further, due to manual operations, all buses will not be able to maintain precise headways and will therefore create additional delays in the schedule. To ensure a relative free flow of buses and provide flexibility in the scheduling of buses in the future, a safety factor of 2 was used. Therefore, at the CBD station the theoretical requirement of 8 bus stalls would be doubled to 16 bus stalls to account for the safety factor.

These 16 bus stalls are required based on the 1995 on-and-off volumes at the CBD station. Generally, fixed facilities of this type should be sized for anticipated volumes beyond a 15 year period. Thus, to provide adequate facilities to handle volumes beyond 1995, an increase of 1/3 the number of bus stalls would be provided. Therefore, a total of 22 bus stalls would be provided at the CBD station. In order to keep the bus stations at a reasonable size and to minimize the number of escalators, double-stall bus platforms are proposed. Therefore, at the high volume CBD station, 11 platforms in one direction would be required or a total of 22 platforms for both directions.

To provide a comparable level in quality of service and facilities as the other alternative concepts, the station facilities on the busway will be provided with escalators, elevators, and stairs for vertical circulation between ground, concourse and platform levels, fare collection equipment to expedite the loading and unloading of buses to minimize dwell times, closed-circuit television surveillance, and other comparable passenger safety and convenience features. Similar quality of architectural finishes, landscaping, and other environmental considerations have also been applied to the system facilities.

2. Roadway Requirements

A high volume busway must be provided with proper roadway facility to accommodate manually operated vehicles with a minimum of interruptions and delays. Acceleration and deceleration lanes should be provided at high volume stations to provide operational flexibility. An added lane for deceleration would provide 2 lanes from each direction entering the stations and thus permit through buses to by-pass stations without delay. It would also provide the flexibility of permitting queuing of buses on one of the two lanes entering the stations, if necessary, and still permit other buses to dock. Similarly, the additional acceleration lane would permit almost simultaneous departure of 2 buses and thus improve the operating capability of the system.

On most of the system length, the line volumes are sufficiently high, with closely spaced stations of approximately 1/2 mile apart, to require the roadway width to remain at 4 equivalent lanes between stations. With 4 lanes, the roadway would permit buses to move freely in both directions even with a stalled vehicle on the busway.

Beyond the acceleration and deceleration lanes, in segments where the line volumes are low, the minimum roadway width requirement would be 2 lanes. The 2 lane segments would be provided with sufficient shoulder widths to permit 2 way traffic to continue at reduced speed with a disabled vehicle on the busway.

3. Ancillary Facilities

a. Communication Facilities

A radio communication system will be provided between stations, bus drivers, and the central control to aid in traffic control on the busway.

b. Maintenance and Storage Facilities

Under the short-range bus improvement program, 2 new storage and maintenance facilities are being implemented to accommodate a total of 500 buses. By 1995, 2 additional 250 bus storage and maintenance facilities would be required to accommodate the bus fleet required by the busway transit system to meet transit demand.

E. CONCEPT ANALYSES

1. General

Within this section will be presented the findings of the busway system patronage analysis and the subsequent development of the actual busway operating plan including routes, vehicle requirements, vehicle miles, costs and benefits, and other pertinent statistical data. Other qualitative factors such as "no-transfer" convenience and community factors were also examined but are discussed in the next chapter. The findings of these quantitative and qualitative analyses will be summarized and presented in the final chapter of this report as part of an overall comparative evaluation of all alternative transit concepts investigated.

2. Patronage Projections

Based on the busway transit network utilized in the computer models, a total of 456,250 passengers would be attracted daily to a busway system and its accompanying feeder bus system in the year 1995. Of this total, 206,640 or 45.3% would be work trips. During the P.M. peak hour in 1995, a total of 78,790 trips would be made on the transit system, of which, 46,050 or 58.4% are work trips.

In terms of the total daily travel on Oahu in 1995, some 13.8% of all trips and approximately 30.7% of all work trips would be made by transit. During the P.M. peak hour a total of 21.4% of all trips and 42.4% of all work trips would be diverted to the transit system. Approximately 27.8% of all daily trips carried by the transit system originate in areas outside of urban Honolulu which are basically served by a system of local and express buses.

The patronage analysis is summarized in Table VI-3. A summary of selected trip characteristics such as total passenger hours, miles, average trip distance and average trip speed is presented in Table VI-4.

3. Operations Analysis

Based on the projected patronage and specifically the link volumes of the various routes that operate on the busway itself, the operating plan as shown in Figure VI-2 was developed. Based on this operating plan other system operating characteristics such as number of vehicles required during the peak hour, miles of vehicle operation

TABLE VI-3: 1995 PATRONAGE PROJECTIONS
BUSWAY SYSTEM

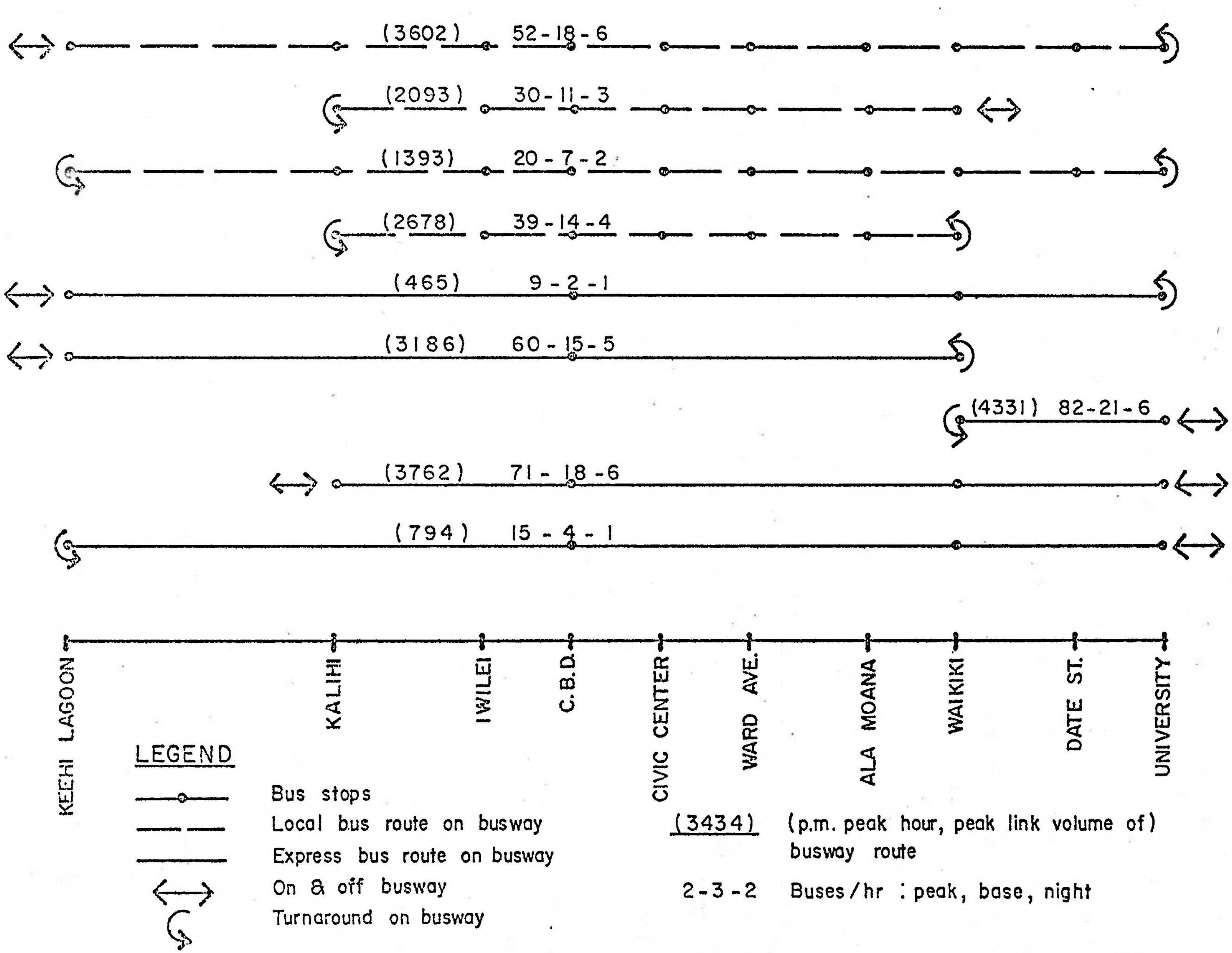
ANALYSIS CATEGORY	TOTAL DAILY	% TOTAL	P.M. PEAK HOUR	% TOTAL
1. TRANSIT PERSON TRIPS	456,250	100.0	78,790	100.0
WORK	206,640	45.3	46,050	58.4
NON-WORK	249,610	54.7	32,740	41.6
2. TRANSIT PERSON TRIPS AS:				
% TOTAL TRIPS	13.8	-	21.4	-
% TOTAL WORK TRIPS	30.7	-	42.4	-
% TOTAL NON-WORK TRIPS	9.5	-	12.6	-
3. TRANSIT TRIPS BY MODE *				
BUSWAY	326,850	-	57,110	-
BUS	554,898	-	97,780	-
4. TRANSIT USE BY AREA				
URBAN HONOLULU	329,540	72.2	56,910	72.2
WINDWARD	64,140	14.1	11,080	14.1
CENTRAL	15,410	3.4	2,660	3.4
LEEWARD	47,160	10.3	8,140	10.3

* INCLUDES INTRA-MODAL TRANSFERS

TABLE VI-4: SELECTED TRIP CHARACTERISTICS - 1995

	DAILY		PEAK HOUR	
CHARACTERISTIC	TOTAL SYSTEM	BUSWAY	TOTAL SYSTEM	BUSWAY
PASSENGER MILES	3,131,331	754,301	576,220	135,446
PASSENGER HOURS	142,361	31,467	25,785	5,911
AVERAGE TRIP TIME (MIN.)	-	-	36.3	-
AVERAGE TRIP LENGTH (MI.)	6.86	2.31	7.31	2.37
AVERAGE TRIP SPEED (MPH)	-	-	12.1	-

FIG. VI-2. BUSWAY OPERATING PLAN



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hours of vehicle operation, and passengers per vehicle mile, were computed. These data are necessary in estimating capital and operating expenses and also as a measure of the efficiency of the system. Table VI-5 presents a summary of selected operational statistics of the buses operating on both the busway and the feeder routes.

TABLE VI-5: SELECTED OPERATING STATISTICS - 1995

STATISTIC	TOTAL SYSTEM	BUSWAY LOCAL	BUSWAY EXPRESS	FEEDER BUS LOCAL	FEEDER BUS EXPRESS
VEHICLE HOURS (DAILY)	7,838	729	616	3,594	2,899
VEHICLE MILES (DAILY)	151,716	14,651	15,657	43,126	78,282
VEHICLES IN PEAK HOUR					
SERVICE	847	81	82	291	393
SPARES	84	8	8	29	39
PASSENGERS/VEHICLE MILE	3.01	-	-	-	-

In determining the vehicles per hour required for each of the routes on the busway, the peak hour, peak link volumes and a load factor of 70 passengers per local bus and 53 passengers per express bus on the busway were used. The combination of these load factors and the distribution of local versus express buses on the busway would provide an average of approximately 60 passengers per bus through the maximum screenline volume link on the busway, which provides a comparable vehicle loading to that used in the analyses of the other alternative systems.

4. Capital And Operating Cost

Table VI-6 shows the total estimated capital cost for the busway system including labor, materials, and equipment. Also included in the estimate is the cost of acquiring the right-of-way and allowances for legal and title fees and for the cost of severance damages and relocation. These costs are based on late 1974 prices. A contingency allowance of 10% of both construction and right-of-way cost is provided for in the cost estimate. An allowance of 13% of the construction cost is assumed for the cost of administration, detailed design and construction management.

Under the feeder bus system, improvements to Kalanianaole Highway from Kahala to Hawaii Kai to accommodate the at-grade, reversible bus lane in an exclusive right-of-way in the middle of the highway has also been included in the cost estimate. Also, the vehicle requirements to accommodate the 1995 travel demand on both the feeder and busway portions of the transit system, has been included in the total capital cost estimate.

The operating costs were based on the total labor and material necessary to maintain and operate the system, including maintenance of the guideway and stations and were expressed in late 1974 prices. The annual operating and maintenance cost based on the 1995 system operation is shown in Table VI-7.

TABLE VI-6: CAPITAL COST ESTIMATE
($ Thousand)

BUSWAY FACILITIES	COST
WAY STRUCTURE	$ 92,850
STATIONS	88,862
COMMUNICATION	1,000
YARD & SHOPS	5,000
SUBTOTAL	$187,712
CONTINGENCY (10%)	18,771
ADMIN. & ENGRG. (13%)	26,843
TOTAL	$233,326
BUSWAY ROW & RELOCATION	
ROW & RELOCATION	$ 83,380
CONTINGENCY (10%)	8,338
ADMIN. (3%)	2,752
TOTAL	$ 94,470
FEEDER BUS SYSTEM	
KALANIANAOLE HWY IMPVMTS	$ 26,100
BUSES	60,515
TOTAL	$ 86,615
GRAND TOTAL	$414,411

TABLE VI-7: ANNUAL OPERATING AND MAINTENANCE COST
($ Thousand)

BUSWAY FACILITIES	COST
WAY & STRUCTURE	$ 986
STATION OPERATION	846
GENERAL & ADMIN.	78
STATION POWER	490
SUBTOTAL	$ 2,400
CONTINGENCY (10%)	240
TOTAL	$ 2,640
TRANSPORTATION	$40,073
GRAND TOTAL	$42,713

5. Other Analyses

The principal difference between the busway concept and other concepts is in the vehicle or more specifically in the propulsion unit. Guided systems normally use electric motors while the buses are powered by conventional diesel engines. One of the primary reasons for the difference between concepts in terms of technical, environmental and community factors, relate to the propulsion unit.

Diesel engines are inherently noisier than electric motors and thereby are more intrusive to communities along the transit route. Buses are also a major source of air pollutant emission which is especially critical in the downtown area where pollution concentration is normally very high. It is also a major source of cost, to properly ventilate underground facilities including the tunnel and stations.

The single unit operation of buses as compared to trained unit operation of guideway systems is another source of difference. In trained units, a motor may not perform up to par but the other units can "pick-up the slack" and continue operation. In a single unit operation, a vehicle that stops will block the roadway until cleared and this requires a wider structure to provide for a by-pass lane. In the stations, the single unit operation requires more space for the docking area which results in a much larger station size than the guideway station.
The larger roadway and station structure causes greater visual intrusion, requires more right-of-way which results in more displacement of residents and businesses, and is generally more disruptive to communities. Further analysis of the busway for the various factors are more appropriately covered in the later chapter where comparisons can be made between the alternatives.

VII. THE LIGHT RAIL TRANSIT CONCEPT

A. GENERAL

The Light Rail Transit (LRT) has its genesis in the President's Conference Committee (PCC) vehicle developed in the early 1930's. It is the result of a joint development program by the U.S. Department of Transportation and the Cities of San Francisco and Boston, both of which still operate PCC cars in transit service.

Basic objectives of the LRT program include development of a vehicle technology incorporating proven components and applicable to medium volume demands between conventional bus operations and full scale rapid transit such as the Bay Area Rapid Transit (BART) system. Another objective was the flexibility to operate on non-exclusive rights-of-way such as city streets and also offer trained operation on exclusive rights-of-way. These attributes of the LRT offer increased application potential for the system.

1. System Applications

Initial application for this system will be in San Francisco and Boston. In San Francisco, existing street rail operation on 5 lines using PCC cars is to be up-graded to accept the new LRT vehicles. In several instances, the rail bed is being completely rebuilt together with street improvements including passenger loading islands, new street illumination, traffic signal modifications, new trolley poles and underground distribution.

The new system in San Francisco also utilizes the operational flexibility offered by this concept. The service plan will entail street operation in mixed traffic as well as subway operation in Market Street. It will also involve both in-service consist changes at branches and merging of branches to produce a minimum headway of 2 minutes and maximum of 4 minutes. Because several of the improvement projects have already received bids and the fact that the San Francisco system employs the full range of flexibility offered by the LRT concept, much of the basic data used to develop the LRT alternative in Honolulu has been derived from data on that system.

In addition to San Francisco and Boston, several other cities or regions including Dayton, Ohio, Austin, Texas, and Portland, Oregon are or have been analyzing the system for potential application. In addition, several cities including Cleveland (Shaker Heights), Philadelphia, Newark, and Pittsburgh have lines with light rail characteristics but using out-moded equipment. In Europe, light rail applications are common.

2. Positive and Negative Features

As in any general purpose system designed to cover a broad range of applications, some compromises are inherent in the design. As a result, some features incorporated to provide flexibility may be redundant or introduce some negative features for specific application. Some of the more important features of the vehicle system are described below.

Feature	Positive	Negative
Articulation	Vital for on street operation of car with this length; permits short radius curves in street rights-of-way.	Redundant for most grade separated applications although short radius permits alignment flexibility in tight rights-of-way.
Pantograph power pick-up	Essential for street operation in non-exclusive ROW to prevent contact with power rail.	Requires added overhead structure in exclusive at-grade ROW and in aerial configuration. Some adverse aesthetic impact.

Feature	Positive	Negative
Narrow width	Important for street operation.	Reduces aisle width and limits seat width in exclusive ROW application.
All cars double-ended	Permits single car operation.	Produces some redundancy in trained operation and precludes use of "A" & "B" cars to reduce control system costs, also precludes walk-through of trained vehicles.
Trainability	Permits flexibility in routing and capacity.	Current 4-car maximum train limits capacity in grade separated or exclusive ROW. (Modest redesign may expand capability).

In general, none of the necessary compromises in this vehicle system produce significant negative aspects. Also, modest redesign of selected vehicle components can permit tailoring the vehicle to more specific applications within the basic system concept. In fact, although the 71 foot articulated car will constitute the initial order, the manufacturer's literature proposes a "family" of light rail vehicles including both articulated and non-articulated concepts. This will expand the ability to tailor a more or less standardized vehicle concept to specific application.

3. Application to Honolulu

While this "family" of vehicles may ultimately be produced, the current articulated vehicle has been used in the alternative system evaluation for Honolulu since it offers a distinctly different operating concept. Other alternatives focused on an all-bus with busway system with variations in operating approach and a fixed guideway system supported by bus feeders. Introduction of the LRT concept permits combining both approaches where appropriate by taking advantage of the LRT ability to operate both in mixed traffic and as a rapid transit fixed guideway system.

However, some features of the current vehicle were not retained as limiting elements. For example, the current 4-car limit in train consist would have severely limited capacity at comparable quality of service with respect to the other alternatives tested or else required multiple lines in the primary corridor. Therefore, it was assumed that modest redesign of limiting elements would permit expansion to longer trains. Other limitations and assumptions relative to a Honolulu application of LRT will be discussed in subsequent sections as appropriate.

B. VEHICLE DESCRIPTION AND OPERATING CHARACTERISTICS

The LRT is an electrically powered vehicle system with power pickup through a pantograph from an overhead trolley wire. The cars are articulated to afford short-radius turn capability necessary for on-street operation. Pertinent physical and performance specifications are shown in the following table. Data shown is for the San Francisco MUNI configuration [20]. Features such as seating, air conditioning, signal and control systems and other ancillary features may be adapted to individual applications.

CAR BODY -

Length	71'-0" (over anticlimbers)
Width	8'-10"
Height	11'-6" (top of rail to locked down pantograph)
Overhead Contact Wire Range	12' to 19'
Weight (empty)	69,000 pounds
Weight (normal load)	84,500 pounds
Weight (crush load)	102,945 pounds

SEATING -

Number	68
Minimum Seat Width	34" (double seat)
Minimum Seat Spacing	29"
Minimum Aisle Width	29"

PERFORMANCE -

Acceleration (nominal)	2.8 MPHPS
Time - 0 to 50 mph	37 seconds (normal load)
Max. Service Speed	55 MPH
Braking (Service)	3.5 MPHPS (crush load)
Braking (Emergency)	6.0 MPHPS

TRUCKS AND TRACK -

Gauge	4'-8-1/2"
Min. Horizontal Radius	42' (to track ℄)
Min. Vertical Curve (crest)	310'
Min. Vertical Curve (sag)	460'
Maximum Grade	9%
Maximum Superelevation	6"

TRAINING -

Min. Train	1 car
Max. Train (Service)	4 cars
Max. Train (Emergency)	8 cars

POWER COLLECTION -

Single arm pantograph, spring raised pneumatic lowering.

CONTROL -

Manual with block signal system, cab signal display, automatic stop and speed control.

VEHICLE CAPACITIES -

Seated Load	68 passengers
Normal (schedule) Load	100 passengers
Crush Load	(See following discussion)

1. System Capacity

Two factors make up system capacity; vehicle capacity (and train capacity) and headways. With respect to vehicle capacity, published literature on the LRT system indicates the following capacities for the present articulated vehicle (MUNI configuration).

Seated Load	68	
Normal Load	100	(147% load factor)
Crush Load	219	(322% load factor)

These data would imply that under maximum conditions the LRT would have a capacity at 2 minute headways in excess of 6000 passengers per hour for a single car and over 24,000 per hour for a 4 car train. However, some added examination of these values for reasonableness should be made.

For this evaluation, floor areas available for standees were first tabulated for both "normal" and "crush" conditions. It was assumed that under normal conditions, door passageways would not be occupied by standees. All these spaces were, however, included in crush-load floor areas.

Floor areas and computations for space available to standees at rated capacities are summarized below:

NORMAL LOAD FLOOR AREA	AREA PER STANDING PASSENGER	CRUSH LOAD FLOOR AREA	AREA PER STANDING PASSENGER
173.42 sq. ft.	5.42 sq. ft.	234.99 sq. ft.	1.56 sq. ft.

As can be seen from the space per standee values, the rated normal load represents a reasonable value. However, the rated "crush" load represents an "always room for one more" philosophy and should not be considered for a high quality system.

For purposes of this analysis, and to provide an equal quality service, per passenger space allocation equal to those used in other system concepts will be used. Table VII-1 presents the resulting vehicle capacities based on total floor area of the car including space occupied by seats since variations in seat arrangement can materially influence vehicle capacity.

TABLE VII-1: VEHICLE CAPACITIES

	FIXED GUIDEWAY		LRT	
LOAD CONDITION	SQ. FEET/ PASSENGER*	CAPACITY	SQ. FEET/ PASSENGER*	CAPACITY
SEATED	9.14	36	6.75	68
NORMAL (DESIGN)	4.57	72	4.57	100
CRUSH	2.99	110	2.99	154

* Total effective floor area for fixed guideway vehicle = 329 sq. ft. and for LRT = 459 sq. ft. Passenger capacity for LRT calculated by dividing total effective floor area by sq. ft./pass. equivalent to fixed guideway allowances.

As can be seen from the above table, the normal load determined from the fixed guideway vehicle is equivalent to that stated in the LRT literature, however, the crush load is a more realistic value. In any event, the normal load capacity should be used for design purposes since basing system capacity on crush conditions is not consistent with improved quality of transit operation.

2. Headways

The other capacity factor, headway, is determined by several variables including maximum dwell time, stopping distance, etc. In the case of the LRT system with block signal and speed control coupled with manual operation and cab signals, headways in the 90 to 120 second range should be acceptable at the projected operating speeds. However, where in-service consist changes and/or surface operations are contemplated, another area of uncertainty must be considered.

In the case of San Francisco Municipal Railway (MUNI) where 5 branch lines will be merged into the Market Street subway, changes in train consist are projected to occur at two points in the branches where headways are four minutes. The resulting two branches are then projected to merge at the entrance to the subway to produce two minute headways but train consist will remain the same. This proposed operational plan is still under analysis and information on which to assure workability has not yet been released. Some problem areas are however, apparent.

One area of uncertainty results from the on-street operations where traffic problems could delay the arrival of a car intended to be added to a train. This could have serious consequences on down-stream scheduled headway maintenance and also produce back-up on up-stream trains at close headways. This leads to an obviously desired condition where branch lines are held to a minimum and will place a limitation or minimum headways in order to permit the coupling operation.

With respect to surface operation in mixed traffic, headways of two minutes or less should pose no problems because of the low speeds involved. For operation at-grade in exclusive rights-of-way in street or highway medians however, another factor must be considered. This method of operation is anticipated in both Kalanianaole and Kamehameha Highways to minimize capital cost by taking full advantage of LRT flexibility.

In these instances, operating speeds in the range of 35-40 miles per hour are contemplated to make the system reasonably comparable with the posted automobile speed. Both of these highways involve several at-grade intersections where heavy cross or turning traffic movements are required. In these conditions, care must be taken to assure that these traffic movements can be accomplished within the operating headways of the transit system.

To determine the limiting factors in these conditions, a time/space analysis was conducted. The analysis was based on a 35 mph maximum operating speed and diagrams prepared for both 90 and 120 second headways. From this parametric study, it was apparent that the traffic signal cycle at each intersection must coincide or be a multiple of the train headway.

It was also clear that the time available for crossing traffic is a function of the composite headways of trains operating in both directions. At a location where opposing trains are exactly staggered, for example, the effective headway would be 1/2 the train headway. With 2 minute headways, this would produce an effective headway of 60 seconds. Allowing reasonable clearance times and safety margins, headways in this range will definitely limit cross traffic capacity.

Based on this analysis, it appears that a 120 second headway is a reasonable minimum for the Kalanianaole Highway section. Any headway less than 120 seconds would severely hamper the flow of traffic either crossing or turning left unto the highway. To insure safe operation, all traffic signals are assumed to be interlocked with train detection and that crossing semaphores and flashing lights will be installed at track-side in addition to standard traffic signals at each intersection.

On this basis, 2 minutes has been set as a minimum safe headway throughout the system. This also assumes that the change in train consist at branch lines can be made in that time. It also does not permit merges except by train consist changes since 60 second headways would produce a serious speed reduction on the grade separated sections and could also produce unstable operations with minor variation in dwell time.

C. NETWORK DESIGN

1. Primary Corridor

The definition of a test network employing LRT in Honolulu requires some initial evaluation of the potential service areas. Chapter IV of this report describes the basis for selection of the primary service corridor for the City.

While the dominant primary corridor is readily apparent, it is also apparent that some important secondary corridors cannot be directly linked because of location or physical constraints. For example, the length of Waikiki and its location at the edge of the corridor are such that direct service is difficult without missing several other important service areas. At the same time, the intensity of development as both an origin and destination point result in a heavy travel demand.

Similarly, the growing residential development around Salt Lake, north of the airport, is somewhat isolated by topography and adjacent land uses. The number of residential units in this area and the limited ingress/egress points produce a fairly concentrated traffic condition at those points.

Another secondary corridor reflects the off-line location of the military complexes associated with Pearl Harbor and Hickam Field. This corridor may be defined by the "Y" formed by Nimitz Highway and Kamehameha Highway just west of the airport.

Other smaller corridors are produced by the fingers of development extending northerly into the mountains along the entire length of the corridor. However, with the exception of Manoa and Nuuanu Valleys, these corridors are very short with steep grades and very narrow streets.

Other important or major secondary corridors are of a more regional nature. These include access to the Windward district via Pali and Likelike Highways, the Central district via H-2 and the developments toward Ewa Beach and beyond in the Leeward district. These are discussed in their regional context in earlier sections of this report.

2. Route and Network Configuration

In defining the test network and route configurations for the LRT alternative, a major effort has been made to maximize the flexibility opportunities inherent in the concept to extend direct service to secondary corridors through use of the at-grade potential and in-service change in train consist. At the same time, care was exercised to assure that the final network was reasonably cost-effective so as not to bias the evaluation. These trade-offs imply an optimizing process in network development.

3. Limitations of Train Length In Mixed Traffic Operations

Because of the necessity for access to street frontage for at least drop-off and pick-up if not curb parking, it will be necessary to operate the LRT cars in the center lanes under on-street operation. Early street car operations often did not provide passenger islands for loading and unloading operations. However, this method of operations, particularly in Honolulu with narrow streets and high passenger volumes, produces an unsafe condition and any new system should provide load/unload islands for passenger safety.

This requirement, combined with vehicle length, will produce a limitation on train length under on-street operation. The LRT is approximately 71 feet long with three doors per side. Thus, a loading platform must be approximately 60 feet for a single car operation and 120-140 ft. for two car operation. Recognizing that many block faces in Waikiki and urban Honolulu are in the range of only 200 feet, this clearly dictates a maximum train length of 2 cars and even that length will produce some limiting of driveway access to parking lots, business establishments and residential locations if passenger loading islands are provided.

However, in this project, as in any other involving a wide range of potential alternatives, it was not feasible to conduct full scale network and model simulation of all possible combinations in an effort to achieve the optimized solution. Therefore, a set of parametric guidelines were established to provide a reasonable basis on which to define the extent of the network. These guide lines included:

- Corridor volume necessary to justify the cost of LRT as a surface replacement for buses.

- Limitations of at-grade mixed traffic application.
- Minimum headway in at-grade exclusive right-of-way operation.

The last two items above have been discussed in the previous section on operating characteristics. The question of corridor volume relates directly to the cost-effectiveness of one mode versus another. In this case, this evaluation was made to determine where it would be reasonable to replace surface feeder buses with LRT branch lines or corridor extensions in mixed traffic.

To conduct the analysis, several assumptions were necessary:

- Schedule speed in mixed traffic was set at 12 mph for both bus & LRT since general traffic flow will govern and stops per mile can be considered about equal.
- Vehicle capacities: bus - 60; LRT - 100
- Operating Cost: Bus - $1.33 per vehicle mile; LRT - $1.48 per vehicle mile.
- Vehicles/hour determined to match passenger demand for both bus and LRT.
- Annual car miles per vehicle constant for both bus and LRT since vehicle requirements based on demand volume.

- Construction cost for at-grade LRT estimated to be $2.4 million per mile without wayside signals.
- Vehicle costs (current cost) bus-$65,000 each; LRT-$400,000 each.
- Expected life: Bus - 10 years; LRT-30 years; Fixed Facilities (trackage) - 50 years.
- Interest rate 7%.
- Annualized costs based on capital recovery method.

Using these assumptions and holding all speed constant at 12 mph for each demand level, it was determined that a line volume of approximately 9,000 passengers per hour was necessary to produce a more economical operation with the LRT system. However, in actual operating conditions, bus operations will be more seriously impacted by high volume demand than will the LRT. For example, at 9,000 passengers per hour, approximately 150 buses per hour would be required or a headway of 24 seconds. Also, at these volumes, boarding and alighting movements will also be heavy and dwell times relatively long. Under these conditions, a 12-mile per hour operation is unlikely unless exclusive bus lanes and multiple bus positions are provided at each stop. In the case of the LRT, 9000 passengers per hour will require only 90 vehicles per hour or 80 second headways with two car trains. This headway is more attainable without speed reduction.

Therefore, it is reasonable to assume that the cross-over point will be less than the 9,000 per hour volume indicated in this analysis but will be in excess of 4,000 where bus headways in the range of 55 seconds are more reasonable. On this basis, any corridor with patronage projections in excess of 5,000 passengers per hour were considered candidates for LRT replacement for buses. It should be pointed out that this analysis does not consider other non-economic values such as noise, air quality, aesthetics, etc., which may have added value in selecting one mode over another.

To gain insight into probable cost effective LRT branches, patronage estimates from fixed guideway and busway networks were used and compared to the demand volume criteria. On this basis, extension of the basic corridor from Kahala to Hawaii Kai and from Halawa to Pearl City combined with a branch to serve the Waikiki area appeared justifiable.

A second criterion was operability. As indicated earlier, a 2 minute headway had been established as a minimum. It was also shown that multiple branches in a single line could introduce increasing uncertainty and hence should be avoided.

Comparisons of projected maximum link volumes on the busway and fixed guideway systems clearly indicated that the current limit in train length to a 4 car maximum could not accommodate the Honolulu demand. Therefore, it was assumed that a redesign could be accomplished to permit longer trains. Unless this assumption was made, it would have required parallel service routes or crush loading, neither of which would provide comparable conditions with competing alternatives.

With respect to vertical alignment, a cursory examination of the central urban area volumes clearly shows a requirement for full grade separation. The capacity constraint imposed by two car trains coupled with severe speed limitation imposed by on-street operation indicate that this is an unacceptable configuration in the denser areas of Honolulu. For example, in San Francisco, present rail operations using P. C. C. cars in surface operation average less than 10 mph for end to end travel with one line averaging less than 8 mph. In Honolulu, an average speed comparable to that of a bus could be expected or about 11 to 12 miles per hour. A speed this low is likely to produce a significant patronage reduction and the added cost for the LRT would be of questionable value.

The resulting LRT network is shown in Figure VII-1. The segment between Halawa and Kahala stations is projected to be on grade

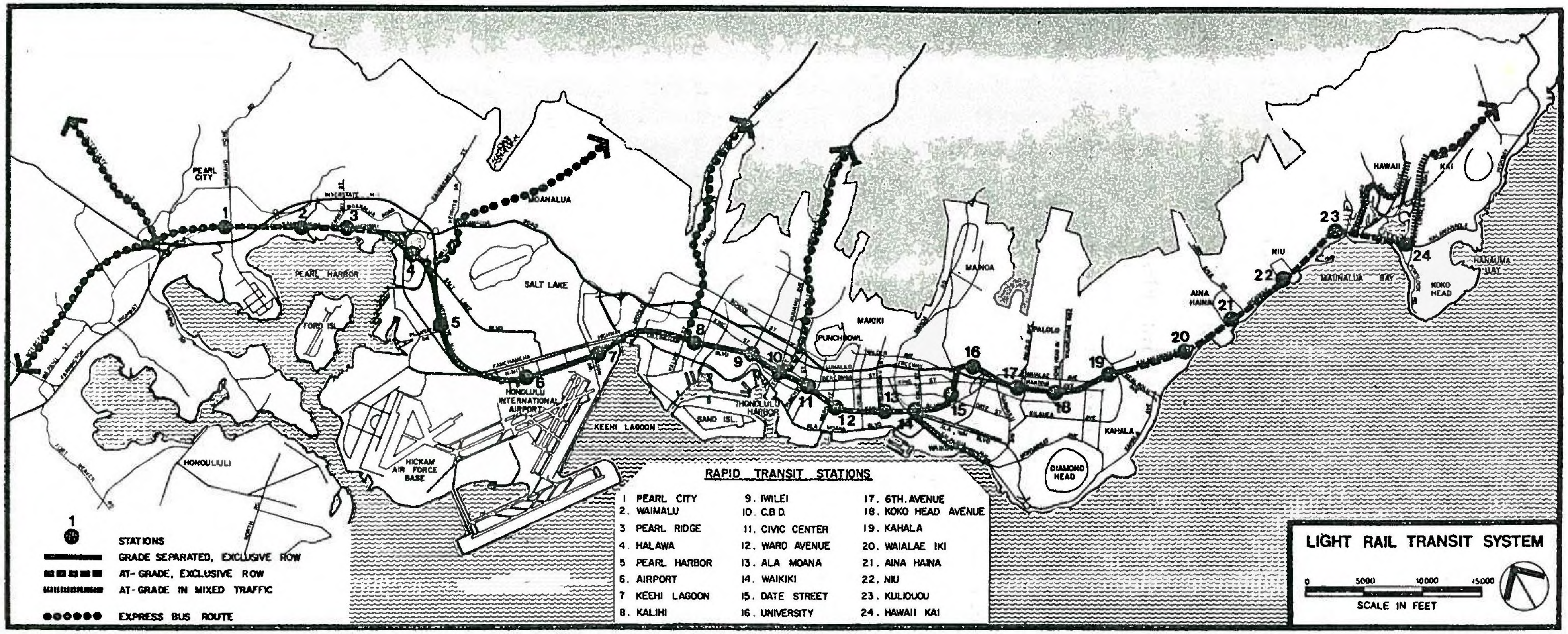

LIGHT RAIL TRANSIT SYSTEM
0 5000 10000 15000
SCALE IN FEET
RAPID TRANSIT STATIONS
1 PEARL CITY
2. WAIMALU
3 PEARL RIDGE
4. HALAWA
5 PEARL HARBOR
6. AIRPORT
7 KEEHI LAGOON
8. KALIHI
9. IWILEI
10. C.B.D.
11. CIVIC CENTER
12. WARD AVENUE
13. ALA MOANA
14. WAIKIKI
15. DATE STREET
16. UNIVERSITY
17. 6TH. AVENUE
18. KOKO HEAD AVENUE
19. KAHALA
20. WAIALAE IKI
21. AINA HAINA
22. NIU
23. KULIOUOU
24. HAWAII KAI
STATIONS
GRADE SEPARATED, EXCLUSIVE ROW
AT-GRADE, EXCLUSIVE ROW
AT-GRADE IN MIXED TRAFFIC
EXPRESS BUS ROUTE
PEARL CITY
PEARL HARBOR
FORD ISL.
HONOULIULI
HICKAM AIR FORCE BASE
HONOLULU INTERNATIONAL AIRPORT
SALT LAKE
MOANALUA
KEEHI LAGOON
SAND ISL.
HONOLULU HARBOR
PUNCHBOWL
MAKIKI
MANOA
PALOLO
KAHALA
DIAMOND HEAD
AINA HAINA
NIU
MAUNALUA BAY
HAWAII
KAI
KOKO HEAD
HANAUMA BAY

FIGURE VII-1

separated right-of-way with the segment through the CBD in subway. The Waikiki branch is projected to be surface operation in mixed traffic as are the legs into Hawaii Kai. The portions in Kamehameha Highway and Kalanianaole Highway are projected to be surface operation in exclusive rights-of-way. On these exclusive right-of-way segments, traffic signal interlocks, vehicle detection and crossing signals are assumed at each intersection. In addition, New Jersey barriers are assumed on each side of the right-of-way to preclude incursion into the transit lanes.

The network includes 24 stations in the exclusive right-of-way section between Pearl City and Hawaii Kai. Branch lines in Waikiki and Hawaii Kai are projected to use passenger loading islands spaced at approximately 800 feet. Station dwell time was set at 20 seconds.

As in any trunkline system, a comprehensive bus feeder system is required. The system for the LRT network is essentially the same as that used in the 23 mile fixed guideway network except that buses have been eliminated in Waikiki and Hawaii Kai due to the surface operation of the LRT.

Service characteristics for the LRT network are summarized in the Table VII-2.

TABLE VII-2: LRT NETWORK SERVICE CHARACTERISTICS

CHARACTERISTIC	PEAK	BASE	NIGHT
FREQUENCY (ALL LINES)	2 Min.	4 Min.	4 Min. *
TRAIN LENGTH **	2 To 8 Cars	1 To 6 Cars 2/	1 To 2
SCHEDULE SPEED (MPH)	On-street-12	Same	Same
	Exclusive-29	Same	Same
MAX. SPEED (MPH)	50	50	50
SCHEDULED LOAD/CAR	100	68	68

* Night frequency on Hawaii Kai branches becomes 8 minutes by alternating service on each leg with one-car train.

** Assumes cars are added or dropped from trains to serve branches and at turn-backs. Minimum shown indicates minimum no. of cars on any leg. At-grade street operation may require higher loading due to two-car limit on train length. On exclusive sections, projected demand at scheduled load determines train length.

D. SYSTEM DESCRIPTION

The system description is based on the San Francisco Municipal Railway application of the light rail vehicle and the roadbed used there for street operations. Exclusive sections of the guideway and stations reflect Honolulu requirements with respect to aesthetic design and climate as well as the rights-of-way circumstances anticipated to produce a safe operation.

The guideway, stations, control and any special features are described in detail in the following subsections.

1. Guideways

Guideways for the LRT system will include:

- Aerial Structure
- Subway
- At-grade In Exclusive Rights-of-way
- At-grade In Mixed Traffic

Aerial structures will use precast, prestressed concrete girders supported on single reinforced concrete columns with spread footing or pile foundations. Noise barriers will be placed at the outer edges of the structure to minimize noise propagation into the adjacent community. Overhead trolley wires will be supported over each track from a "T" support located at the center of the guideways. Total width of the aerial structure will be 23' to the outside of the noise barriers with rails at 12'-6" centers to accommodate clearance of the dynamic envelope plus a reasonable margin from the center trolley support. Rail will be mounted directly on the concrete girders with appropriate leveling and isolation provisions at each rail anchorage.

All horizontal curves will be superelevated and spiral transitions will be provided. Parabolic vertical curves will be used to minimize vertical accelerations. Design conditions for maximum speed and passenger comfort will be based on association of American Railroads standards. These conditions and considerations will be applied to all grade separated and exclusive rights-of-way. Geometric considerations for on-street alignments will be dictated by street configuration and appropriate vehicle capabilities as defined in the vehicle description.

Subway structure will be double box construction using cut and cover procedures. Height of the box structure will be a minimum 13'-6" above top of rail to allow the trolley wire to be supported directly from the soffit. Emergency walkways 2 feet wide will be provided at each side of the subway section. The double box structure will be 13 feet inside dimension for each box. Ventilation will be by piston effect of trains passing through the tubes with appropriately spaced vent shafts at each station and at intermediate locations. Emergency exhaust fans will be provided in vent shafts. Rails will be mounted directly to the concrete floor slab with appropriate isolation as in the aerial structure.

At-grade structure for exclusive operation in the median of the highways will be conventional tie and ballast construction in a minimum right-of-way of 24 feet. Overhead trolley wire will be supported from "T" structures as in aerial alignments. To minimize added width, traffic barriers will be used along all sections of at-grade, exclusive alignment for safety of operation.

At-grade street structure will also be tie and ballast construction but will be flush-paved with Portland cement concrete to permit joint use with other traffic. Rails will be set at 11'-1/2" centers within a total right-of-way of 23'-6". The rail right-of-way section will be raised 3" above the adjacent traffic lanes and white mountable curbs will define the right-of-way. Overhead trolley wires will be suspended over each track from trolley poles set at each curb to minimize in-street obstructions.

2. <u>Station Facilities</u>

Station facilities will also include four general types: aerial, subway, at-grade in exclusive right-of-way, and at-grade in mixed traffic.

The subway and aerial stations will be similar to those used in the fixed guideway alternative except that platform length will be dictated by the maximum train expected at each station. This will produce somewhat longer stations in the subway section and in the aerial section from the Waikiki station to the Halawa station. All stations will provide stairs, escalators and an elevator for vertical circulation between ground, concourse and platform levels. Ticketing, money-changers, waiting areas, etc. will be associated with the station concourse. Stations will have side or center platforms as dictated by right-of-way and operational requirements at specific locations.

Stations in the at-grade exclusive right-of-way segments will have a minimum concourse over the platforms connected by pedestrian bridges to the abutting highway frontage. As in the case of other exclusive right-of-way stations, stairs, escalators and elevators will be provided for vertical circulation.

Stops in at-grade street operation will be at passenger loading islands adjacent to the rail right-of-way. Islands will be 6'-3" wide and 60 to 130 feet long. Islands will be defined by 6" barrier curbs painted with reflective paint. Pedestrian railings will be installed along the traffic side of the islands to afford increased passenger protection and to channelize pedestrian movements to designated cross-walks. Islands will be lighted but not covered.

3. Vehicles

The vehicle used in the LRT alternative is the United States Standard Light Rail Vehicle manufactured by Boeing and currently on order for San Francisco and Boston. The specifics of the vehicle presented in Section B "Vehicle Description and Operating Characteristics" reflect the current San Francisco specifications.

4. Control and Communication

The control and communication system used with the LRT alternative is a conventional block signal system with way-side control and cab signals. It is essentially an Automatic Train Protection (ATP) system which protects against overspeed or collision regardless of manual operator commands. All other functions are under manual control. This train protection system will be used on all grade separated and exclusive at-grade sections of the alignment. It will not be incorporated on the at-grade street branch lines, operating in mixed traffic. In addition, standard highway traffic control devices will be used at all at-grade crossings in the exclusive right-of way sections of the lines. These traffic control devices will be interlocked with the rail system so that all traffic signals will be coordinated with the train movements.

While actual train operation is in the hands of a train attendant, automatic wheel slip/spin detection and jerk limiting are incorporated in the vehicle design in the interest of passenger safety and comfort.

5. <u>Ancillary Facilities</u>

a. <u>Fare Collection</u>

For grade separated and at-grade exclusive alignments, automated fare collection will be provided in the station areas to expedite loading/unloading and minimize dwell times.

Fare collection in the at-grade street segments will be by on-board fare boxes using the exact-fare system. The combination of exact fare with a flat-fare system will minimize boarding time and hence dwell time.

b. Maintenance and Storage Facilities

As in the fixed guideway alternative, a central maintenance and storage facility is required and located in the industrial area adjacent to Keehi Lagoon.

c. Electrification

Traction power will be 600 volt d. c. distributed to the vehicle by overhead trolley wire and pantograph power pick-up. Negative return will be by conventional methods using the running rails. (This may be expected to produce some electrolysis problems requiring cathodic protection of unknown magnitude). Primary distribution will be underground in duct banks to minimize visual impact. Substations containing transformers, rectifiers, switchgear and other electrical machinery will be in underground vaults or enclosed structures except in industrial locations where an open substation will not produce a negative visual impact.

E. CONCEPT ANALYSES

1. General

This section of the concept description will present the analysis of the system for 1995 in terms of its operations (vehicle requirements, vehicle miles, etc.), patronage, costs and benefits, and other pertinent statistical items. In addition, it will examine those qualitative aspects of the system such as urban impact, implementation staging, environmental sensitivity, etc. The statistical and qualitative analyses will be used in the subsequent chapter to permit a comparative evaluation of all tested alternatives as a basis for a recommendation as to system concept and extent.

2. Patronage Projections

Anticipated patronage is the crucial measure of system performance and effectiveness. From that statistic, system requirements can be set and impacts on other travel facilities determined. In this LRT alternative, a total of 474,520 passengers per day are projected by 1995. (See Table VII-3). Of this total 217,710, or 45.9% will be for work purposes. In terms of the critical p.m. peak hour, this system will attract 82,210 trips with 58.9% or 48,430 representing work trips.

Translating these absolute numbers to a percent of regional travel provides a good indicator of overall benefit accruing to the various segments of the population in terms of reduced travel time and cost as well as reduced traffic congestion, air pollution, land and investment required for parking structures, and other factors. In terms of total daily travel, the LRT alternative will attract 14.4% of all trips and 32.3% of all daily trips for work purposes.

TABLE VII-3: 1995 PATRONAGE PROJECTIONS - LRT ALTERNATIVE

ANALYSIS CATEGORY	TOTAL DAILY	% TOTAL	P.M. PEAK HOUR	% TOTAL
1. TRANSIT PERSON TRIPS	474,520	100.0	82,210	100.0
WORK	217,710	45.9	48,430	58.9
NON-WORK	256,810	54.1	33,780	41.1
2. TRANSIT TRIPS AS:				
% TOTAL TRIPS	14.4	-	22.3	-
% TOTAL WORK TRIPS	32.3	-	44.6	-
% TOTAL NON-WORK TRIPS	9.8	-	13.0	-
3. TRANSIT TRIPS BY MODE				
GUIDEWAY	358,750	75.6	65,420	79.6
BUS *	398,060	-	69,469	-
4. TRANSIT USE BY AREA				
URBAN HONOLULU	342,730	72.2	59,380	72.2
WINDWARD	66,710	14.1	11,560	14.1
CENTRAL	16,030	3.4	2,780	3.4
LEEWARD	49,050	10.3	8,490	10.3

* INCLUDES INTRA-MODAL TRANSFERS

Transit generally is most successful in attracting peak hour trips when congestion levels are the greatest. The LRT alternative follows that pattern and will carry a total of 22.3% of all peak hour trips and 44.6% of peak hour work trips.

The relative importance of the various elements of the system are good indicators of cost-effectiveness. In the LRT alternative, 75.6% of all transit trips will use the rail system for all or part of their trip.

The effectiveness of the transit system in servicing outlying areas of Oahu is shown by the fact that 27.8% of all transit patronage originates outside of urban Honolulu. These trips are carried on an express bus system fanning out from urban Honolulu with interface points at the terminal stations on the LRT guideway portion of the system and also in central Honolulu for trans-Pali express routes.

3. Analysis of Trip Characteristics

The level of service and efficiency of the transit system can be assessed by analyzing the trip characteristics in terms of total passenger hours, miles, average trip distance and average trip speed. These data will be used in subsequent comparative evaluations relative to all other alternatives examined. Table VII-4 presents a summary of these statistics for the LRT alternative.

TABLE VII-4: SELECTED TRIP CHARACTERISTICS - 1995

STATISTIC	DAILY TOTAL SYSTEM	DAILY GUIDE-WAYS *	P.M. PEAK HOUR TOTAL SYSTEM	P.M. PEAK HOUR GUIDE-WAYS *
PASSENGER MILES	3,224,748	1,758,631	594,096	333,286
PASSENGER HOURS	131,649	64,774	24,007	12,266
AVERAGE TRIP TIME (MIN.)	-	10.8	32.4	11.2
AVERAGE TRIP LENGTH (MI.)	6.79	4.90	7.22	5.09
AVERAGE SPEED (MPH)	-	27.2	13.4	27.2

* Includes branch lines on street but excludes feeder bus portion of linked trips.

4. Operations Analysis

Based on the projected patronage and specifically the link volumes in the LRT alignments at the specified headways, other system requirements such as numbers of vehicles per train and turnback points may be determined. From these data, various operating statistics such as peak vehicle requirement, miles of vehicle operation, passengers per vehicle mile, vehicle utilization, etc. can be estimated. These data are essential in estimating capital and operating costs and also as measures of system efficiency. Table VII-5 presents some selected statistics on the LRT alternative.

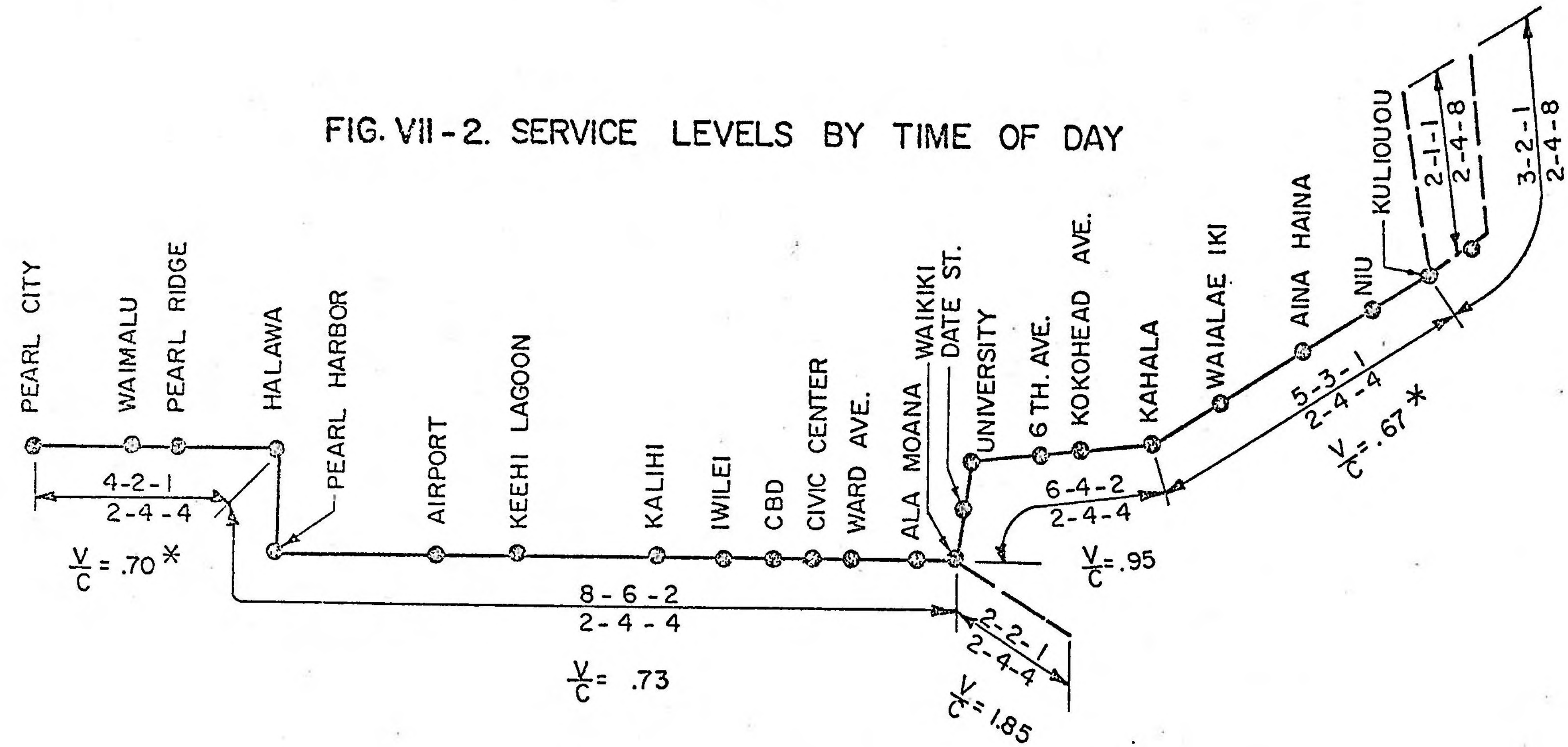
TABLE VII-5: SELECTED OPERATING STATISTICS - 1995

	TOTAL SYSTEM	GUIDE-WAY	BUS	
			LOC.	EXP.
VEHICLE MILES (DAILY)	151,160	79,515	25,920	45,724
VEH. IN PK. HR. SERVICE	776	373	182	221
SPARES	77	37	18	22
PASSENGERS/VEH. MI.	3.14	4.52	-	-

Vehicle capacity has been used to determine the total vehicle requirement shown above based on the link volume on the guideway system and route volume for the bus routes. The link volumes for the LRT route has been translated into train requirements at specified headways as shown in Figure VII-2.

As in all other alternatives, system capacity has been set to reasonably match demand to produce a maximum system efficiency. In this case, the maximum link volume in the Ala Moana to Ward Avenue link of the guideway system would normally become the determining factor. However, because of the almost comparable volume in the Date to Waikiki link, a six car train is required to meet the design standards. This produces an eight car train after the Waikiki junction which in turn reduces the volume/capacity ratio (v/c) at the maximum link to 0.73 or only slightly above a seated load v/c of 0.68. At the same time, the in-street configuration of the Waikiki Branch produces a significant overload because of the two-car train limitation of in-street operation.

FIG. VII-2. SERVICE LEVELS BY TIME OF DAY



LEGEND

⊗	Station name.
8 - 6 - 2 / 2 - 4 - 4	No. cars/train _ Peak, Base, Night / Frequency _ Peak, Base, Night
$\frac{V}{C}$	Peak hour volume/Capacity ratio at maximum link in segment at design load (100 pass/car)
*	$\frac{V}{C}$ ratio of 0.68 represents full seated load.

The Waikiki branch will also result in a very high transfer volume at the Waikiki station since passengers to and from the easterly direction must transfer at this station. Thus, while the branch line demonstrates a very high utilization, it also introduces an operational complexity both from the standpoint of the change in train consist and limited ability to accurately match volume/capacity measures, either side of the Waikiki station. It is clear however, that the resulting system produces a high quality service aside from the Waikiki line. Figure VII-2 presents a diagrammatic layout of the LRT system and shows train lengths, headways and volume/capacity ratios for the maximum link in each segment.

In addition, it is clear that, with the exception of the Waikiki branch, this system has a large reserve capacity to accommodate post 1995 patronage growth. This is an important feature of any system with significant capital investment in fixed facilities. The uncertainties of future gasoline availability and price could have pronounced impact on future transit patronage should the supply condition worsen. This factor alone makes reserve capacity important.

5. Capital and Operating Cost

Table VII-6 shows the total estimated capital cost for the LRT system based on late 1974 price levels for material and labor. The LRT vehicle and feeder bus requirements are based on projected 1995

TABLE VII-6: CAPITAL COST ESTIMATE
($ Thousand)

LRT FACILITIES & EQUIPMENT	COST
WAY STRUCTURE & TRACKS	$146,947
STATIONS	85,429
POWER & CONTROL	49,618
YARD & SHOPS	13,194
VEHICLES	164,000
SUB-TOTAL	$459,188
CONTINGENCY (10%)	45,920
ADMIN. & ENGRG. (13%)	65,665
TOTAL	$570,773
LRT RIGHT-OF-WAY & RELOCATION	
RIGHT-OF-WAY & RELOCATION	$ 59,980
CONTINGENCY (10%)	5,998
ADMIN. (3%)	1,967
TOTAL	$ 67,945
FEEDER BUS SYSTEM	
BUSES	$ 28,795
GRAND TOTAL	$667,513

patronage volumes and included in the total capital cost estimate.

Operating costs for the 1995 system are shown in Table VII-7 also based on 1974 prices. Operating costs are based on total labor and material necessary to maintain and operate the system including maintenance of the guideway and stations.

6. Other Analyses

a. Safety

Several factors enter into a determination of relative safety including passenger accidents boarding or alighting the vehicles, falls on board and miscellaneous operating accidents; accidents involving collisions with other vehicles or stationary objects; and accidents in stations.

Since no actual operation of LRT is available it is necessary to gain some insight into potential accident rates. Statistics from a prior study in San Francisco, which operates PCC street cars in street service showed approximately 12% fewer passenger accidents per million passengers on the street cars than in conventional motor coaches. Since the LRT used in this concept is an improved vehicle it should be expected to be at least equal in terms of passenger accommodation and potential on-board accidents. Similarly the incorporation of jerk limit in vehicle control should also reduce potential

TABLE VII-7: ANNUAL OPERATING & MAINTENANCE COST ESTIMATE
($ Thousand)

ITEM	COST
LRT SYSTEM	
MAINT. OF WAY & STRUCTURES	$ 2,863
VEHICLE MAINTENANCE	3,005
CONDUCTING TRANSPORTATION	4,381
GEN. & ADMINISTRATION	4,193
POWER	6,150
SUBTOTAL	$20,692
CONTINGENCY (10%)	2,069
TOTAL LRT	$22,761
FEEDER BUS SYSTEM	$19,387
TOTAL ANNUAL COST	$42,148

falls on-board. Therefore, it is reasonable to assume that the guideway portion of the concept will be safer than the bus operation.

With respect to vehicle accidents, the grade separated segments of the system should produce a very safe operation, particularly since the control system incorporates train protection. In addition, train operation in these grade separated segments and in the exclusive at-grade sections will incorporate floor height platforms. Passenger boarding and alighting accidents should also be reduced, however, in-station accidents may tend to negate a certain portion of that gain. In this context, the system should be safer than buses and about equal to other rapid transit concepts.

With respect to vehicle accidents on non-grade separated facilities, two conditions in this alternative are relevant. First, in the exclusive at-grade segments in Kamehameha and Kalanianaole Highways, the traffic barriers provided along the right-of-way should produce an operation almost as safe as grade separation. However, the at-grade intersections, even though protected by interlocked signals and train detection, will introduce an accident potential. In the case of in-street operation, the LRT may be expected to offer approximately equal accident potential to a bus system. While "pull-in/ pull out" accidents associated with bus operation at curbside stops are reduced, the physical length of the 2-car train could expand the accident potential at intersections.

In summary, the LRT alternative should produce a high level of transit safety and should fall between a conventional bus service and a totally grade separated fixed guideway system of equivalent length.

b. Reliability and Delay Potential

Two factors are important in terms of reliability and delay potential - probability of in-service vehicular failure and ability of the system to function according to specified service levels.

Road calls are a good indicator of vehicle reliability assuming a high level of preventative maintenance and inspection of the service fleet. Since no operating experience with the LRT is available, the San Francisco PCC cars may provide some measure of reliability. Examination of road calls in a prior study showed incidence of road calls on PCC cars was less than 30% that of standard motor coaches. Assuming a similar measure of preventative maintenance, this ratio certainly implies a more reliable vehicle attributable to both electrical vs. internal combustion propulsion and basic design. It is reasonable to assume that at least equivalent reliability could be expected from the new LRT.

With respect to system operability, any system which incorporates grade separated, exclusive right-of-way for transit operation will perform better and faster than one which isn't. Similarly, the greater the percentage of grade separated, exclusive route vs. non-exclusive route within a given system, the higher the reliability.

c. System Staging on Progressive Introductions

One of the features of the LRT transit system is a potential for a gradual up-grading of transit service as transit demand increases without incurring heavy capital investment from the beginning when the demand is still low.

In theory, a reasonable progression in terms of capacity can be produced leading from the bus systems to LRT in streets to a grade separated operation. This is a logical progression which in many instances may be the best course of action. However, each potential application must be examined on its own merits.

In Honolulu with very high residential concentration and well defined major destination areas, line volumes in the urban core are already high and are projected to be well beyond the capacity of a surface street operation by 1995, unless multiple lines are provided. As described earlier under the network description, Honolulu has a limited number of through streets wide enough to accommodate the street rail lines without significant impact on the general traffic flow. In order to provide a level of service in terms of travel time with any measurable improvement over surface bus operation would also require turn restrictions and possibly closure of cross streets.

In addition, while in-street construction is less costly than any form of grade separation, it is nonetheless a significant cost when compared to bus operation which utilizes existing street and highway system. Therefore, in order to be cost effective in replacing bus service with at-grade LRT application, a reasonable service span would be necessary to amortize the capital cost. This would imply a fairly modest growth potential while the transit system were operating in the 6,000-10,000 passenger per hour demand level. In Honolulu, a more rapid development history has been evidenced which would imply that a change over directly from surface bus operation to a grade separated, exclusive right-of-way system with greater ability to absorb growth might be more appropriate in those corridors where demand volumes are approaching maximum bus capacity.

In general, in Honolulu, the progressive staging does not appear to be a significant advantage for LRT. The combination of limited physical ability to absorb on street trackage, projections of high line volumes in the relatively near future, and the present density and historic growth rate and pattern indicate that potentials for at-grade operation outside Kamehameha and Kalanianaole Highways, where some exclusivity is possible, will have limited applications.

d. Community Factors

There are many community factors involved with development of a new or improved transit system. These relate to development patterns and induced growth, disruption of neighborhoods, noise, air quality, changes in traffic patterns, visual impact and many others. These factors are more appropriately covered in the later chapter where comparisons are made between alternative concepts.

VIII. THE FIXED GUIDEWAY CONCEPT

A. GENERAL

A fixed guideway rapid transit system was analyzed as early as 1966 under the Oahu Transportation Study as previously described. Detailed planning of a similar system was also conducted under the Honolulu Rapid Transit Program completed in late 1972. From these previous studies, transit demand data in the high volume travel corridor of urban Honolulu was available as well as various planning considerations relative to community and environmental factors to form the basis for defining the vehicle type best suited for Honolulu.

Taking into consideration the projected demand volumes, the topographic and geologic conditions, the tropical environment, and the scale or size of the area, the key features of the most desirable vehicle system was defined. In short, the vehicle system defined was a light weight, medium capacity vehicle whose physical and performance features would permit the design of an aesthetically pleasing facility and the operation of the system with the least amount of environmental intrusion. Unlike most urban regions on the Mainland, a high speed system is not needed, and would in fact be detrimental in terms of right-of-way requirement, noise emission, and energy consumption.

The design and operating requirements of the fixed guideway transit concept are well established with a long history of operating experience. The concept is characterized by high capital investment and high passenger carrying capability which lends itself to high volume corridor application. Large rail rapid transit systems are carrying over 50,000 passengers per hour on many systems in the world.

Honolulu's requirements are not quite in the same magnitude as that of most major cities of the world. The demand can be bracketed between 25,000 and 30,000 passengers per hour and maximum vehicle speed of approximately 50 mph would be required. The primary transit corridor is intensively developed and requires extraordinary planning and design considerations in minimizing the obtrusiveness of the system on the various communities through which the system traverses. Based on the above parameters, a medium capacity, medium speed, and light weight vehicle system was defined as being the most desirable. 16/

B. VEHICLE DESCRIPTION & OPERATING CHARACTERISTICS

The fixed guideway concept is defined as a grade separated, exclusive right-of-way system with trained vehicles operated under the traditional transit mode of operation, i.e. all trains stopping at each station. Nearly all fixed guideway systems of the world are either rail or rubber-tired rapid transit. The particular type of fixed guideway system assumed for this study is a medium size, rubber-tired vehicle system. Rubber-tired systems in revenue operation are found in Paris, Montreal, Mexico City, and Sapporo (Japan), which are all high capacity systems 21/. Since the patronage projected for Honolulu is in the medium capacity range of maximum 25,000 to 30,000 passengers per hour and due to various other considerations, a nominal 40-foot long car has been selected.

There shall be two types of cars in daily operation. Each train will be made up of two end cars (A cars), which will contain the automatic train control equipment and space and instruments for the train attendant. If more than two cars are required in a train, middle cars (B cars) would be added between the A cars. The B cars would have no cab for a train attendant although provisions would be made for a plug-in operator console for use in the yards and shops or for emergency operations. The physical and performance features of the vehicle system are as follows:

CAR BODY

Length	A Car - 45'-0"
	B Car - 41'-8"
Width	9'-2"
Height	11'-0"
Weight (empty)	A Car - 32,000 lbs.
	B Car - 29,000 lbs.
Weight (normal load)	A Car - 42,800 lbs.
	B Car - 39,800 lbs.
Weight (crush load)	A Car - 48,500 lbs.
	B Car - 45,500 lbs.

SEATING

Number	36
Minimum Seat Width	19"
Minimum Seat Space	31"
Minimum Aisle Width	27"

PERFORMANCE

Acceleration	3.0 MPHPS
Max. Service Speed	50 MPH
Braking (Service)	2.6 MPHPS
Braking (Emergency)	3.3 MPHPS

TRUCKS & ROADWAY

Gauge	6'-8"
Min. Horizontal Radius	500'
Min. Vertical Curve	100'
Maximum Grade	8%
Maximum Super Elevation	8"

TRAINING

Minimum Train	2 Cars
Max. Train (Service)	10 Cars

CONTROL

Automatic train control system composed of two fully automatic subsystems-automatic train protection and automatic train operation with provisions for future addition of automatic train supervision.

VEHICLE CAPACITIES

Seated Load	36 Passengers
Normal Load (Schedule)	72 Passengers
Crush Load	110 Passengers

Based on the normal vehicle load of 72 passengers, a 10-car train will have a capacity of 720 passengers. With a fully automatic train control system, a minimum headway of 1.5 minutes would provide a line capacity of 28,800 passengers per hour.

C. NETWORK DESIGN

The rapid transit corridor through urban Honolulu was defined in an earlier chapter. Running from Pearl City to Hawaii Kai, this distance of over 20 miles would be served by a fixed guideway route with stations appropriately located to provide the best possible service to various high activity centers. Since the success of the fixed guideway system depends, in large measure, on a dependable and broad coverage feeder system, stations should also be appropriately located to permit effective interfacing with feeder buses. The proposed system route and station locations are shown in Figure VIII-1.

The system network and operation are interrelated and were, therefore, analyzed to determine the best network concept for Honolulu. The feasibility of providing express, skip-stop, and branch line services was studied to determine if any one would be superior to a single line network with conventional transit mode of operation.

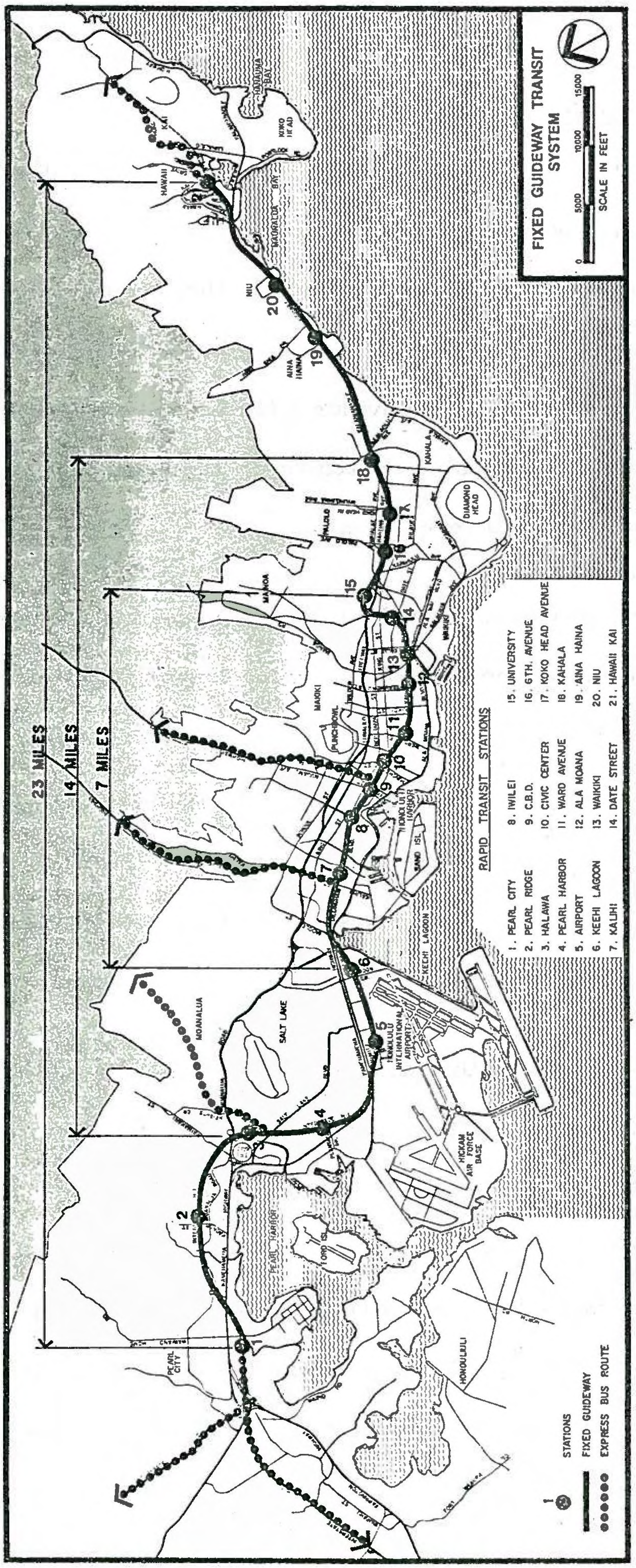


FIGURE VIII-1

1. <u>Alternative Network Analysis</u>

The off-line express service study [14] evaluated the feasibility of providing express service between the Pearl City and CBD stations and between the Hawaii Kai and the University stations, with all trains operating in local service between the CBD and University Stations. The off-line concept provides 4 tracks for stations at selected locations with local trains switching off the main line and giving the right-of-way to express trains.

It was determined that the time savings for patrons using the express service was generally offset by the longer trip time for a larger number of patrons who were not using the express service. Furthermore, the amount of time actually saved by the express patrons was minimal. In an economic analysis evaluating the costs and benefits of the express service, express services with both 1-1/2 and 2 minute total system headways, including local service, were evaluated.

It was concluded that with the 2 minute headway, there was no time savings and that the economic benefits of express service attributable to time savings with the 1-1/2 minute headway was less than 1/3 of the additional capital cost required to provide this service. This combined with the greater environmental impacts on the adjacent neighborhood from the larger 4-track stations made the off-line express concept inferior to the conventional on-line station concept.

Other variations of express service examined were the "skip-stop" and the separate express track concepts. It was determined that time savings with skip-stop were minimal, the concept tended to create greater congestion on station platform, and it limited operating flexibility.

The separate express track concept, utilizing a third track, was also found to be inferior to the conventional on-line station concept. The major advantage of this concept over the previously described off-line concept is that frequent switching of local trains would be eliminated. However, the installation of the third track would be more costly and would result in only slightly greater time savings than the off-line concept.

An examination of the feasibility of providing branch line service to Waikiki, the University, and the Airport determined that construction of guideway lines to these areas would be unwarranted 14/. Due to the relatively small percentage of total transit patrons destined to the University and the Airport, service to these centers would be infrequent, discouraging potential transit users. In addition, branch lines would be very costly to construct and would greatly increase the complexity of train operation with very little or no benefit to the user.

In consideration of the high capital costs of the branch line and the difficulties involved in the operation of the main line, it was also concluded that a branch line to Waikiki was not desirable. Based on the projected distribution of transit users with Waikiki as their origin or destination, every third eastbound train would be diverted to the Waikiki branch line. This results in every 2 of 3 trains remaining on the main line to provide service to areas east of Waikiki. To accommodate the excess demand placed on the system by patrons with trip origin from or destination to areas between Waikiki and Hawaii Kai, shuttle trains will be required to provide the required capacity. Operationally, this scheme is feasible, however, there are certain technical and economic implications.

To economically justify the construction of the branch line, line volumes in excess of 10,000 passengers per hour must be obtained; otherwise, bus operation would be more economical. From the technical aspect, the merging of trains at headways as low as 90 seconds is currently unproven. Therefore, the branch line concept of serving Waikiki was discarded in favor of a single line network configuration with conventional transit mode of operation.

2. Fixed Guideway Routes

The fixed guideway will be routed in subway, at grade, and in aerial configurations through a travel corridor which, as described in previous chapters, connects the major activity centers of Honolulu. Route determination as defined previously, was based on a thorough evaluation of service quality, local community characteristics and needs, relocation requirements, right-of-way acquisitions, and construction costs. The proposed route includes 1.7 miles in subway in the high value and historically significant downtown area, 15.2 miles of aerial alignment located predominantly in public rights-of-way, and 6.3 miles at grade in freeway rights-of-way. The following paragraphs describe the 23-mile route.

Beginning at Pearl City, the fixed guideway is routed in the H-1 Freeway median to the Pearl Harbor Interchange. In this area, the guideway is at-grade, except as it makes transitions to and from aerial stations along this section of the alignment.

As the route extends through the airport area, it leaves the H-1 Freeway and follows Aolele Street in an aerial configuration to Keehi Lagoon Drive. The route then follows the northerly boundary of Keehi Lagoon Park and crosses Nimitz Highway near Middle Street, to Dillingham Boulevard.

The route follows Dillingham Boulevard, through the Kalihi area, with the aerial guideway structures located in the street right-of-way. West of the intersection of Dillingham Boulevard and King Street, the guideway changes from an aerial to an underground alignment.

Through the CBD and Civic Center, the alignment is underground and is located below Hotel Street which is planned for conversion to a pedestrian mall. The route, in underground configuration enters Kapiolani Boulevard, passes Cooke Street and proceeds in a southeasterly direction and changes to an aerial configuration west of Ward Avenue near Waimanu Street.

Through the Kakaako area,, the route which is in aerial configuration, crosses Ward Avenue, follows Waimanu Street, enters and follows Kona Street, and then proceeds to Kalakaua Avenue.

East of Kalakaua Avenue, the route crosses McCully Street and enters Kapiolani Boulevard to University Avenue. It proceeds north on University Avenue, crosses the H-1 Freeway, and then proceeds east along the southerly boundary of the University of Hawaii, Manoa Campus and Old Waialae Road to the intersection west of Waialae Avenue.

The route through the Kaimuki area follows the H-1 Freeway with the guideway in an at-grade configuration in the freeway median. At the end of the H-1 Freeway, the route continues on Kalanianaole Highway, in an aerial configuration to Hawaii Kai.

3. Feeder Bus System

To carry people to and from the guideway stations and to provide public transportation in areas not served directly by the fixed guideway system, a feeder system consisting of express, local and shuttle buses was developed. To develop an adequate service plan, each projected bus route was laid out on an area map, given a service level, and coded as part of the island-wide network.

After assignments were made the capacity of each route was tested against the assigned passenger volume to ensure that enough buses were available to carry the anticipated volume and that there was enough patronage to warrant the level of service assumed in the original route planning. The bus routes included in the final assignment contain all of the improvements made in the routing and service levels.

To accommodate the anticipated number of bus passengers, a network of 73 bus routes operating over some 550 two-way route miles was identified to support a 23-mile fixed guideway system. Of the total number of bus routes, 55 are local and shuttle bus routes and 18 are express bus routes.

D. SYSTEM DESCRIPTION

1. Guideway

The principal alignment criteria adopted for the guideway design are as follows:

- Minimum allowable mainline curve radius of 500 feet with maximum superelevation, for curves located near stations.
- A desirable minimum mainline curve radius of 2300 feet without superelevation.
- Superelevation designed for maintenance of equilibrium and for sustained velocity of vehicles on curves.
- Superelevation constant throughout curves.
- Spiral easement curves to be utilized for superelevation transition.
- Tangent alignment through all stations.
- Maximum gradient of 8% for short segments.
- Desirable maximum gradient of 6% for sustained grades.
- Vertical curve required for grade changes.
- Vertical transitions at summits will be designed to limit lifting accelerations to 0.05g or 1.61 feet per second per second to satisfy normal comfort criteria.
- Vertical transitions at sags will be designed to limit centrifugal acceleration to 1 foot per second per second.
- Desirable level certical alignment through stations, but in no case greater than 1% gradient.

The basic guideway configuration includes aerial, at-grade, and underground or subway structures. The typical aerial structure will use precast, pre-stressed concrete girders supported on single reinforced concrete column with spread footing or pile foundations. A typical span of 80 feet was selected as the most economical and best suited for the selected routes. Noise barriers would be provided at the outer edges of the structure in the noise sensitive segments of the route. The double track structure would be approximately 23 feet wide with the depth of the girders varying between 4'-6" to 5'-0".

The at-grade configuration will utilize a double "T" section of precast concrete supported on conventional spread footings, at 20'-0" spacing. Since at-grade sections are utilized only in existing grade-separated highway rights-of-way, barrier walls are provided to keep automobiles off the guideway. A chain link fencing would also be provided which would extend above the barrier walls to restrict access to the guideway at all times.

The underground construction would be by cut and cover method since the route will be located in rights-of-way with limited vehicle traffic. The structure will be double box construction with each box approximately 12'-6" high and 13'-0" wide, inside dimensions.

2. Station Facilities

A total of 21 stations will serve the 23-mile fixed guideway system of which 3 are underground, 3 are at grade, and the other 15 in aerial configuration. Each of the 21 stations was sited in relationship to traffic patterns, to the physical character of the area, and to provide for bus transfer and parking.

A fundamental consideration was the distance between stations. Except in the central core area, where stations are spaced for easy walking access, stations are located at average spacing of one mile. This helps to increase total system speed and reduces passenger travel time..

The terminal stations at Pearl City and Hawaii Kai which are planned for park and ride facilities will be constructed with approximately 750 and 400 parking spaces, respectively. At the Halawa Stadium, the stadium parking facilities are assumed to be available for the use of transit patrons. Most of the remaining stations are provided with limited short-term or kiss-and-ride parking facilities for the convenient pickup or discharge of transit riders from taxis or private cars.

Bus interface facilities, either on or off public rights-of-way will be provided at the stations. At the Iwilei and Waikiki Stations, pedestrian overpasses will be constructed for transit patrons to cross King Street and Kalakaua Avenue, respectively. Stations will also be furnished with special loading and unloading areas for the handicapped.

All stations will be provided with escalators for general use and elevators for the handicapped. Stations are designed to provide attractive and convenient facilities for transit patrons and to be handsome additions to the communities in which they are located.

3. Support Systems

The rubber-tired transit vehicles are approximately 40 feet long, are of medium size, and are light weight construction. These vehicles are trainable up to 10 cars, and can operate at a maximum service speed of 50 miles per hour. They are electrically propelled and can operate safely and reliably at 1-1/2 minute headways with the use of a modern automatic train protection system.

The vehicles, stations, yard and shops area, and central control will be interconnected with a voice communication system consisting of telephone, two-way radio, and public address systems.

A closed circuit TV system will monitor station activities which are outside the station agent's immediate view. An automatic fare collection system will be utilized for passenger's entry to the transit system.

The yard and shops will be located on the site adjacent to Keehi Lagoon. This facility will offer complete vehicle repair, service and inspection capability. Storage of vehicles up to 1995 requirements can also be accommodated on this site.

E. CONCEPT ANALYSES

1. General

The fixed guideway concept was planned for a full 23-mile system with 21 stations supported by an island-wide network of feeder and express buses. Since the system can be logically constructed in stages, a 7-mile, 14-mile, and the full 23-mile lengths were developed and analyzed. (See Figure VIII-1). The extent of the various system lengths are as follows:

- 7-mile length - Keehi Lagoon station to University station
- 14-mile length - Halawa station to Kahala station
- 23-mile length - Pearl City station to Hawaii Kai station

This section will present the analysis of the system in 3 lengths, each length assumed operational in the year 1995. Quantitative and qualitative analysis of projected patronage, system operating characteristics, costs, benefits, community, and environmental factors were conducted to permit a comparative evaluation of alternative concepts on a uniform basis.

2. Patronage Projections

Utilizing the modal split model, patronage estimates were developed for the 3 guideway system lengths and their appropriate feeder and express bus systems for 1995. The 1995 patronage projections are tabulated in Table VIII-1.

3. Analysis of Trip Characteristics

The level of service and efficiency of the transit system can be assessed by analyzing the trip characteristics in terms of total passenger hours, miles, average trip distance and average trip speed. These data will be used in subsequent comparative evaluations relative to all other alternatives examined. Table VIII-2 presents a summary of these statistics for the fixed guideway concept.

TABLE VIII-1: 1995 PATRONAGE PROJECTIONS - FIXED GUIDEWAY SYSTEM

ANALYSIS CATEGORY	7-MILE				14-MILE				23-MILE			
	TOTAL DAILY	% TOTAL	P.M. PK. HOUR	% TOTAL	TOTAL DAILY	% TOTAL	P.M. PK. HOUR	% TOTAL	TOTAL DAILY	% TOTAL	P.M. PK. HOUR	% TOTAL
1. TRANSIT PERSON TRIPS	462,000	100.0	79,830	100.0	473,300	100.0	81,860	100.0	490,000	100.0	84,920	100.0
WORK	210,960	45.7	46,980	58.8	215,300	45.5	47,910	58.5	224,500	45.8	49,890	58.7
NON-WORK	251,040	54.3	32,850	41.2	258,000	54.5	33,950	41.5	265,500	54.2	35,030	41.3
2. TRANSIT PERSON TRIPS AS:												
% TOTAL TRIPS	14.0	-	21.7	-	14.3	-	22.2	-	14.8	-	23.1	-
% TOTAL WORK TRIPS	31.3	-	43.3	-	32.0	-	44.2	-	33.3	-	46.0	-
% TOTAL NON-WORK TRIPS	9.5	-	12.7	-	9.8	-	13.1	-	10.1	-	13.5	-
3. TRANSIT TRIPS BY MODE												
GUIDEWAY	289,580	62.7	52,020	65.2	306,900	64.8	56,000	68.4	332,600	67.9	60,800	71.6
BUS *	565,730	-	99,940	-	527,600	-	92,800	-	586,800	-	103,700	-
4. TRANSIT USE BY AREA												
URBAN HONOLULU	333,700	72.2	57,660	72.2	341,850	72.2	59,120	72.2	353,920	72.2	61,340	72.2
WINDWARD	64,950	14.1	11,220	14.1	66,530	14.1	11,510	14.1	68,880	14.1	11,940	14.1
CENTRAL	15,600	3.4	2,700	3.4	15,990	3.4	2,780	3.4	16,550	3.4	2,870	3.4
LEEWARD	47,750	10.3	8,250	10.3	48,930	10.3	8,450	10.3	50,650	10.3	8,770	10.3

* INCLUDES INTRA-MODAL TRANSFERS

TABLE VIII- 2: SELECTED TRIP CHARACTERISTICS - 1995

CHARACTERISTIC	7-MILE FIXED GUIDEWAY DAILY TOTAL SYSTEM	7-MILE DAILY GUIDE-WAY	7-MILE P.M. PEAK HOUR TOTAL SYSTEM	7-MILE P.M. PEAK HOUR GUIDE-WAY	14-MILE FIXED GUIDEWAY DAILY TOTAL SYSTEM	14-MILE DAILY GUIDE-WAY	14-MILE P.M. PEAK HOUR TOTAL SYSTEM	14-MILE P.M. PEAK HOUR GUIDE-WAY	23-MILE FIXED GUIDEWAY DAILY TOTAL SYSTEM	23-MILE DAILY GUIDE-WAY	23-MILE P.M. PEAK HOUR TOTAL SYSTEM	23-MILE P.M. PEAK HOUR GUIDE-WAY
PASSENGER MILES	3,099,315	736,600	571,546	133,367	3,228,410	1,178,140	594,450	210,591	3,458,125	1,747,793	637,107	324,422
PASSENGER HOURS	134,945	25,600	24,520	4,650	134,326	38,570	24,400	6,871	137,510	53,390	25,044	9,815
AVERAGE TRIP TIME (MIN.)	-	5.3	35.7	5.4	-	7.5	33.7	7.4	-	9.6	31.6	9.7
AVERAGE TRIP LENGTH (MI.)	6.71	2.54	7.15	2.56	6.82	3.84	7.26	3.76	7.06	5.25	7.50	5.34
AVERAGE TRIP SPEED (MPH)	-	28.8	12.1	28.7	-	30.5	12.9	30.6	-	32.7	14.2	33.0

TABLE VIII- 3 : SELECTED OPERATING STATISTICS - 1995

STATISTIC	7-MILE FIXED GUIDEWAY TOTAL SYSTEM	7-MILE GUIDE-WAY	7-MILE FEEDER BUS LOCAL	7-MILE FEEDER BUS EXPRESS	14-MILE FIXED GUIDEWAY TOTAL SYSTEM	14-MILE GUIDE-WAY	14-MILE FEEDER BUS LOCAL	14-MILE FEEDER BUS EXPRESS	23-MILE FIXED GUIDEWAY TOTAL SYSTEM	23-MILE GUIDE-WAY	23-MILE FEEDER BUS LOCAL	23-MILE FEEDER BUS EXPRESS
VEHICLE MILES (DAILY)	158,940	34,335	45,645	78,960	158,485	64,225	31,080	63,180	189,885	111,495	31,680	46,710
VEHICLES IN PEAK HOUR SERVICE	850	146	308	396	767	240	210	317	831	383	223	225
SPARES	85	15	31	39	77	24	21	32	83	38	22	23
PASSENGERS/VEHICLE MILE	2.91	8.43	-	-	2.99	4.78	-	-	2.58	2.98	-	-

4. Operations Analysis

System operating plans for 1995 were developed for each of the three alternative guideway lengths and selected operating statistics are shown in Table VIII-3. The operating plans provided through routing of all trains between the terminal stations with no intermediate turnbacks utilized. This would provide sufficient seats for boarding patrons at the outlying stations. Turnback points would be provided at Pearl City, Halawa, University, Kahala and Hawaii Kai stations. The intermediate turnback points between the terminal stations would be utilized only in emergency situations and at the beginning or ending of revenue service operation of each train to reduce "deadhead" time.

The trains will operate from 5:00 a.m. to 1:00 a.m., seven days a week. During the two, 2-hour peak-periods of the day, trains will be scheduled to provide sufficient carrying capacity to accommodate peak-hour, peak-link volumes in a manner comparable to that provided by the other alternative concepts. During off-peak hours, weekends and holidays, adequate number of trains with sufficient number of cars will be scheduled to ensure frequent service and adequate seating capacity for all passengers.

The maximum scheduled speed of the train will be 50 miles per hour with a system average speed of 32 miles per hour, including station stops. An average station dwell time of 20 seconds is assumed in the calculation of total round trip time.

5. Capital & Operating Cost

Capital cost estimates include all labor, materials, and equipment necessary to operationalize the initial fixed guideway system. Also included is the estimated cost of purchasing rights-of-way, including allowances for legal and title fees and for the cost of severance and relocation. These estimates were prepared using late 1974 prices as the base cost and are summarized in Table VIII-4.

A contingency allowance of 10% of the construction and rights-of-way costs is provided in the cost estimate. An allowance of 13% of the construction cost is assumed for the cost of administration, detailed design, and construction management.

Improvements to Kalanianaole Highway from Kahala to Hawaii Kai are currently underway and includes the construction of an at-grade busway with a single exclusive, reversible lane. Under the feeder bus system, this cost item is included for the 7- and 14-mile lengths since with the 23-mile length fixed guideway system, this busway would not be required.

TABLE VIII-4: CAPITAL COST ESTIMATE
($ Thousand)

	SYSTEM LENGTH		
F.G. FACILITIES & EQUIP.	7-MILE	14-MILE	23-MILE
WAY STRUCT. & GUIDERAILS	$ 79,696	$112,235	$157,051
STATIONS	47,489	65,996	84,194
POWER & CONTROL	24,130	39,976	52,951
YARD & SHOPS	11,935	13,546	14,807
VEHICLES	52,800	86,600	137,800
SUBTOTAL	$216,050	$318,353	$446,803
CONTINGENCY (10%)	21,605	31,835	44,680
ADMIN. & ENGRG. (13%)	30,895	45,524	63,892
TOTAL	$268,550	$395,712	$555,375
F. G. ROW & RELOCATION			
ROW & RELOCATION	$ 47,410	$ 51,020	$ 53,380
CONTINGENCY (10%)	4,741	5,102	5,338
ADMIN. (3%)	1,565	1,684	1,762
TOTAL	$ 53,716	$ 57,806	$ 60,480
FEEDER BUS SYSTEM			
KAL. HWY. IMPROVEMENTS	$ 26,100	$ 26,100	-
BUSES	50,310	37,700	$ 32,045
TOTAL	$ 76,410	$ 63,800	$ 32,045
GRAND TOTAL	$398,676	$517,318	$647,900

A detailed analysis was conducted of all major operating and maintenance functions related to the fixed guideway system. Manpower requirements of the overall system and related material and service requirements were developed and cost estimates prepared based on prevailing prices in late 1974. Table VIII-5 summarizes the 1995 operating and maintenance cost of the fixed guideway systems and their supporting feeder bus systems.

The City's bus operating experience provided the basis for developing the operating and maintenance costs for the feeder bus system. The integration of the current and planned bus fleet and maintenance facilities as part of the proposed transit system anticipates the continuation of all normal operation and maintenance functions for the feeder bus system which exist presently.

6. Other Analyses

a. Staged Development

The implementation of the guideway system can be staged beginning with the shortest viable system and progressively extending the system as justified by demand. Since the guideway system depends on the feeder and express bus system for service beyond the system terminals, minimum conflict or disruption to this service would be encountered during the construction of the guideway extensions.

TABLE VIII-5: ANNUAL OPERATING & MAINTENANCE COST ESTIMATE ($ Thousand)

FIXED GUIDEWAY SYSTEM	F.G. SYSTEM LENGTH 7-MILE	14-MILE	23-MILE
WAY & STRUCTURE	$ 1,458	$ 1,891	$ 2,643
VEHICLE	950	1,474	2,369
TRANSPORTATION	2,021	2,690	3,467
GENL. & ADMIN.	2,400	2,873	3,793
POWER	1,766	3,031	4,965
SUBTOTAL	$ 8,595	$11,959	$17,237
CONTINGENCY (10%)	859	1,196	1,724
TOTAL	$ 9,454	$13,155	$18,961
FEEDER BUS SYSTEM	$33,840	$24,900	$21,900
GRAND TOTAL	$43,294	$38,055	$40,861

In Honolulu, good accessibility can be provided by highways and freeways for buses to interface with the guideway terminal stations. Therefore, once the segment of the guideway system is constructed, complete flexibility in making extensions are available.

b. <u>Environmental & Community Factors</u>

Various environmental and community factors must be considered in implementing and operating a wholly new transit system in any region. In Honolulu, this is especially critical due to the intensively developed urban area that the guideway route traverses. Relocation of residents and businesses are very critical due to the extreme shortage of housing and developable lands. By the judicious selection of route alignments, including the maximum use of existing street and highway rights-of-way, relocation requirements have been minimized.

Unlike freeway construction, the guideway system will not create a physical barrier through a community. The route configurations which are underground and aerial will provide full crossing for vehicular and pedestrian traffic. For the at-grade configuration, the alignment is in existing freeways which already creates barriers and divides communities.

From the environmental standpoint, air pollutants from automobile exhaust emission should be reduced as will be discussed in the next chapter. Noise pollution is considered to be minimal where the guideway route is located in freeways, highways and major arterials due to the ambient noise level generally being higher than the preducted transit vehicle noise level. However, where the guideway segment is located in local streets or in its own transit right-of-way and adjacent to noise sensitive facilities, sound barriers and other noise reducing means will be provided to minimize noise intrusion.

Visual intrusion will exist with the construction of any major facilities such as the guideway structure and stations. With careful and sensitive design of the facilities and by keeping the mass of the structure to a minimum, visual intrusions can be mitigated. These critical factors are more appropriately covered in the following chapter where comparisons are made between alternatives.

IX. COMPARATIVE EVALUATION OF ALTERNATIVES

A. SUMMARY OF SYSTEMS

Previous sections of this report have established the basic criteria which should be met by any new transit system implemented in Honolulu. In response to those criteria and the projected growth and development of the region, individual system alternatives were developed and tested. These alternatives range from a 7-mile busway concept to a 28-mile LRT concept. Each of these alternative concepts has been discussed in detail in previous sections and basic requirements and performance of each system identified. Significant characteristics of each alternative are shown in Table IX-1.

The purpose of this final section is to summarize the data generated for each alternative, compare each against the baseline (null-hypothesis) or against each other and, based on this comparative evaluation, to draw reasonable conclusions for a recommended transit system approach for Honolulu. The basic parameters used in the evaluation are:

- Travel Characteristics
- Operations
- Capital & Operating Costs
- Benefit-Cost Evaluation
- Other Factors

TABLE IX-1: SUMMARY OF OPERATING CHARACTERISTICS

SYSTEM CHARACTERISTIC	BUSWAY	LRT	FIXED GUIDEWAY 7-MILE	FIXED GUIDEWAY 14-MILE	FIXED GUIDEWAY 23-MILE
A. TWO-WAY GUIDEWAY MILES (TOTAL)	(7.3)	(27.9)	(7.3)	(13.7)	(23.2)
GRADE SEPARATED					
- AT-GRADE	-	2.5	-	3.1	6.3
- AERIAL	5.6	11.0	5.6	8.9	15.2
- SUBWAY	1.7	1.7	1.7	1.7	1.7
AT-GRADE IN EXCLUSIVE ROW	-	7.6	-	-	-
AT-GRADE IN MIXED TRAFFIC	-	5.1	-	-	-
B. STATIONS (SUBWAY, GRADE, AERIAL)	(3, 0, 7)	(3, 11, 10)	(3, 0, 7)	(3, 3, 10)	(3, 3, 15)
C. SERVICE HEADWAYS *					
PEAK	12 Sec.	2 Min.	2 Min.	2 Min.	2 Min.
BASE	40 Sec.	4 Min.	4 Min.	4 Min.	4 Min.
NIGHT	128 Sec.	4 Min.	4 Min.	4 Min.	4 Min.
D. VEHICLES (INCL. 10% SPARES)					
GUIDEWAY	179	410	161	264	421
BUS-LOCAL	320	200	339	231	245
BUS-EXPRESS	432	243	435	349	248
E. VEHICLE CAPACITY (DESIGN LOAD)					
GUIDEWAY (SEATED-TOTAL)	53-60	68-100	36-72	36-72	36-72
BUS-LOCAL (SEATED-TOTAL)	53-70	53-70	53-70	53-70	53-70
BUS-EXPRESS (SEATED-TOTAL)	53-50	53-50	53-50	53-50	53-50
F. VEHICLES PER TRAIN *					
PEAK	1	8	7&9	7&9	7&10
BASE	1	6	7	7	7
NIGHT	1	2	2	2	2
G. TWO-WAY FEEDER BUS ROUTE MILES					
LOCAL	446	318	446	387	339
EXPRESS	306	229	306	284	247
H. MAXIMUM VEHICLE SPEED (MPH)					
GUIDEWAY	50	50	50	50	50
BUS	50	50	50	50	50

* ON GUIDEWAY PORTION THROUGH CBD AREA

B. TRAVEL CHARACTERISTICS

Patronage is the most significant measure of the transit system effectiveness in serving the travel needs of the population it serves. For this reason, a number of statistical comparisons were made for each alternative in an effort to identify any significant differences. As shown in Table IX-2, all systems produced a major increase in total transit use over the baseline bus concept which would attract some 214,300 average daily trips in 1995. Each alternative produced more than twice as many transit trips. However, within alternatives, the differences were less dramatic, ranging from a difference of 1.3% between the two lowest patronage systems and 7.4% between the lowest and highest systems. Essentially, the variation within alternatives is attributable to the extent of exclusive, grade separated guideway with its potential for increased travel speed.

An important feature of the projected mode split is the high percentage of transit work trips. Since these trips are predominantly in the peak traffic hours, an overall attraction of nearly 1/3 of all work trips daily to transit will produce a measurable positive impact on traffic congestion. Since service coverage is essentially the same for all alternatives, no real measurable differences exist relative to usage by trip purposes.

TABLE IX-2 : SUMMARY OF TRAVEL CHARACTERISTICS

TRAVEL CHARACTERISTICS	ALTERNATIVE				
			FIXED GUIDEWAY		
	BUSWAY	LRT	7-MILE	14-MILE	23-MILE
A. TRANSIT PASSENGERS (AVG. DAILY)					
1. GUIDEWAY	326,850	358,750	289,580	306,900	332,600
2. FEEDERS - LOCAL	403,670	282,040	403,300	386,600	460,400
FEEDERS - EXPRESS	151,230	116,020	162,430	141,000	126,400
3. TOTAL SYSTEM *	456,250	474,520	462,000	473,300	490,000
B. TRANSIT % OF TOTAL TRIPS					
1. DAILY (WORK-NONWORK)	30.7-9.5	32.3-9.8	31.3-9.5	32.0-9.8	33.3-10.1
2. P.M. PK. (HR. WORK-NONWORK)	42.4-12.6	44.6-13.0	43.3-12.7	44.2-13.1	46.0-13.5
C. TRIPS GENERATED					
1. URBAN HONOLULU	329,540	342,730	333,700	341,850	353,920
2. WINDWARD	64,140	66,710	64,950	66,530	68,880
3. CENTRAL	15,410	16,030	15,600	15,990	16,550
4. LEEWARD	47,160	49,050	47,750	48,930	50,650
D. DAILY PASSENGER MILES					
1. GUIDEWAY	754,301	1,758,631	736,600	1,178,140	1,702,790
2. TOTAL SYSTEM	3,131,331	3,224,748	3,099,315	3,228,410	3,458,125
E. DAILY PASSENGER HOURS					
1. GUIDEWAY	31,467	64,774	25,600	38,570	53,390
2. TOTAL SYSTEM	142,361	131,649	134,945	134,326	137,510
F. PK. HR. AVG. TRIP TIME (MIN.) **					
TOTAL SYSTEM	36.3	32.4	35.7	33.7	31.6
G. PK. HR. AVG. TRIP DISTANCE (MILES)					
TOTAL SYSTEM	7.31	7.22	7.15	7.26	7.50
H. PK. HR. AVG. TRIP SPEED (MPH) **					
TOTAL SYSTEM	12.1	13.4	12.1	12.9	14.2

* TOTAL DOES NOT INCLUDE TRANSFER MOVEMENTS BETWEEN MODES

** BASED ON A PORTAL TO PORTAL TRIP

Another measure of system effectiveness is how well it serves major origin and destination areas. Major increases in all categories over the baseline condition which would attract approximately 50% fewer daily transit patrons than any of the alternatives is a result of the superior service provided by these alternatives. In terms of origins, each of the 4 districts on Oahu is projected to generate a proportional increase in patronage to the total, hence the higher the total patronage, the higher the patronage from each district. The increases reflect the improved overall transit service to these areas provided by each alternative system with no significant superiority of one alternative over the other.

Relative to trip characteristics, the average trip time reflects the trip speed and trip distance which varies with each alternative. Generally, the shorter the grade separated exclusive guideway length, the longer the trip time due to lower average trip speed. The busway system has the longest average trip time and the 23-mile fixed guideway system has the shortest average trip time. The LRT system has the second best or shortest average trip time due to its relatively extensive network of guideway although not entirely grade separated. In short, systems with the greatest length of exclusive, grade separated guideway with attendant number of stations provide the fastest trip time.

As can be seen from the various travel characteristics, although the 23-mile fixed guideway system performs the best and the 7-mile fixed guideway and busway are the worst, the variations are in fact slight and no compelling advantage can be attributed to any of the alternatives. This result is not too surprising in light of the similarities between the test networks.

As has been pointed out in several prior discussions in this report, the urban area of Honolulu is unique among the U.S. cities in that the development is reasonably uniform at a high density level and almost totally contained within a narrow, linear corridor extending from Hawaii Kai in the east to Pearl City on the west. In other U.S. cities, development is generally concentric about the central city and multiple corridors and service routes are essential. This situation does not exist on Oahu and a single, line haul corridor serves the urbanized area very well.

In each of the alternatives, these factors were recognized and the system designed was responsive to indicated travel demands. Therefore, the resulting patronage is a primary function of travel time since coverage is essentially equivalent under each alternative.

Although significant differences in patronage do not exist between alternatives, there are some other differences. The more significant differences occur in capital and operating costs. Therefore, no attempt has been made to evaluate the alternatives on travel characteristics alone, but is evaluated together with system costs to provide a measure of cost effectiveness.

C. OPERATIONAL COMPARISONS

The summary of operating statistics for the various alternatives which are pertinent to cost of operation and measure of system efficiency, which is actually reflected in cost, is shown in Table IX-3. Since guideway vehicles are of different size and capacity, a direct comparison of passengers per vehicle mile cannot be made. All vehicle miles are therefore converted to equivalent vehicle miles using the average bus design loading of 60 passengers per vehicle.

A comparison of passengers per equivalent vehicle mile between the 7-mile busway and the fixed guideway systems reflects the flexibility of scheduling single bus units and being operationally capable of turning back vehicles on the busway to efficiently meet demand. The fixed guideway system using trained units, does not provide the same degree of operational flexibility and hence results in a lower load factor on a per equivalent vehicle mile basis.

The relative efficiency of the LRT system is also reflected in its nearly comparable value with the shorter 23-mile fixed guideway

TABLE IX-3: SYSTEM OPERATING STATISTICS

OPERATING STATISTIC	BUSWAY 7-MILE	LRT 28-MILE	FIXED GUIDEWAY 7-MILE	FIXED GUIDEWAY 14-MILE	FIXED GUIDEWAY 23-MILE
A. ANNUAL PATRONAGE (MILLIONS)	137.8	143.3	139.5	142.9	148.0
B. ANNUAL VEH. MI. (MILLIONS)					
GUIDEWAY	9.15	24.01	10.37	19.39	33.67
FEEDER BUS MILES *	36.67	21.64	37.63	28.47	23.67
TOTAL VEH. MI.	45.82	45.65	48.00	47.86	57.34
C. PASS./VEH. MI. **	3.01	3.14	2.91	2.99	2.58
D. VEHICLE DESIGN LOAD	60	100	72	72	72
E. EQUIV. VEH. LOAD FACTOR	1.00	1.67	1.20	1.20	1.20
F. ANNUAL EQUIV. VEH. MI. (MILLIONS)					
EQUIV. GUIDEWAY VEH. MI.	9.15	40.10	12.44	23.27	40.40
FEEDER BUS MILES	36.67	21.64	37.63	28.47	23.68
TOTAL EQUIV. VEH. MI.	45.82	61.74	50.11	51.74	64.08
G. PASS./EQUIV. VEH. MI.	3.01	2.32	2.78	2.76	2.31

* INCLUDES ALL LOCAL AND EXPRESS FEEDER BUS ROUTES

** PASSENGERS PER VEHICLE MILE EXPRESSED AS TOTAL SYSTEM REVENUE PASSENGER, DIVIDED BY TOTAL OF ALL VEHICLE MILES OPERATED TO ELIMINATE DOUBLE COUNTING DUE TO TRANSFERS.

system due to its coupling and uncoupling feature to permit smaller trained units to operate at the ends of the system as well as on the branch lines. The fixed guideway system is based on no operational turnbacks for all lengths in order to provide seats to all passengers boarding or alighting at terminal stations.

In terms of operating statistics for passengers carried per vehicle mile, both the busway and LRT systems would rank as being superior to the fixed guideway system on a comparable system length basis. But as mentioned at the beginning of this section, these statistics are presented because they are pertinent to cost and not as a measuring factor of alternatives in itself.

D. CAPITAL AND OPERATING COSTS

1. Capital Costs

Capital and operating costs were developed for each alternative transit concept as described in previous sections. Table IX-4 presents a summary of the capital costs of all alternative concepts for ease of comparison. The costs of the transit cars and buses reflect the total number required to meet the 1995 patronage volume and does not reflect the cost of replacing the bus fleet which has a much shorter life than the transit cars.

TABLE IX-4: SUMMARY OF COSTS

CAPITAL COSTS
($ Million)

	BUSWAY	LRT	FIXED GUIDEWAY 7-MILE	14-MILE	23-MILE
CONSTRUCTION	259.4	366.9	229.0	314.2	384.1
RIGHT-OF WAY	94.5	67.9	53.7	57.8	60.5
TRANSIT CARS *	-	203.9	65.6	107.6	171.3
BUSES *	60.5	28.8	50.3	37.7	32.0
TOTAL	414.4	667.5	398.6	517.3	647.9

* REQUIRED CARS AND BUSES FOR 1995 PATRONAGE

OPERATING AND MAINTENANCE COSTS
($ Million)

	BUSWAY	LRT	FIXED GUIDEWAY 7-MILE	14-MILE	23-MILE
GUIDEWAY	2.64	22.76	9.45	13.15	18.96
BUS	40.07	19.39	33.84	24.90	21.90
TOTAL	42.71	42.15	43.29	38.05	40.86

COST PER TRIP
($ Million)

	BUSWAY	LRT	FIXED GUIDEWAY 7-MILE	14-MILE	23-MILE
ANNUAL CAPITAL COST					
CONSTR. & ROW	20.46	25.15	16.35	21.51	25.71
TRANSIT CARS	-	11.79	3.79	6.22	9.91
BUSES	7.46	3.55	6.20	4.64	3.95
TOTAL CAPITAL COST	27.92	40.49	26.34	32.37	39.57
O & M COST	42.71	42.15	43.29	38.05	40.86
TOTAL CAPITAL & O&M COST	70.63	82.64	69.63	70.46	80.43
CAPITAL COST/TRIP	20.3¢	28.3¢	18.9¢	22.7¢	26.7¢
O&M COST/TRIP	31.0¢	29.4¢	31.0¢	26.6¢	27.6¢
CAPITAL & O&M COST/TRIP	51.3¢	57.7¢	49.9¢	49.3¢	54.3¢

The 7-mile fixed guideway system with 11 stations has the lowest capital cost followed very closely by the busway system which also has approximately 7 miles of grade-separated way structure and the same number of stations. The busway system does not require electrical propulsion power and automatic train control installations and its bus equipment is much cheaper than the equivalent fixed guideway transit cars. However, the lower costs for the above items are more than offset by the higher costs for the much larger stations, wider way structures and greater tunnel ventilation requirements. The most pronounced difference between the 7-mile busway and guideway systems is in the right-of-way cost. The large bus stations that occur in the urban core area require some very expensive properties. Also, the much wider way structures do not conveniently fit into existing street rights-of-way thus requiring the purchasing of more land than the comparable length fixed guideway system.

The highest capital cost alternative is the LRT system with its 28 miles of double track guideway. The station costs for the LRT system is somewhat higher than for a comparable fixed guideway system primarily due to its greater platform length. The aerial structure cost is also slightly more due to the heavier weight of the cars. The greatest cost differential occurs in the cost of the vehicles primarily due to the larger equivalent number of cars required. This is attributable to the longer length system and the lower operating speeds required for surface operations.

The capital costs clearly reflect the length of the system and the number of stations. The requirement for larger way and station structures are also reflected in the costs, both in construction and right-of-way costs. Guideway transit cars are inherently more costly than conventional buses but they feature longer life and greater reliability.

2. Operating Costs

To local operating agencies, the annual operating and maintenance (O&M) cost is a very important consideration since this is a recurring cost which must be borne by the local operation. As shown in Table IX-4, the alternative with the lowest O&M cost is the 14-mile fixed guideway system. The shorter 7-mile fixed guideway system has a higher O&M cost reflecting the higher cost of bus operation in the inner, high volume segments of the corridor. Conversely, the 23-mile fixed guideway system has a higher O&M cost than the 14-mile system which reflects the lower cost of bus operation in the outer segments of the urban corridor where the volumes are not as high as in the inner segments.

The LRT system shows a relatively high cost of operation due to its extensive system length and the lower speed on surface operations. The higher guideway operation is somewhat offset by the lower feeder bus operation since the LRT system replaces certain bus feeder routes required for other alternative systems.

In terms of total annual O&M cost, the 14-mile fixed guideway system is the lowest and the 7-mile fixed guideway system is the highest. However, since these costs reflect different patronage volumes, the O&M costs should be measured in terms of cost per trip.

3. Cost Per Trip Comparison

One measure of cost effectiveness is the unit cost of a passenger trip carried by a system. All costs were annualized based on appropriate economic life of the various elements of the system. Major structures such as the way and stations are generally assumed to have an economic life of 50 years with various mechanical and electrical equipment having an economic life of about 30 years. Since all elements of the system require component replacements, an average 30-year economic life was assumed for both fixed facilities and equipment including the transit cars.

The only element of the system with a shorter economic life is the bus. An economic life of 10 years is normally used in the industry. All of the above would have some salvage value after their assumed economic life, however, they have not been included in the analysis. A test of varying the economic life and inclusion or exclusion of salvage value indicated that the result of the comparative analysis would not vary. A 4% discount rate was used in annualizing the capital costs.

Table IX-4 shows the comparison of cost per trip for the various alternative concepts. Since the patronage volumes did not vary significantly between concepts, in terms of capital cost, the lower the capital cost, the lower the unit cost per trip with the 7-mile fixed guideway system having the lowest cost. For the operating cost only, the 14-mile system was found to have the lowest unit cost per trip. Based on the combined capital and operating costs, the 14-mile fixed guideway system has the lowest cost per trip, which reflects its greater overall cost-effectiveness over the other alternatives.

E. BENEFIT/COST EVALUATION

The traditional benefit/cost method of evaluating public works programs provides another measure for evaluating alternatives with varying system attractiveness. The approach taken for comparison of alternatives was to consider only those direct travel benefits which reflects patronage volumes. Since capital costs are incurred early in the project life and benefits usually increase downstream, it is necessary to assume some time frame and bring both costs and benefits to present value. In keeping with other aspects of this study, a 30 year period of operations has been used for this purpose. In determining present worth, a net 4% discount rate has been assumed and therefore costs and benefits are based on constant dollars.

1. Capital & Operating Costs

Some simplifying approximations have been assumed for this comparative analysis. A 30-year period is assumed with 1995 selected as the midpoint representing the average operating level. This appears a reasonable assumption since anticipated increase demand beyond 1995 (the design year) can be expected to require more miles and hours of service while fewer miles and hours will be required in the initial years of operation.

Similarly, direct use of 1974 costs for construction and rights-of-way overlooks the actual cost stream that would result from a staged construction program. This will have the effect of overstating the relative economic cost of the facilities to a small extent, particularly for the longer systems represented by the LRT and 23-mile fixed guideway alternatives. This will produce a slight penalty on those two alternatives since the construction and right-of-way costs for other alternatives are more similar and approximately equal construction periods could be anticipated.

2. Benefits

The total economic benefits which will accrue to the Honolulu region by the implementation of each of the alternative transit concept tested, during the 30 year analysis period, is based on the assumption that the annual benefits attained during the year 1995, represents an average benefit level that can be reached during the entire analysis period. In the analysis of benefits only quantifiable transportation benefits were considered and these were in terms of:

- Time savings to both transit users and non-users.
- Vehicle operating, insurance, parking, and ownership savings to the diverted motorists.
- Reduction in fatalities.

a. Time Savings

Most individuals diverted from the automobile to one of the alternative transit systems will realize a time saving in work commute trips by avoiding traffic congestion problems usually associated with peak hour commuting travel on streets and highways while utilizing the exclusive right-of-way portions of the transit systems. The individuals traveling to work by the present public transportation system or baseline system face many of the same problems that face the automobile commuters. The alternative transit systems by virtue of avoiding the normal traffic flow in portions with exclusive rights-of-way and in conjunction with the decreased headways causing shorter wait time, will provide a time saving for work commute trips. The removal of the diverted motorist from the highways and the improved express and feeder bus system will decrease the degree of congestion that would otherwise occur. It follows then that the remaining motorist who commute to work and also commercial vehicles on the highway system will realize decreased travel time.

The time savings accruing to the transit user and the continued motorist was valued on the basis of a 1969 study presented to the 49th Highway Research Board Conference in 1970. This study concluded the value of time connected with work trips to be $2.82 per person per hour, in 1968 prices which was adjusted to $3.92 to represent 1974 prices. The value of commercial vehicles time was valued at $5.75 per hour (1965 dollars) based on a 1967 study by Texas Transportation Institute. This value of time was then adjusted to $10.18 per hour to represent 1974 dollars.

b. Operating Savings

The vehicle miles avoided by the diverted motorist will result in auto operating cost savings to the former auto user. Vehicle operating cost avoided accruing to the transit user included gas, oil, maintenance and tires. A 1972 report by the U. S. Department of Transportation, Federal Highway Administration, determined the per mile cost of gas and oil at 2.8 cents and maintenance, accessories, parts and tires at 2.3 cents per mile. Based on these unit costs the total per mile cost of operating and maintaining the automobile would be 6.3 cents in 1974 dollars.

c. Insurance Savings

In addition to the actual cost of operating the vehicle, the commuters who forego the use of their automobile for work trips will save on their automobile insurance premiums and parking cost. Current practice in the automobile insurance industry calls for a minimum surcharge of 15 percent if the automobile is used for work commute trips. In 1974 this represented a $33.63 markup on a basic insurance policy.

d. Parking Savings

The commuter driving his automobile to work must, in most cases, pay for parking. Therefore, those diverted motorists will avoid this out-of-pocket expense. The average parking cost for all day parking in 1974 dollars was 80.1 cents per day.

e. Ownership Savings

Many households will realize the savings obtained by the elimination of the need for a second or third car, or in some cases the first car, as a result of the use of the transit system. Those individuals who eliminate ownership of an automobile, eliminate the annual insurance premium and depreciation. The average annual cost of insurance for basic coverage of a new automobile in 1974 dollars was $272.50. The average depreciation of a new automobile in terms of 1974 dollars was $467.18.

f. Reduction In Fatalities

The fatality rate on transit is much lower than that of automobiles and will result in a saving of lives. The value of a human life cannot be objectively measured, however, we can measure the lost income attributable to a fatality. The reduction in fatalities represents a savings of this lost income.

3. Benefits/Cost Evaluation

A 4% discount rate was used to determine the present worth of the annualized total benefits accrued by the use of each alternative transit system by the population of the City and County of Honolulu over a 30 year period. The total present worth of benefits and costs for each of the alternative systems is tabulated in Table IX-5. Among the basic alternative transit concepts, the fixed guideway system has the highest benefit/cost ratio, with the 14-mile system length having the highest ratio of 1.28 to 1. The large benefits attained due to higher patronage attracted to the fixed guideway system, far outweighs the higher capital costs associated with the system, in comparison to the other alternatives.

F. EVALUATION OF OTHER FACTORS

The following evaluations represent a relative comparison of each alternative with respect to all others. Quantitative values have been used where possible although they are not representative of absolute values but simply comparative values.

1. Technical Risk

In general, all the vehicle and operating concepts included in these alternatives represent proven hardware. In the case of the LRT, it is simply an improved PCC streetcar with years of proven operation. The control system is essentially a proven block signal system and should not produce difficulty.

TABLE IX- 5 : SUMMARY OF BENEFIT/COST ANALYSIS
($ Million)

ANALYSIS FACTOR	BUSWAY	LRT	FIXED GUIDEWAY 7-MILE	FIXED GUIDEWAY 14-MILE	FIXED GUIDEWAY 23-MILE
A. CAPITAL COST *					
1. CONSTRUCTION & ROW	353.9	434.9	282.7	372.0	444.6
2. TRANSIT CARS	-	203.8	65.6	107.6	171.3
3. BUSES	126.3	60.1	105.1	78.7	66.8
B. O&M COST (PRESENT WORTH)**	738.5	728.8	748.5	657.9	706.5
C. TOT. COSTS (PRESENT WORTH)	1218.7	1427.6	1201.9	1216.2	1389.2
D. TOT. BENEFITS (PRESENT WORTH)	1397.4	1618.5	1437.0	1556.4	1735.6
E. BENEFIT/COST RATIO	1.15	1.13	1.20	1.28	1.25

* ECONOMIC FACTORS DETERMINED ON BASIS OF 30 YEARS OPERATION: CAPITAL COSTS FOR CONSTRUCTION AND TRANSIT VEHICLES ASSUMED COVERED FOR 30 YEAR LIFE; USEFUL LIFE OF BUSES TAKEN AS 10 YEARS WITH INITIAL PURCHASE REPLACED TWICE IN 30 YEARS AT 1974 COST LEVELS AND BROUGHT TO PRESENT WORTH AT 4%.

** O&M COSTS REPRESENT PRESENT WORTH OF 30 YEARS ANNUAL OPERATION.

Similarly, the fixed guideway vehicle, while somewhat more advanced in terms of suspension and controls, is essentially a proven technological application. However, whenever even proven subsystems are integrated into a whole system, some element of risks is unavoidable and initial "sorting-out" must be expected. In this context, the fixed guideway with the highest level of mechanical and electronic subsystems must be assigned the highest risk, the LRT system second highest, and the bus equipment the lowest risk relative to hardware technology.

However, the busway system has certain technical risks in its operations regarding schedule reliability on the high volume segment of the busway. There are no current busway system in operation with on-line stations and the high volumes projected for the Honolulu system. Further, bus equipment does not have comparable reliability as the electrically propelled LRT or fixed guideway vehicles.

The LRT system assumes the capability of main line coupling and uncoupling of vehicles and short headway merging of surface operation with grade separated operation. Both of these factors contribute to potential risks in the system operation and hence reduce schedule reliability of the system. In consideration of the above, the fixed guideway has the best schedule reliability, the LRT system next, and the busway system last.

2. Relationship To Development Policy

In general, all alternatives may be rated as supportive of stated development objective and policy. Due to the locational influence of fixed routes and stations on development, those systems possessing these features may be expected to produce the greatest impact on development policy. Similarly, since an important policy deals with encouraging downtown growth and concentration, those systems possessing the greatest capacity to deliver passengers will produce the greatest impact. Recognizing these and other factors, the alternatives may be ranked as follows in terms of increasing support for stated policy.

The staged construction of the fixed guideway concept to its full 23-mile length with 21 stations would be nearly comparable to the LRT concept with its 24 stations. The short 7-mile busway system with only 11 stations would still be supportive of the development policies but to a lesser extent by virtue of its length in comparison with the longer or potentially longer length LRT and fixed guideway concepts.

3. Environmental Factors

The full range of environmental factors were considered but due to the similarity of the degree of impact between alternative, only those that had pronounced differences are discussed. For comparative purposes in this discussion, only relative qualitative assessments will be included.

a. Visual and Noise Intrusion

In terms of the natural environment, each alternative has similar impacts since each follows essentially the same alignment. However, system length, particularly in terms of aerial and at-grade configurations, will have some increasing impact with increasing length. In some cases, extensions will mean elimination of median landscaping as in the case of the LRT in Kalanianaole Highway.

The busway will be a more intrusive structure than either the LRT or the fixed guideway because of wider way structure and larger stations required. In that context, smaller vehicles and guideway sections associated with the fixed guideway may be considered less intrusive than either the LRT or busway. The LRT with its catenary power system will substantially add to the visual intrusion of its aerial way structure in comparison to the fixed guideway utilizing the third rail concept.

Honolulu, with its "open window" living is very sensitive to noise intrusion. The bus engine emits higher noise level than either the fixed guideway or LRT vehicle systems[22/]. The busway system would create greater noise intrusions to the environment than the LRT or fixed guideway systems.

b. Air Quality

Transit, in general, can be considered a basic improvement to air quality as a direct function of its patronage level because of reduced auto travel. Further, it can be stated that electrically propelled transit vehicles are less polluting than vehicles with internal combustion engine except for sulfur dioxide (SO_2).

Diverted motorists for each alternative have been estimated by determining total passenger miles of travel for each alternative less passenger miles on the baseline bus system to determine person miles diverted from auto travel. Applying the average auto occupancy factor produces vehicle miles avoided.

The differential in emission between the baseline system and the alternative concepts have been calculated for 1995 using the following emission factors:

	AUTO [23/]	BUS [23/]	POWER PLANT [24/]
CO	12.00 gm/mi.	20.4 gm/mi.	-
HC	1.7 gm/mi.	3.4 gm/mi.	-
NOX	1.8 gm/mi.	34.0 gm/mi.	1.43 gm/KWH
PART.	0.6 gm/mi.	1.2 gm/mi.	0.09 gm/KWH
SO_2	0.2 gm/mi.	2.4 gm/mi.	1.67 gm/KWH

Table IX-6 shows the differential in emission between the baseline system and each alternative. The busway system reduces the carbon monoxide emission by the least amount and causes the highest increase in nitrogen oxides making this alternative the least desirable from the air quality standpoint. The LRT system causes the greatest increase in sulfur dioxide due to its high power consumption.

The baseline system is estimated to emit over 50,000 tons of CO in 1995 with its reduction estimated to be less than 10% by any of the alternatives. For this analysis the emission factors were not adjusted for speed since only relative values were desired. By taking into account the variations in speed and appropriately adjusting the emission factors, a greater reduction in CO and HC would occur.

In terms of composite reduction of all emissions, the 23-mile fixed guideway ranks the highest or best followed in order by the LRT, 14-mile and 7-mile fixed guideway, and the busway concept.

TABLE IX-6: AIR QUALITY
(Differential From Base System - Tons)

	CO	HC	NOX	PART.	SO_2
BUSWAY	- 2,970	- 400	+ 470	- 130	+ 10
LRT	- 3,730	- 510	- 160	- 160	+ 310
7-MILE F.G.	- 3,150	- 390	+ 170	- 130	+ 110
14-MILE F.G.	- 3,580	- 480	- 90	- 160	+ 110
23-MILE F.G.	- 4,190	- 590	- 260	- 200	+ 220

4. Community Factors

a. Residential And Business Displacement

One of the primary factors contributing to the high cost of living on Oahu is housing. The combination of high construction cost and high land value due to shortage of developable land causes housing to be both expensive and in short supply. Dislocation necessitated by removal of existing housing stock is a major factor in further aggravating the shortage which is reflected in an average of less than 1-1/2% vacancy rate existing in Honolulu.

For all alternative concepts, maximum utilization of existing street and highway rights-of-way is made. With the route alignment basically the same for all alternatives, the difference in relocation is attributed to facilities' size and location. The following compares the residential and business dislocation for the alternatives.

	RESIDENTIAL UNITS	BUSINESS UNITS
7-MILE FIXED GUIDEWAY	161	164
14-MILE FIXED GUIDEWAY	162	183
23-MILE FIXED GUIDEWAY	167	184
LRT (28-MILE)	171	188
BUSWAY (7-MILE)	233	257

The slightly higher number of relocation for the LRT system over the 23-mile fixed guideway system is due to the greater number of stations as well as the larger size of the stations.

The busway system, although only 7-miles in length, creates the largest number of dislocation which is attributable to several factors. First the wider aerial way structure with its attendant large or wide support piers cannot be accommodated in existing street medial strips without widening the existing roadway. The widening process requires the acquisition of additional residential and business structures. Especially critical is in the downtown area where the combination of a large station and wide underground way structure which is greater than the existing street right-of-way width affects a sizable number of structures, both residential and commercial.

In summary, the fixed guideway concept involves the fewest number of residential and business displacement. The busway concept, as explained above, entails a substantially larger number of displacements.

b. Service Quality

A broad range of factors can be considered in the service quality and availability of transit to various segments of the population.

With respect to service, no major discriminating factor can be reasonably applied to any of the alternatives since essentially equal coverage is provided by all. However, alternatives that attract higher patronage volumes should be credited as providing higher service quality and hence greater availability to special and all segments of the population.

Although improvements in bus design as a result of the Transbus program will aid the handicapped, the floor height platforms of transit stations will offer easier and safer boarding and alighting of these passengers. Service to the handicapped can be assumed to be superior for alternatives with the largest number of transit stations. From this standpoint, systems with the most stations available would rank slightly better although the bus systems and, to a lesser extent, the LRT reduce transfer requirements. Since any advantage of one alternative over the others would be quite small, all are considered to offer the same service quality for purposes of this comparison.

c. Short-Term Disruption

In terms of short-term disruption, any system that involves major construction will increase the disruption in direct relation to the amount of construction. In that context, the LRT system with its greater length and in-street construction will produce the greatest disruption. However, short-term disruption should not be considered as a primary factor in the choice of a system.

5. Energy Implications

Generally, vehicle systems using electrical propulsion will be more energy efficient, particularly where nuclear or hydro power is available. However, in Hawaii where all power generation is by fossil fuel plants, this variation will be minimized.

Of more direct benefit however, are the auto vehicle miles avoided by diversion to transit. Assuming 15 miles to a gallon of gas and applying the auto vehicle miles avoided used in the air quality discussion, the gallons of gasoline saved by each alternative is shown in Table IX-7. Also shown is the net diesel fuel consumption, i.e. over the baseline bus system operation, based on 5 miles per gallon consumption in bus operation and fuel oil consumption in the power plant based on 14 KWH generated per gallon of oil. Although 3 different types of fuel are used, the table shows the composite total of fuel savings for each alternative.

TABLE IX-7 : FUEL SAVINGS AND CONSUMPTION
(Million Gallon)

	BUSWAY	LRT	7-MILE	14-MILE	23-MILE
FUEL (GAS) SAVINGS DUE TO DIVERTED MOTORISTS	- 17.78	- 18.83	- 17.45	- 18.83	- 21.32
FUEL (DIESEL) CONSUMPTION FROM BUS OPERATIONS *	+ 5.28	+ 0.44	+ 3.16	+ 1.80	+ 0.85
FUEL (OIL) CONSUMPTION FOR GENERATING ELECTRICAL POWER	**+ 1.16	+ 14.64	+ 4.21	+ 6.05	+ 10.49
NET SAVINGS	- 11.34	- 3.75	- 10.08	- 10.98	- 9.96

* NET CONSUMPTION BY DEDUCTING BASELINE BUS SYSTEM FUEL CONSUMPTION.

** STATION AND TUNNEL POWER CONSUMPTION.

G. CONCLUSIONS

Where the selection of alternatives for evaluation are limited to only viable concepts which are carefully planned and optimized into efficient system plans, generally there should be no single overriding factor that would be the basis for the selection or rejection of a concept. The results of this study confirmed the selection and development of each alternative concept into a viable system plan that compared favorably with other alternatives in many aspects.

However, a careful examination of key evaluation factors would indicate the relative superiority or inferiority between alternatives as shown by the rankings in Table IX-8. Some of the more important tangible factors used in measuring alternatives are related to benefits and costs. Benefits are directly related to patronage which in turn is heavily influenced by trip speed. Capital costs are closely related to the extent of the system in terms of length and facilities provided with the operating and maintenance costs strongly influenced by the single unit or trained unit operation and scheduled speed of the system.

The more extensive a high level system, the more passengers would be theoretically attracted. This is exemplified by the difference in patronage volumes between the various fixed guideway system lengths. However, the marginal cost for each additional passenger attracted by the

TABLE IX-8: SUMMARY OF EVALUATION MEASURES

TRANSPORTATION COST-EFFECTIVENESS MEASURES *

	BUSWAY	LRT	FIXED GUIDEWAY 7-MILE	14-MILE	23-MILE
ANNUAL PASSENGERS (Million)	137.8 (5)	143.3 (2)	139.5 (4)	142.9 (3)	148.0 (1)
TOTAL ANNUAL COST ($ Million)	70.6 (3)	82.6 (5)	69.6 (1)	70.5 (2)	80.4 (4)
TOTAL COST/TRIP	51.3¢ (3)	57.7¢ (5)	49.9¢ (2)	49.3¢ (1)	54.3¢ (4)
BENEFIT/COST RATIO	1.15 (4)	1.13 (5)	1.20 (3)	1.28 (1)	1.25 (2)

OTHER EFFECTIVENESS MEASURES *

	BUSWAY	LRT	14-MI. FIXED GUIDEWAY
TECHNICAL RISKS			
- HARDWARE TECHNOLOGY	(1)	(2)	(3)
- SCHEDULE RELIABILITY	(3)	(2)	(1)
DEVELOPMENT POLICIES	(2)	(1)	(1)
ENVIRONMENTAL FACTORS			
- VISUAL INTRUSION	(3)	(2)	(1)
- NOISE	(2)	(1)	(1)
- AIR QUALITY	(2)	(1)	(1)
DISPLACEMENT (Residential and Business)	(3)	(2)	(1)
ENERGY IMPLICATION	(1)	(3)	(2)

* (1) denotes - ranking

23-mile system over the 14-mile system is significantly more than that between the 7-mile and 14-mile systems. Therefore, the 14-mile fixed guideway system would be the optimum length for Honolulu prior to the year 1995.

In comparing the various alternative concepts and their lengths and patronage volumes, the short 7-mile busway system is only slightly more costly than the 7- and 14-mile fixed guideway systems. It is however, less costly than the longer 28-mile LRT or the 23-mile fixed guideway systems implying that in the outer segments of the corridor where line volumes are less than 10,000 passengers per hour, the bus line haul system is more economical than the guideway system. Conversely, where line volumes are higher than 10,000 passengers per hour, the labor intense bus operation becomes more expensive than the guideway system.

The LRT alternative with some 28-miles of double tracks has the highest total annual cost of all alternatives and hence ranks the lowest with its high unit cost per passenger carried. This substantiates the above explanation of the greater efficiency of bus line haul system as compared to any guideway systems where line volumes are less than 10,000 passengers per hour.

An examination of a shorter 23-mile LRT system was made by dropping all branch lines and retaining the main line operation from Pearl City to Hawaii Kai. This LRT length was an improvement over the 28-mile length and only slightly more costly than the 23-mile fixed guideway system. However, it was more costly than the 14-mile fixed guideway which optimizes the best features of 2 modes, i.e. the high volume efficiency of the fixed guideway system in the central core and the low volume efficiency of the bus line haul system in the outer segments of the corridor. Although the facilities for an at-grade LRT is less costly than a grade-separated guideway system, the lower operating speed reduces its attractiveness and increases its operating cost.

From the foregoing, it is concluded that the basic fixed guideway concept is superior to other alternative concepts in terms of transportation cost effectiveness. The 14-mile length is the most cost effective fixed guideway length to implement up to 1995.

Other measures of system effectiveness are also tabulated in Table IX-8 by the ranking method. For ease of comparison, the fixed guideway system is represented as only one alternative concept utilizing the 14-mile length.

Based on the rankings shown in the table, the busway concept is found to be inferior to the LRT and fixed guideway systems for several key factors including schedule reliability, relationship to development policies, environmental factors, and residential and business displacements. In comparing the LRT concept with the fixed guideway concept, the latter shows distinct advantages in schedule reliability, visual intrusion, and residential and business displacement. The LRT concept has a very light advantage in the areas of technical risk in hardware technology and relationship to development policies.

In considering all measures evaluated, the fixed guideway concept is concluded to be superior to the other concepts. The fixed guideway concept shows its superiority in the most important transportation cost-effectiveness measure which is also supported by its many advantages related to various technical, environmental, and community factors. The refinement of the fixed guideway concept is fully described in a separate report [25/].

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