HONOLULU RAPID TRANSIT DEVELOPMENT PROJECT

REPORT ON BUS ON BUSWAYS

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BUS
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INTRODUCTION

The Oahu Transportation Study (1967) recommended that fixed facility rapid transit be included as an important element of the balanced transportation plan for metropolitan Honolulu.

Due to the City's long association with buses and the inherent flexibility of buses, there has always been a considerable interest in using buses to satisfy the City's mass transit needs and specifically in using a busway for the fixed facility rapid transit requirement. As a result, bus/busway alternatives were included in the major follow-on studies for the Honolulu Rapid Transit Project.

Specifically, three major studies were completed which thoroughly examined and evaluated busway systems for Honolulu. These studies are:

- Honolulu Rapid Transit Project Preliminary Engineering and Evaluation Program Phase I (PEEP I).
- Evaluation of Alternative Transportation Systems for the Pearl City-Hawaii Kai Corridor by Alan M. Voorhees & Associates, Inc.
- Honolulu Rapid Transit Project Preliminary Engineering and Evaluation Program Phase II (PEEP II).

This report summarizes the scope and conclusions of these studies. In the colored pages at the end of this document, this report provides a current assessment of the above studies' conclusions and their applicability to the situation that exists in Honolulu today and the current environment.

HONOLULU RAPID TRANSIT PROJECT PRELIMINARY ENGINEERING AND EVALUATION PROGRAM PHASE I (PEEP I)

Following the recommendation of the Oahu Transportation Study, the City applied for a Federal Urban Mass Transportation planning grant of $1.5 million to do a preliminary engineering evaluation study of a guideway system. Planning conducted in the first phase of the Preliminary Engineering and Evaluation Program (PEEP I) resulted in the definition of the basic transportation corridor and system. The system was designed to improve access to the major activity and employment centers located in the Honolulu core from all areas of the island, and to provide an alternative to the private car on the heavily congested streets and roads of Honolulu. The PEEP I Study recommended an island-wide system of local and express buses, operating both in mixed traffic and in reserved bus lanes. Buses would be integrated with a high volume, fixed guideway trunk line extending from Pearl City, through the urban core, to Hawaii Kai.

The total system proposed provided a local and express feeder bus system and a fixed guideway system with 20 stations along a 22-mile route. By 1995, approximately 500,000 daily passengers were estimated to use both the bus and guideway. Of this total, 350,000 passengers would use the fixed guideway system for at least part of their trip.

A medium capacity, lightweight, rubber-tired vehicle, 42 feet in length was recommended to accommodate this volume of riders.

This vehicle would be trainable to 10-car consists, and with the use of an automatic train control system, a minimum headway of 1-1/2 minutes could be attained. The maximum capacity of the system would be nearly 30,000 passengers per hour, one way, which would provide adequate system capacity to meet projected demands beyond the year 2010.

In addition to a bus system for local and express service, PEEP I evaluated a Bus on Busway alternative which would provide an exclusive, grade-separated roadway for express buses and perform the same function as the fixed guideway in a rapid transit system. In order to make an equitable comparison, the busway system was designed to meet the travel demands on which the fixed guideway rapid transit system was predicated. Therefore, the system was designed to carry 350,000 riders per day in the base year of 1995. The route and station locations were basically the same as those of the fixed guideway system and are indicated in Figure 1 on the following page. Two types of bus service would be provided on the exclusive busway: 1) express bus service with buses making limited stops, and 2) "local" service with buses making all stops along the busway.

The basic vehicles utilized in this alternative would be standard 40' transit buses with a seating capacity of 50 people, similar to those presently operating on City streets. In addition, 60' articulated buses that can seat 70 passengers per bus were examined in this analysis. These large buses would be limited to operations on the busways only.


HONOLULU RAPID TRANSIT SYSTEM
Alternate System II
BUS ON BUSWAY SYSTEM
Express Bus in Exclu. Busway
Express Bus in Mixed Traffic
Express Bus Stop
Local Feeder Bus

FIGURE 1

The Bus on Busway concept was developed as a modified trunk line/feeder system similar to the recommended fixed guideway system. It would serve as the fast link, high volume trunk line servicing the major activity centers in a general east-west direction. Collection and distribution to and from this trunk line would be performed by local feeder buses. Some of these local buses would operate in a flexible mode capacity by operating as feeder buses on surface streets, then driving onto the exclusive busway to perform a line haul function on the busway. Additionally, with the provision of on-and-off ramps at required locations, express buses operating on streets and highways will also operate on the busway. In general, service coverage for the Bus on Busway system is identical to that of the fixed guideway rapid transit system.

COMPARATIVE COST ANALYSIS:

In presenting the results of the comparative costs, the PEEP I study utilized the present-worth cost comparison method. Based on a 5% per year escalation rate and a 5% interest rate, the present-worth values would remain unchanged from the 1972 dollar costs irrespective of the time of the expenditure. The time period used was 30 years which is the normal life expectancy of many major system components such as electrical conductors and switchgears, transformers, and rectifiers, and heavy structural steel elements such as guiderails and switches.

The capital costs shown in Table 1 are in two parts; the initial capital expenditures and the additional capital and replacement costs. Under the initial capital costs, the cost of vehicles to meet the 1985 demand was included. Under the additional capital and replacement costs for the fixed guideway, cost items are: 1) additional and replacement vehicles based on a 30-year life, 2) additional traction power cables required to operate maximum train consists, and 3) additional storage tracks required to accommodate the increase in the vehicle fleet for the fixed guideway system. For the busway system, the items include additional and replacement buses and a second storage and maintenance facility to maintain the larger fleet of buses. All capital costs are reflected in 1972 dollars.

Table 1 presents costs of the full 22-mile busway system using all 40' buses under one condition and a mixture of 40' and 60' buses under a second condition. Table 1 also presents a summary of the present worth costs of a 19-mile busway system* from Halawa to Hawaii Kai with the segment between Halawa and Middle Street utilizing the proposed H-1 Freeway lanes. This table also reflects two conditions with the use of 40' buses only and the use of a combination of 40' and 60' buses.

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*Note: This 19-mile busway system is identical to 22-mile busway system in terms of patronage, service characteristics and equipment. In place of the exclusive busway structure from Middle Street to Pearl City, buses would operate in pre-empted lanes on the H-1 Freeway.

TABLE 1

SUMMARY OF COST ESTIMATES[1]
($ THOUSANDS)

	22-Mile Systems			19-Mile Systems		
	Fixed Guideway	Busway w/40' Buses	Busway w/40' & 60' Buses	Fixed Guideway	Busway w/40' Buses	Busway w/40' & 60' Buses
CAPITAL COSTS						
Way Structure & Stations	$ 188,500	$ 234,500	$ 238,100	$ 166,340	$ 200,730	$ 203,430
Power & Control Systems	57,000	2,000	2,000	49,700	1,700	1,700
Storage & Maint. Facilities	16,500	5,000	6,000	16,500	5,000	6,000
Vehicles	52,200	14,200	15,400	46,250	13,070	14,520
Subtotal	$ 314,200	$ 255,700	$ 261,500	$ 278,790	$ 220,500[3]	$ 225,650[3]
Admin. & Engrg. (13%)	$ 40,850	$ 33,240	$ 34,000	$ 36,240	$ 28,660	$ 29,330
R.O.W. & Relocation	95,600	112,000	112,000	93,440	106,100	106,100
Contingency (15%)	67,590	60,140	61,120	61,270	53,290	54,160
Total Initial Capital Costs	$ 518,240	$ 461,080	$ 468,620	$ 469,740	$ 408,550	$ 415,240
Add'l Capital & Replacement Cost	$ 59,540	$ 76,570	$ 80,470	$ 56,830	$ 73,860	$ 78,540
Total Capital Cost	$ 577,780	$ 537,650	$ 549,090	$ 526,570	$ 482,410	$ 493,780
OPERATING & MAINT. COSTS[2]						
Guideway or Busway System	$ 512,250	$ 676,500	$ 603,150	$ 469,500	$ 612,700	$ 546,300
Feeder System	559,500	559,500	559,500	601,500	601,500	601,500
Total O & M Cost	$1,071,750	$1,236,000	$1,162,650	$1,071,000	$1,214,200	$1,147,800
TOTAL COST	$1,649,530	$1,773,650	$1,711,740	$1,597,570	$1,696,610	$1,641,580

[1]Costs shown are 1972 dollars which would be the same as present worth cost based on 5% escalation & 5% interest rate.
[2]Present worth cost for 30-year period.
[3]Includes $20 million for worth of bus lanes on H-1 Freeway

The results of this comparative analysis are as follows:

- For the full 22-mile systems, the present worth cost of the busway alternatives are in excess of $120 million and $60 million more, utilizing 40' buses and 40'and 60' buses, respectively, than the equivalent 22-mile fixed guideway system. (See Table 2 below.)

- For the 19-mile system, the present worth cost of the busway alternatives are $99 million and $44 million more, utilizing 40' buses and 40' and 60' buses, respectively, than the equivalent 19-mile fixed guideway system. It is pointed out that in the busway capital cost, approximately $20 million worth of freeway facilities required for the exclusive use of the buses are included. (See Table 2 below.)

TABLE 2
Present Worth Comparison
($ Thousands)

	Fixed Guideway	Busway 40'Buses	Busway 40' & 60' Buses
22-Mile System			
Total Cost (Difference)	$ 1,649,350	$ 1,773,650 (+124,120)	$ 1,711,740 (+62,210)
19-Mile System			
Total Cost (Difference)	$ 1,597,570	$ 1,696,610 (+99,040)	$ 1,641,580 (+44,010)

In these cost estimates, it is significant to note that capital costs for the busway structure and stations, right-of-way acquisition and vehicle replacement are appreciably higher than for fixed guideway rapid transit alternative. Propulsion power and automatic train control systems and rapid transit vehicles provide the only costs where the fixed guideway costs are initially higher than the busway. The operating and maintenance cost for the busway system is higher than that for the fixed guideway system which is primarily due to higher cost of labor in operating the buses.

BUSWAY SYSTEM OPERATING CONCEPTS

Two basic 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 other buses and are unconstrained to dock at any station, to enter or leave the busway at ramps, and to completely by-pass stations.

SINGLE-FILE CONCEPT

Under the "single-file" concept, there are two methods of operations, 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 feet long.

The second method of operation is the random method where buses 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.

1. Line Capacity

In order to determine the capacity of the platoon concept, the following theoretical 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

*Dwell time is the time at a bus stop to receive and discharge passengers.

Based on the above minimum headway, the theoretical maximum line capacity for a 10-bus platoon carrying 50 passengers per bus is 13,000 passengers per hour. This capacity is considered as theoretical only with the volume subject to probable decrease depending on the application of the 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.

2. 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 station. However, when the buses perform both a line-haul function on the busway and a collection-distribution function on surface streets and highways, certain constraints are imposed as follows:

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

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

c. 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.

d. 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 queue of buses were assigned the entrance end of the platform for docking, it would hold up the entire queue 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. However, generally under a low volume operation, the random method may be more flexible while under a high volume operation, the platoon method appears to be more orderly and safe and easier to schedule.

3. <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 80,000 bus miles per day expected in 1995, this could mean four road calls on mechanical failures occurring each day on the busway. Although the possibility 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.

4. <u>Station By-Pass</u>

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 running 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 interruptible to the busway operations.

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 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 each station, on a "limited stop" basis with only certain buses stopping at selected station, 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. 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 station. The difference is that the buses operate on an express basis. The buses, upon loading at certain stops, 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 the PEEP I analysis, the system utilized a combination of busway operating methods one and four, mentioned above, but with a slight change in operating method four in that there was also 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 analysis, a busway system was compared with a fixed guideway system, therefore, to keep this comparison on an equal level, only the activities of the buses on the exclusive busway were considered. Bus activities on the feeder routes were not considered because they were assumed to be the same for both systems. However, bus on-ramps were included in capital costs to allow the no-transfer benefit of the busway alternative. In the operations of the busway system, the flexibility inherent in bus operations has been recognized and appropriate turnbacks have been incorporated along with express bus service on the busway.

C. SUMMARY AND CONCLUSIONS OF OPERATING CONCEPTS

A comparison of operating concepts is shown in Table 3. A review of the comparison indicates that the single-file concept has serious deficiencies 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.

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 continue 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 operation conditions of the single-file concept.

The PEEP I study, therefore, concluded that the flexible concept is far superior to the single-file concept and was selected for the busway system analysis.

TABLE 3

COMPARISON OF BUSWAY OPERATING CONCEPTS

	Single File Concept		
	Platoon	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

BUSWAY SYSTEM OPERATIONS AND SCHEDULE

Each bus was assumed to accelerate from 0 to 30 mph in 18 seconds and from 30 to 50 mph in 31 seconds. The buses were also assumed to decelerate at an average rate of 2.0 mph/second. With the distance between stations and bus acceleration and deceleration rates known, the speed and time between any two stations can be calculated. The maximum scheduled speed was assumed to be 50 mph. To compute the scheduled speed and size of the bus fleet, the average dwell time at stations between Liliha and Koko Head was assumed to be 30 seconds, while all other station dwell times were assumed to be 20 seconds. For buses to operate without delay, in and out of the stations, high loading platforms would be required. Also, the buses were assumed to be designed with a special device at each door sill which would extend outwards towards the platform to load and unload passengers expeditiously.

If a bus passed through a station without stopping, the speed was assumed to be reduced to 30 mph through the station. Each bus was assumed to carry an average of 58 persons during the peak period. The average speed for buses stopping at every station along their route was approximately 27 mph while express buses average approximately 31 mph.

It was assumed that buses could get on and off of the busway at certain stations along the busway. These stations were at Pearl City, Halawa, Kalihi, Waikiki, University, 6th Avenue, and Hawaii Kai. These stations were selected because, from the patronage study, these were the stations at which a higher number of transit riders would be arriving by either feeder buses or express buses. At these stations, all express buses and approximately 75% of the feeder buses that arrives at the stations were assumed to proceed onto and operate on the busway. To meet the number of required vehicles needed to handle the additional riders that get on the system at stations besides those mentioned above, it was assumed that there would be a certain number of buses that operate only on the busway stopping at every station. To accommodate these buses, bus turnarounds were assumed to be located at the Pearl City, Halawa, Kalihi, 6th Avenue, Kahala, and Hawaii Kai stations. The location of on and off and turnaround points of all bus routes were based on projected ridership volumes at the various origin and destination stations.

There are 8 operating routes along the busway during the peak periods. The buses, on 6 of these 8 routes, would stop at all stations along their respective routes while the buses on the other 2 routes would stop only at selected stations along their routes.

The required vehicles for the years 1980, 1995, and 2010 was determined to be 222, 458, and 598, respectively.*

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*It should be restated at this point that only the operations of buses on the busway were analyzed. The express and feeder bus system are the same for both the fixed guideway and busway systems. Therefore, the number of required vehicles are additional buses that are required for that portion of the bus operations that occurs on the busway.

The total number of vehicles required includes 10% additional vehicles needed for rotation of vehicles when regular and special maintenance is required.* The number of buses needed between any two stations during the peak period was calculated to meet the peak period load. The basic objective of instituting different turnarounds and on or off points for routes originating from the same stations was to minimize transfers and to maximize the load on each bus up to an average of 58 persons per vehicle. By varying route lengths, the total round trip time of each bus could be reduced while still meeting the peak period load. Reducing the total trip time for buses on a route would decrease the number of actual vehicles needed on that route while at the same time maintaining the required headway.

With the headways and number of vehicles required for each bus route during the peak period known and also the round trip times and distances for each route obtained, the total number of vehicle hours and vehicle miles for the peak hour could be calculated. The analysis of the bus operation on the busway was based on operating 40' buses on the full 22-mile system. The same analysis was done for:

1. 40' buses on the shortened 19-mile system,
2. 40' and 60' buses on the full 22-mile system, and
3. 40' and 60' buses on the shortened 19-mile system.

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*It is noted that UMTA is insisting that a 20% spare ratio be used in Honolulu's current studies.

In the analysis of operating 40' and 60' buses on the busway, the 60' buses were assumed to be the buses that operate only on the busway stopping at every station. The 40' buses were assumed to be the buses that could get on or off the busway at the above-mentioned stations. Also, the 60' buses, due to its larger size, could carry up to 40% more passengers than a 40' bus using the same space standards. Therefore, each 60' bus was assumed to carry an average of 81 persons during the peak period.

For the shortened 19-mile system, there are 6 operating routes along the busway during the peak periods. There is one route on which buses would stop only at selected stations and on the remaining 5 bus roues, the buses would stop at all stations along their respective routes.

Table 4 contains a summary of operating data obtained from the analysis of operating only 40' buses on both the 22-mile system and the 19-mile system. Table 5 contains a summary of operating data obtained from the analysis of operating 40' and 60' buses on both the 22-mile system and the 19-mile system.

TABLE 4

BUSWAY SYSTEM OPERATING DATA
40' BUSES ONLY
SUMMARY

	22-Mile System			19-Mile System		
	1980	1995	2010	1980	1995	2010
No. Buses Required	202	416	544	189	378	506
10% Spares	20	42	54	19	38	51
Total No. Buses	222	458	598	208	416	557
Bus Hours/Day	1,740	3,590	4,700	1,630	3,270	4,370
Bus Hours/Year (thousand bus-hours)	523	1,077	1,410	489	981	1,312
Bus Miles/Day	41,540	87,750	116,390	38,540	79,210	105,740
Bus Miles/Year (thousand bus-miles)	12,463	26,326	34,918	11,562	23,764	31,722

TABLE 5

BUSWAY SYSTEM OPERATING DATA
40' & 60' BUSES
SUMMARY

	1980			1995			2010		
22-Mile System	40'	60'	Total	40'	60'	Total	40'	60'	Total
No. Buses Required	80	87	167	161	183	344	180	260	440
10% Spares	8	9	17	16	18	34	18	26	44
Total No. Buses	88	96	184	177	201	378	198	286	484
Bus Hrs/Day	690	750	1,440	1,390	1,580	2,970	1,560	2,240	3,800
Bus Hrs/Yr (thousand bus hrs)	208	226	434	418	474	892	467	672	1,139
Bus Miles/Day	17,510	17,140	34,650	35,700	37,180	72,880	40,950	53,850	94,800
Bus Miles/Yr (thousand bus-mi)	5,254	5,143	10,397	10,711	11,153	21,864	12,285	16,154	28,439
19-Mile System									
No. Buses Required	76	84	160	150	169	319	189	193	382
10% Spares	8	8	16	15	17	32	19	19	38
Total No. Buses	84	92	176	165	186	351	208	212	420
Bus Hrs/Day	660	720	1,380	1,300	1,460	2,760	1,440	2,100	3,540
Bus Hrs/Yr. (thousand bus hrs)	197	217	414	389	438	827	431	630	1,061
Bus Miles/Day	15,920	16,160	32,080	31,760	33,890	65,650	36,160	49,670	85,830
Bus Miles/Yr (thousand bus-mi)	4,775	4,848	9,623	9,529	10,168	19,697	10,849	14,902	25,751

BUSWAY AND STATION REQUIREMENTS

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 to 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 more bus miles operated in the same length of time as well as significant time savings by transit patrons.

Busways, with an uninterrupted and continuous flow of buses through a long segment of the busway without stops, can theoretically accommodate as many riders as the fixed guideway system. However, the operations of a large number of buses through an on-line station poses many problems and provides significant constraints on theoretical capacity.

A. STATION REQUIREMENTS

By the year 1995, it is projected that the highest volume station located in the CBD would have some 9,000 passengers boarding and alighting, in one direction, during the peak hour period. It is estimated that during this peak period, approximately 400 buses per hour will be operating in one direction, through this station. Taking this number of buses and the average dwell time for the number of passengers boarding or alighting at this station and factoring in a safety factor for the inability of buses to meet precise schedules and to maintain the free flow of buses, it was determined that 10 bus stalls would be required.

These 10 bus stalls are required to only handle the 1995 on- and off-volumes at the CBD station. Generally, fixed facilities of this type are designed to last for more than 15 years. Thus, to provide adequate facilities to handle additional volumes in the years beyond 1995, an increase of 1/3 the number of bus stalls should be provided. Therefore, a total of 14 bus stalls should 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, 7 platforms in one direction would be required. There should also be enough loading platforms to handle the different bus routes that stop at each of the stations. Each bus route should be assigned to a certain bus loading platform so that the passengers could enter the correct platform to catch their correct buses. Some of the bus routes with a lower number of buses operating on them could be assigned to the same loading platform, but to prevent overcrowding of passengers on the platforms, no more than two routes should be assigned to any one platform. At this particular high volume CBD station, there is a total of 8 bus routes that operate through this station in either direction.

If every bus route that passes through this CBD station in either direction were assigned a particular loading platform, then the minimum number of bus platforms needed in the Koko Head direction would be 6 platforms and in the Ewa direction, 4 platforms. But it has already been determined that to minimize delays in the system and to maintain free flow in any one direction, 7 platforms will be required. Therefore, at this station, a total of 14 bus platforms for both directions will be provided. This same analysis was used to determine the number of bus platforms required for each of the other stations.

In comparison, for the fixed guideway system, the stations require either a single center platform or two platforms on either side of the tracks, long enough to handle the peak number of cars per train which would occur during the peak periods. Therefore, the platforms for the fixed guideway system were assumed to be approximately 400' long (40'/car x 10 cars/train).

Plate 1 (Plates are at the back of this document.) shows a comparison between the plan views of a typical <u>high</u> volume station for both the fixed guideway system and the busway system. Plate 2 shows a comparison between the plan views of a typical <u>low</u> volume station for both the fixed guideway and the busway system. The cross-sectional views of a typical <u>high</u> volume, <u>underground</u> station and a typical <u>low</u> volume, <u>aerial</u> station for both the fixed guideway system and the busway system are shown in Plates 3 and 4, respectively.

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 entering the stations and thus permit through buses to by-pass stations without delay. It would also provide the flexibility of permitting trailing buses to dock even if the front bus must wait for its assigned docking space to clear. Similarly, the additional acceleration lane would permit almost simultaneous departure of 2 buses and thus improve the operating capability of the system.

On segments where roadway link volumes are high and where stations are approximately 1/2-mile apart, i.e., the downtown area, the roadway width should remain equal to 4 equivalent lanes through the entire distance between stations. With the roadway between stations being 4 equivalent lanes wide, the roadway would be wide enough for buses to move freely in both directions even with a stalled vehicle in the way.

Beyond the acceleration and deceleration lanes, in segments where the roadway link volumes are low, the minimum roadway width requirement should be 2 lanes. But these 2 lane segments should be provided with sufficient shoulder widths such that if a vehicle with mechanical problems pulls over to the side of the roadway, the buses moving in either direction could squeeze through the remaining width of the roadway. To squeeze through the remaining portion of the roadway, the buses would have to reduce their speed and therefore create delays in the schedule but these delays would be small in comparison to what the delay would be if no room was provided for buses to by-pass the stalled bus.

In comparison, the fixed guideway system which is less prone to mechanical failure has only two sets of tracks. This is due to the fact that even with one or two vehicles in a train inoperable, the other vehicles in the train or consist can pull the disabled vehicles at slower speeds, but the system can still operate. Storage tracks would be provided at various points to store the disabled train until off-peak periods at which time it could proceed to the maintenance facility.

The cross-sectional views of an equivalent 3-lane aerial busway structure and an equivalent 4-lane aerial busway structure are compared with the aerial way structure for the fixed guideway system in Plates 5 and 6, respectively. Plate 7 shows a comparison between the cross-sectional views of the underground portions of the way-structure for both the fixed guideway system and the busway system.

ENVIRONMENTAL AND SERVICE CONSIDERATIONS

A. AIR POLLUTION

A regional analysis of air pollution environmental impact was conducted.* This study identified five (5) primary types of pollution emissions which are: hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), and particulates. The following is a comparison of these five pollutants based on 1995 trip volumes and shown as absolute tonnage differential from a base system which is an extrapolation of the current transportation system, i.e., autos plus buses.

	HC	CO	NO_x	SO_2	Particulates
Fixed Guideway	-1,420	-16,800	-36	+224	-23
Busway	-1,220	-16,170	+763	+10	-2

The above table shows that the fixed guideway system reduces all major pollutants except SO_2 for the entire region. The busway system reduces the HC, CO, and Particulates but contributes to increase of NO_x and SO_2. Relative to the fixed guideway system and its SO_2 generation, the power plant emission source is located away from the downtown area where major concentration of pollutants occur. Based on the fact that only a negligible amount of pollutants will be dispersed over the highly developed urban area traversed by the fixed guideway system, the differential in pollutant tonnages are as follows:

*"Air Pollution Environmental Impact Study for the Proposed Honolulu Rapid Transit System," by James N. Pitts, Jr., Ph.D., et al., September 7, 1972.

	HC	CO	NO_x	SO_2	Particulates
Fixed Guideway	-1,420	-16,900	-437	-78	-44
Busway	-1,220	-16,170	+763	+10	-2

The fixed guideway system will reduce all pollutants in the urbanized area while the busway system will continue to contribute pollutants in the form of NO_x and SO_2.

B. NOISE POLLUTION

A comparison of noise emission by the two systems was made for both daytime and nighttime conditions.* During the daytime, the fixed guideway system will be operating trains up to 10-car consists during peak travel periods and reduce to an average of 5-car consists during non-peak periods. At nighttime, the trains will be operated with a minimum of 2-car consist. The buses will, of course, all operate individually throughout the day. The comparison of noise emissions are as follows:

	Fixed Guideway	Busway
Daytime	64 to 72 dBA	75 to 80 dBA
Nighttime	61 to 68 dBA	75 to 80 dBA

The above noise levels are based on a distance of 50 feet from the emission source. It can be concluded that buses will generate significantly higher noise pollution than the fixed guideway vehicles. The difference of approximately 10 dBA is considered to be "one-half as loud" subjectively, thus the 10 dBA

*"Noise and Vibration Characteristics - Honolulu Rapid Transit System," by Wilson, Ihrig & Associates, Inc., August 1972.

higher noise level of the buses may be considered as twice that of the fixed guideway vehicles in loudness.

C. AESTHETIC AND VISUAL IMPACT

The aerial structure for the busway will be over 30 feet in width at the minimum section and widens out to over 50 feet in width adjacent to the stations. The fixed guideway structure is planned to be between 22 to 23 feet of constant width for the entire system. The busway station structures are also much wider than the fixed guideway station and also much larger in total area at the high volume stations.

The net effect of the larger busway facilities would make it more obtrusive to the communities which the route traverses. Its greater width would also make it much more difficult to properly landscape the area underneath the structure. In addition, the on- and off-ramp structures would add to the obtrusiveness of the total system. Thus, the greater physical dimensions required of a busway system is more likely to have a greater aesthetic and visual impact on the community than the fixed guideway system.

D. SERVICE RELIABILITY

Service reliability may be defined as including adherence to operating schedules, minimal down-time, i.e., part or all of system not operating, due to equipment breakdown or external effects such as inclement weather.

One of the primary factors which influences system attractiveness for transit service is service reliability. Service reliability means not only schedule reliability but also system reliability or service availability all year around.

The first of the key features which determine service reliability is conducting the vehicles. The fixed guideway system is planned to be fully automated with starting and stopping, door opening and closing, and maintaining safe separation between trains as all automatically controlled. The operations will be computer programmed to automatically adjust the operations such that any slight unscheduled delays can be corrected.

The second key feature is the vehicles themselves. The electric motor is a simple machine with a high degree of reliability. A high performance internal combustion (diesel) engine has many components and, when compared to the electric motor, it has a lesser degree of reliability. Additionally, single unit operations versus a trained-unit operation has certain flexibility but conversely a trained-unit can continue to operate near its programmed schedule even if one motor were out of commission. (See pages 31 and 32.)

The third feature is the concept of guided vehicles versus manual guidance. Automated systems with proper design and maintenance can achieve a high degree of reliability. The reliability of a system operated by a human being, however, is much more difficult to control and predict. Where only a few persons are required with proven skill, they can be carefully selected and a high degree of reliability can be expected. However, where some 1,000 drivers are required to operate a fleet of 500 buses, the selection and monitoring of each driver becomes more difficult and consequently the reliability reduces. This is not to imply that bus operation is unsafe but merely a comparison of the degree of reliability for safe operation in guiding the vehicles on the way structure.

E. "NO-TRANSFER" SERVICE CONVENIENCE

Perhaps the feature that distinguishes the busway system from the fixed guideway system to the greatest degree, in fact more than cost, environmental impact, or service reliability, is the basic operational concept of the vehicles. The fixed guideway system, as the name implies, is a vehicle system fixed to the way structure and capable of being operated in a trained-unit. The busway system utilizes a single, manually operated road vehicle which can operate both on the busway as well as surface streets and highways. This capability to operate on both the busway and streets permit the vehicles to perform both the line-haul (on busway) function as well as the collection-distribution function (on streets).

The classical argument that has prevailed since the beginning of rail transit and motor buses is that with motor buses, no transfers are required. Transfers are certainly undesirable and the value of "no-transfer" should not be minimized. However, it must also be recognized that even with a flexible bus system, transfers cannot be eliminated for all transit trips.

It is a known fact that an ideal situation is where all trips have a single concentrated origin and a single concentrated destination. As the origin or destination ends of the trips become more dispersed, then the collection-distribution function relative to the line-haul function becomes greater in terms of time and distance. It may be assumed that the greater the dispersal of trip ends, the more difficult it becomes for a single vehicle to perform both functions of line-haul and collection-distribution efficiently. In fact, it is difficult to efficiently perform the collection-distribution function even with a separate vehicle tailored in size and type to meet the demand. This then becomes a trade-off between the convenience of no-transfer against greater operational efficiency with transfers.

An analysis of transit trip characteristics and volumes indicate that on the origin end, various modes of arrival to the rapid transit facility exist of which some 60% of total trips arrive by feeder and express buses. The feeder bus routes and schedule as planned indicates that about 1/3 of the routes are relatively low volume with headways averaging 15 minutes or greater. For these low volume routes, the operating plan of the busway systems provides separate feeder buses which do not enter the busway. Thus, about 40% of the total riders using the busway services are provided with "no-transfer" service with buses performing both line-haul and collection functions. The remaining 60% are therefore, not affected by this operational concept.

FINDINGS AND CONCLUSIONS

The comparative matrix shown on the following page summarizes the major evaluative factors considered for the alternative systems. It can be seen that except for the "no-transfer" convenience factor, all remaining factors are clearly in favor of the fixed guideway system. The question then is, would the "no-transfer" convenience to some 40% of the total riders using the busway system outweigh the sum of the advantages of all the other factors which are in favor of the fixed guideway system. If each of the factors were equally weighted in value, then the fixed guideway system must be assumed to be the "better" system. For the busway system to be considered as being superior to the fixed guideway system, the "no-transfer" convenience factor must be weighted to at least 5 times the value of each of the other factors.

Based on the foregoing discussions, it is concluded that, in terms of all relevant factors analyzed, the fixed guideway system is considered to be superior to the busway system and would be a better investment of public funds on the long-run basis.

COMPARISON MATRIX

	Fixed Guideway	Busway	Comments
Air Pollution	X		Less total pollution in 1995 by 1500 tons.
Noise Pollution	X		Less noise emission by 10 dBA which is equivalent to on-half the subjective loudness.
Aesthetic & Visual	X		Less obtrusive due to less massiveness of way and station structures.
System Reliability	X		More reliable due to fully automatic operation of trained units utilizing electric motors with many years of proven experience.
Service Convenience		X	More convenient to approximately 40% of total rapid transit riders by eliminating inter-modal transfers.
Economics	X		Less total present worth cost over 30-year period from $40 million to $120 million depending on size of buses used and length of system.

STATE DEPARTMENT OF TRANSPORTATION BUSWAY CONCEPT

The State Department of Transportation suggested as an alternate the inclusion of an interim system consisting of standard 40-foot buses with special mechanical guidance operating on the same structure that is envisioned for the long-range fixed guideway system.

This concept envisioned a marriage of the modes. Transit buses would utilize suburban city streets for collection and distribution of passengers, exclusive bus lanes on freeways for line haul, and an exclusive transit guideway to serve the core of the urban area (Kapiolani Interchange to Keehi Interchange).

The State busway concept was intended as an interim system with a capacity of 12,000 passengers per hour peak direction. It would be converted to an electrically propelled, fully automated rapid transit system when patronage requiring the movement of 20,000 passengers per hour is reasonably assured.

The basic vehicle would be a standard transit bus 40 feet in length altered to include an exterior mechanical guidance device connected to the standard steering mechanism of the bus.

The PEEP I study concluded that the State busway concept was not acceptable as an alternative for consideration for the following reasons:

a. It would not satisfy future patronage demands. Therefore, as an interim system, it did not appear prudent or economical to invest in an automated busway when it was expected to be converted into a fixed guideway rapid transit system. In other words, as long as it was known that a fixed guideway system was ultimately going to be installed, it was better to go that route initially.

b. It did not meet the criteria as established for alternative systems in the study in that it was not in production or in an advanced prototype stage.

c. The guideway as proposed by the State made no provision for passing of disabled vehicles. Assuming operations at 12,000 passengers per hour (50 passengers per bus and 240 buses per hour), bus headways would be 15 seconds. A breakdown of a bus during peak hours could pose real problems in terms of the buses stacked on the guideway behind the disabled coach.

d. Conversion of the busway to the long-range system must be considered. Regardless of the construction phasing, there would undoubtedly be serious interruption of transit service during the conversion period. In addition, testing of the automated vehicles to assure fail-safe service could interrupt normal transit service unless a separate test track would be constructed.

e. Other operational problems of a busway system, such as platooning to assure specific locations for buses serving specific routes at the station platforms, were previously discussed.

EVALUATION OF ALTERNATIVE TRANSPORTATION
SYSTEMS FOR THE PEARL CITY-HAWAII KAI CORRIDOR

After completion of the PEEP I study, the City of Honolulu and the State of Hawaii jointly sponsored a study of an automated rapid transit (ART) system and a review of the busway alternative which was completed under PEEP I. The State DOT specifically requested that the renowned busway expert, Mr. Thomas Deen, Vice President, Alan M. Voorhees & Associates, conduct the study. (T. Deen is the Executive Director of the Transportation Research Board at present.) This study provided a comprehensive review of the PEEP I busway alternative analysis including review of the physical design, operating concept, and costs to determine the validity of the analysis and if any improvements could be made to the system.

The busway alternative followed the alignment of the PEEP I alternative. It consisted of a grade-separated busway of sufficient width to permit two-way operation. Stations were provided at the same places as the PEEP I alternative and ramps were provided at selected locations to permit combined feeder-express routes.

The task of this study was to conceive of busway systems that seem most appropriate for Honolulu, and to evaluate them in comparison to a fixed guideway system. The approach used was to evaluate the PEEP I analysis, with particular respect to seek in other alternative busway concepts, assumptions, or analyses which might reasonably be performed and which would have a significant impact on the comparison of the two modes. The purpose was not to second-guess PEEP I on all of these points; instead it was to look for only those points which would have a "significant" impact on the result. The question was what was significant? It can be noted that the PEEP I comparison of busway and fixed guideway costs (including land, construction, and operation) showed the rail system with a present worth of about 1.6 billion dollars and with the busway system at 4 to 7 percent more costly. Thus, for the busway system to be <u>less costly</u> than the fixed guideway would require that the analysis be in error by 50 to 125 million dollars (estimated on a present-worth basis). This, then, provided some guidelines as to the size of errors and of the dimensions of the word "significant" when looking for significant impacts on the final cost conclusions.

This led to the following specific areas of inquiry:

- Are there ways to utilize buses operating on separate roadways which will save $50 to $100 million (after discounting to present worth) compared to the PEEP I busway system, either in capital costs, operating costs, or a combination of the two? Alternative schemes which have a smaller cost impact would not likely alter the final outcome.

- Do busway schemes provide a level of service significantly greater than the guideway system? If busway schemes provide better service, is the present worth of this betterment equal to $50 to $100 million?

- If costs between the two systems are equal (or the difference between them is less than the likely error in the cost estimates) the community must decide between the systems on their subjective differences: in other words, their air pollution impacts, noise levels, public acceptance, and reliability.

STUDY CONCLUSIONS

Based on their analysis of potential ways in which costs of the busway might be reduced or the busway concept improved such that it is clearly superior to the fixed guideway system, the consultants concluded "there is no reason to believe that a busway system would be less costly in Honolulu than a fixed guideway system when both construction and operation cost is considered." They also agreed with the PEEP I findings "that from the standpoint of air pollution impact, noise, aesthetic and visual impact, and system reliability the fixed guideway system was superior." The consultants further stated that "we have been able to produce no calculations which can refute [the PEEP I finding] that the fixed guideway was superior from an economic standpoint."

The following are the consultant's conclusions concerning specific areas of inquiry:

a. With regard to Busway System Costs and Bus Operating Concepts:

"Use of the single "cost-service" measure in comparison of the alternatives cited above suggests that the hybrid system used for analysis by [PEEP I] should be as efficient as any other in the Honolulu context. It seems to appropriately exploit the flexibility and other capabilities of bus operations. There is no apparent reason to suppose that changing the operating concept analyzed by [PEEP I] would result in any significant savings or improvement in performance of the system."

b. With regard to Busway Standards:

"We must conclude that the busway standards proposed by [PEEP I] for the busway evaluations are adequate for their purpose (i.e., to estimate construction costs), that if anything they are on the conservative side (i.e., they tend to underestimate busway cost estimates), and that to assume a small, less expensive busway with lower costs would not allow a fair comparison to the fixed guideway system."

c. With regard to using Platoon Method to reduce bus station size:

"Thus, using optimistic assumptions concerning operating methods on the busway system, about development of new longer buses with much larger doors, and about construction costs of the underground busway, it appears that no significant savings would accrue from using the platoon method of busway operation."

d. With regard to underground stations:

"We conclude that surface stations might provide some cost reductions as compared to underground station construction, contingent on the very difficult problem of finding suitable sites and upon efforts to solve the currently unknown problem of layout and design of the terminals."

e. With regard to the use of "free" freeway lanes:

"[T]he cost comparison still favors the fixed guideway system by more than $100 million. It seems unlikely that any combination of other assumptions (e.g., using larger buses, using surface bus stations in the central section, changing the busways operations pattern, etc.) could overcome this difference."

HONOLULU RAPID TRANSIT PROJECT PRELIMINARY ENGINEERING AND EVALUATION PROGRAM PHASE II (PEEP II)

Phase II of the Preliminary Engineering Evaluation Program (PEEP II) examined a greater range of system lengths and alignments, the feasibility of off-line stations, and mixed-mode systems. The supplementary systems vary in some details but provide comparable levels of service in terms of schedule frequency, coverage, and travel time. As a result of PEEP II, several previous decisions on general locations, length, and vehicle system were verified. In addition, a more precise alignment was established which minimized relocation and disruption. This alignment was engineered in more detail than PEEP I, stations were located and designed, and relocation, management and financial plans were prepared. An initial program to satisfy the Island's short range needs was determined.

In addition to a 28-mile light rail transit (LRT) system and 7-, 14- and 23-mile medium capacity fixed guideway, PEEP II conducted a detailed analysis of a short 7-mile busway system. This busway was limited to the highly developed urban core area of Honolulu and made maximum use of existing highways and freeways in the remainder of the corridor to minimize capital costs.

BUSWAY OPERATING COSTS

The PEEP II study re-evaluated the busway operating concepts described earlier under PEEP I. The study concluded that the single-file concept has serious deficiencies and constraints that cannot be tolerated for an efficient, high capacity rapid transit operation. The study also concluded that to have a viable bus rapid transit system, the two primary criteria which must be met are system reliability and provisions for express operations. 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. However, since the time savings due to "no-transfer" may be substantially exceeded due to the inflexible operating conditions of the single-file concept, the flexible concept was considered superior and used for the evaluation.

BUSWAY SYSTEM OPERATING PLAN

System Route

Through the central portion of urban Honolulu, from Middle Street to the University area, 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 ten high capacity stations located at major trip origin or destination points. On the western end, from Pearl City to Middle Street, the H-1 Freeway was considered to provide adequate roadway capacity to meet future travel demands. Express bus operations would use the freeway facilities, either in mixed traffic or on reserved lanes, at relatively high speed. 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 lanes. On the eastern end between Kahala and Hawaii

Kai, the study assumed the completion of the Kalanianaole Highway widening with addition of an exclusive reversible, at-grade busway in the center of the highway. The system route is indicated in Figure 2 on the following page.

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 station 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, 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

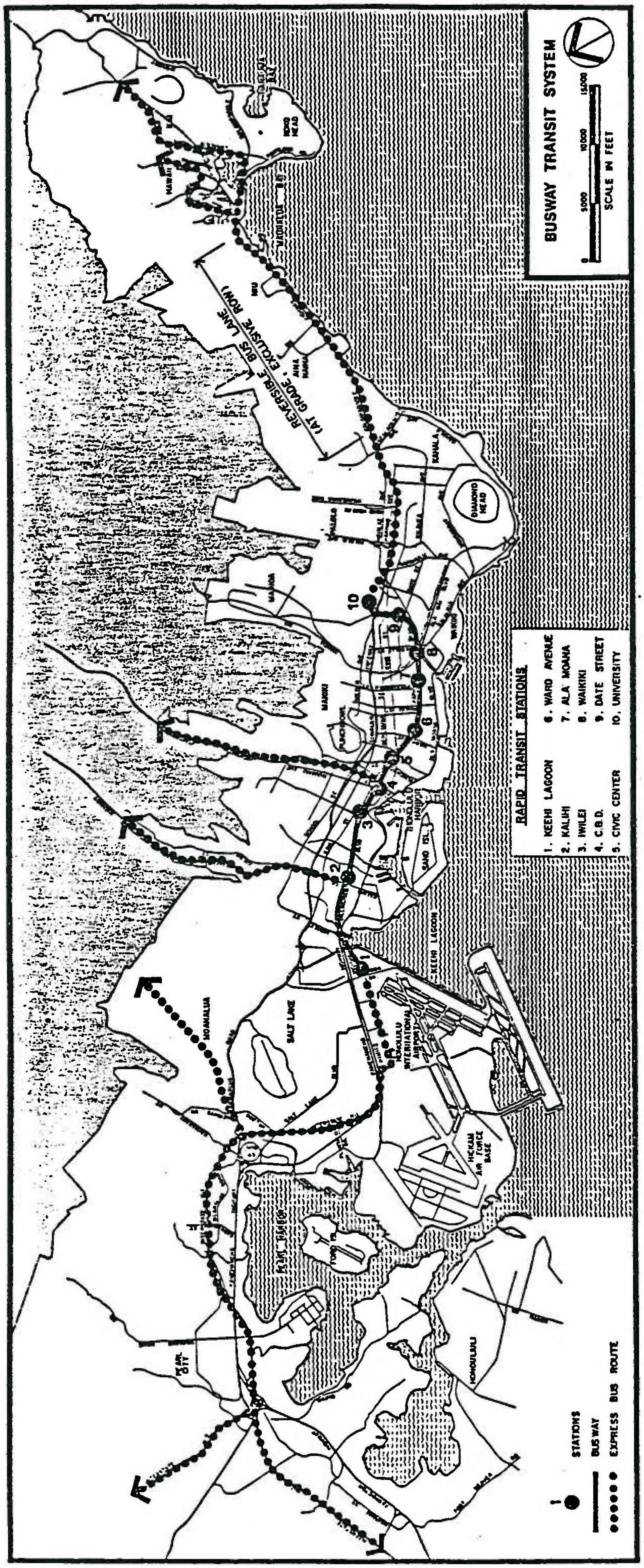

BUSWAY TRANSIT SYSTEM
0 5000 10000 15000
SCALE IN FEET
RAPID TRANSIT STATIONS
1. KEEHI LAGOON
2. KALIHI
3. IWILEI
4. C.B.D.
5. CIVIC CENTER
6. WARD AVENUE
7. ALA MOANA
8. WAIKIKI
9. DATE STREET
10. UNIVERSITY
STATIONS
BUS WAY
EXPRESS BUS ROUTE
REVERSIBLE EXCLUSIVE BUS LANE
(AT GRADE EXCLUSIVE ROW)
DIAMOND HEAD
KOKO HEAD
KAHALA
WAIKIKI
SAND ISL.
KEEHI LAGOON
SALT LAKE
HONOLULU INTERNATIONAL AIRPORT
HICKAM AIR FORCE BASE
PEARL HARBOR
FORD IS.
MOANALUA

FIGURE 2

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. 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.

Based on the projected patronage and specifically the link volumes of the various routes that operate on the busway itself, the operating play as shown in Figure 3 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, hours of vehicle operation, and passenger 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.

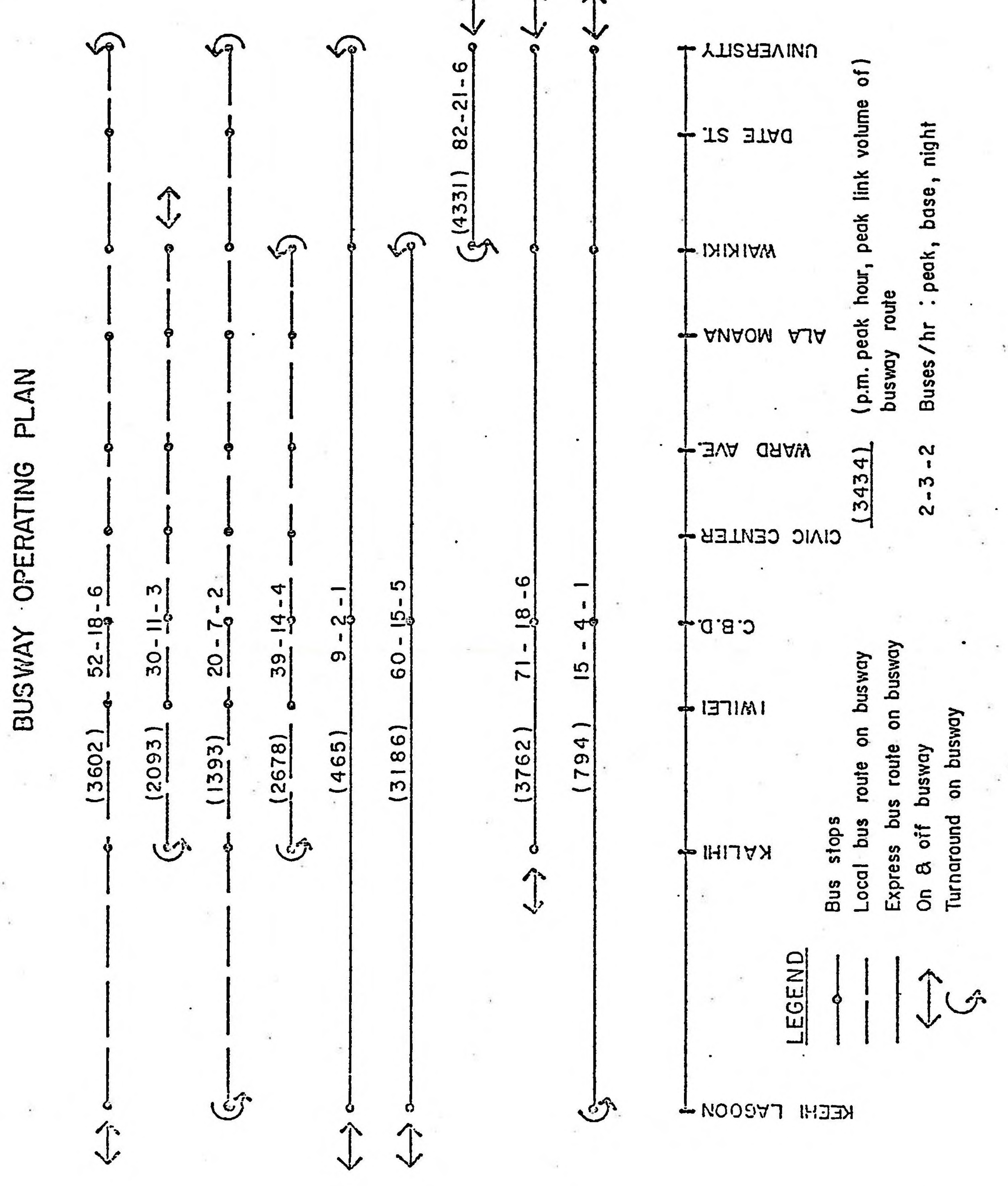

BUSWAY OPERATING PLAN
(3602) 52-18-6
(2093) 30-11-3
(1393) 20-7-2
(2678) 39-14-4
(465) 9-2-1
(3186) 60-15-5
(4331) 82-21-6
(3762) 71-18-6
(794) 15-4-1
UNIVERSITY
DATE ST.
WAIKIKI
ALA MOANA
WARD AVE.
CIVIC CENTER
C.B.D.
IWILEI
KALIHI
KEEHI LAGOON
LEGEND
Bus stops
Local bus route on busway
Express bus route on busway
On & off busway
Turnaround on busway
(3434) (p.m. peak hour, peak link volume of) busway route
2-3-2 Buses/hr : peak, base, night

FIGURE 3

FIXED FACILITIES

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.

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 platforms required to allow for this is a function of the number of different bus routes and the distribution of passenger volumes. To handle unusual situations of longer than normal dwell time by a number of buses, thus constraining the free flow of other buses, there must be enough bus stalls to prevent excessive delays in the system operation. 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, to provide flexibility in the scheduling of buses and to provide adequate facilities to handle volumes beyond 1995, 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 were proposed.

Therefore, at the high volume CBD station, 11 platforms in one direction would be required or a total of 22 platforms for both direction.

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 included 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.

Maintenance and Storage Facilities

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.

COMPARATIVE EVALUATION OF ALTERNATIVES

The significant characteristics of the alternatives evaluated in the PEEP II study are shown in Table 6.

Following are excerpts of the findings of the evaluations particularly as they refer to busways.

PATRONAGE

As shown in Table 7, 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. 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.

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

TABLE 6

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	63,880
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

TABLE 7

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.

TRAVEL CHARACTERISTICS

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. Systems with the greatest length of exclusive, grade separated guideway with attendant number of stations provide the fastest trip time.

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 8. 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

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.

TABLE 8

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.

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. However, these statistics are presented only because they are pertinent to cost and not as a measuring factor of alternatives in itself.

CAPITAL AND OPERATING COSTS

Capital Costs

Capital and operating costs were developed for each alternative transit concept evaluated by PEEP II. Table 9 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.

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 and 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 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.

Operating Costs

As shown in Table 9, the alternative with the lowest O&M cost is the 14-mile fixed guideway system.

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. A 4% discount rate was used in annualizing the capital costs.

Table 9 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 costs, 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.

TABLE 9

SUMMARY OF COSTS

CAPITAL COSTS
($ Million)

	BUSWAY	LRT	FIXED GUIDEWAY 7-MILE	FIXED GUIDEWAY 14-MILE	FIXED GUIDEWAY 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	FIXED GUIDEWAY 14-MILE	FIXED GUIDEWAY 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	FIXED GUIDEWAY 14-MILE	FIXED GUIDEWAY 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¢

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. 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 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 10. Among the basic alternative transit concepts, 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.

TABLE 10 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.

EVALUATION OF TECHNICAL RISK

In general, all the vehicle and operating concepts included in these alternatives represent proven hardware. 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 systems 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.

COMPARISON OF ENVIRONMENTAL IMPACTS

Visual and Noise Intrusion

A. 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.

The busway will be a more intrusive structure than 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 busway.

Honolulu, with its "open window" living is very sensitive to noise intrusion. The bus engine emits higher noise levels than the fixed guideway vehicle systems. The busway system would create greater noise intrusions to the environment than the 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 engines except for sulfur dioxide (SO_2).

Diverted motorists for each alternative has 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 difference in emission between the baseline system and the alternative concepts have been calculated for 1995 using the following emission factors:

	AUTO	BUS	POWER PLANT
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 11 shows the difference 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 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 11 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

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 on Oahu. Dislocation necessitated by removal of existing housing stock would further aggravate the shortage.

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 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 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 displacements. The busway concept, as explained above, entails a substantially larger number of displacements.

CONCLUSION

A careful examination of key evaluation factors indicates the relative superiority or inferiority between alternatives as shown by the rankings in Table 12. 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 travel time. 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.

From the foregoing, it was 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.

TABLE 12 SUMMARY OF EVALUATION MEASURES

TRANSPORTATION COST-EFFECTIVENESS MEASURES *

	BUSWAY	LRT	FIXED GUIDEWAY 7-MILE	FIXED GUIDEWAY 14-MILE	FIXED GUIDEWAY 23-MI[illegible]
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

Based on the rankings shown in the table, the busway concept was 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.

CONCLUSIONS AND CURRENT ASSESSMENT

The Honolulu Rapid Transit Project Preliminary Engineering and Evaluation Program Phase I and Phase II provided a very detailed analysis of busway operations and evaluation of a Bus on Busway alternative compared to other forms of mass transit. A review of these studies indicates that every effort appears to have been made to show Busways in their most favorable light. However, considering the advantages of the other options, the studies concluded that busways were clearly inferior, in that they are less cost-effective, less efficient, and had greater environmental impacts.

The Voorhees study was a joint City and State effort and appears to have been an obvious attempt to challenge the findings of the original PEEP I study. After an extensive examination of potential ways in which cost of the busway might be reduced or that the busway system concept improved such that it is clearly superior to the fixed guideway system, the Voorhees effort concluded:

a. "there is no reason to believe that a busway system would be less costly in Honolulu than a fixed guideway system when both construction and operation is considered."

b. "there seems little doubt that busway systems are less favorable"..."from the standpoint of air pollution impact, noise, aesthetic and visual impact and system reliability."

c. "we have been able to produce no calculations which can refute"..."that the fixed guideway was superior from an economic viewpoint."

As with the PEEP studies, the Voorhees study was conducted in a manner so as to "enhance [the] strengths" of the Busway alternative.

Whether or not the findings of these previous studies are accepted at their face value, they do point out the key factors that place busways at a relative disadvantage to the fixed guideway alternative. These factors, which are as applicable today as when the previous studies were done, are:

a. Busway way structures, both above ground and underground, are considerably larger and more massive than fixed guideway structures. (See Plates 5, 6 and 7.)

b. Rather than the modest structures required for fixed guideway stations, the busway concept requires massive stations particularly in the high volume areas where real estate is scarce and high-priced. (See Plates 1, 2, 3 and 4.)

c. The impact of a. and b., above, is:

(1) Construction costs for busway structures are significantly higher than a fixed guideway

alternative.

(2) Whereas the smaller fixed guideway way structures and stations permit the maximum utilization of existing street and highway rights-of-way, the larger busway facilities and their location require considerably more right-of-way taking with their attendant increased costs. An additional consequence is that there would be a dramatic increase in the number of displacements of residential and business properties required.

(3) The busway would have much greater environmental impacts during construction.

(4) The busway will have greater aesthetic and visual impacts since the wider way structures and larger stations present greater visual intrusion.

d. Due to the large labor factor involved in bus operations, operating costs are higher for a busway concept than fixed guideway.

e. Even though the cost of buses is considerably cheaper than fixed guideway vehicles and the fixed guideway control systems, the difference is not sufficient to make a busway concept cost-effective.

f. Diesel-powered buses produce higher levels of air pollution than electrically-powered fixed guideway vehicles, which is especially critical in the Downtown area where pollution concentration is normally very high.

g. Depending on the particular fixed guideway technology used for comparison, buses could actually be a noisier alternative due to the diesel engine noise.

h. The "no-transfer" ride from all origins to all destinations that is theoretically possible with bus operations can only be accomplished by either sacrificing service frequency (delays waiting for a bus) or speed (directness of travel and number of stops). The need to circulate the travel origin areas to collect 50 or more passengers (at least during peak periods) per vehicle, and the need to keep the number of stops for each route to a reasonable number and to maintain service frequencies to some reasonable minimum standard even in low-demand areas resulted in "no-transfer" service to about 40% of total system riders.

i. Busway system service reliability is less than fixed guideway systems since electric motors are more reliable than diesel engines and there is a high degree of dependence in bus operations on human beings. Further, fixed guideway systems operate on multiple units, so the failure of a single electric motor does not halt operation of a train or the guideway system. On the other hand, when a single diesel engine quits, the busway is blocked.

j. High volume busway and station operations with 200-300 buses per hour arriving and departing major stations present operational problems and require the adoption of suitable operational concepts to ensure system reliability and minimize delays.

There is absolutely no reason to believe that these factors are any less significant today than they were when these studies were done or that the relative difference and impacts would be any different compared to a fixed guideway alternative.

None of the busway operations in the United States or "new" systems offer any significant break-through in operational concepts that would reduce the costs of a busway system or provide any significant improvement in operations that would make busways superior to a fixed guideway. Most busway operations in the United States today are in reality nothing more than dedicated freeway lanes. Use of freeway lanes was already evaluated in the Voorhees study and PEEP II.

In this regard, the general operational concept of busways on the mainland and some other parts of the world, is to collect passengers in the outlying or suburban areas and then express them via dedicated freeway lanes or an actual busway to a main attraction point like a downtown area or terminal. In Honolulu, however, the situation is much more complex with a number of collection points and, more importantly, a number of destinations or attractions, e.g., Downtown, Ala Moana, UH, Waikiki, etc. The previous studies on the "no-transfer" feature of bus operations indicate that only 40% of Honolulu's transit riders could be served by such a concept.

Concepts, such as "dual-mode" (diesel and electric) propulsion are exactly that--propulsion--not operational concepts. Electric propulsion of buses would reduce ventilation requirements in underground operations for buses and reduce construction costs somewhat. However, this factor by itself would not provide enough savings to influence the selection of the busway alternative.

There is also a "dual-mode" operational concept in which a bus driven by an operator circulates streets to collect passengers; then after it gets on the busway, an automatic pilot system takes over. The idea is that automated systems would permit minimum headways with greater safety by eliminating the margin for human error. However, there are no such systems in existence nor operation today.

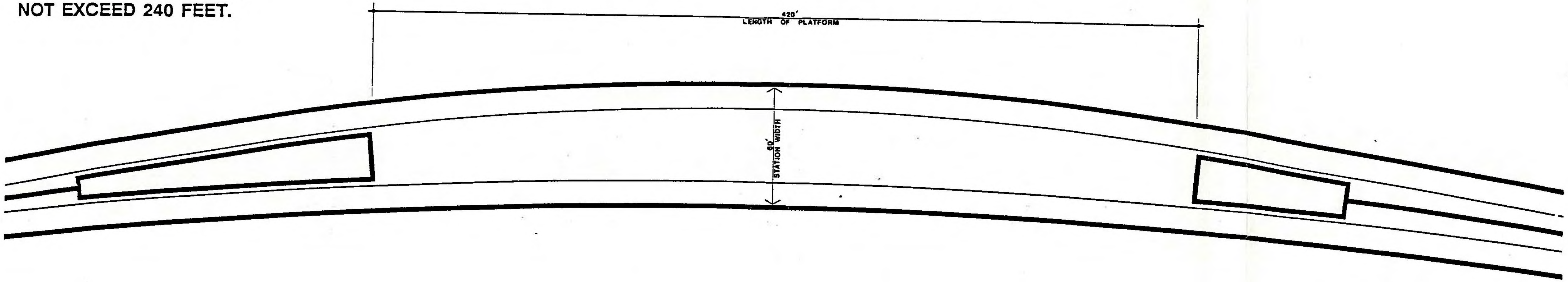
There are busway systems that provide a guidance mechanism for the buses on the busway, but these are still operator-controlled systems. They have not eliminated the operational problems caused by a breakdown on the busway. Whether the buses operate individually or as trained units, these systems still present the same operational problems of platooning buses. Further, there are none of these type systems in existence today that handle the ridership levels presently experienced in Honolulu or projected for the future.

In terms of a high volume operation as a rapid transit system, automated or guided busways are still not a proven technology.

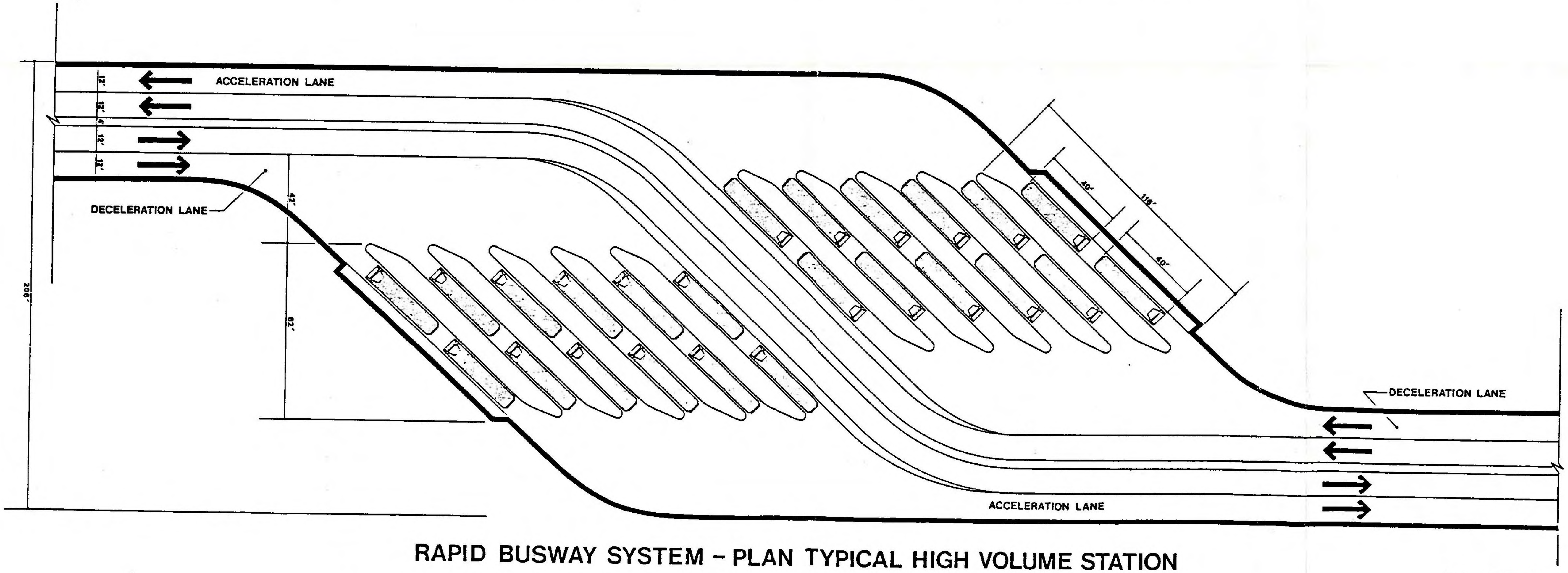
Due to the foregoing, "automated" busway or guided systems are not considered a viable alternative for Honolulu. Whether automated or not, a busway is a busway which is subject to all of the same cost considerations, operational problems, and environmental impacts, which put them at a relative disadvantage to automated fixed guideway system.

HONOLULU RAPID TRANSIT SYSTEM

NOTE: FIXED GUIDEWAY PLATFORM LENGTH IN CURRENT STUDIES DOES NOT EXCEED 240 FEET.



RAPID TRANSIT SYSTEM – PLAN TYPICAL HIGH VOLUME STATION



RAPID BUSWAY SYSTEM – PLAN TYPICAL HIGH VOLUME STATION

PLATE 1

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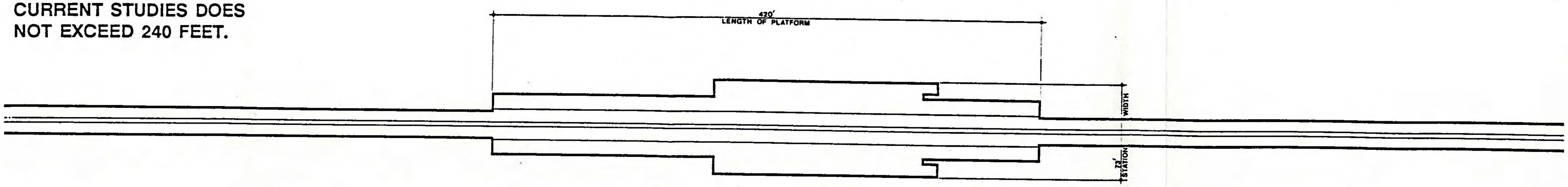
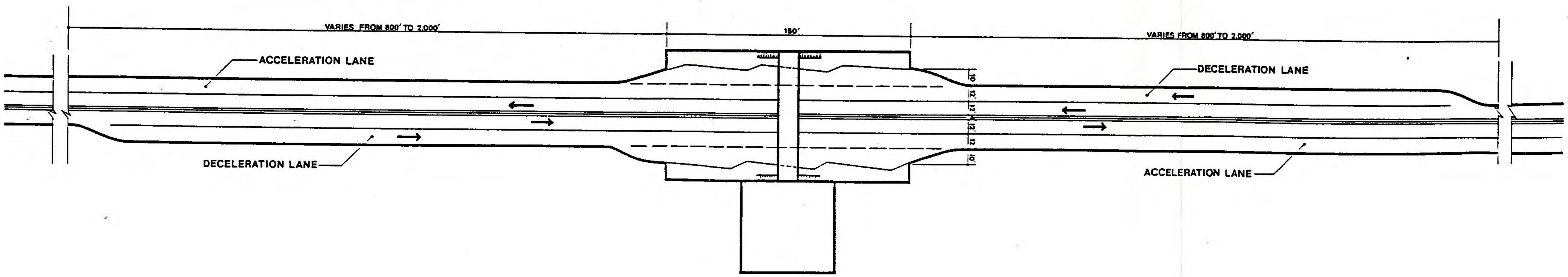
HONOLULU RAPID TRANSIT SYSTEM

NOTE: FIXED GUIDEWAY PLATFORM LENGTH IN CURRENT STUDIES DOES NOT EXCEED 240 FEET.



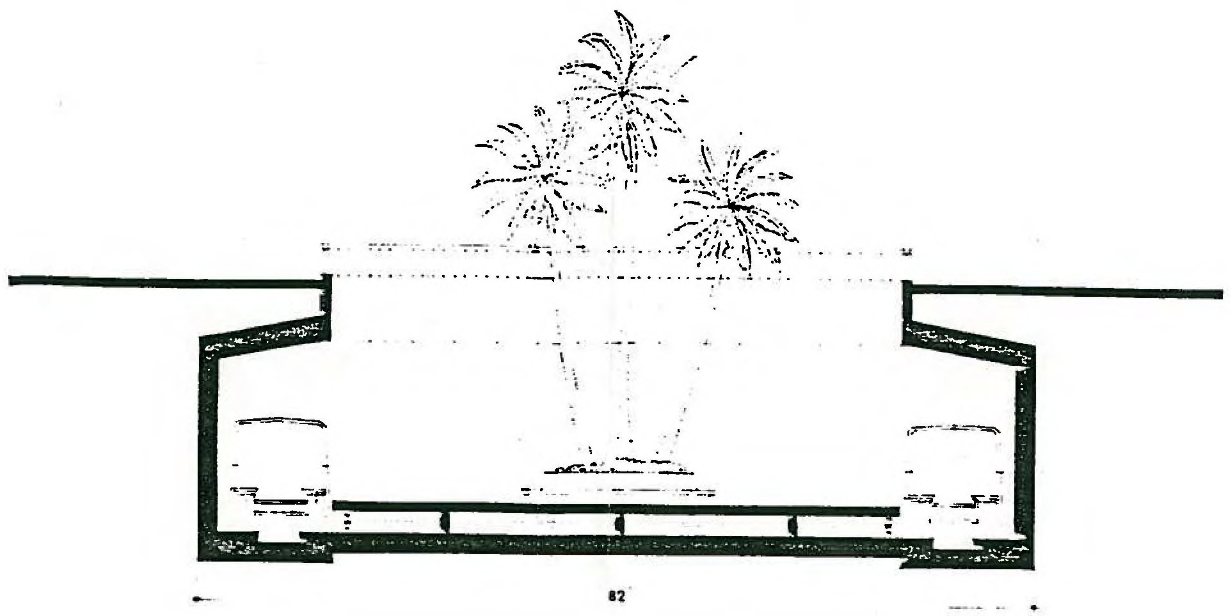
RAPID TRANSIT SYSTEM – PLAN TYPICAL LOW VOLUME STATION



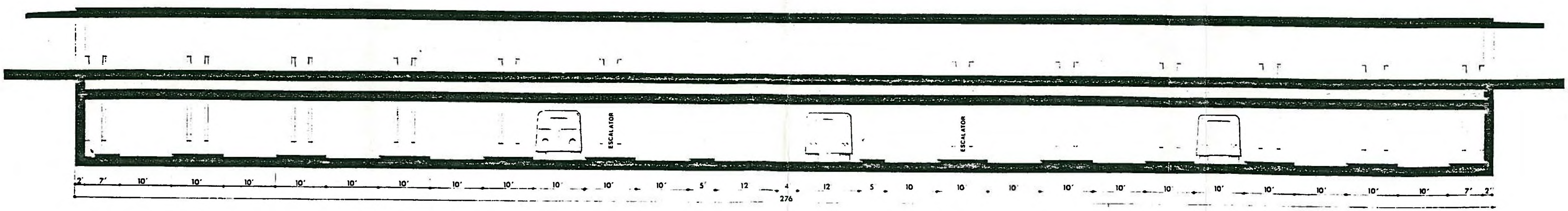
RAPID BUSWAY SYSTEM – PLAN TYPICAL LOW VOLUME STATION

PLATE 2

HONOLULU RAPID TRANSIT SYSTEM



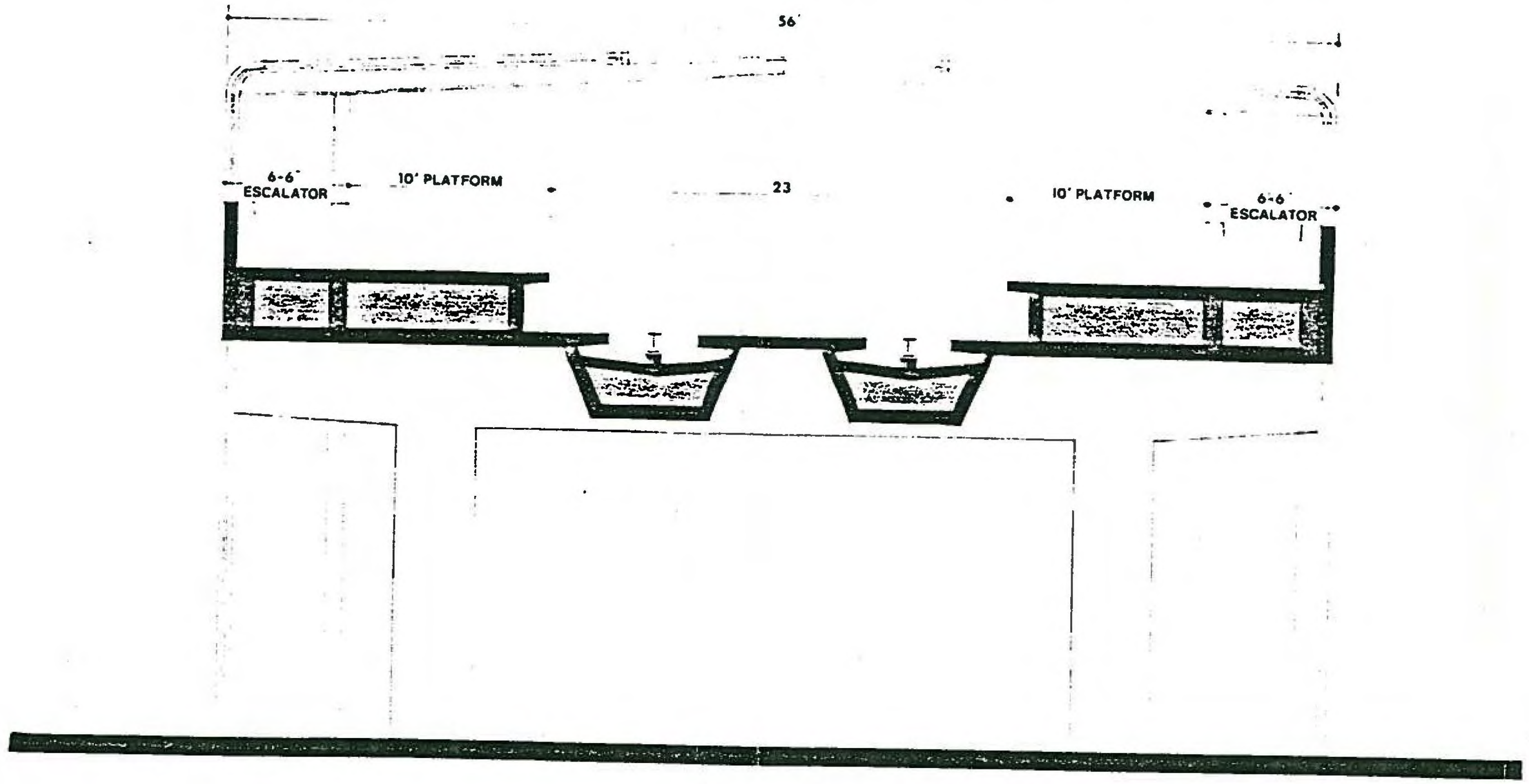
RAPID TRANSIT SYSTEM — SECTION TYPICAL HIGH VOLUME STATION



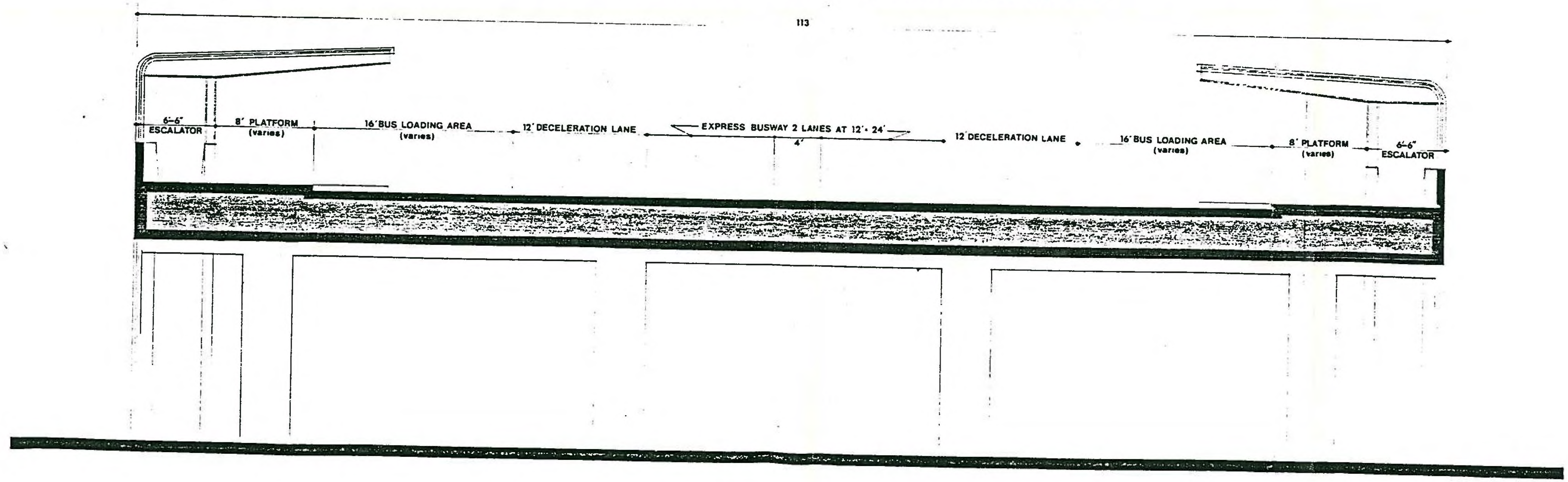
RAPID BUSWAY SYSTEM — SECTION TYPICAL HIGH VOLUME STATION

PLATE 3

HONOLULU RAPID TRANSIT SYSTEM



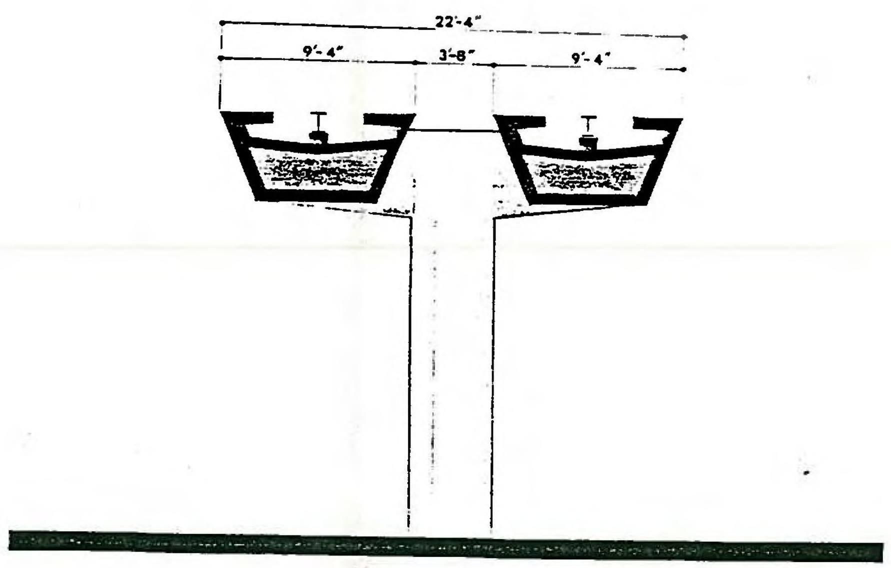
RAPID TRANSIT TYPICAL AERIAL STATION



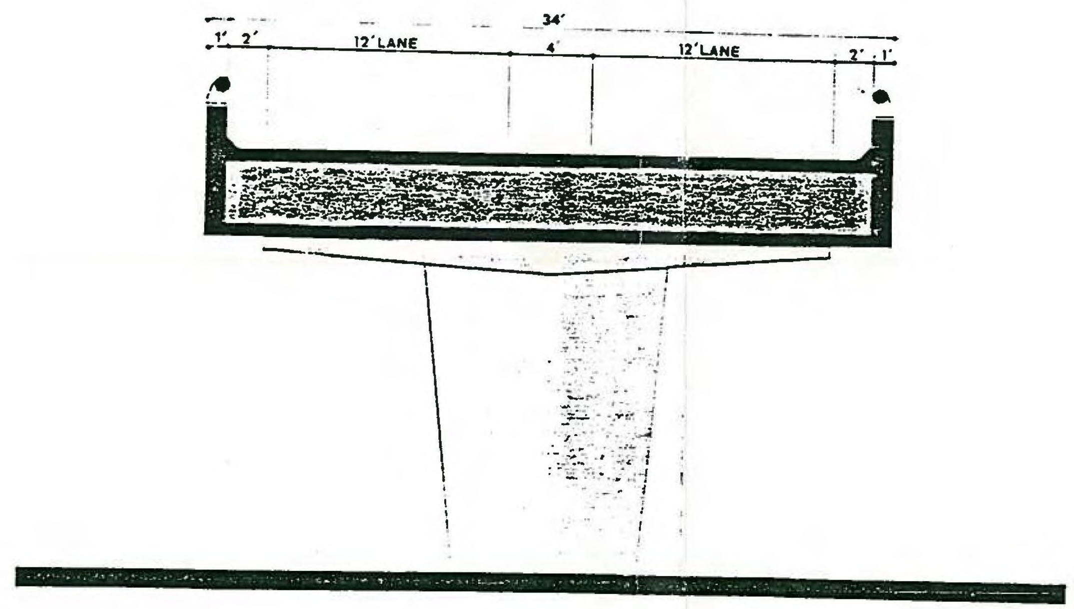
BUSWAY-TYPICAL AERIAL STATION

PLATE 4

HONOLULU RAPID TRANSIT SYSTEM



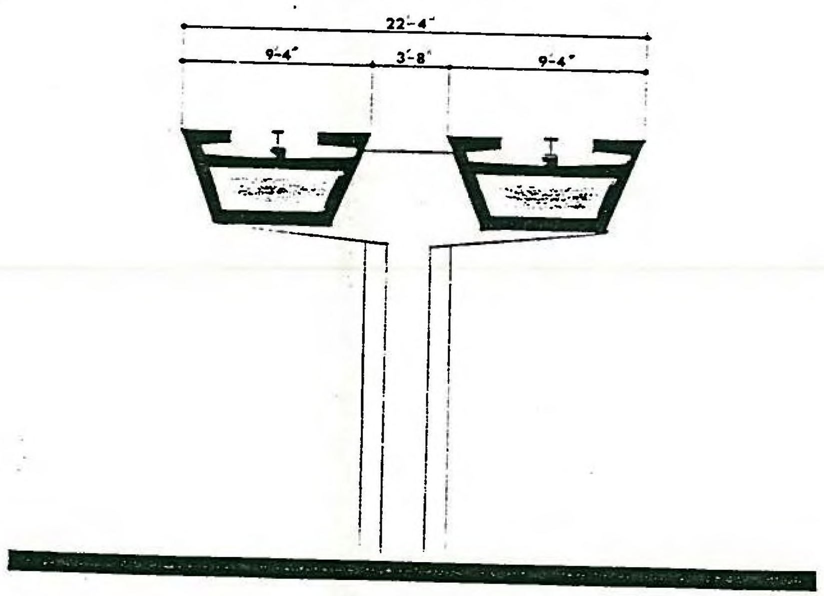
RAPID TRANSIT AERIAL GUIDEWAY



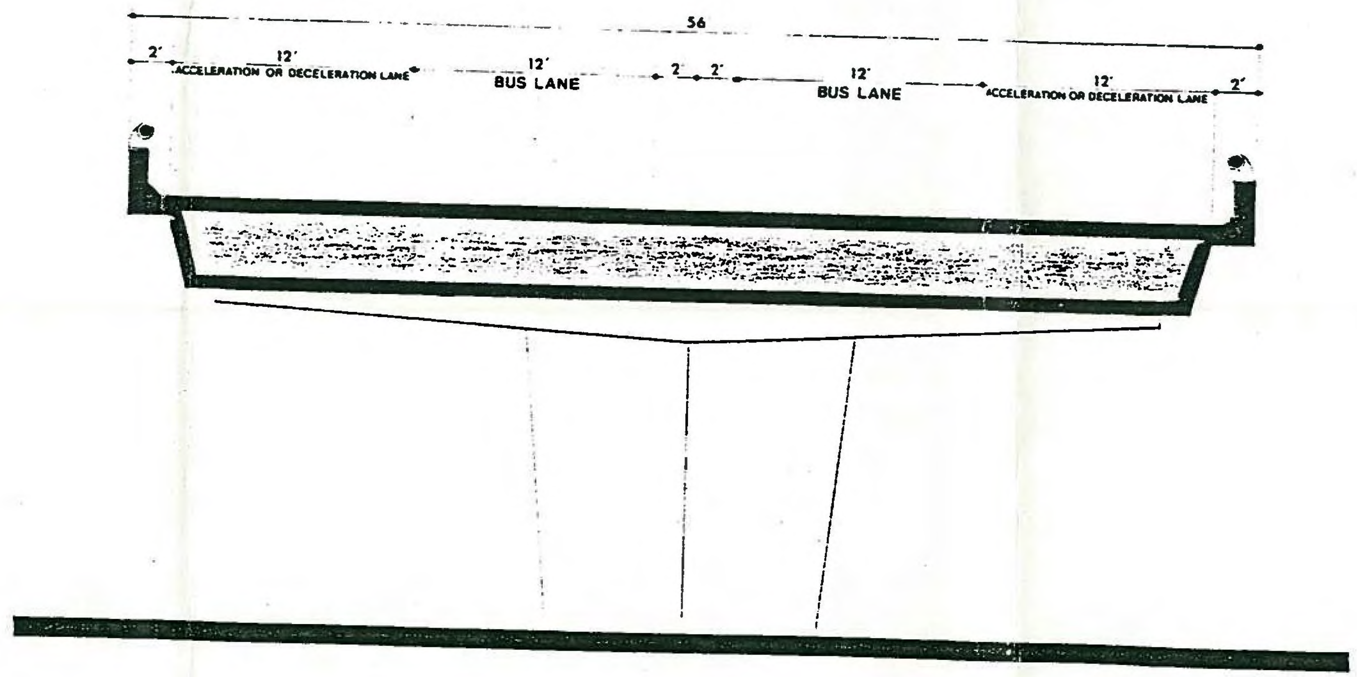
AERIAL BUSWAY

PLATE 5

HONOLULU RAPID TRANSIT SYSTEM



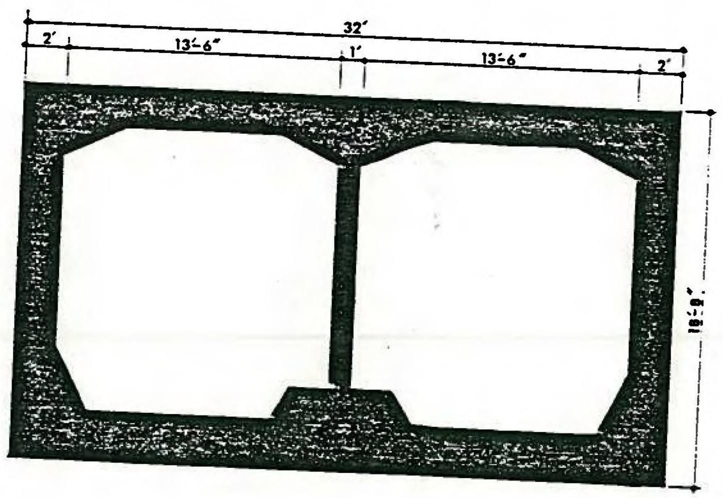
RAPID TRANSIT AERIAL GUIDEWAY



AERIAL BUSWAY WITH ACCELERATION AND DECELERATION LANES

PLATE 6

HONOLULU RAP



RAPID TRANSIT UNDERGROUND STRUCTURE

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2. Evaluation of Alternative Transportation Systems for the Pearl City-Hawaii Kai Corridor, March 1973, Alan M. Voorhees & Associates, Inc.

3. Alternative Transit Concepts Analysis, Technical Report, Honolulu Rapid Transit, Preliminary Engineering & Evaluation Program Phase II, July 1975, Daniel, Mann, Johnson & Mendenhall.