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SUPPLEMENT I
SUMMARY OF CAPITAL AND OPERATIONS AND MAINTENANCE COST EXPERIENCE OF AUTOMATED GUIDEWAY TRANSIT SYSTEMS COSTS AND TRENDS FOR THE PERIOD 1976-1978

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SUMMARY COST REPORT

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16. Abstract

This report summarizes operations and maintenance cost experience for the following Automated Guideway Transit systems for the period 1976-1978:

Airtrans, Dallas/Fort Worth Airport, TX
Morgantown People Mover, Morgantown, WV
Satellite Transit System, Seattle-Tacoma International Airport, WA
Passenger Shuttle System, Tampa International Airport, FL
WEDway People Mover System, Disney World, FL

Capital cost data on these and the following additional systems are also reviewed:

People Mover, Atlanta-Hartsfield International Airport, GA
Busch Gardens People Mover, Williamsburg, VA
Satellite Transit Shuttle, Miami International Airport, FL
ACT System, Fairlane Town Center, Dearborn, MI
UMI Tourister AGT System, King's Dominion, Ashland, VA

The report also includes information on O&M and capital costs for bus and rail transit and indicates how AGT cost experience compares with the conventional modes.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
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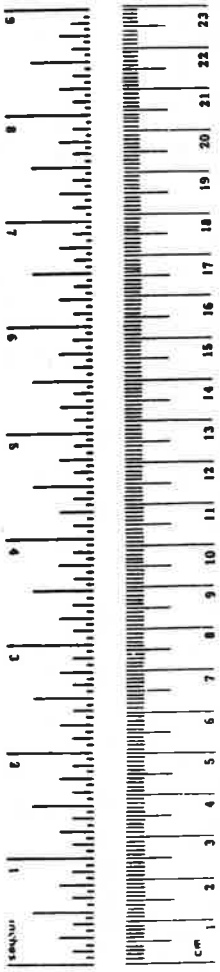
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

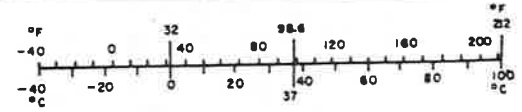


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SUMMARY

In 1978 the five major Automated Guideway Transit systems (AGT) in the United States carried approximately 36 million passengers at an average operations and maintenance (O&M) cost of 17¢ each. This was less than one third of the transit industry's average O&M cost per passenger transported.

Three of these systems are at airports - Dallas-Fort Worth, Tampa and Seattle-Tacoma. One serves West Virginia University and the city of Morgantown and the fifth is an amusement ride at Walt Disney World at Orlando, FL. Collectively these systems operated 5.7 million vehicle miles in 1978 at an average O&M cost per vehicle mile of $1.10 which is significantly less than the transit industry average of $2.07.

Despite automation, labor amounted to more than half of the O&M cost for AGT systems. Nevertheless, these AGT systems are less labor intensive than conventional transit, requiring an average of 1.6 employees per vehicle operated, well below the transit industry average of 2.6.

The capital cost of AGT systems is comparable with that of six representative light rail installations, averaging about $25 million per route mile. However, the five AGT systems surveyed provided a significantly higher level of service in terms of available place miles of transportation capacity per mile of route.

Both O&M and Capital Costs are influenced by a variety of factors, many of which are dictated by local site conditions and the specific transportation functions to be performed. Thus cost comparisons may lead to erroneous conclusions, since data developed from one specific system may not be readily transferrable or even applicable to another.

SUMMARY OF AGT CAPITAL AND OPERATIONS & MAINTENANCE COST DATA FOR THE PERIOD 1976 - 1978

INTRODUCTION

This report supplements and builds upon the data presented in the original AGT Summary Cost Report No. UMTA IT-06-0157-78-2 of June 1978. Capital cost information has been obtained and analyzed on three additional systems at Busch Gardens in Williamsburg, VA., Miami International Airport and the Hartsfield - Atlanta International Airport. Operational and O&M cost data has been obtained for the calendar years 1977 and 1978 to supplement the 1976 information compiled in the original report. In some instances, the operators of AGT systems provided cost and operational data for 1976 which was at variance with the data initially assembled, due to changes in methods of accounting and estimating. In such cases, particular care was given to insure that the information for these three successive years was treated consistently.

This costs supplement is presented in the form of a series of tables and figures which summarize the data obtained as well as the results of analysis. Comments and explanatory notes relative to individual tables and figures are made on facing pages as appropriate.

The preparation of this report has been a cooperative effort by the N. D. Lea & Associates staff and that of the Department of Transportation's Transportation Systems Center (TSC), which compiled and analyzed most of the information relating to the comparative cost of other transportation modes. TSC personnel also contributed to the process of analyzing both the AGT capital and O&M data.

This report represents another step forward in the complex process of gaining a better understanding of the factors which influence the cost of building and operating automated guideway transit systems. It does not purport to be an estimating guide, nor should the unit cost relationships presented be considered to be more than indicative of general relationships.

OPERATIONS AND MAINTENANCE COSTS

Data on system performance, as well as operations and maintenance cost information obtained from the five major system operators who were in a position to provide detailed information, are presented in Tables 1, 2 and 3.

Summary data on these systems is as follows:

	Active Vehicle Fleet Size	Vehicle Miles Traveled in 1978	Total O & M Cost (1978)
AIRTRANS	51	3,470,000	3,360,000
MORGANTOWN	29	550,000	1,330,000
SEA-TAC	12	505,000	718,000
TAMPA	8	412,000	514,000
WEDway	30	710,000	363,000

As will be noted, the total level of expenditures for these five systems, which accounted for over 95 percent of the vehicle miles produced by AGT systems in the United States, remain relatively constant over the three-year period, 1976 through 1978. This is shown graphically on Figure 1 which indicates average vehicle mileage, as well as the total miles traveled by each of the five systems. Figures 2 and 3 show total O&M expenditures together with vehicle mileage for the individual systems surveyed for 1978. Figure 4 shows unit costs per vehicle mile traveled for each of these systems and Figure 5 indicates how these costs have varied over the three-year period.

An interesting conclusion from the analysis of this O&M data is the close correlation between total O&M expenditures and the number of vehicles in the active fleet. This is shown graphically in Figure 6, which indicates that for the three most similar systems, namely AIRTRANS, SEA-TAC and TAMPA), all of which are at airports, the O&M cost per vehicle remains relatively constant. These costs range from $59,800 to $64,300 for 1978, with an average for the three systems of $62,900.

This serves to emphasize the point that there is little difference in the cost of maintaining and operating medium versus large vehicles, as they all have approximately the same number of sub-systems requiring preventative maintenance and repair.

Tables 4, 5 and 6 provide a breakdown of the operations and maintenance costs for each system for the calendar years 1976-77-78, all expressed in terms of 1978 dollars. Figure 7 indicates graphically how the total 1978 expenditures for O&M were distributed for the five systems in question. As will be noted, labor consituted approximately 60 percent of the operations and maintenance costs. For these five systems, a total of 215 personnel are employed which amounts to an average of 1.6 people per vehicle in the active operation fleet.

TABLE 1

1976 OPERATIONS AND MAINTENANCE SUMMARY

	SEA-TAC (ST)	MORGANTOWN (M) (2)	TAMPA (T)	WEDway (WED)	AIRTRANS (A) (2)	5 SYSTEMS TOTAL	5 SYSTEMS AVERAGE
Total O&M Cost ($) (1)	747,000	1,480,000	509,000	401,000	3,340,000	6,480,000	1,300,000
Vehicle Miles Traveled (VMT) (7)	450,000	631,000	403,000	712,000	3,700,000 (6)	5,940,000	1,190,000
Active Vehicle Fleet/Equiv.Veh.Cap.	12/81	29/23 (3)	8/81	30/29	51/42 (4)	130/256	26/51
Active Fleet Capacity (places)	972	667	648	870	2,226	5,360	1,070
Place Miles Traveled	36,500,000	14,500,000	32,600,000	20,700,000	157,000,000	262,000,000	52,300,000
O&M Cost per VMT ($)	1.66	2.34	1.26	0.56	0.90	N/A	1.09
O&M Cost per Vehicle Operated ($)	62,300	51,000	63,600	13,400	63,000	N/A	49,500
O&M Cost per Unit of Fleet Capacity ($)	769	2,220	785	461	1,500	N/A	1,210
O&M Cost per Place Mile Traveled ($)	0.021	0.10	0.016	0.019	0.021	N/A	0.025

Note (1) O&M costs adjusted to 1978 price levels are rounded to 3 significant digits.

(2) O&M cost and VMT adjusted to represent one year of operation.

(3) Only 29 of the total of 45 vehicles at MORGANTOWN constitute the active fleet. The remaining 16 vehicles were permanently out of service.

(4) Since only passenger vehicles are being considered, the two utility vehicles are not included in this figure.

(5) SEA-TAC, TAMPA and AIRTRANS operate 24 hours a day, 365 days per year. Morgantown operates 13 hours per weekday, and 5-1/2 hours on weekends. WEDway operates 9 to 17 hours per day (depending on the general level of activities at Disney World), 365 days per year.

(6) Total VMT by all vehicles is 3,750,000 of which only about 1.2% is logged by the service vehicles.

(7) Figure for WEDway reflects train miles, since the system operates with 5-car trains.

TABLE 2

1977 OPERATIONS AND MAINTENANCE SUMMARY

	SEA-TAC (ST)	MORGANTOWN (M)	TAMPA (T)	WED way (WED)	AIRTRANS (A)	5 SYSTEMS TOTAL	5 SYSTEMS AVERAGE (AVG)
Total O&M Cost ($) (1)	702,000	1,430,000	521,000	393,000	3,330,000	6,380,000	1,280,000
Vehicle Miles Traveled (VMT)(6)	461,000	581,000	396,000	705,000	3,630,000 (5)	5,810,000	1,160,000
Active Vehicle Fleet/Equiv.Veh.Cap.	12/81	29/23 (2)	8/81	30/29	51/42 (3)	130/256	26/51
Active Fleet Capacity (places)	972	667	648	870	2,226	5,360	1,070
Place Miles Traveled	37,300,000	13,400,000	32,100,000	20,500,000	154,000,000	257,000,000	51,400,000
O&M Cost per VMT ($)	1.52	2.46	1.32	0.56	0.92	N/A	1.10
O&M Cost per Vehicle Operated ($)	58,500	49,300	65,100	13,100	62,800	N/A	48,700
O&M Cost per Unit of Fleet Capacity ($)	722	2,140	804	452	1,500	N/A	1,190
O&M Cost per Place Mile Traveled ($)	0.019	0.11	0.016	0.019	0.022	N/A	0.025

Note (1) O&M costs adjusted to 1978 cost levels.

(2) Only 29 of the total of 45 vehicles at MORGANTOWN constitute the active fleet. The remaining 16 vehicles were permanently out of service.

(3) Fifty-one (51) passenger vehicles were operated regularly. The 2 utility vehicles are not included in this figure.

(4) SEA-TAC, TAMPA and AIRTRANS operate 24 hours a day, 365 days per year. Morgantown operates 13 hours per weekday, and 5-1/2 hours on weekends. WEDway operates 9 to 17 hours per day (depending on the general level of activities at Disney World), 365 days per year.

(5) Reflects the actual vehicle miles traveled by passenger vehicles.

(6) Figure for WEDway reflects train miles, since the system operates with 5-car trains.

TABLE 3

1978 OPERATIONS AND MAINTENANCE SUMMARY

	SEA-TAC (ST)	MORGANTOWN (M) (1)	TAMPA (T)	WEDway (WED)	AIRTRANS (A)	5 SYSTEMS (TOTAL)	5 SYSTEMS AVERAGE (AVG)
Total O&M Cost ($) (1)	718,000	1,330,000	514,000	363,000	3,360,000	6,280,000	1,260,000
Vehicle Miles Traveled (VMT) (6)	505,000	550,000	412,000	710,000	3,470,000(5)	5,690,000	1,140,000
Active Vehicle Fleet/Equiv.Veh.Cap.	12/81	29/23 (2)	8/81	30/29	51/42 (3)	130/256	26/51
Active Fleet Capacity (places)	972	667	648	870	2,142	5,360	1,070
Place Miles Traveled	40,900,000	12,700,000	33,400,000	20,600,000	148,000,000	255,000,000	51,000,000
O&M Cost per VMT ($)	1.42	2.40	1.25	0.51	0.97	N/A	1.10
O&M Cost per Vehicle Operated ($)	59,800	45,800	64,300	12,100	65,900	N/A	48,300
O&M Cost per Unit of Fleet Capacity ($)	739	1,990	793	417	1,510	N/A	1,170
O&M Cost per Place Mile Traveled ($)	0.018	0.11	0.015	0.018	0.023	N/A	0.025

Note (1) Since the Morgantown system was shut down early July 78, the 1978 O&M cost for Morgantown is an estimate based on the last year of operation.

(2) Only 29 of the total of 45 vehicles at MORGANTOWN constitute the active fleet. The remaining 16 vehicles were permanently out of service.

(3) An active fleet of 51 refers to the passenger vehicles operated regularly. The two utility vehicles are not included in this number.

(4) SEA-TAC, TAMPA and AIRTRANS operate 24 hours a day, 365 days per year. Morgantown operates 13 hours per weekday, and 5-1/2 hours on weekends. WEDway operates 9 to 17 hours per day (depending on the general level of activities at Disney World), 365 days per year.

(5) Proportion of the total vehicle miles traveled by passenger vehicles.

(6) Figure for WEDway reflects train miles, since the system operates with 5-car trains.

TABLE 3 NOTES

- Equivalent vehicle capacity has been calculated on the basis of 33 percent of passengers seated and 67 percent standing, with an allowance of 4.5 square feet of floor space per seated passenger and 2.36 square feet per standing passenger. By use of these equivalent vehicle capacities, the passenger carrying capabilities of the five systems can be compared more realistically.

- In 1978, the average vehicle logged about 43,400 miles, with the three airport systems averaging 62,400 per year.

- With the exception of WEDway, which is not typical, O&M costs per vehicle were reasonably uniform. Thus, the cost per place mile for the systems with the largest vehicles (SEA-TAC and TAMPA) were the lowest.

- Morgantown's O&M cost per vehicle mile traveled was the highest, due to a number of factors, including the comparatively severe operating environment, degree of sophistication and limited hours of operation. The latter resulted in low annual mileage per active vehicle - about 19,000 in 1978 which was less than half the average for all five systems.

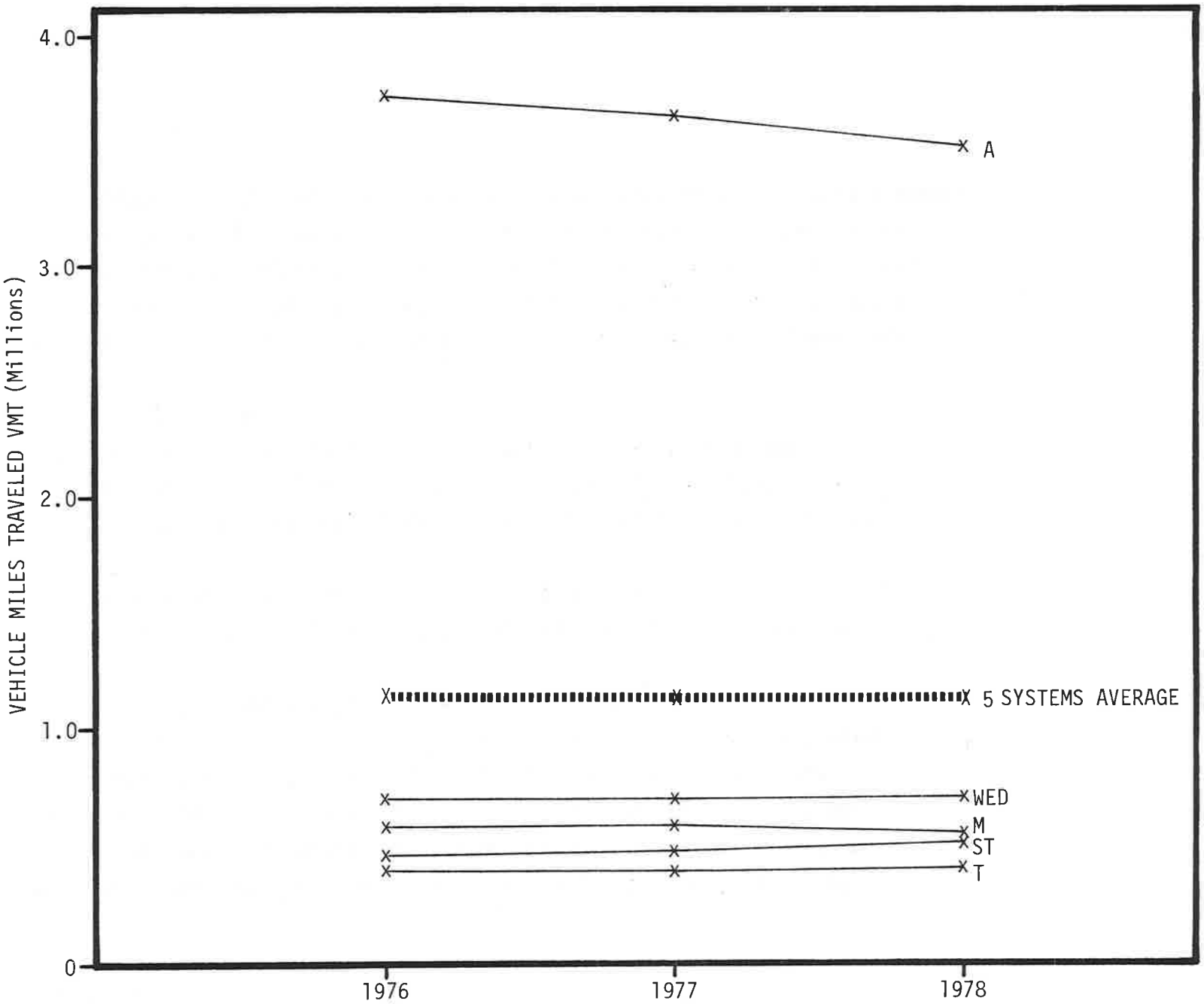


FIGURE 1. TREND OF VEHICLE MILES TRAVELED FOR 5 AGT SYSTEMS

FIGURE 1 NOTES

- Fleet mileage dropped off slightly for the five systems examined, as indicated

  1976 - 5,940,000

  1977 - 5,810,000

  1978 - 5,690,000

  Most of this reduction was attributable to AIRTRANS which reduced its mileage from 3.75 million in 1976 to 3.51 million in 1978.

- System identification as follows:

  A - AIRTRANS at Dallas/Fort Worth Airport, TX

  WED - WEDway at Walt Disney World, Orlando, FL

  M - MORGANTOWN, WV

  ST - SEA-TAC at Seattle, Tacoma International Airport

  T - TAMPA International Airport

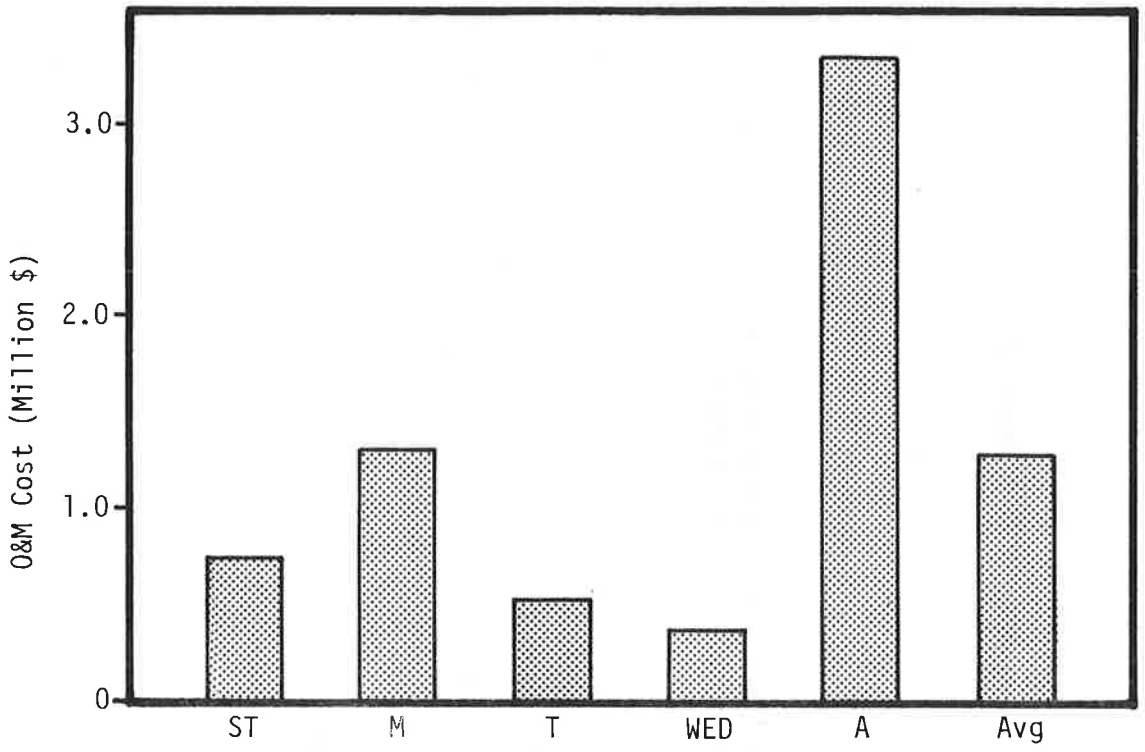


FIGURE 2. 1978 O&M COST FOR 5 AGT SYSTEMS

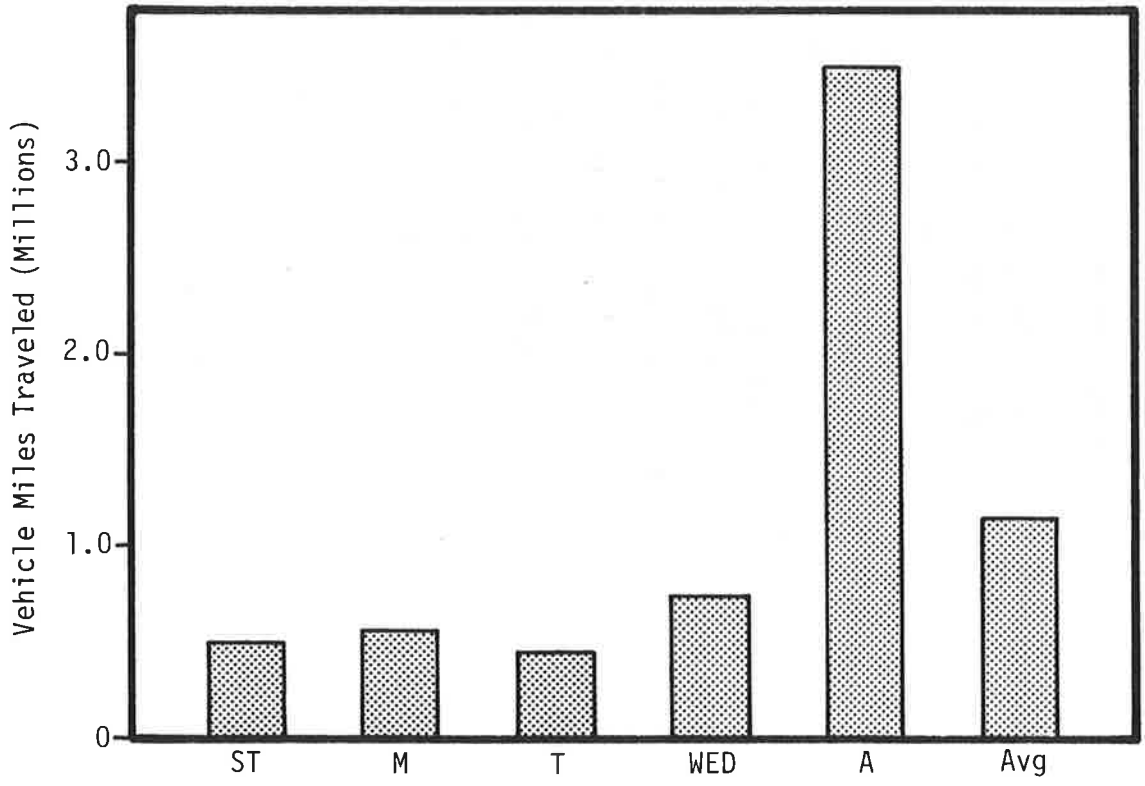


FIGURE 3. 1978 VEHICLE MILEAGE TRAVELED BY 5 AGT SYSTEMS

FIGURE 2 & 3 NOTES

As indicated, it costs more to operate and maintain AGT systems which run substantial mileages than those which log modest fleet mileages. However, the relationship between O&M cost and fleet mileage is complex, and varies significantly from one installation to another. For example:

- Systems which operate substantial mileage generally involve numerous vehicles, and the size of the vehicle fleet is a major factor in determining the number of people required to maintain and operate the system. Another determining factor is complexity of the guideway systems and station complex.

- The hours of operation will also have a major influence on the size of the O&M staff. If three shifts are required 7 days a week, it will normally require 5 employees to man a single functional position.

- The salaries for the O&M staff is the largest single component of the O&M cost and must be met regardless of the mileage logged by the vehicle fleet. Essentially, this may be considered a fixed cost.

- Variable costs of operation which are dependent on the number of vehicle operating hours and vehicle miles include propulsion power, spare parts and consumable supplies. For each AGT system, the ratio of variable costs to fixed costs will be different. However, there are indications that only 20-30 percent of the O&M costs are affected by variations in fleet mileage. Other factors such as weather, especially ice and snow, can also cause significant changes in O&M costs.

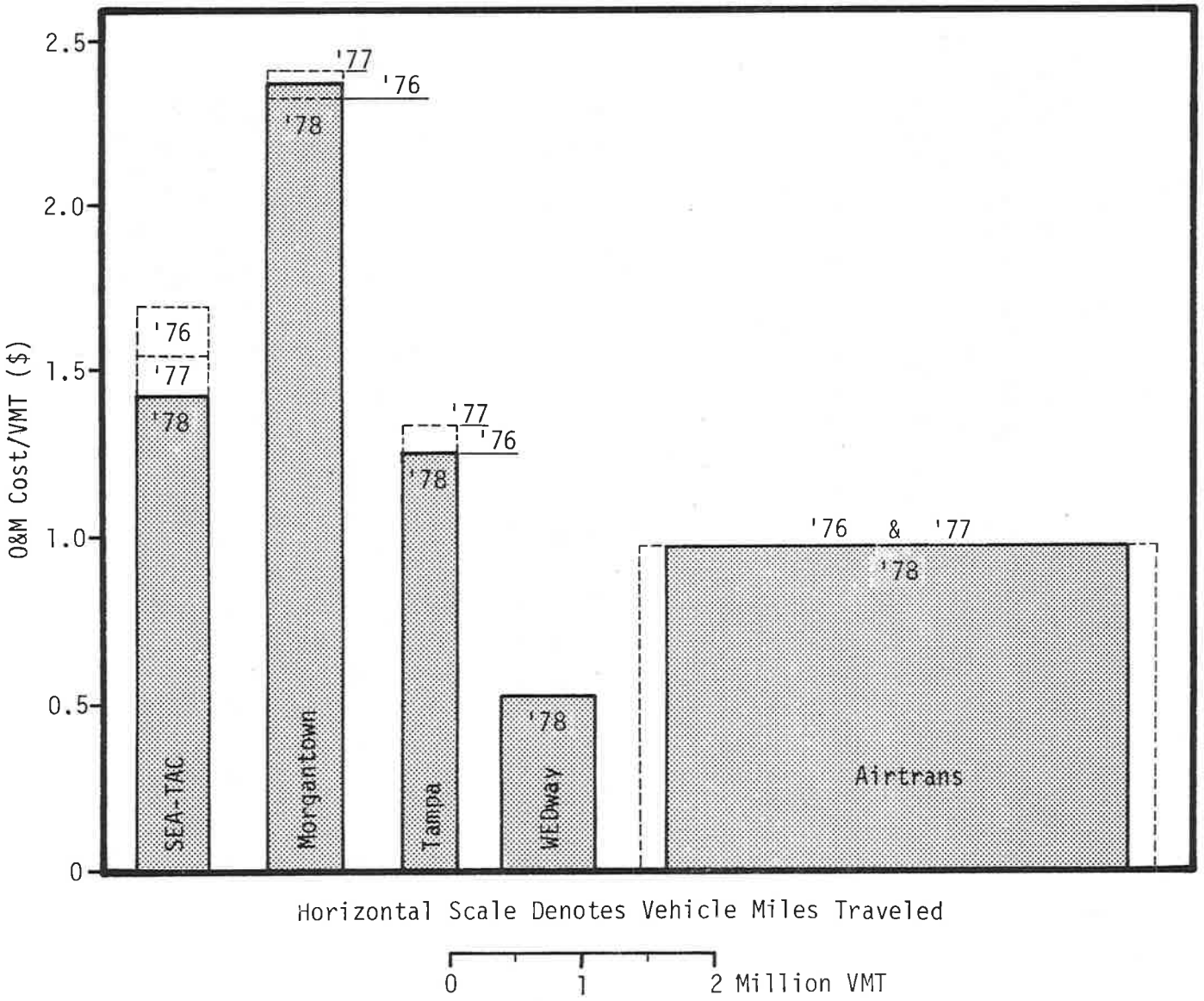


FIGURE 4. COMPARISON OF O&M COSTS PER VEHICLE MILE TRAVELED (VMT) FOR 1978

FIGURE 4 NOTES

- Shaded areas reflect 1978 data. Where 1976 and 1977 data differ, these amounts are indicated by dotted lines.

- The area of each bar represents the total annual O&M cost for each system.

- Due to the substantial mileage of the AIRTRANS system, its unit O&M cost/VMT of $.96 has a pronounced influence on the overall average of $1.10/VMT for all five systems.

- The Morgantown system was shut down for major modification and expansion during the first week of July 1978. Hence, only six months actual cost and operating data were available. Accordingly, for purposes of this analysis, cost and performance data for the last operational year, July 1977 - June 1978, were used, with 1977 costs adjusted appropriately to 1978 price levels.

- Morgantown's O&M cost of $2.40/VMT reflects the fact that it is the only one of the five systems which operates in severe winter weather. Also, its limited hours of operation resulted in the lowest average mileage per vehicle, which resulted in higher unit O&M cost/VMT.

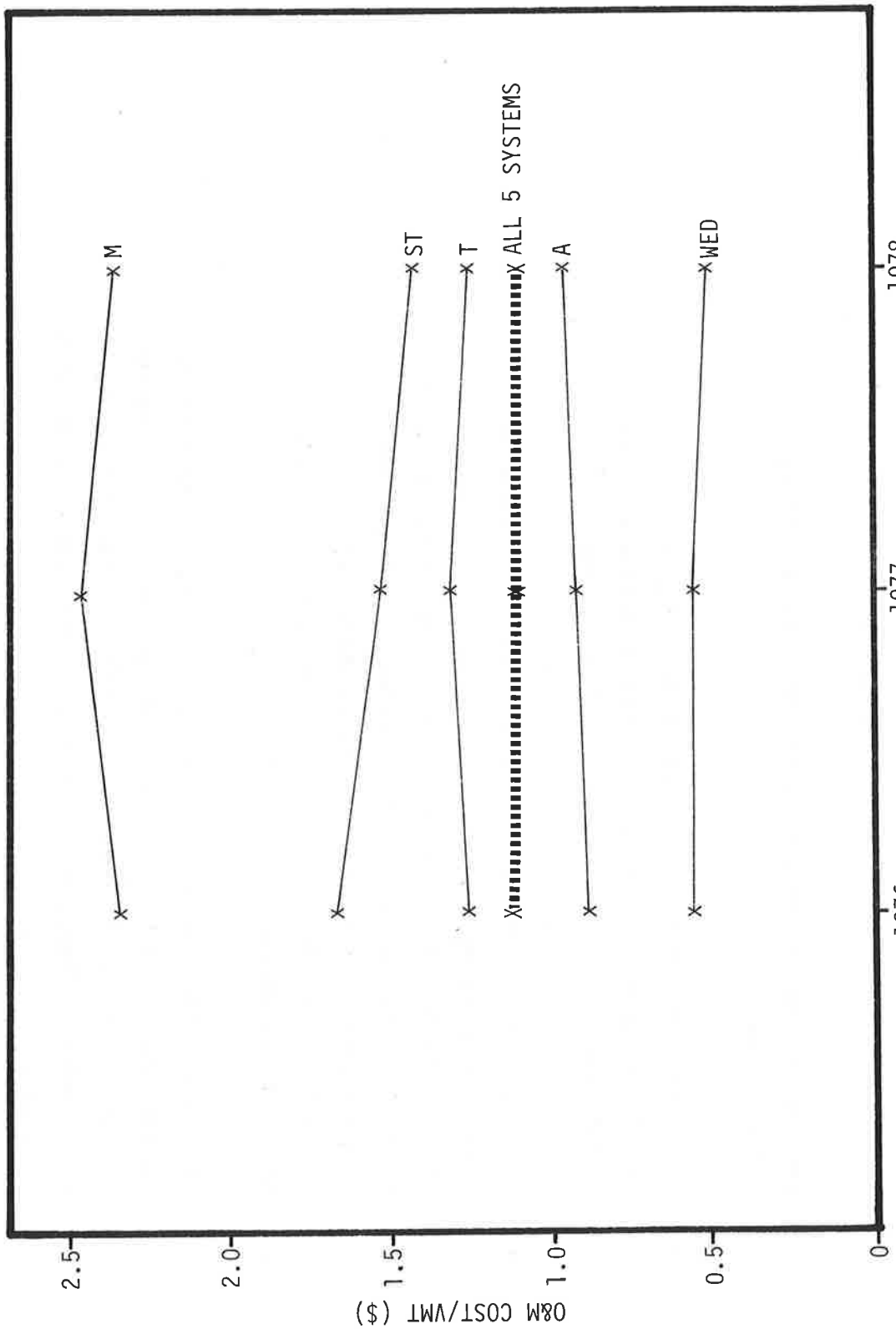


FIGURE 5. TREND OF O&M COST PER VEHICLE MILE FOR 5 AGT SYSTEMS
(Adjusted to 1978 Price Levels)

FIGURE 5 NOTES

- A significant decrease in terms of constant 1978 dollars was achieved at SEA-TAC where O&M cost/VMT dropped from $1.66 in 1976 to $1.42 in 1978. This was due to an increase in fleet mileage of 12 percent while actual O&M costs increased at a rate less than inflation.

- There are a number of reasons for Morgantown's higher O&M costs/VMT.

  - Only about half of the ultimate system was involved in the Phase I operation. Also, the limited hours of operation serves to spread the fixed costs over relatively few vehicle miles. Once the complete Phase II system has shaken down, reductions in the O&M cost/VMT should be realized.

  - The Phase I system has numerous maintenance problems which are being corrected in Phase II.

  - It is the most sophisticated system, with a different operating philosophy which includes non-stop origin to destination service and on-demand service. This has the effect of minimizing VMT and operating vehicles with higher load factors. Therefore, the O&M cost/VMT will naturally be higher than for systems with multi-stop scheduled services which traditionally operate at lower load factors.

  - It is the only system which operates in a severe winter environment. Guideway heating together with maintenance problems associated with cold weather operations contributes to higher costs.

- With the exception of Morgantown, all of the systems are approaching operational maturity. Thus, although some further improvements in efficiency may be possible , further significant reductions in O&M costs/VMT will probably depend upon increased fleet mileage.

- AIRTRANS O&M costs remained almost constant in terms of 1978 dollars, but fleet mileage decreased during the three-year period. This resulted in an 8 percent increase in O&M cost/VMT from 1976 to 1978.

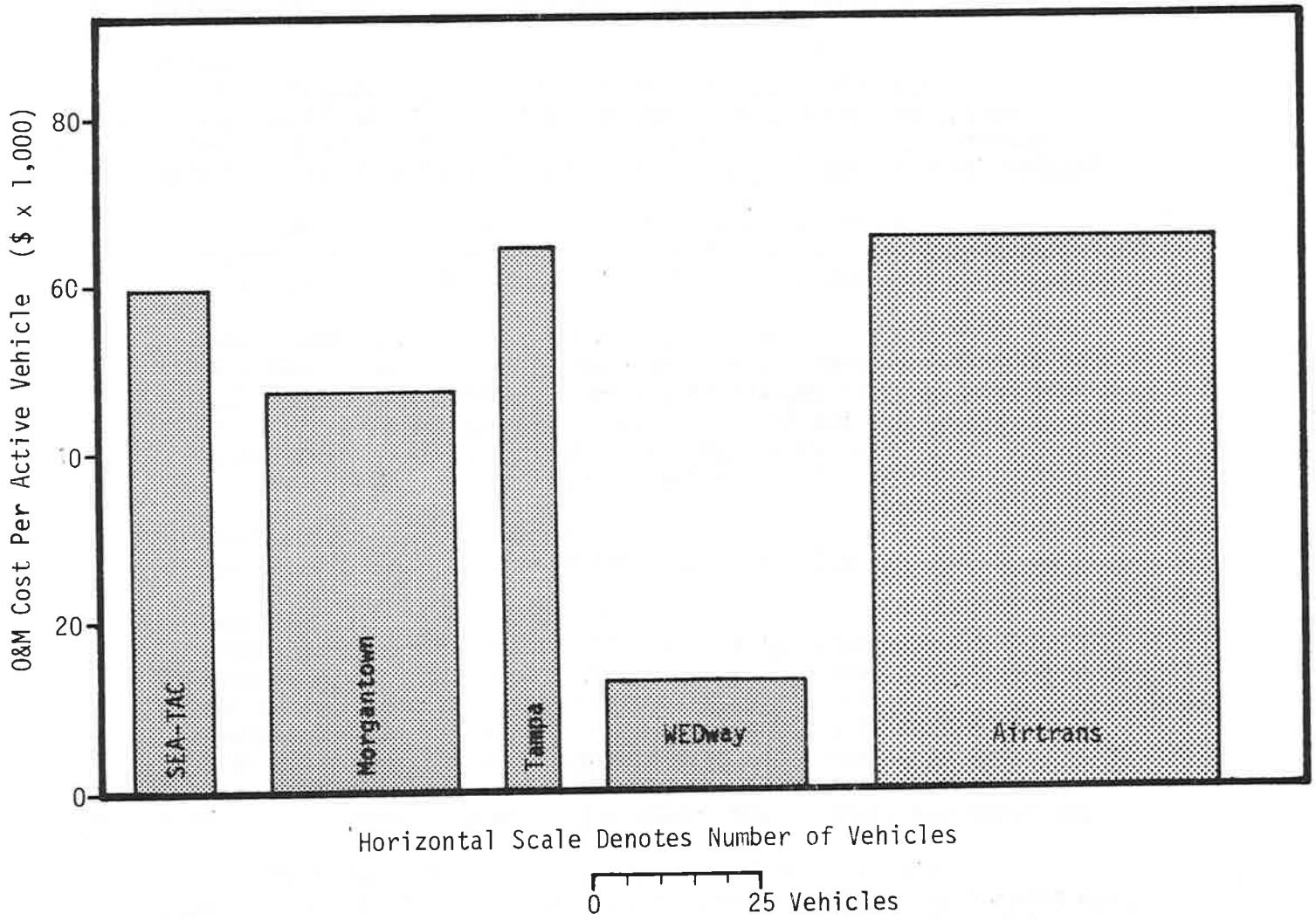


FIGURE 6. COMPARISON OF O&M COST PER ACTIVE VEHICLE for 1978

FIGURE 6 NOTES

- O&M cost per vehicle for the three airport systems were as follows for 1978:

AIRTRANS	65,900	51 vehicles
SEA-TAC	59,800	12 vehicles
TAMPA	64,300	8 vehicles
Average	64,700	

- The active fleet at MORGANTOWN includes only 29 vehicles, as 16 of the 45 delivered have been taken out of service for Phase II modifications.

- The small passive WEDway vehicles are completely different from the other AGT vehicles, and do not exert comparable influences in the O&M costs. Excluding WEDway, the average O&M cost per vehicle for the remaining four systems would be:

  $5,922,000 ÷ 100 vehicles = $59,200

TABLE 4

1976 O&M COST BREAKDOWN (1)

(Rounded to thousands of dollars)

	SEATAC	MORGANTOWN (2)	TAMPA	WEDway	AIRTRANS (2)
Labor					
Operations	86,000	142,000	3,000	164,000	387,000
Maintenance	334,000	388,000	9,000	108,000	1,570,000
Custodial	-	-	-	19,000	-
Utilities					
Electricity	11,000	108,000	65,000	51,000	257,000
Other	-	110,000	-	-	-
Materials & Services					
Contract Service	316,000	576,000	-	-	372,000
Spare Parts & Materials			420,000	42,000	760,000
G&A	N/A	152,000	12,000	17,000	N/A
TOTAL	747,000	1,480,000	509,000	401,000	3,340,000

Note: (1) All O&M costs adjusted to 1978 cost levels.

(2) Figures are adjusted to represent one full year of operation.

TABLE 5

1977 O&M COST BREAKDOWN

(Rounded to thousands of dollars)

	SEATAC	MORGANTOWN	TAMPA	WEDway	AIRTRANS
Labor					
Operations	84,000	165,000	4,000	138,000	455,000
Maintenance	315,000	399,000	10,000	104,000	1,400,000
Custodial	-	-	-	19,000	-
Utilities					
Electricity	11,000	108,000	67,000	51,000	288,000
Other	-	90,000	-	-	-
Materials & Services					
Contract Service)	292,000	510,000	-	-	322,000
Spare Parts & Materials)			428,000	63,000	868,000
G&A	N/A	159,000	12,000	18,000	N/A
TOTAL	702,000	1,430,000	521,000	393,000	3,330,000

Note: All O&M costs adjusted to 1978 cost levels.

TABLE 6

1978 O&M COST BREAKDOWN

(Rounded to thousands of dollars)

	SEATAC	MORGANTOWN (1)	TAMPA	WEDway	AIRTRANS
Labor					
Operations	81,000	156,000	4,000	148,000	489,000
Maintenance	409,000	426,000	10,000	78,000	1,430,000
Custodial	-			20,000	-
Utilities					
Electricity	17,000	109,000	74,000	52,000	288,000
Other	-	76,000	-	-	-
Materials & Services					
Contract Service	112,000	) 399,000	-	-	329,000
Spare Parts & Materials	99,000	)	415,000	49,000	818,000
G&A	N/A	167,000	11,000	16,000	N/A
TOTAL	718,000	1,330,000	514,000	363,000	3,360,000

(1) Note: Figures are adjusted to represent one year of operation

TABLE 6 NOTES

- The $76,000 indicated as "other utilities" at MORGANTOWN is the cost of natural gas for guideway heating. This is less than the $90,000 spent for gas in 1977, due to better coordination of boiler operations with weather forecasts.

- At TAMPA, most of the maintenance is performed by Westinghouse under contract to the airport. Currently, the Westinghouse staff consists of a supervisor and 6 mechanics and technicians. Thus, a significant portion of the $415,000 indicated for contract services was actually for maintenance labor. It is estimated that about $225,000 of this total is for salaries, fringe benefits and overhead costs associated with the Westinghouse maintenance staff.

- For SEA-TAC and AIRTRANS, the G&A costs are included in other cost categories.

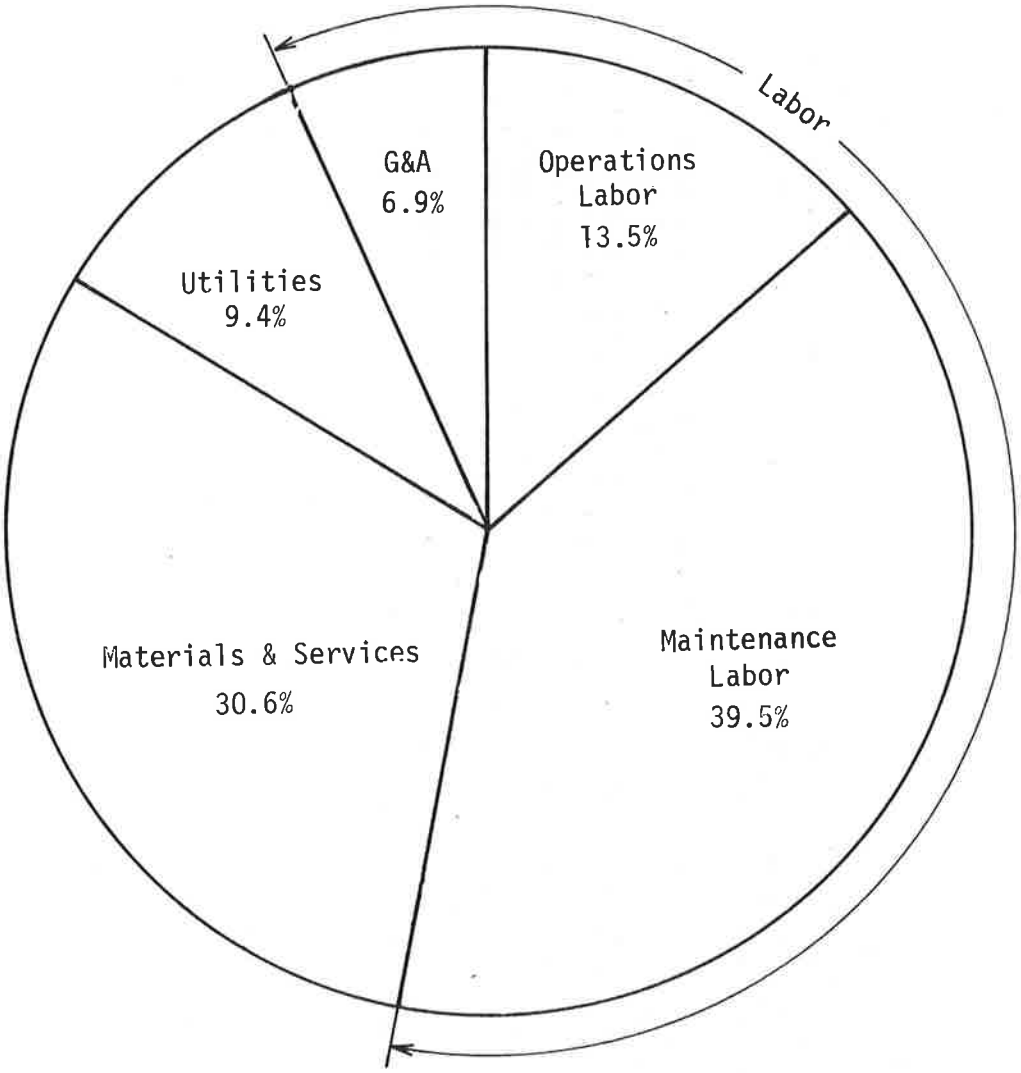


FIGURE 7. 1978 O&M COST DISTRIBUTION FOR FIVE MAJOR SYSTEMS

FIGURE 7 NOTES

- Labor amounted to about 60 percent of total O&M expenditures. For the 5 systems surveyed, manpower utilized was as follows for 1978:

	Supervisory/ Administrative/ Technical	Operations	Maintenance	Total
AIRTRANS	11	12	88	111
MORGANTOWN	18	12	31	61
SEA-TAC	4	5	10	19
TAMPA	0	1	7	8
WEDway	4	6	2	12
TOTALS	37	36	138	211

- The 39.5% indicated as Maintenance Labor includes an estimate of $225,000 for the labor component of the Westinghouse Contract to maintain the TAMPA System.

- Since all systems do not account for expenditures on a uniform basis, cost distribution has been estimated in some instances. For example, 3 of the 5 systems provided G&A costs, but SEA-TAC and AIRTRANS did not identify them separately. Hence, an estimate has been made, based on the average for those systems reporting.

- The cost of guideway heating at MORGANTOWN is included in the total cost of utilities for the five systems. This amounts to about one-tenth of the total cost of utilities for these systems.

- Materials and services accounted for 30.6 percent of total expenditures. This includes spare parts and consumable supplies as well as contract services for specialty work such as motor rewinding, computer maintenance, outside cleaning services, etc. Obviously a portion of these costs involved labor but it is difficult to estimate how much.

CAPITAL COSTS

Capital cost data for seven of the ten AGT systems surveyed in the initial report No. UMTA-IT-06-0157-78-2 titled "Summary of Capital and Operations & Maintenance Cost Experience of Automated Guideway Transit Systems", together with information on three new systems, at the Miami and Atlanta airports and at Busch Gardens in Williamsburg, VA., are presented in Table 7. For purposes of this analysis, these costs have been grouped into three major categories as follows:

Equipment - This includes the vehicles; the command, control and communications equipment; the power rails; the wayside control elements; station equipment (such as coordinated station doors); fare collection equipment; graphics; closed circuit TV; and special maintenance equipment (hoists, test devices and other features of the maintenance complex).

Facilities - This category includes the guideway foundations, structures, guidance surfaces, stations (excluding the equipment indicated above), maintenance buildings and other construction features.

Engineering and Project Management - Included in this category are architectural and engineering services, overall project management, system acceptance and testing, etc. Design engineering associated with the vehicles' control system or other equipment features is normally included in the equipment category.

Figures 8 and 9 indicate how total system costs can be related to system guideway mileage, expressed in equivalent lane miles of elevated guideway as well as in terms of the passenger carrying capacity provided by the vehicle fleet. As indicated, the average total system cost, excluding the Atlanta Airport, for which facilities cost data was not available, amounts to approximately $10.1 million per equivalent lane mile, and about $4,000 per unit of passenger carrying capacity. However,

it is apparent from inspection of these two graphs that actual values vary considerably from these averages, as indicated in the explanatory notes accompanying them.

For a better examination of comparable features of AGT capital costs, Figure 10 has been prepared to indicate the relationship between the total costs of equipment and its passenger carrying capabilities. As will be noted from Figure 10, with two exceptions, i.e., the Morgantown system which is considerably more sophisticated than the others, and the King's Dominion system which is quite simple by comparison, all the other AGT systems follow the general pattern closely.

As regards the cost of vehicles, information obtained from system operators and manufacturers has proved to be somewhat inconclusive. This is indicated by the rather wide scattering of points on Figure 11. With reference to the broad range of costs for the Westinghouse vehicles furnished for TAMPA, SEA-TAC, MIAMI, BUSCH GARDENS and ATLANTA, some of the reasons are outlined in the accompanying notes. However, this is the subject of continuing investigation which it is expected will provide better answers to the questions of what factors determine AGT vehicle costs.

TABLE 7

AGT CAPITAL COSTS
(Adjusted to 1978 Price Levels)

	MORGANTOWN Phase I	AIRTRANS	TAMPA	SEA-TAC	MIAMI AIRPORT	ATLANTA AIRPORT	WEDway	KING'S DOMINION	FAIRLANE	BUSCH GARDENS
EQUIPMENT										
Vehicles										
Number	45	51	8	12	4	17	30	6	2	2
Actual Vehicle Capacity	21	40	100	102	99	80	20	96	24	90
Equivalent Vehicle Capacity (1)	23	42	81	81	81	84	29	109	27	81
TOTAL COST	10,200,000	13,900,000	3,100,000	5,700,000	1,200,000	9,800,000	3,600,000	2,600,000	800,000	940,000
Per Vehicle	227,000	273,000	388,000	475,000	300,000	576,000	120,000	433,000	400,000	470,000
Per Equivalent Passenger Place	9,855	6,489	4,784	5,864	3,395	6,863	4,138	3,975	15,000	3,333
Other Equipment										
Command & Control	11,600,000	9,000,000	1,600,000		500,000	4,400,000	3,700,000	40,000	800,000	
Power Rail (equipment)	3,100,000	6,000,000	2,500,000		370,000	1,900,000	915,000	370,000	1,100,000	
Station Equipment	458,000	900,000	620,000	5,400,000	630,000	796,000				1,180,000
Maintenance Equipment	521,000	4,000,000	240,000		200,000	780,000	680,000	45,000		
Equipment Engineering	3,100,000	8,100,000	1,300,000	2,400,000	600,000	2,200,000		485,000	800,000	
TOTAL	29,000,000	41,900,000	9,300,000	13,500,000	3,400,000	19,800,000	8,900,000	3,500,000	3,500,000	2,120,000
FACILITIES										
Guideway	22,100,000	13,400,000	4,000,000	14,200,000	2,900,000	N/A	2,300,000	1,200,000	2,400,000	1,970,000
Lane Miles	5.26	12.8	1.35	1.71			0.87	2.06	0.61	1.33
Equivalent Elevated Lane Miles	4.52	6.66	1.35	5.13	0.51		0.87	0.88	0.61	0.84
Total Cost Per Equiv. Lane Mile	4,900,000	2,000,000	3,000,000	2,800,000	5,700,000		2,600,000	1,400,000	4,000,000	2,300,000
Other Facilities										
Stations	2,500,000	5,200,000	2,000,000	6,400,000	2,500,000		1,500,000	207,000	500,000	
Power Supply	700,000	N/A	N/A	N/A			N/A			240,000
Maintenance Shop		640,000	820,000	2,100,000	600,000		300,000	192,000	140,000	
TOTAL	25,300,000	19,200,000	6,800,000	22,700,000	6,000,000		4,100,000	1,600,000	3,000,000	2,210,000
ENGINEERING & PROJECT MANAGEMENT	12,200,000	6,700,000	640,000	3,600,000	1,900,000	N/A	1,000,000	1,200,000	500,000	970,000
TOTAL COST	66,500,000	67,800,000	16,8[illegible]00	39,800,000	11,300,000	N/A	14,000,000	6,300,000	7,000,000	5,300,000

TABLE 7 NOTES

- Capital cost data included in the original Summary Cost Report has been adjusted to 1978 price levels and rearranged into the categories of Equipment,Facilities and Engineering and Project Management. Similar information for Busch Gardens and the Miami Airport was derived from NDL's ongoing assessment of these projects. For the Atlanta Airport People Mover, information on equipment costs only was available.

- In instances where there was insufficient information available on the cost of individual or groups of subsystems, engineering estimates have been made.

- Actual lengths of at-grade, elevated and underground guideways have been converted to Equivalent Elevated Lane Miles by use of the following factors: 0.4 for at-grade, 1.0 for elevated, and 3.0 for underground.

- Equipment, Facilities and Engineering & Project Management costs have been adjusted to 1978 price levels by use of the Wholesale Price Index for Machinery and Motive Products, the Engineering News Record Cost Index for 20 cities, and the Consumer Price Index for Urban Wage and Clerical Workers, U.S. City Average, respectively.

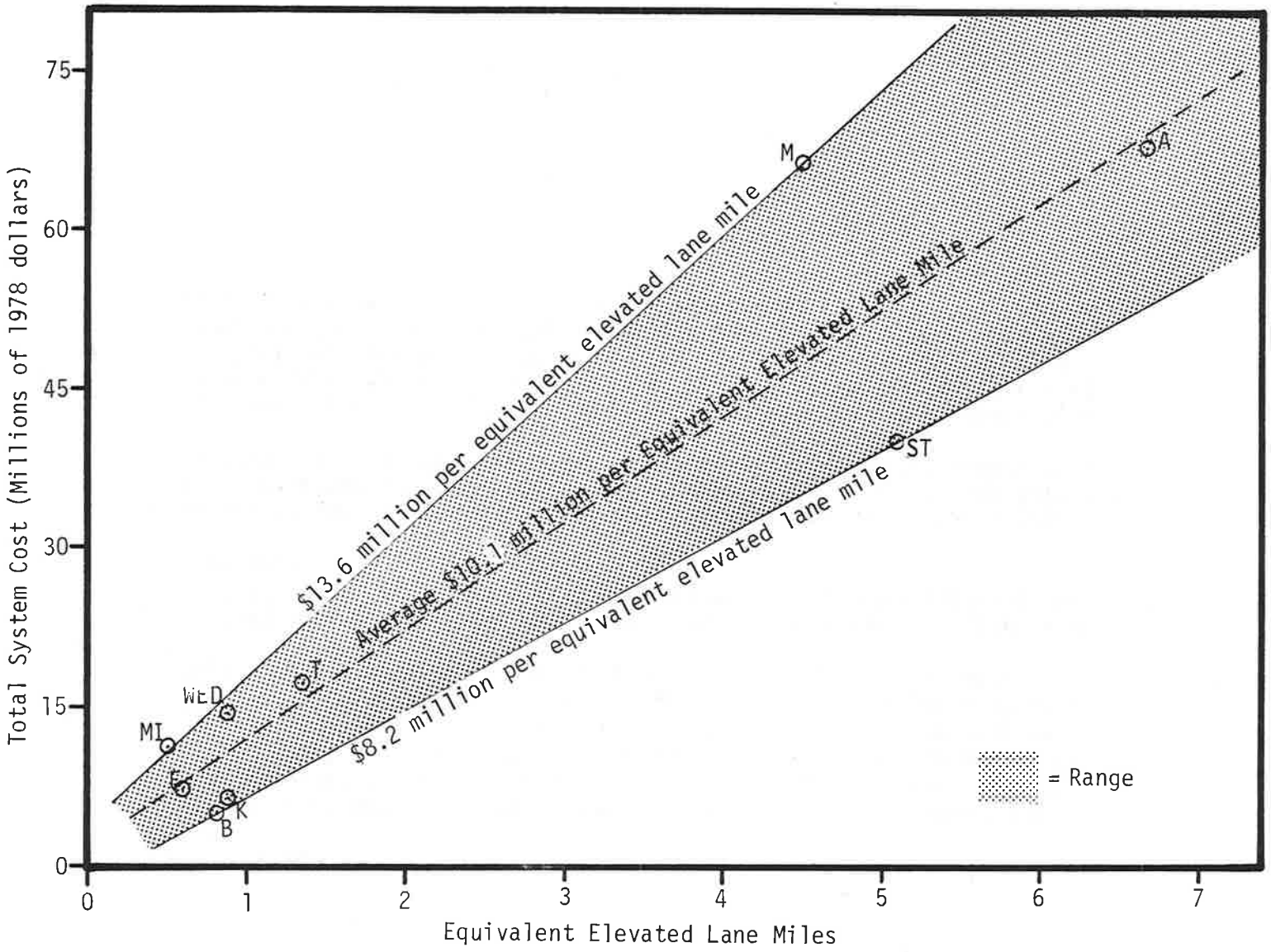


FIGURE 8. TOTAL SYSTEM COST AS RELATED TO NORMALIZED GUIDEWAY LENGTH

FIGURE 8 NOTES

- AGT systems are identified as follows:

A	AIRTRANS	M	MORGANTOWN
B	BUSCH GARDENS	MI	MIAMI AIRPORT
F	FAIRLANE	ST	SEA-TAC
K	KING'S DOMINION	WED	WEDway

- Equivalent elevated lane miles have been estimated on the following basis:

  0.4 x at-grade length = equivalent elevated length
  3.0 x underground length = equivalent elevated length

  These normalizing factors have been developed by the DOT Transportation Systems Center, based upon analysis of actual cost data as well as estimates for proposed projects.

- The Morgantown system is the most sophisticated of the 9 AGT systems examined and represents a first-of-a-kind effort. This accounts for its deviation from the normal cost trend.

- SEA-TAC is completely underground and tunneling costs were estimated at the time of the initial assessment. Total guideway length is 1.7 lane miles. The deviation from the general trend line is probably due to the normalizing factor.

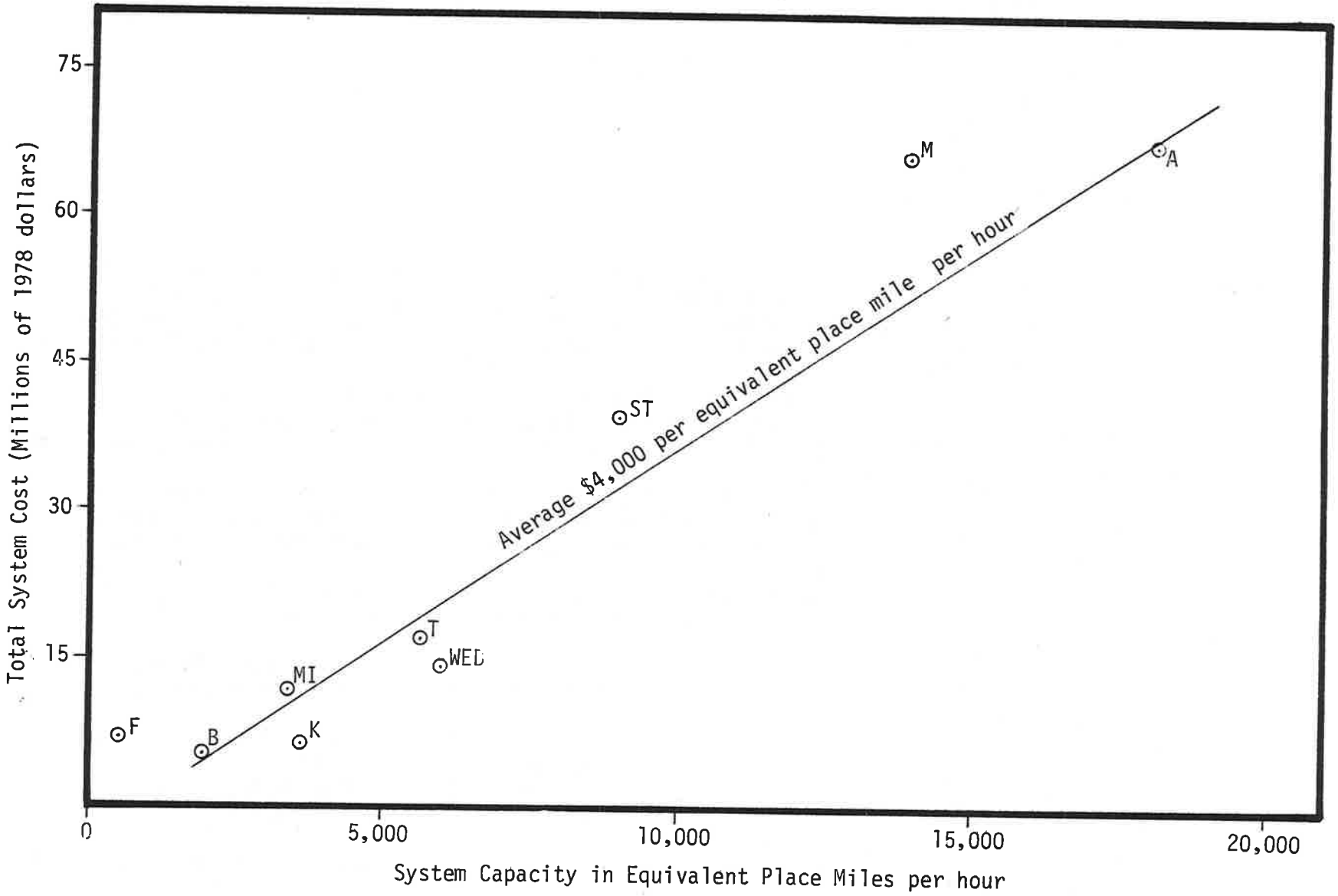


FIGURE 9: TOTAL SYSTEM COST AS RELATED TO SYSTEM CAPACITY

FIGURE 9 NOTES

- Because of the significant differences in system configuration, for comparison purposes, the capacities of these AGT systems may be expressed in terms of place miles per hour. This takes into account the size of the vehicle fleet, their average speed and their passenger carrying capacity.

- Equivalent vehicle capacities have been used in calculating equivalent place miles per hour. Thus, instead of the actual capacity which is dictated by the interior arrangement of a vehicle, normalized capacities have been estimated for purposes of comparability on the basis of a uniform distribution of 33 percent seated and 67 percent standing passengers. Floor space of 4.5 sq. ft. is allowed per seated passenger and 2.36 sq. ft. per standee.

- The entire MORGANTOWN fleet of 45 vehicles has been used in determining the capacity of the Phase I system. Based upon on-site analysis of operation at MORGANTOWN an average system-wide speed of 13.4 miles per hour (including station stops) is considered feasible. This may be converted to system capacity as follows:

  45 vehicles x 23 equivalent passenger places each x 13.4 miles per hour = 13,869 equivalent place miles per hour.

- As indicated in the graph, the system cost/capacity data follow a pattern which approximates to a linear relationship with an average system cost of $4,000 per equivalent passenger place per hour.

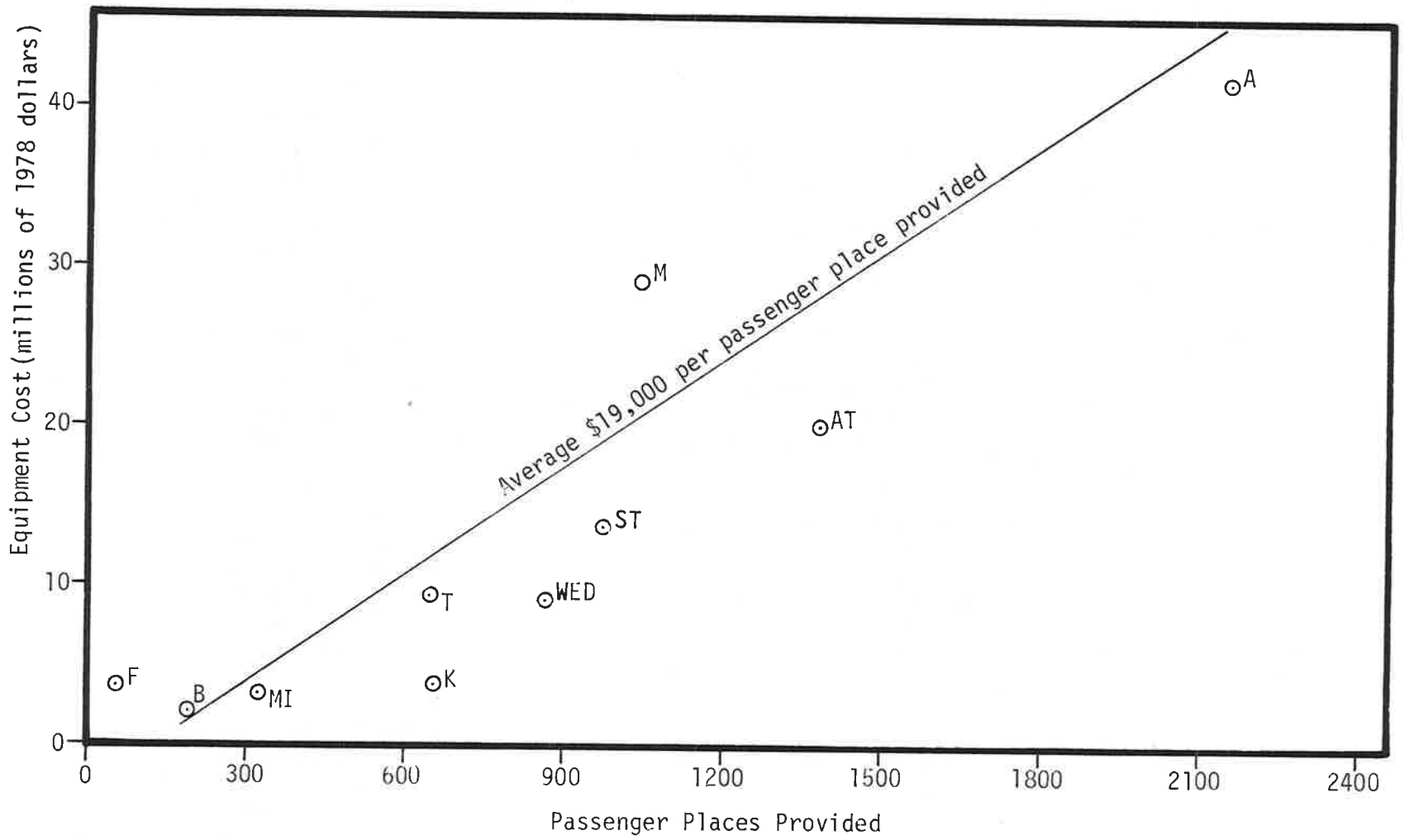


FIGURE 10. EQUIPMENT COST AS RELATED TO PASSENGER PLACES PROVIDED

FIGURE 10 NOTES

- Equipment includes vehicles, controls and communications, switches, station doors, graphics, fare collection, special maintenance equipment and other hardware items.

- Equipment costs are generally independent of specific site geography, or the influence of adjoining facilities.

- Passenger places provided is the normalized capacity of the vehicle fleet, based upon uniform passenger accommodations, i.e., 33 percent seated and 67 percent standing, with 4.5 sq ft of floor space for each seated passenger and 2.36 sq ft for standees.

- Excluding MORGANTOWN and KING'S DOMINION which deviate significantly from the general trend, there is good correlation between equipment costs and total fleet capacity.

  - MORGANTOWN is the most sophisticated of the AGT systems surveyed, and therefore has the most expensive equipment.

  - Because KING'S DOMINION is a light amusement park system which provides a limited level of service, it requires less expensive hardware.

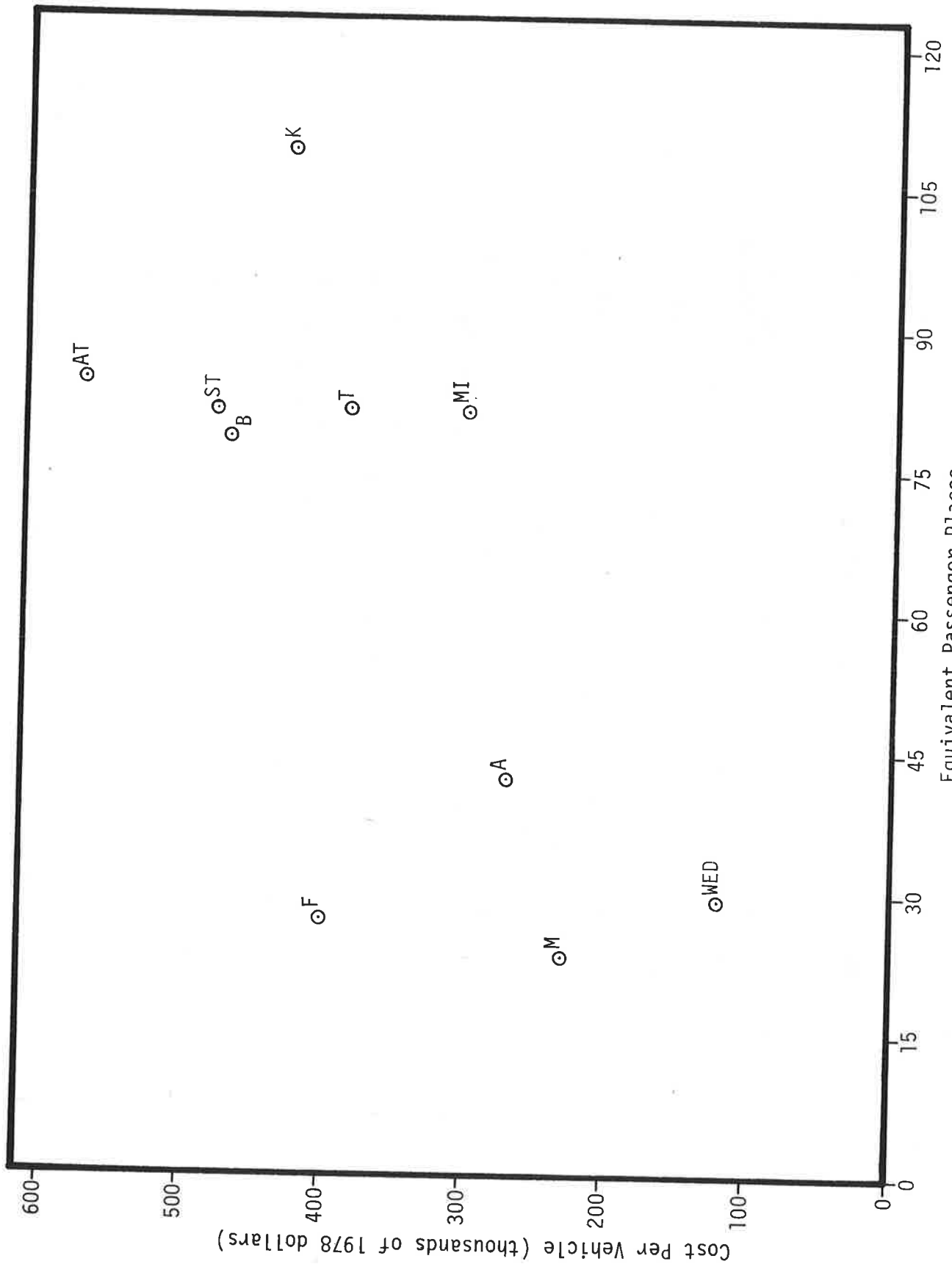


FIGURE 11. VEHICLE COST AS RELATED TO CAPACITY

FIGURE 11 NOTES

- The cost data are too scattered to establish a definitive trend.
- WEDway and KING'S DOMINION costs are for trains of 5 and 8 cars, respectively.
- The 5 Westinghouse systems, though similar in capacity and configuration, have significant differences. The following information on cost and features illustrates this point:

	No.	Year Purchased	1978 Cost (000)	Vehicle Features
TAMPA	8 vehicles	1969	388	2 motors/vehicle, no coupling capabilities, doors 2 sides.
SEA-TAC	12 vehicles	1972 1976	475	1 motor/vehicle, automatic coupling, doors one side, block controls.
BUSCH GARDENS	2 vehicles	1975	470	2 motors/vehicle, doors both sides, block system, towbar coupling and trainlines.
MIAMI	4 vehicles	1973	300	1 motor/vehicle, doors both sides, towbar coupling and train lines, half of vehicles are slaves, i.e., have no on-board controls.
ATLANTA	17 vehicles	1978	576	2 motors/vehicle, 2 doors both sides, block controls semi-automatic coupling.
AVERAGE COST			482	

- Manufacturers are reluctant to disclose detailed cost information on their hardware, hence, cost data on individual subsystems are difficult to obtain and may be unreliable.
- Fairlane system cost is probably not representative since it has only 2 vehicles. WEDway vehicles are trains of small passive open cars with no moving parts and are therefore less costly.

COMPARISON OF AGT WITH OTHER TRANSIT MODES

In an effort to determine how automated guideway transit systems compare on a cost basis with other transit modes, representative data has been assembled from a variety of sources including the extensive statistical base compiled by the American Public Transit Association. As to general O&M cost trends, the average cost per vehicle mile for automated guideway transit has been superimposed on APTA's cost trend chart and included as Figure 12. As will be noted, the O&M cost of AGT systems have held steady in terms of constant dollars, whereas a progressive increase has been a general experience with conventional bus and rail transit systems.

Figure 14 indicates graphically how the operations and maintenance cost per vehicle mile for the five AGT systems surveyed compared with representative bus and light rail systems. It is interesting to note that the average cost of the AGT systems was well below the average of $2.36/VMT for buses and $3.48 for light rail. However, as indicated, the ranges overlap in some instances.

At the outset of any consideration of comparative cost of AGT and other modes, it is important to recognize the fundamental differences in the level of service and types of application. Thus, it would be inappropriate to compare O&M costs data developed from activity center systems, such as are exemplified by the five AGT systems examined, with linehaul rail applications. Accordingly, it would be preferable to confine comparisons between modes to logical domains of types of applications. Similarly, it should be recognized that simplified comparisons of such parameters as the cost per vehicle mile can lead to erroneous results.

Since the bulk of O&M costs are based on hourly expenditure, a comparison of O&M cost per place hour is considered very appropriate. This takes into account the relative capacities of the vehicles, as well

as the total hours each vehicle was in operation. Figure 14 indicates how AGT systems compare with other modes on this basis.

In an effort to assess the relative costs of providing an equivalent level of transportation service by alternative transit modes, it is appropriate to evaluate the capital costs involved in providing transportation throughput capacity for each class of system. To illustrate this, Figure 15 has been prepared which relates total cost per equivalent route mile of system length to average systemwide service capacity provided, expressed in annual place miles traveled over each mile of route. As will be noted, rapid rail systems, which characteristically provide the highest level of travel density in the form of long trains moving at fairly frequent intervals during rush hour periods, involve the highest capital expenditure on an equivalent route mile basis. Next, from the point of view of cost per route mile are light rail and AGT systems which average about $25 million. However, the AGT systems examined provided a higher average systemwide service capacity than light rail. Lowest in capital cost per equivalent route mile are exclusive busways, as indicated by data compiled for the Shirley Highway demonstration in the Washington Metropolitan area. However, the service capacity achieved was considerably lower than for AGT.

The foregoing comparisons, of course, do not take into account more than a few of the factors which must be considered in making valid comparisons. Such factors as comfort convenience, frequency of service, travel time and ease of access to and from the public transit system must be appropriately evaluated. Nevertheless, they do indicate that there is a definite economic range within which automated guideway transit is very competitive on the basis of initial investment with conventional transit modes.

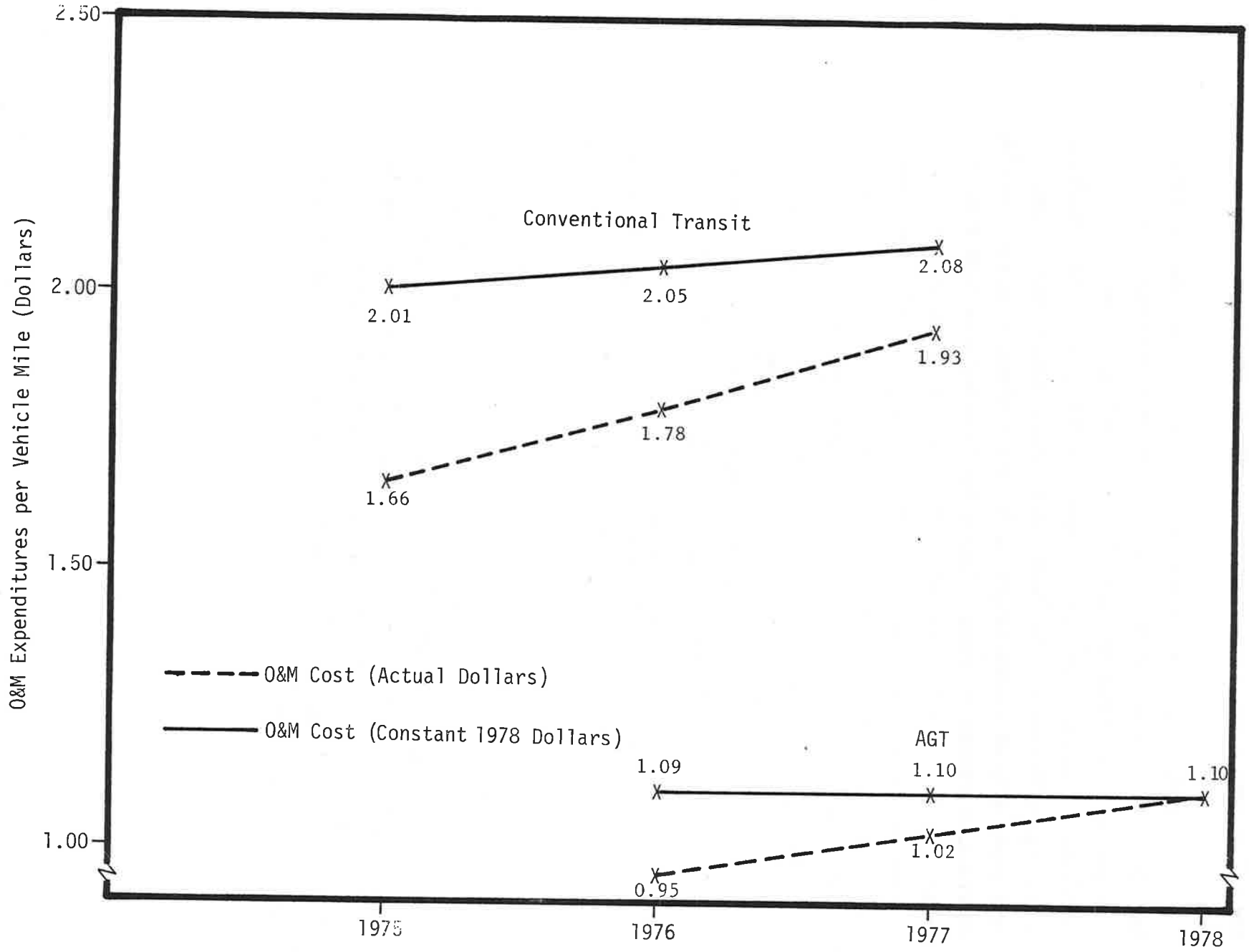


FIGURE 12: O&M COST TRENDS FOR AGT AND CONVENTIONAL TRANSIT

FIGURE 12 NOTES

- Costs for conventional transit, i.e., bus and rail as reported in APTA's Transit Fact Book, have been adjusted to exclude amounts spent for traffic solicitation, advertising, depreciation, amortization, taxes, licenses, rents, etc., since the AGT O&M costs do not include them. Data on conventional transit cost for 1978 are not yet available.

- Both AGT and conventional transit costs have been adjusted to 1978 price levels on the basis of CPI index as follows:

	Index	Escalation Factor
1974	147.1	1.33
1975	161.2	1.21
1976	170.3	1.15
1977	181.5	1.08
1978	195.4	1.00

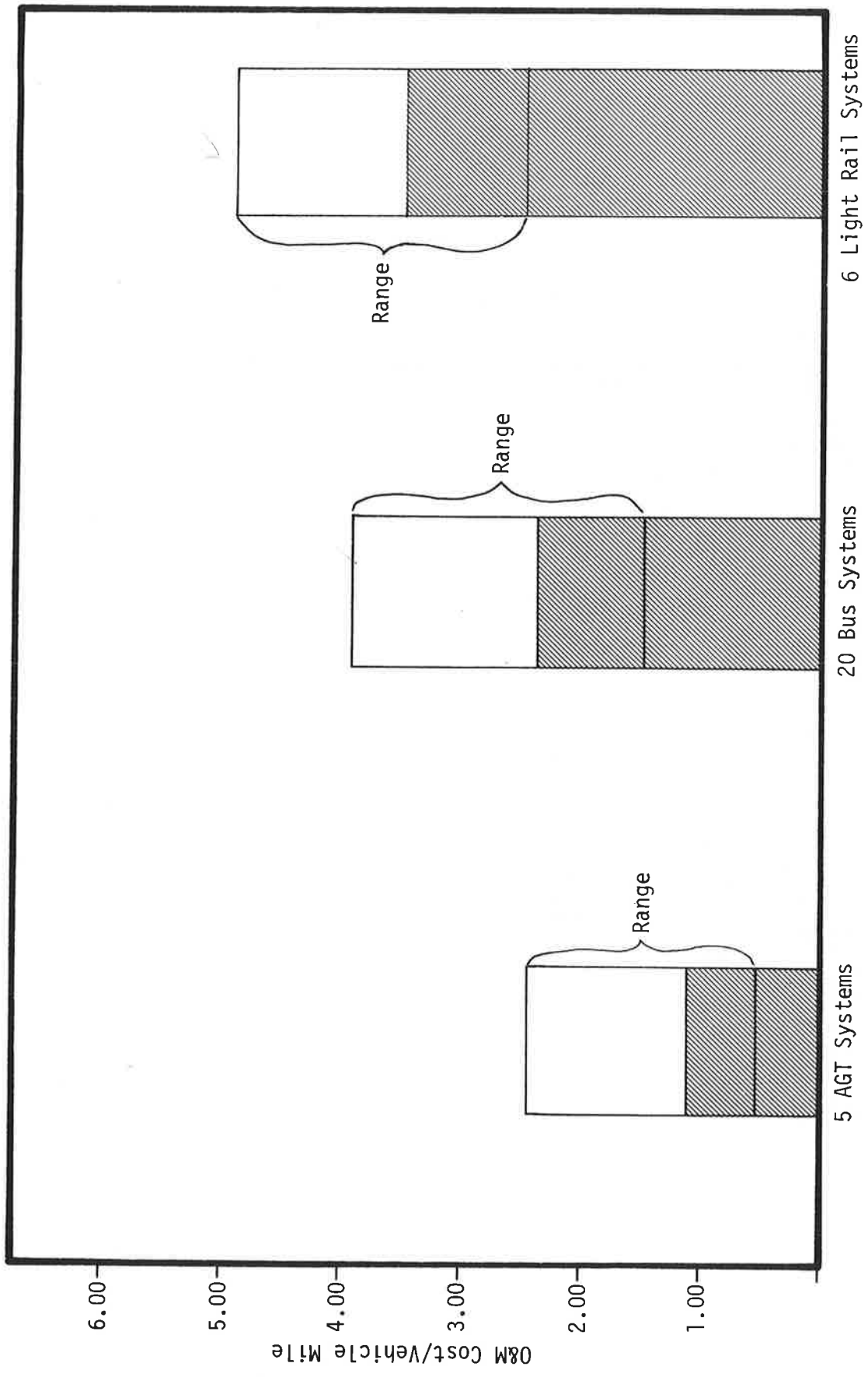


FIGURE 13. COMPARISON OF O&M COST PER VEHICLE MILE TRAVELED

FIGURE 13 NOTES

- The shaded bars indicate the average O&M costs.
- Ranges for O&M costs are as indicated:

	AGT	Bus	Light Rail
High	2.40 MORGANTOWN	4.20 MANHATTAN/BRONX	4.83 PHILADELPHIA
Low	0.51 WEDway	1.24 DALLAS	2.46 CLEVELAND
Average	1.10	2.36	3.48

- Bus and light rail costs were for 1976 and 1977 operations, respectively, escalated to 1978 prices and AGT costs refer to 1978 operations.

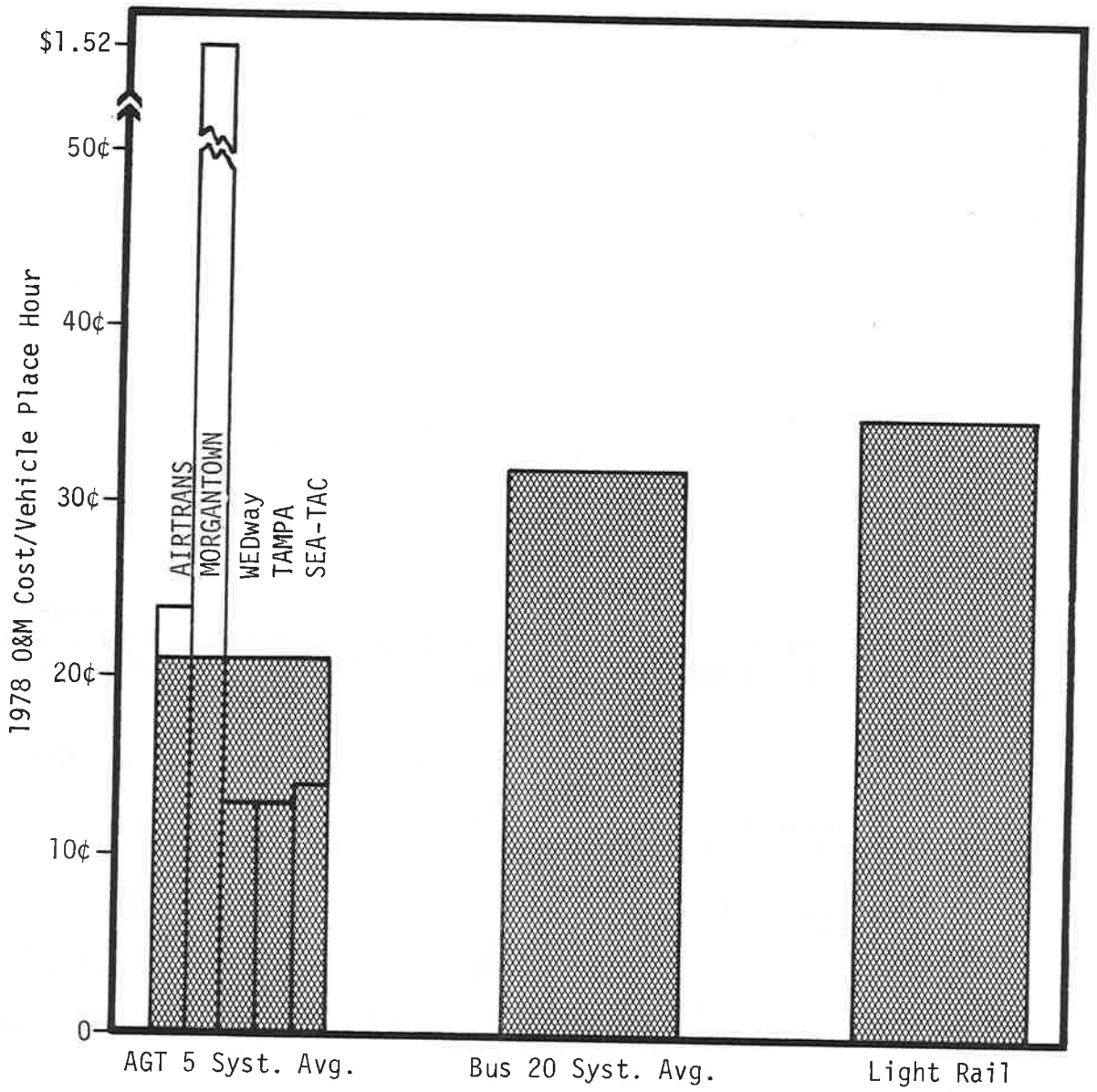


FIGURE 14. COMPARISON OF O&M COST PER PLACE HOUR OF OPERATION

FIGURE 14 NOTES

- With the exception of MORGANTOWN, which has relatively small vehicles and is the most sophisticated system in passenger service, O&M costs per vehicle place hour were within a range of 13¢ to 24¢.

- For purposes of comparison among the three modes, the capacities of vehicles were calculated on a uniform basis as follows:

  gross area (length X width) ÷ 4 Sq Ft/passenger = Passenger places.

- Place hours were based on the actual vehicle hours of operation over a year's time.

- AGT compares favorably with bus and light rail on the basis of cost per hour of passenger space provided.

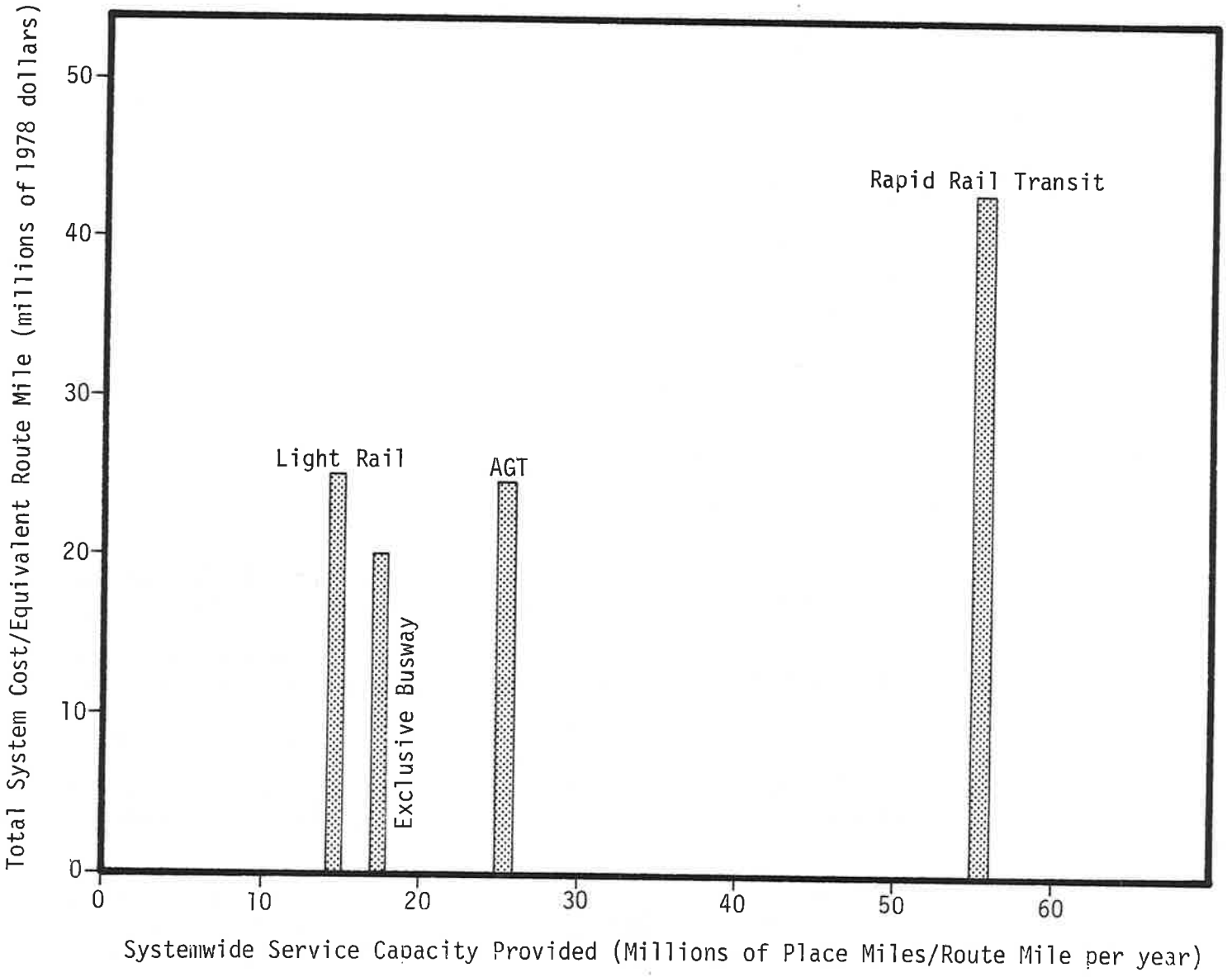


FIGURE 15: COMPARISON OF CAPITAL COST AS RELATED TO SERVICE CAPACITY PROVIDED

FIGURE 15 NOTES

- The average capital cost of the 5 major AGT systems per equivalent route mile was $24.3 million in 1978 dollars. This is quite comparable to the cost for 3 recent light rail systems for which cost data was available. For the 5 newest rail rapid transit systems, WMATA, BART, ATLANTA, BALTIMORE and MIAMI, the average capital cost per equivalent route mile is $43.1 million.

- Lowest in capital cost on a route mile basis was the Shirley Highway exclusive busway serving the Washington, D. C. suburbs, which averaged $20.0 million.

- Actual route miles were adjusted uniformly by applying an 0.4 factor for surface or at grade mileage and a 3.0 factor for underground distances. For AGT which involves substantial ramps, test loops, etc., equivalent route miles were estimated by dividing total equivalent elevated lane miles by 2.2.

- The position of each bar on the horizontal scale indicates the systemwide service capacity provided for each of the four modes, expressed in place miles per route mile per year. For comparison purposes, vehicle capacities were calculated on the basis of 4 sq ft of gross area per passenger. Annual mileage was either obtained from operating records or estimated on the basis of the size of the proposed vehicle fleet and overall averages for rapid rail (44,753 vehicle miles per vehicle owned per year) and light rail (22,480 vehicle miles per vehicle owned per year) developed from the APTA Transit Operating Report.

- Whereas AGT and light rail capital costs were approximately equal, the AGT systems surveyed provided a 78 percent greater service capacity. Thus, for the same average capital cost, the AGT systems operated almost two times more passenger place miles over each mile of route than the light rail systems.

FINDINGS AND CONCLUSIONS

OPERATIONS & MAINTENANCE

There are so many factors that influence the cost to operate and maintain Automated Guideway Transit systems, that the use of such simplified units as the cost per vehicle mile, the cost per passenger carried, or the cost per vehicle operated, should be treated with great caution. Each system is affected by a number of different influences which have cost implications. Accordingly, cost comparisons from one system to another are likely to be inconclusive.

Labor accounted for approximately 60 percent of the O&M cost for the five major AGT systems examined. In most instances, the work force for individual systems remained relatively constant, with special requirements being handled by the use of overtime.

The number of people required to operate and maintain an AGT system is determined by a number of factors, including the following:

- The number of vehicles in the operating fleet, their size and the level of sophistication.
- The size and complexity of the system, i.e., the configuration of the guideways, the number of stations, the number of switches, and general terrain conditions.
- The hours of operation which dictate the number of shifts that must be manned throughout the year.

- Local requirements and policies on system availability and the effect of occasional breakdowns on the system's ability to provide an acceptable level of service. For example, "must-ride" systems such as SEA-TAC, where a failure in one of the loops would prevent the movement of passengers between the main terminal and the satellite, must provide for more emergency personnel to correct deficiencies and restore service than systems which are capable of tolerating occasional service interruptions.

Essentially the O&M cost for an individual AGT system may be considered to be a function of the following:

Site-Specific Fixed Costs - as dictated by climatic and geographic factors, hours of operation and level of service provided, degree of sophistication, etc. (C_f)

Station Related Costs - determined by the number, size and complexity of stations in the system as well as the amenities provided. (C_s)

Guideway Related Costs - affected by the length and configuration of the guideway system, the number and type of switches and the amount of wayside control equipment dictated by the level of operational sophistication. (C_g)

Vehicle Related Costs - influenced primarily by the number, size, type and complexity of the vehicles in the fleet. (C_v)

Fleet Operational Costs - determined by the vehicle miles traveled and level of fleet activity. (C_o)

This cost model may be expressed mathematically as indicated below:

$$C_{O\&M} = f\ (C_f,\ C_s,\ C_g,\ C_v,\ C_o)$$

Of the foregoing components of O&M cost, the last two, which are related to fleet size and level of operation, are most significant. At AIRTRANS, for example, where detailed cost data was accumulated in connection with TSC's comprehensive assessment program, these two operating fleet-related cost categories appear to have accounted for about 65% of the total O&M cost.

Other factors which affect O&M costs have very little to do with the configuration of the system or the level of activity. These include climatic conditions, local wage rates, institutional influences which affect labor productivity, and the local environment which may dictate special measures for passenger security.

The cost experience at a given AGT installation reflects the interplay of numerous individual factors and influences. Whereas, the data presented in this report may be used for general planning purposes in predicting what costs for new installations may be, they must be treated with caution. Thus, each installation should be considered as an individual case.

CAPITAL COSTS

The capital cost for a typical AGT system is almost evenly divided between facilities and equipment. With applicable engineering and project management expenditures allocated to the system's physical features, these two major cost categories include the following:

- Facilities - The guideways, stations, maintenance shops, supporting utility systems and associated engineering and project management.

- Equipment - The vehicles, control and communication system, power rails, fare collection and other station equipment, emergency vehicles and shop equipment and related engineering.

Because the configuration of the guideway network, as well as the number, type and general arrangement of the stations, is dictated by site specific factors, facilities cost information on existing AGT installations should be treated with caution. Among the local considerations which influence the scope and cost of the facilities are: geography, sub-surface foundation conditions, land use and availability, climatic conditions, prevailing wage rates and construction practices, and the transportation needs of the urban area to be served. Thus, unit cost data compiled from existing installations should be considered merely as indicative of general orders of magnitude.

The required capital investment in AGT equipment is less influenced by local site conditions than is the cost of the fixed facilities. Accordingly, cost experience from existing installations is more likely to be transferrable to other locations. Once daily and peak hour capacities have been determined and decisions reached on desired level of service, the capabilities of the vehicle fleet and the operational requirements for the control and communications system may be established. These performance characteristics may then be compared with the capabilities of existing equipment on which cost data has been accumulated. Providing both the differences and similarities between existing and proposed systems are given due consideration, past cost experience may be used with reasonable confidence in predicting the equipment cost for new installations. Also, because most of these costs are incurred at manufacturing facilities remote from the project site, regional cost differentials should be minimal.

COMPARISON WITH OTHER MODES

In 1978, the five major operational AGT systems carried approximately 36 million passengers at an average cost of 17¢ each. This was less than one-third of the transit industry's cost per passenger transported.

These five AGT systems logged 5.7 million vehicle miles at an average cost of $1.10/VMT, significantly less than the transit industry average of $2.07/VMT.

AGT is less labor intensive than conventional transit. The five AGT systems required 1.6 O&M employees per vehicle operated, as compared to the transit industry average of 2.6

AGT O&M costs per vehicle mile traveled have remained constant during the past three years, in terms of 1978 price levels. However, the average cost per VMT for conventional transit has increased by 4 percent, thus outpacing inflation.

AGT is capital intensive, involving an average investment of $11 million per lane mile, about the same as for a typical light rail system. However, the AGT systems provided service capacity almost two times higher than light rail, expressed in terms of place miles per mile of route.